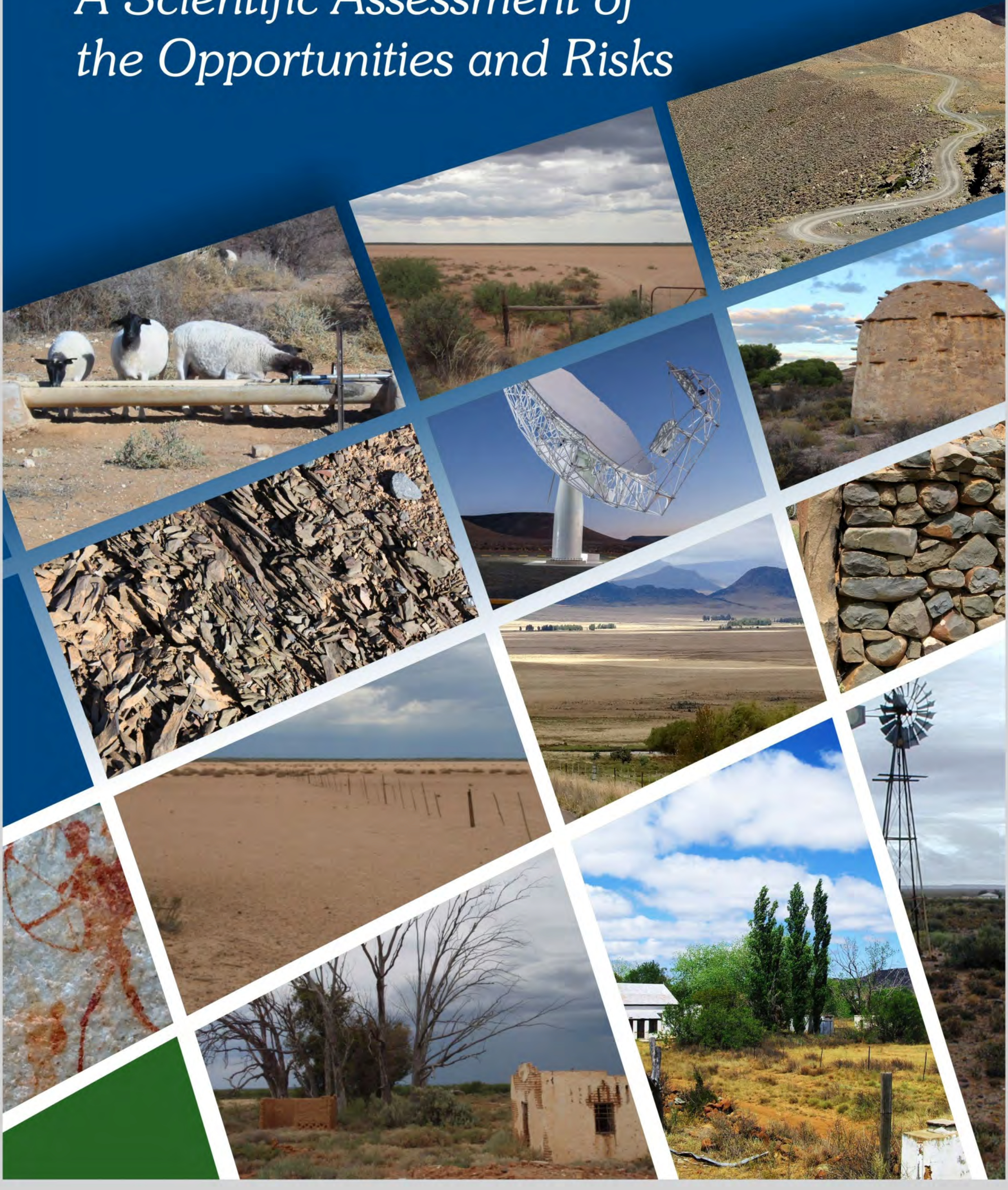
Shale Gas Development in the Central Karoo:

A Scientific Assessment of the Opportunities and Risks



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The Central Karoo is an arid, extensive landscape, experienced by many people as a sanctuary of austere but captivating beauty. At the same time, the people who live in the region are mostly poor - high levels of unemployment and inequality characterise the local economies and social fabric. South Africa is investigating the opportunities for introducing more natural gas into the predominantly coal-dominated energy mix. One option is to exploit naturally occurring methane, liberated from deep shale layers in the Central Karoo through horizontal drilling and hydraulic fracturing technologies ('fracking'). Very little is known about the distribution and magnitude of the gas resource, or whether it can be extracted at economically viable rates. If shale gas development were found to be economically viable, the economic and energy security opportunities of a medium to large shale gas resource would be substantial; as would be the social and environmental risks associated with a gas industry in the Central Karoo. This has been presented to the public and decision-makers as a stark choice between economic opportunity on the one hand and environmental protection on the other. It has become a highly divisive topic, but one which has been, up to now, poorly informed by publically-available and trusted evidence. To address this lack of critically-evaluated information, a Strategic Environmental Assessment (SEA) for shale gas development was commissioned in 2015 by five national government departments of the Republic of South Africa. Phase 2 of the SEA process was undertaken as an independent 'scientific assessment' and is reported in this book. The 18 chapters were drafted by 146 authors and peer reviewed by a further 75 independent experts and also by stakeholders involved in the process. It is the largest scientific assessment ever undertaken in South Africa and has set a national precedent on how strategic issues of great importance and consequence should be dealt with if critical development choices are to be guided by evidence-based policies.

Prof Robert (Bob) Scholes is a systems ecologist at the University of the Witwatersrand. He has led many assessments over the past 25 years, including parts of the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, the South African Assessment on Elephant Management, and the global Land Degradation and Restoration Assessments.

Paul Lochner is an environmental assessment practitioner at the CSIR in Stellenbosch, with over 25 years of experience in a wide range of environmental assessment and management studies. His particular experience is in the renewable energy, oil and gas, and industrial and port development sectors. He has been closely involved in the application of Strategic Environmental Assessment in South Africa.

Greg Schreiner started work at CSIR in 2011. He is interested in innovative and novel approaches to environmental assessment and management; and the social processes which underpin good decision-making. He has a Masters Degree in Environment and Development from the University of Cambridge. He has for the past 2 years managed the day to day processes of the shale gas SEA.

Luanita Snyman-Van der Walt has worked at the CSIR for the past 3 years as an environmental assessment practitioner focussing on environmental assessment and Geographic Information System analyses. She has a Masters Degree in Environmental Science from North West University and assisted in managing the shale gas SEA.

Megan de Jager holds a Masters Degree in Environmental Geography from the Nelson Mandela Metropolitan University. She is employed at CSIR as an intern on the shale gas SEA and is currently undertaking a PhD on baseline monitoring in the Central Karoo.

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A Scientific Assessment of the Opportunities and Risks

Edited by Bob Scholes, Paul Lochner, Greg Schreiner,
Luanita Snyman-Van der Walt, Megan de Jager

Electronic publication

Authors

Selwyn Adams, Graham Alexander, John Almond, Katye Altieri, Megan Anderson, Emma Archer van Garderen, Doreen Atkinson, Karin Badenhorst, Dave Baldwin, Oliver Barker, Corinna Bazelet, Stephen Berrisford, Roger Bills, Tobias Bischoff-Niemz, Christy Bragg, Bill Branch, Peter Bruyns, Michael Burns, Clinton Carter-Brown, Albert Chakona, Matthew Child, Simon Clarke, Nicholas Clarke, Ralph Vincent Clarke, Henk Coetzee, Andrew Coetzer, Willem Coetzer, Jonathan Colville, Werner Conradie, Fahiema Daniels, Claire Davis, Elizabeth (Liz) Day, Jenny Day, Megan de Jager, Michael de Jongh, Richard Dean, Moctar Doucouré, Amanda Driver, Gerrie du Rand, Justin du Toit, Katie du Toit, Raymond Durrheim, Connal Eardley, Ismail Ebrahim, Dave Edge, Surina Esterhuyse, Justine Ewart-Smith, Saliem Fakir, Roger Fisher, Rebecca Garland, Dave Gaynor, Simon Gear, Caroline Gelderblom, Bettina Genthe, Cheri Green, Simon Hall, Michelle Hamer, Dai Herbert, Philip Hobbs, Danita Hohne, Stephen Holness, Liana Jansen, Adrian Jongens, Marthie Kemp, Mahlatse Kgatla, James Kinghorn, Menno Klapwijk, Gerrit Kornelius, Patricia Kramer, Kedibone Lamula, Quinton Lawson, Given Leballo, Anthony Leiman, Lehman Lindeque, Paul Lochner, Leslie London, Robin Lyle, Judy Maguire, Ashton Maherry, Antonia Malan, Norma Malatji, Mervyn Mansell, Sethulego Matebesi, Dave McKelly, Ian McLachlan †, Matthew Meas, Silvia Mecenero, John Midgley, Vunganai Midzi, Jolynn Minnaar, Musa Mlambo, David Morris, Muvhuso Mosetsho, Zainab Mowzer, Hlengiwe Mtshali, Bernard Oberholzer, Suzan Oelofse, Noel Oettlé, Mark Oranje, Jayson Orton, Anthony Osler, Braam Otto, Phil Paige-Green, Louwrens Pretorius, Domitilla Raimondo, Nick Rivers-Moore, Peter Rosewarne, Nigel Rossouw, Hanna-Andrea Rother, Melville Saayman, Igshaan Samuels, Catherine Schenk, Bob Scholes, Johan Schoonraad, Greg Schreiner, Roland Schulze, Leanne Seeliger, John Simaika, Andrew Skowno, Kate Snaddon, Luanita Snyman-Van der Walt, Barry Standish, Herman Staude, Maronel Steyn, Adrian Tiplady, Simon Todd, Daan Toerien, Krystal Tolley, Ikechukwu Umejesi, Les Underhill, Dewidine van der Colff, Paul van der Merwe, Elsona van Huyssteen, Wikus van Niekerk, Simon van Noort, Lize von Staden, Hugo van Zyl, Susi Vetter, Andrew Wade, Mieke Willems, Harald Winkler, Jarrad Wright, Graham Young, Owen Zinaman

   

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Foreword

Much has been said and written about the importance of evidence-based policy-making, about the benefits that will accrue from decisions that are based on sound evidence, and from the ability to accurately compare the real to the expected results of our actions. As scientists we have welcomed these developments - this is of course the world with which many of us are intimately familiar, a world where the facts matter and our theories and inventions have to prove that they are able to deal with reality. However, this welcome development brings with it a great responsibility. The consequences of getting it wrong, of making mistakes, are no longer limited to our academic standing amongst our peers, or to the opportunities we spurn by following dead ends. Now, the consequences are potentially much more serious, and may involve the lives and livelihoods of entire communities, the shape and size of our economy and the very ability of our environment to sustain human life.

The question of whether or not South Africa should exploit, through hydraulic fracturing, its natural gas reserves trapped within the deep shale layers in the Karoo Basin emerged in 2010. This question is a clear example of both the importance and complexity of working in the policy environment - the stakes could not possibly be higher, with important long-term consequences, either environmentally or economically, for South Africa's future. It is to the great credit of both parties - the policy-makers who will take responsibility for our course of action and the scientists who have been asked to advise them - which neither has baulked at the task that has been placed before them.

The result of this collaboration, reported on in this document, is a meticulous and multi-disciplinary assessment which presents, in an objective and balanced fashion, the opportunities and risks associated with shale gas development in South Africa across different scenarios. Over 200 of the best national and international scientists have, over 18 months, contributed to this study, and through a process of rigorous peer-review ensured that we have made the best use of the evidence and insights at our disposal.

The process has included close collaboration with government, non-governmental organisations and research institutions, and consisted of an extensive stakeholder outreach programme using multiple communication mediums. It is the largest scientific assessment undertaken in South Africa in terms of material scope and participation, both scientific and stakeholder based.

As CEO of the CSIR, the organisation which led this scientific assessment, I am extremely proud of the manner in which such an important national issue has been addressed. I also am grateful to my contemporaries at the South African National Biodiversity Institute (SANBI) and the Council for Geosciences (CGS) for their collaboration through the project. Recognition must go to Government, for commissioning the CSIR, in collaboration with other national scientific bodies, to co-ordinate this independent process. I am grateful to the participating scientists who gave so willingly of their time and expertise.

Most of all, I am grateful to the South African public, for their participation in this landmark process and in exercising their civil rights and duties by contributing so diligently. The collaborative philosophy in which the scientific assessment process has been undertaken has been an astonishing success. I hope that, when confronted with equally important choices, our policy-makers can look back on this exercise as a model for their future actions.

Dr Sibusiso Sibisi

CEO, CSIR

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Reviewers

The process developed to generate the scientific material for this publication relied on a collaborative endeavour between authors, expert peer reviewers and stakeholders. This resulted in a ‘co-production’ of the evidence-base. The Editors would like to acknowledge and thank all the reviewers who made valuable contributions to the book. This includes the 75 national and international expert peer reviewers nominated to review specific First Order Draft chapters, indicated in the list below as [PR] (to denote ‘peer reviewer’) and the Chapter which they were responsible for reviewing. In addition, thanks are extended to the stakeholder reviewers who contributed to the Second Order Draft review process. They are also listed below with their affiliated institutions.

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Marilyn Lilley (Stakeholder)

Daniel Limpitlaw (Limpitlaw Consulting) *PR* Chapter 1

Ian Little (Stakeholder)

Garth Llewellyn (Appalachia Hydrogeological and Environmental Consulting, LLC) *PR* Chapter 5

Jeffrey Logan (National Renewable Energy Laboratory) *PR* Chapter 2

Juan Roberto Lozano Maya (Asia-Pacific Energy Research Centre [APERC]) *PR* Chapter 10

Brian Marston (BGMA Pty Ltd) *PR* Chapter 16

Wilbert Mathews (Mateus Petroleum Consulting) *PR* Chapter 1

Michael McCawley (West Virginia University) *PR* Chapter 16

Char-lee McLennan (Griffith University) *PR* Chapter 9

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Onshore Petroleum Association South Africa (ONPASA)

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John Parkington (University of Cape Town) PR Chapter 15

Andre Pelser (University of the Free State) PR Chapter 11

Ian Perrin (Stakeholder)

Frans Prins (Stakeholder)

Peter Rabinowitz (University of Washington) PR Chapter 12

Brian Rahm (New York State Water Resources Institute) PR Chapter 5

Ragna Redelstorff (Stakeholder, South African Heritage Resources Agency)

Will Rifkin (University of Queensland) PR Chapter 8 and 13

Hans-Holger Rogner (IIASA) PR Chapter 2

Bruce Rubidge (University of the Witwatersrand) PR Chapter 15

Bonnie Schumann (Stakeholder, EWT)

Ramotholo Sefako (Stakeholder, South African Astronomical Observatory)

Mike Shand (Stakeholder, South African Academy of Engineering)

Donald Siegel (Syracuse University) PR Chapter 5

Debbie Stine (Carnegie Mellon University) PR Chapter 14

Elsabe Swart (Stakeholder, Department of Environment and Nature Conservation Northern Cape)

Jeanne Tarrant (Stakeholder)

Cobus Theron (Stakeholder, EWT)

Hans van der Marel (Netherlands Institute for Radio Astronomy) PR Chapter 17

Wim van Driel (International Astronomical Union) PR Chapter 17

Trompie Van Rensburg (Stakeholder, Central Karoo Agricultural Union)

Frank Vanclay (University of Groningen) PR Chapter 11

Danie Vermeulen (University of the Free State) PR Chapter 5

Jeremy Wakeford (Stellenbosch University) PR Chapter 2

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Jonathan Williamson (Lycoming College) PR Chapter 18

Sarah Winter (Heritage Western Cape) PR Chapter 14 and 15

Kathy Witt (University of Queensland) PR Chapter 11

Dave Wolfgang (Pennsylvania State University) PR Chapter 12

Dave Yoxtheimer (Pennsylvania State University) PR Chapter 6

Mark Zoback (Stanford University) PR Chapter 4

Shale Gas Development in the Central Karoo:

A Scientific Assessment of the Opportunities and Risks

PREFACE

Authors:	Bob Scholes[1], Paul Lochner[2], Greg Schreiner[3], Luanita Snyman-Van der Walt[4] and Megan de Jager[5],

[1]Global Change and Sustainability Research Institute, University of the Witwatersrand, Johannesburg, 2000

[2-5]Environmental Management Services, Council for Scientific and Industrial Research, Stellenbosch, 7600

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1. BACKGROUND

The potential economic and energy security benefits of a large shale gas resource in the Karoo Basin could be substantial; as are both the positive and negative social and environmental issues associated with a domestic gas industry. Shale gas development[1] (SGD) has already become a highly divisive topic, but one which is poorly informed by publically-available evidence.

To address this lack of critically-evaluated information, a Strategic Environmental Assessment (SEA) for SGD was commissioned in February 2015 by the Department of Environmental Affairs of the Republic of South Africa, with the support of the National Departments of Energy, Mineral Resources, Water Affairs and Sanitation, Science and Technology, and Agriculture, Forestry and Fisheries; and the Provincial Departments of the Eastern, Western and Northern Cape Governments.

The Council for Scientific and Industrial Research (CSIR) coordinated the SEA, in partnership with the South African National Biodiversity Institute (SANBI) and the Council for Geoscience (CGS). In addition to the national science councils, the SEA includes 146 independent authors contributing to the 18 Chapters of the assessment. The Chapters have been independently reviewed by a further 25 local and 46 international independent peer review experts, and by a large number of stakeholders.

The point of departure for the SEA is that South African Government, through Cabinet and various other decision-making institutions, has made high-level public commitments to shale gas *exploration*.

If the exploration phase reveals economically-viable hydrocarbon deposits and gas-flow regimes, the Government will seriously consider permitting the development of those resources at significant scale. South African society, collectively comprising all levels of government, the private sector and civil society, needs to be in a position to make the decisions relevant to that choice in a timely and responsible manner.

The mission statement for the SEA is to provide an integrated assessment and decision-making framework to enable South Africa to establish effective policy, legislation and sustainability conditions under which SGD could occur. Note that this mission statement, developed in collaboration with government, is phrased in the conditional - it does not presume that SGD *will* occur.

[1] The terms "shale gas development"(SGD) refers to all exploration and production related activities, as well as downstream gas utilisation scenarios, encompassing the full life-cycle of impacts typical of a SGD programme. In Chapter 1 (Burns et al., 2016), clear distinction is made between the phases of SGD to distinguish the nature and extent of SGD activities which can be logically assumed across the scenarios.

The key objective of the SEA is to provide decision makers and stakeholders with an evidence base which will assist South Africa in developing a better understanding of the opportunities and risks associated with SGD. The SEA is not in itself a mandated decision-making process. The intention of the SEA is to provide the evidence base and decision support frameworks which will guide future decision-making processes, for example those associated with Environmental Impact Assessments (EIA) for specific SGD-related activities, once it becomes clear exactly what those are and where they might be located.

> ***Preface Box 1: What is a Scientific Assessment?***
>
> Scientific assessments are aimed at the stakeholders (often specifically decision-makers) in society, who are intelligent but not necessarily technical specialists. The questions are posed by the stakeholders, who help to shape the assessment. Strong attempts to use jargon-free, plain language, summary tables and explanatory diagrams are made. Scientific assessments have a strong focus on balanced and inclusive governance to establish legitimacy and credibility.
>
> The issues addressed are investigated by large and diverse teams of experts. During assessments, subjective judgements are often required, but these are made explicitly, along with statements of confidence. Balance and the elimination of bias are achieved through the establishment of broad multi-author teams representing a range of interests and/or positions, coupled with extensive and transparent review.
>
> The assessment is independently reviewed by other experts and by stakeholders, often amounting to thousands of documented comments and responses, all of which are available in the public domain. Scientific assessments are appropriate to problems which are both technically complex and socially contested; they are policy relevant, but not policy prescriptive.
>
> The first of the modern scientific assessments of a complex, socially-important problem is usually considered to be the Ozone Assessment of 1986. The success of this exercise in paving the way for the Montreal Protocol led to the formation of a permanent assessment body for climate change, the Intergovernmental Panel on Climate Change, in 1990, before the United Nations Framework Convention on Climate Change was signed. The successive climate scientific assessments from 2000, 2007 and 2014 are credited with making possible the agreement by 195 countries in Paris in December 2015 to take concerted action on climate change.

2. PHASED APPROACH

The SEA has three distinct but overlapping Phases (Figure 1). *Phase 1*, beginning in February 2015, and extending to around October 2015 was the Preparation Phase.

The Preparation Phase included the necessary arrangements involving contracts and procurement arrangements, recruitment, convening governance structures, collating literature and data libraries, identifying the multi-author expert teams, undertaking team training, arranging logistics and writing the First Order Draft (FOD) of Chapter 1.

Phase 2 of the SEA is the scientific assessment phase, where information was organised by the multi-author expert teams, including two review rounds of their Chapters, initially by independent review experts, and then (following revision to produce the Second Order Draft [SOD]) by stakeholders plus experts. *Phase* 2 commenced with the first author meeting on 28 September 2015, and ended with the completed final scientific assessment report – this published volume.

Phase 3 of the SEA will translate the scientific assessment into an operational Decision Making Framework. It is undertaken by the statutory science councils - CSIR, SANBI and CGS - in close consultation with the various affected National and Provincial Departments. It commences with initial drafts after the delivery of the SOD, and continues into the final revision of the scientific assessment report. *Phase* 3 of the SEA concludes around March 2017 and will provide the framework for how site and activity specific assessment processes should be undertaken and provide Government with the necessary tools to enable responsible decision-making into the future regarding SGD. This includes guidance on legislation, regulations, EIA processes and monitoring.

The separation between *Phase* 2 and *Phase* 3 is to honour the scientific assessment 'mantra' of being "policy relevant, but not policy prescriptive". The experts involved in *Phase* 2 have not been asked to make decisions about the development of shale gas. They have been asked to give an informed, evidence-based, scientifically-sound and balanced opinion on the consequences of different scenarios and development options for SGD into the future. The ultimate decisions regarding future authorisation processes for shale gas, whether at a national, provincial or local level, will be made by the authorities mandated to do so. In making these decisions they will be guided by the SEA and any other relevant and trusted sources of information that may have become available between the completion of the SEA and the time at which they need to implement policy, which may be years or decades into the future.

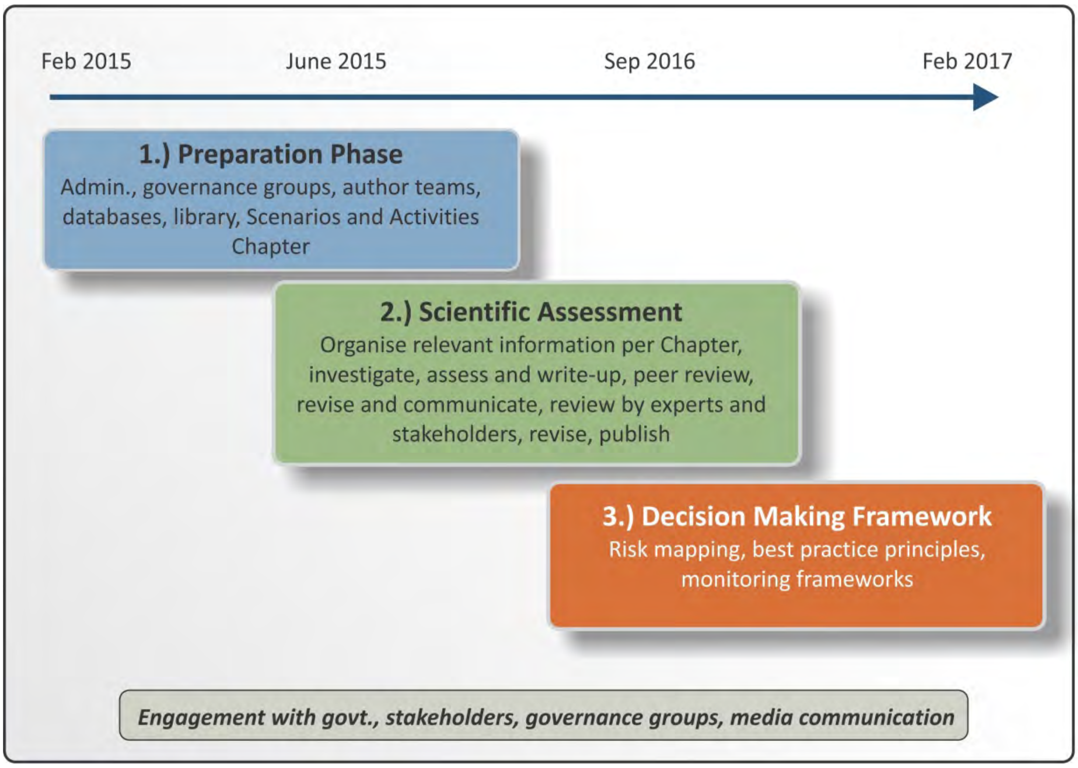


Figure 1: Shows the 3 overlapping phases of the SEA process and how the scientific assessment is used as the evidence base from which to develop an appropriate Decision Making Framework.

3. STRUCTURE OF THE SCIENTIFIC ASSESSMENT

The *Preface* provides the background to the study, explaining why it was commissioned, how it is phased, how it is governed and the manner in which it has been undertaken.

The *Summary for Policy Makers* (SPM) synthesises the key policy-relevant issues arising from the 18 Chapters which make up the body of the scientific assessment, into a form useable for policy makers and stakeholders. The SPM highlights the most salient points and findings of the assessment, each of which is supported by an evidentiary base, located in the Chapters. The location of the evidentiary base is indicated by the symbol '§'. Each section and series of statements contained in the SPM is traceable to a specific source, where further information can be retrieved by anyone interested.

Preface Box 2: Report Structure

…	*Preface*
…	*Summary for Policy Makers*
Ch 1	Shale Gas Development Scenarios and Activities
Ch 2	Effects on National Energy Planning and Energy Security
Ch 3	Air Quality and Greenhouse Gas Emissions
Ch 4	Earthquakes
Ch 5	Water Resources, both on the Surface and Underground
Ch 6	Impacts on Waste Planning and Management
Ch 7	Biodiversity and Ecological Impacts: Landscape Processes, Ecosystems and Species
Ch 8	Impacts on Agriculture
Ch 9	Impacts on Tourism in the Karoo
Ch 10	Impacts on the Economy
Ch 11	Impacts on Social Fabric
Ch 12	Impacts on Human Health
Ch 13	Impacts on Sense of Place Values
Ch 14	Impacts on Visual, Aesthetic and Scenic Resources
Ch 15	Impacts on Heritage
Ch 16	Noise Generated by Shale Gas-Related Activities
Ch 17	Electromagnetic Interference
Ch 18	Impacts on Infrastructure and Spatial Planning

The purpose of Chapter 1, is to describe the nature and scale of activities assumed for three SGD scenarios of increasing magnitude. The scenarios are described in the context of a reference scenario where there is no SGD. The scenarios are selected to cover a range of plausible futures. Chapter 1 serves as a common point of departure for the 17 subsequent Chapters, which evaluate, for the issues on which they focus, the levels of opportunity and risk associated with each of the scenarios and their main defining activities.

Chapters 2-18 are topic specific - they constitute the *actual* assessment. Each Chapter has been structured in a manner which presents a clear definition of the scope of the topic in question, a review of the international literature and evidence, the relevant South African rules, institutions, regulations and legislation; and a description of the key SGD impacts and mitigation options. Each Chapter goes through a systematic and structured risk assessment of the impacts described, assessed both with and without mitigation, and across the three development scenarios relative to the reference case and relative to the '*levels of acceptable change*'. Levels of acceptable change relate to the societal judgements based on historical trends (what have people been happy to accept in the past, and implicit in the baseline); guiding legislation, regulations and international norms; and absolute biophysical or social thresholds.

On the back of the risk assessment, undertaken per Chapter, the multi-author teams make recommendations regarding impact mitigation best practice in relation to that topic; and baseline and ongoing monitoring requirements. The teams also clearly identify, per Chapter, the areas in which there was inadequate information to adequately inform decision-makers and society.

A detailed list of glossary terms and abbreviations is provided in Appendices 1 and 2 respectively. Appendix 3 provides summary biosketches of the Integrating and Contributing Authors who have drafted the Chapters of the scientific assessment (Table 3).

***Preface Box 3:* Principles of a Scientific Assessment: Legitimacy, Saliency and Credibility**

Legitimacy refers to running an unbiased process which considers appropriate values, the concerns and perspectives of different actors, and corresponds with political and procedural fairness. Furthermore, the process must include appropriate people and organisations within project governance structures to ensure that the process is considered legitimate in the eyes of both the public and the decision-makers tasked with using it.

Saliency is established by ensuring that the outcomes of the assessment are of relevance to the public and decision-makers and seeks to address quite specific questions, in other words, a scientific assessment is not a research project. The assessment must consider all the material issues and legitimate stakeholder concerns associated with SGD.

Credibility means meeting the standards of scientific rigor and technical adequacy. The sources of knowledge in an assessment must be considered trustworthy along with the facts, theories, and causal explanations invoked by these sources. Local and traditional knowledge should be included in the assessment where appropriate and possible. Involving eminent and numerous scientists as authors and ensuring that all reports undergo expert peer review are essential.

4. SCIENTIFIC ASSESSMENT PROCESS

The Zero Order Draft (ZOD) of the scientific assessment, which provided a 'skeletal structure' of the full assessment and the range of topics covered, was released for public comment in October 2015; and discussed and communicated with stakeholders at public briefings in November 2015 and May 2016. The scope of work for the assessment was vetted by the Process Custodians Group (PCG) and Project Executive Committee (PEC) (see Section 8).

Based on the ZOD, the multi-author teams drafted the Chapter FODs, which were received by the management team in February 2016. The Chapter FODs were distributed for independent expert peer review. All peer review comments on the FODs were captured by the management team and sent back to the Chapter teams prior to the second author meeting in April 2016.

The SODs, which now included the revisions made following peer review and the responses by the author teams to the peer review comments, were submitted to the management team end-May 2016. The SODs constituted the draft scientific assessment, which were released for stakeholder comment for a 38 day period. All stakeholder comments submitted on the SODs were captured and responded to in a formal manner by the Chapter teams during the third and final revision of the scientific assessment and have been released publically on the project website.

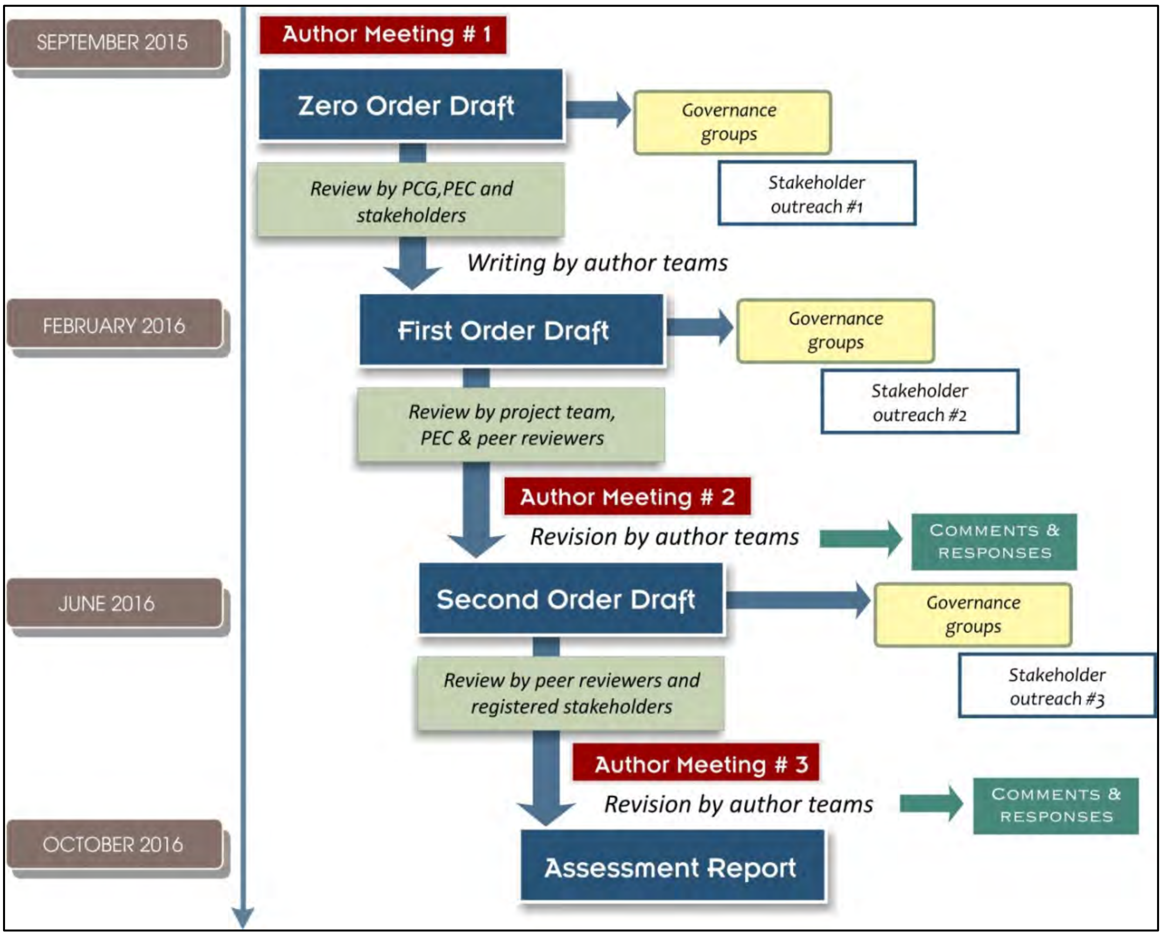


Figure 2: The scientific assessment process initiated with Author Meeting # 1 and the production of the ZOD in September and October 2015 respectively; and was completed with the publication of the final scientific assessment report at the end of 2016.

5. SCOPE OF THE SCIENTIFIC ASSESSMENT

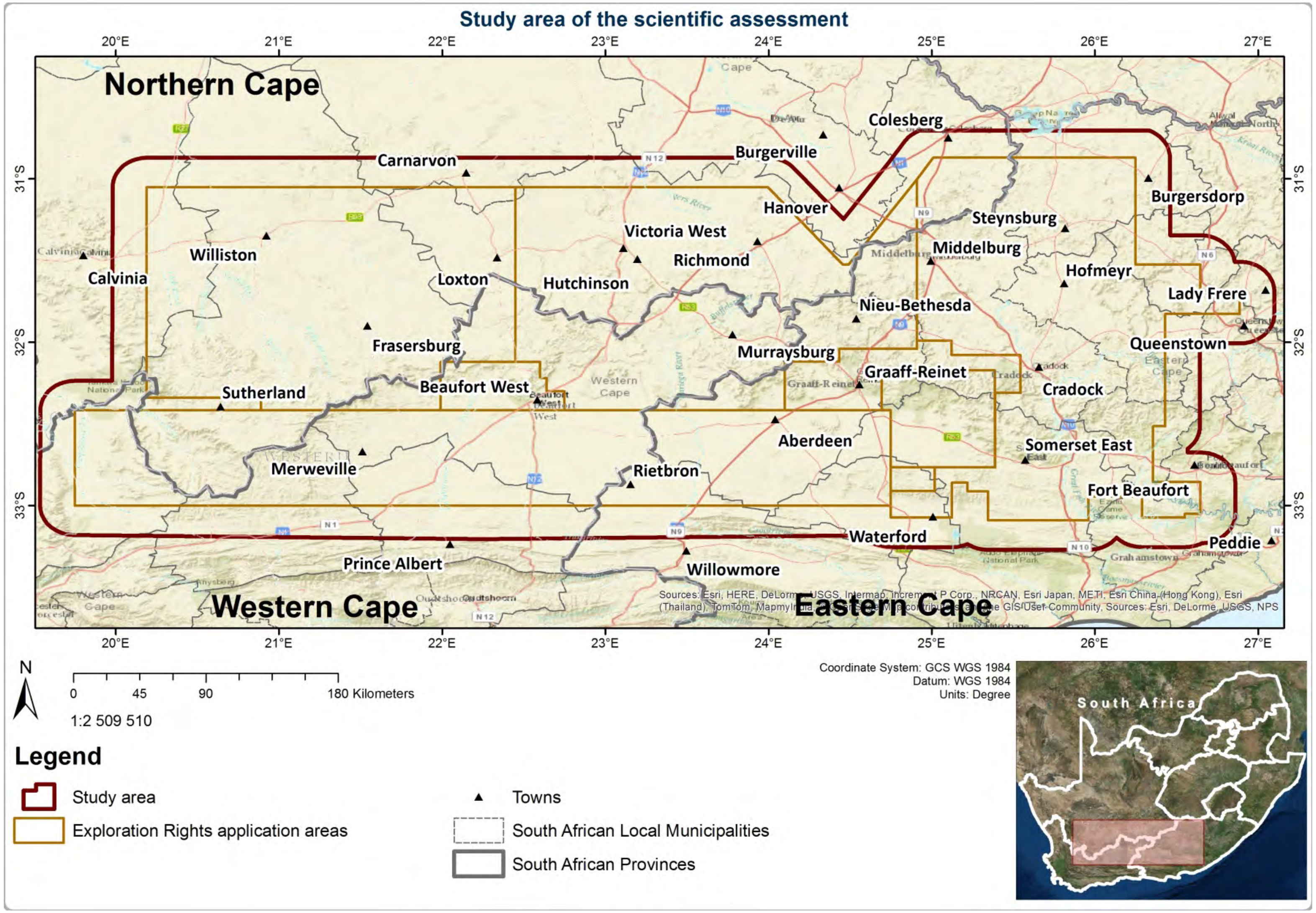


Figure 3: The Scientific Assessment considers SGD origination in the 171 811 km^2 region of the study area delimited by the applications for Exploration Right which have been lodged by Shell, Falcon and Bundu), plus a 20 km buffer. The assessment follows the consequences of SGD in this region to the point of material impact, even if that is outside the study area.

The geographic scope of the assessment was restricted to the potential impacts originating from SGD within the Central Karoo (Figure 3). This is not only the most promising SGD prospect, but also the only one at the date of commencement, for which Exploration Right applications (specifically for shale gas) had been accepted by the Petroleum Agency South Africa (the Exploration Right applications are currently still under consideration).

Other types of unconventional gas reserves may exist in other areas of the South African onshore and offshore territory, and would need separate consideration if their development was considered. The scope of this scientific assessment considers shale gas exploration, production and downstream related activities, up to and including eventual closure of facilities and restoration of their sites (collectively called “development”), and includes an assessment of all the material social, economic and biophysical opportunities and risks associated with the shale gas industry across its entire lifecycle, as described in Chapter 1 (Burns et al., 2016). This temporal scope extends, in some instances up to 40 years into the future. The scope of issues addressed in the scientific assessment (Figure 4) was informed by an in-depth review of similar international assessments undertaken around the world and by engagement with stakeholders and governance groups.

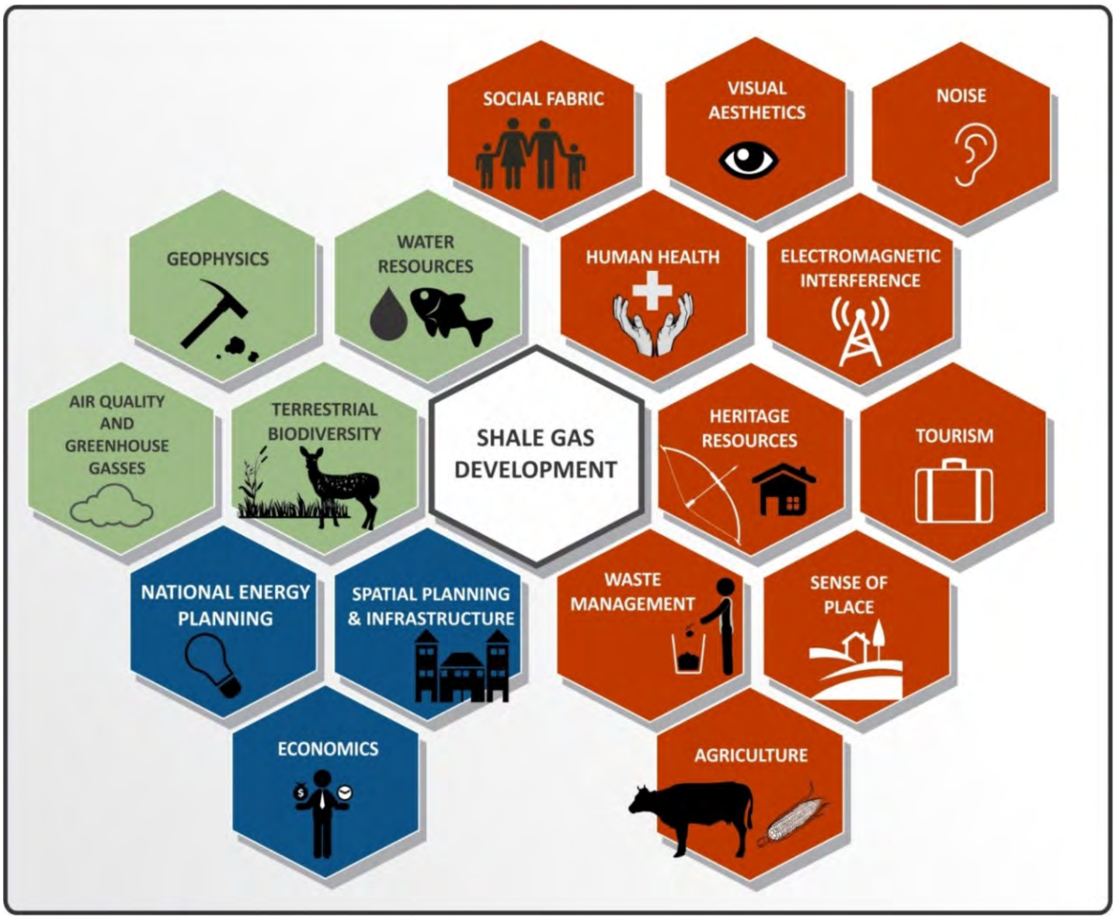


Figure 4: The 17 strategic issue topics identified through the literature review and public / governance engagement process, which now form the basis of the scientific assessment.

6. RISK ASSESSMENT METHODOLOGY

Each Chapter undertakes a rigorous and systematic risk assessment of the impacts relating to SGD. The risk assessment approach takes its point of departure from the fact that there is residual uncertainty about all aspects of the future, even after that uncertainty has been constrained by rigorously assessing the evidence.

The risk assessment, which is based on a transparent expert judgement process, is an approach for considering all impacts of an issue in a common way, and (where possible) within a spatial context. Risk is determined by estimating the *likelihood* of events or trends occurring, in relation to their *consequences* i.e. *likelihood x consequence = risk* (Figure 5). A low-likelihood, high consequence impact could be just as 'risky' as a high probability, low consequence impact. The consequence terms ranging from slight to extreme are calibrated per Chapter topic so that there is consistency in way risk is measured, allowing for suitable integration across different Chapters and disciplines.

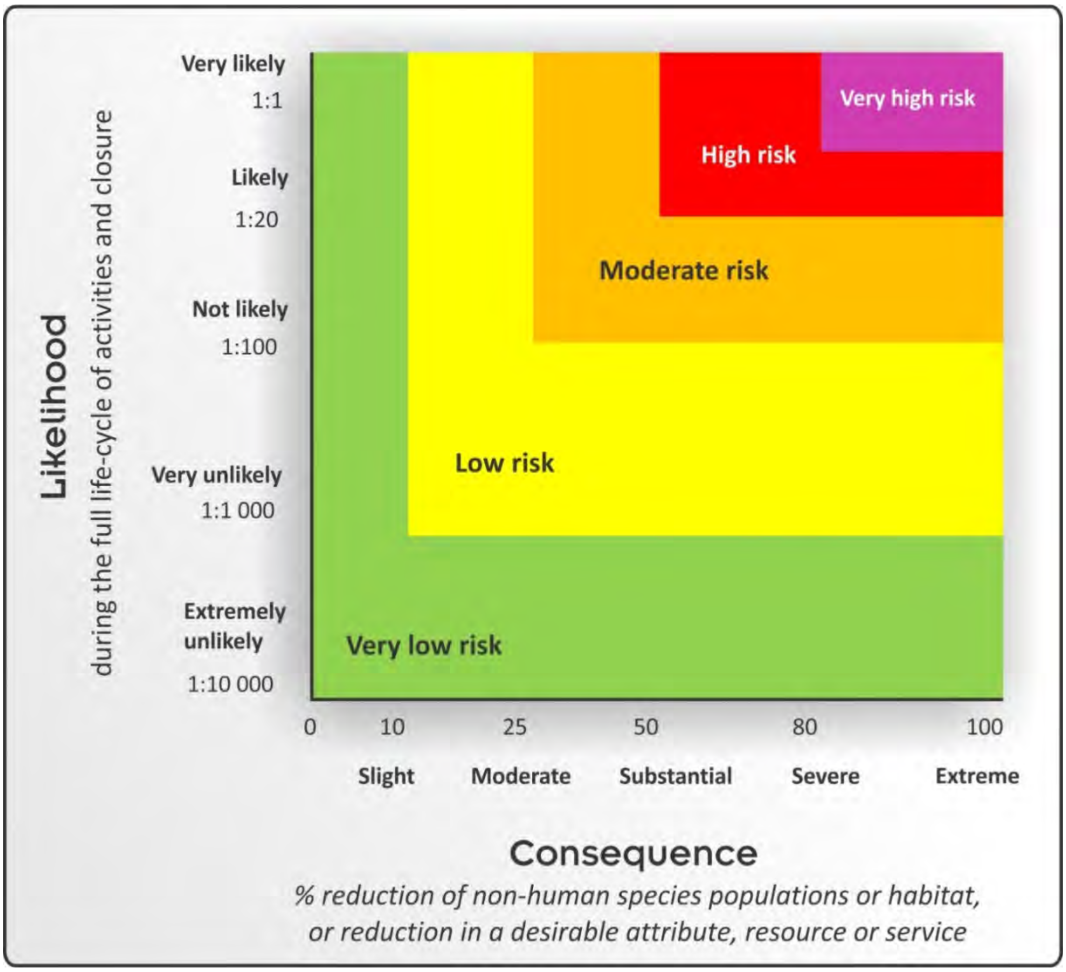


Figure 5: Risk is qualitatively measured by multiplying the likelihood of an impact by the severity of the consequences to provide risk rating ranging from very low, low, moderate, high and very high.

The consequence of an impact depends on three things: 1.) *Exposure to the impact*: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. 2.) *The nature of the impact*: The potential occurrence of a natural or human-induced physical event or trend that may cause negative impacts such as health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. 3.) The *vulnerability of the receiving environment*: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

The risk assessment is based on an interpretation of existing spatial and non-spatial data in relation to the proposed activities described in the scenarios, to generate an integrated picture of the risk related to a specified activity in a given location, with and without mitigation. Risk is assessed for each significant stressor (i.e. impact), on each different type of receiving entity (e.g. the rural poor, a sensitive wetland etc.), qualitatively (undiscernible, very low, low, moderate, high, very high) against a predefined set of criteria (Table 1).

Table 1: Predefined set of criteria applied across the Chapters of the scientific assessment

Risk category	Definition
No discernible risk	Any changes that may occur as a result of the impact either reduce the risk or do not change it in a way that can be differentiated from the mean risk experienced in the absence of the impact.
Very low risk	Extremely unlikely (<1 chance in 10 000 of having a consequence of any discernible magnitude); or if more likely than this, then the negative impact is noticeable but slight, i.e. although discernibly beyond the mean experienced in the absence of the impact, it is well within the tolerance or adaptive capacity of the receiving environment (for instance, within the range experienced naturally, or less than 10%); or is transient (< 1 year for near-full recovery).
Low risk	Very unlikely (<1 chance in 100 of having a more than moderate consequence); or if more likely than this, then the impact is of moderate consequence because of one or more of the following considerations: it is highly limited in extent (<1% of the area exposed to the hazard is affected); or short in duration (<3 years), or with low effect on resources or attributes (<25% reduction in species population, resource or attribute utility).
Moderate risk	Not unlikely (1:100 to 1:20 of having a moderate or greater consequence); or if more likely than this, then the consequences are substantial but less than severe, because although an important resource or attribute is impacted, the effect is well below the limit of acceptable change, or lasts for a duration of less than 3 years, or the affected resource or attribute has an equally acceptable and un-impacted substitute.
High risk	Greater than 1 in 20 chance of having a severe consequence (approaching the limit of acceptable change) that persists for >3 years, for a resource or attribute where there may be an affordable and accessible substitute, but which is less acceptable.
Very high risk	Greater than even (1:1) chance of having an extremely negative and very persistent consequence (lasting more than 30 years); greater than the limit of acceptable change, for an important resource or attribute for which there is no acceptable alternative.

In Chapters 2-18, every author team has conducted a risk assessment in relation to its issue, starting in the FOD, and then refining the assessment in subsequent drafts as a result of independent peer and stakeholder review processes. The risk assessments are conducted using the standardised approach described and terminology has been standardised to improve consistency across the Chapters.

The risk assessment is spatially explicit – each Chapter (where spatial data was available), defines different receiving environments in the form of a spatial Geographic Information System (GIS), generally based on sensitivity, then assesses each impact under the three scenarios in relation to the Reference Case, without mitigation first, and then with mitigation (assuming the application of the best practice management principles applied). The without and with migration assessment provides a plausible range of future outcomes across the scenarios, assuming no mitigation, where there is poor governance capacity and decision-making; to with mitigation, which assumes adequate governance capacity and decision-making.

7. SCENARIOS AND ACTIVITIES

The purpose Chapter 1 (Burns et al., 2016) is to describe, in as much detail as feasible, the scale and type of activities which would logically be associated with three SGD scenarios of increasing magnitude, in relation to the Reference Case which assumes other changes, but no SGD (Table 2, Figure 6).

The Chapter serves as a common point of departure for the subsequent 17 Chapters, to estimate, for the Chapters, the levels of risk associated with each of the scenarios, considering the activity descriptions. As such, Chapter 1 is not itself an assessment, and nor does it make any suggestion about how likely or desirable any of the scenarios are. It simply provides a shared basis from which risk is estimated across the scenarios, across the activities and across the Chapter topics which will follow in due course.

The scenarios depicted in the Chapter do not presuppose that SGD will occur. They are presented in a plausible but hypothetical manner so that the ‘strategic-level’ opportunities and risks associated with the likely range of scenarios can be estimated. The outcome of that assessment will inform responsible decision-making with respect to SGD at a site specific level, when or if applications are made by the oil and gas industry to pursue further pursue exploration in the Central Karoo.

Table 2: Scenarios considered in the assessment and a brief explanation of the associated activities. Tcf is trillion cubic feet of gas. For comparison, the Mossgas resource at Mossel Bay was about 1 Tcf.

Scenario	Brief explanation
Scenario 0: Reference Case	No SGD. Regional trends such as human migration, shifting economic activities and new development alternatives in the Central Karoo are realised. Climate change reduces the availability of water in the region.
Scenario 1: Exploration Only	Exploration proceeds, with results indicating that production would not be economically viable. All sites are rehabilitated, drilled wells are permanently plugged and monitoring of the abandoned wells is implemented. The national energy supply is supported by imported natural gas either via pipeline or from Liquefied Natural Gas (LNG) importation.
Scenario 2: Small Gas	A relatively small but economically viable shale gas discovery is made, in the region of 5 trillion cubic feet (Tcf) produced from 550 wells on about 55 wellpads in one 30 x 30 km production block. Downstream development results in a 1 000 megawatt (MW) combined cycle gas turbine (CCGT) power station located less than 100 km from the production block.
Scenario 3: Big Gas	A relatively large shale gas discovery of 20 Tcf is made, produced from 4100 wells on about 410 wellpads distributed across four production blocks. Downstream development results in construction of two CCGT power stations (each of 2 000 MW generating capacity) and a gas-to-liquid (GTL) plant located at the coast with a refining capacity of 65 000 barrels (bbl) per day.

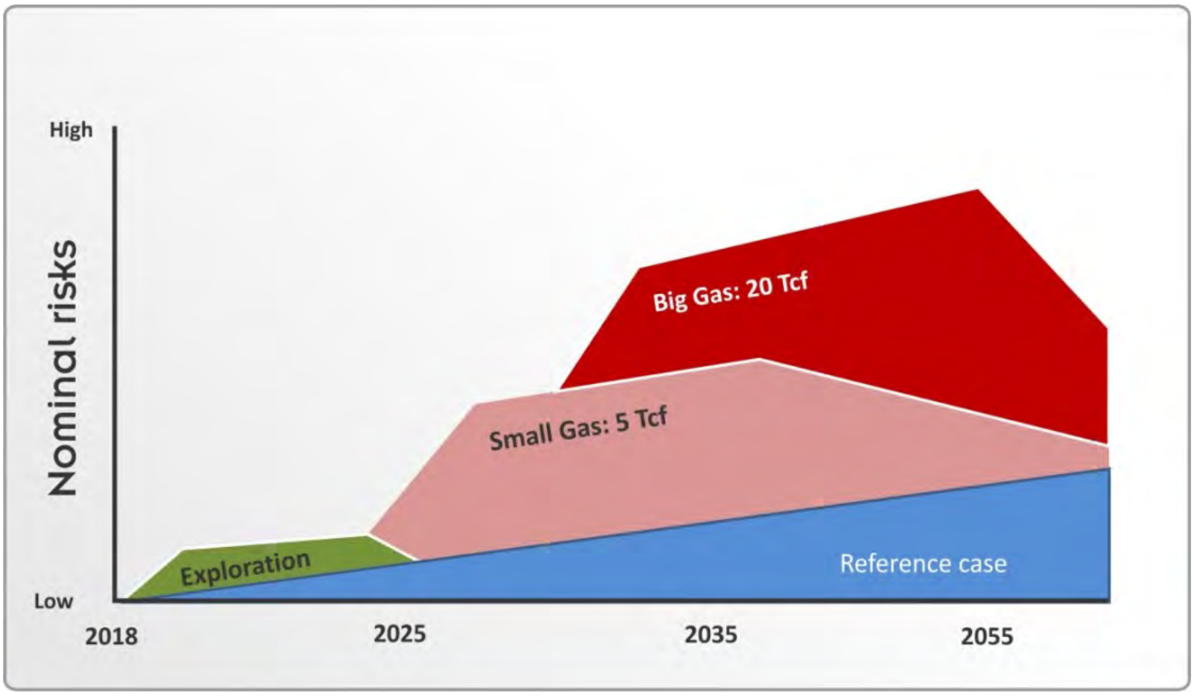


Figure 6: A ‘cartoon’ of the four conceptual scenarios to be considered in this assessment. Note that the scenarios are cumulative: Scenario 1 (Exploration Only) includes Scenario 0 (Reference Case); Scenario 2 (Small Gas) includes 1 and 0; and Scenario 3 (Big Gas) includes 0, 1 and 2. Thus they extend from 2018 to beyond 2055.

8. PROJECT GOVERNANCE

The Project Executive Committee (PEC) comprises representatives of Government who commissioned the SEA. The key responsibilities for the PEC include are as a project oversight body – coordinating and communicating information about the process, ensuring the project remains on scope, within timelines and budget and that strategic and policy issues are adequately addressed.

A key innovation, used specifically for the scientific assessment (*Phase 2)*, is the Process Custodians Group (PCG). The PCG is designed to ensure that the scientific assessment is independent, thorough and balanced. The PCG comprised approximately 16 eminent people, drawn approximately equally from government, NGOs, the private sector and the research community. The PCG met at key junctures during the scientific assessment to ensure that the process has been fair and rigorous. The PCG acted as a 'process referee' to ensure that the assessment had been undertaken in a legitimate, transparent and credible manner.

The organisations from which the PCG members were sourced were selected by the PEC as having credibility in their 'sectors' through having a mandate of some distinction, broad representation and a demonstrated interest in the topic of SGD. Members of the PCG are not appointed as 'representatives' of their organisation in a narrow sense; but were expected to reflect the breadth of opinion in their sectors. The PCG was neither 'approving' nor 'disapproving' of SGD, nor did it have a say on the detail of the content of the scientific assessment. It was a trustworthy collective, tasked with ensuring that the process of evidence collection, evaluation and presentation was comprehensive and unbiased. This distinction remained critical especially for the non-governmental members of the PCG, as they and their respective organisations did not necessarily agree with every outcome of the assessment.

The PCG provided feedback to the PEC, ensuring that the scientific assessment was followed within the prescribed process as approved in the SEA Process Document[2]. Their specific mandate was to evaluate the following five topics of the assessment *process*:

1.) Has the assessment process followed within the guidelines of the SEA Process Document?

2.) Do the Chapter teams have the necessary expertise and show balance?

3.) Does the assessment (as indicated by the Zero Order Draft) cover the material issues?

4.) Are the identified expert reviewers independent, qualified and balanced?

5.) Have the review comments received from expert and stakeholders been adequately addressed and have the responses been adequately documented?

[2] The SEA Process Document downloadable at http://seasgd.csir.co.za/library/

The PCG convened during the scientific assessment to discuss the ZOD in October 2015, the Scenarios and Activities Chapter FOD and SOD in October 2015 and May 2016 respectively, and the FODs of the 17 strategic issue Chapters comprising the scientific assessment in May 2016. Feedback to the PCG was also provided on the progress of stakeholder engagement, public outreach processes and stakeholder commenting mechanisms. The final PCG meeting was undertaken end-September 2016. No objections to the *process*, as outlined in the mandate of the PCG, we registered before final publication of the scientific assessment.

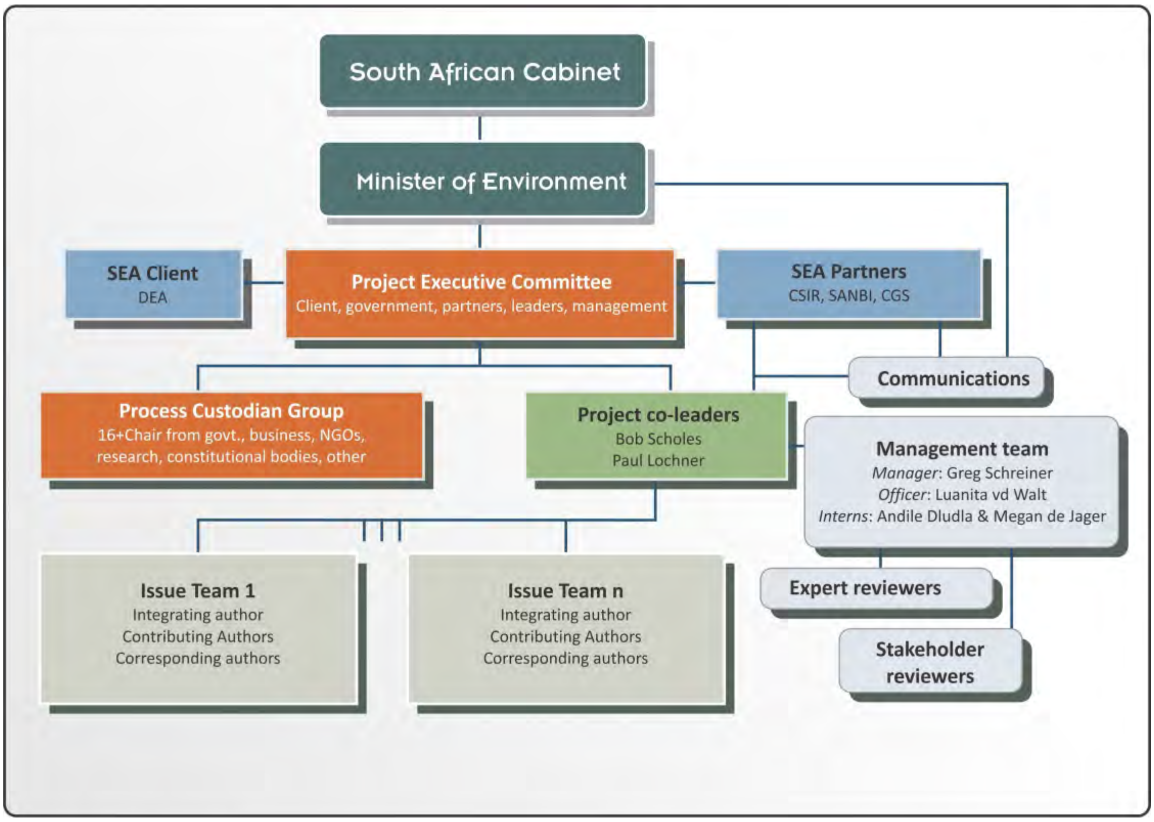


Figure 7: The project governance structure of the entire SEA process showing the interaction between the two governance groups, the SEA partners, the co-leaders and management team, the multi-authors teams, the peer review experts and stakeholders.

9. THE MULTI-AUTHOR TEAMS

In order to advance the principles of balance and comprehensiveness, the main topics in the assessment have been addressed by multi-author teams, rather than the approach often applied in EIAs of using a single expert or consulting group. Each of the Chapters has a team of three to 20 authors - all selected on the basis of their acknowledged *expertise*.

Expertise is usually evidenced by appropriate formal qualifications and experience, but may also be evidenced by widespread peer-group agreement that the candidate has expertise on the topic and by a track record of outputs, widely acknowledged to be of value. Authors have been drawn from a broad range of sectors, including research institutions, consultancies, government, NGOs and universities, and across different regions of South Africa, to ensure a balance of interests, disciplinary background, experience and perspective is represented in the teams.

Each team includes one (in some cases two) Integrating Author/s, several Contributing Authors and potentially many Corresponding Authors (Table 3). The latter did not attend writing meetings, but provided small amounts of text on defined, relatively narrow topics, via email. Authors of the 18 Chapters do not represent their home organisations or any particular constituency. They were selected on a personal basis, reflecting their individual capacity to contribute to the scientific assessment.

Table 3: The three author roles and associated responsibilities in drafting the assessment chapters

Integrating Authors	The ***Integrating Authors*** were responsible for ensuring that all the components written by Contributing and Corresponding Authors were delivered on time, and were incorporated in a logical fashion in each Chapter; and that the scope of the Chapter, as decided at the first workshop, was covered. Integrating Authors ensured that the responses to comments from stakeholders and peer reviewers have been adequately addressed and/or incorporated and documented.
Contributing Authors	The ***Contributing Authors*** were expected to attend all three writing workshops and actively participate in the discussions and decisions there. They delivered text, references, tables and graphics to their Integrating Author/s by agreed dates, and according to agreed formats and templates. They assisted in addressing reviewer comments (especially those relating to text they have contributed).
Corresponding Authors	The ***Corresponding Authors*** typically (although not always) wrote less than one published page - often a box, a table, illustration or a few paragraphs. They delivered text, references, tables and graphics to their Integrating Author/s by agreed dates, and according to agreed formats. They may have been requested to assist in addressing reviewer comments relating to the specific text they provided. Corresponding Authors did not attend writing meetings.

10. PEER AND STAKEHOLDER REVIEW PROCESS

The FODs of each Chapter, written by the multi-author teams, were sent to a minimum of two, and a maximum of six, peer reviewers. The expert peer reviewers were identified from existing scientific publications collected throughout the process and through nominations from the management team, general stakeholders, the PEC and PCG and Chapter Authors. A total of 71 peer reviewers, from international, national and provincial government departments, NGOs, academia and research institutions; and the private sector provided peer review comment on the FODs. Of the 71 peer reviewers, 25 were drawn from South Africa and 46 from other regions of the world, such as the United States, Canada, Australia, the United Kingdom, the European Union and others.

The comments received for each Chapter followed a structured format. The expert peer review submissions were collated into a database for each Chapter, and sent to the author teams prior to the second multi-author team meeting in April 2015. Following incorporation of the comments made on the FOD Chapters, the SOD Chapters were redrafted and sent back to the peer reviewers along with the itemised responses to their comments on the FOD to check that their comments had been sufficiently addressed and at the same time they were released for stakeholder comment in July 2016. All responses to peer review and stakeholder comments have been available and are in the public domain via the project website: http://seasgd.csir.co.za/

The stakeholders were required to follow the same prescribed structure for commenting on the SOD Chapters, in which page and line numbers were provided for each comment. As for the expert reviewers, the stakeholder comments were required to be specific, clear and constructive, and where possible, backed up with references or evidence. The authors addressed the stakeholder comments individually and incorporate appropriate comments into the final scientific assessment.

11. PARTICIPATION

There were four ‘pathways’ for participation through the process. These were designed to be appropriate for various stakeholders. None of the pathways for participation were mutually exclusive of the others e.g. if an individual were a member of the PCG, there was no restriction on participating in the process as a stakeholder by attending public meetings or making comments on draft material. The four pathways were: A.) Through project governance structures (discussed in Section 8); B.) Through the generation of salient questions to define the scope of the assessment; C.) Through the actual content generation of the assessment, developed using the highly inclusive the multi-author team approach (discussed in Section 9); D.) Through stakeholder commentary, public outreach and the review of draft content materials (discussed in Sections 4 and 10).

The 17 specific topics addressed in the scientific assessment were generated by a combination of ‘top down’ and ‘bottom up’ dialogs (Figure 4). ‘Candidate’ topics were gleaned from reviews of SGD literature housed in an extensive electronic library developed specifically for the assessment over 12 months. Topics were then debated and revised, were necessary, by the project governance structures and with stakeholders in public deliberation. The questions of the broader public were gathered in early rounds of three local community meetings in the Central Karoo and a consultative workshop with registered stakeholders in Cape Town in November 2015.

In July 2016, before finalisation of the scientific assessment report, the draft findings were presented to the same local and stakeholder communities to check that the key questions which had been raised in November 2016, had been adequately addressed. Feedback was incorporated via the standard review process (i.e. page/line numbered comments) and facilitated where necessary by capturing verbal input at the meetings for stakeholders without access to internet. Throughout the process, the management team used multiple communication mediums such as face-to-face meetings, the publication of written documents, explanatory video graphics and materials on the project website, interviews with the media and press releases and even novel approaches to raising awareness such as art exhibitions.

The primary, by not exclusive, means of communication was via the project website (http://seasgd.csir.co.za/), launched on 13 May 2015 following the parliamentary launch of the SEA. By the time of the scientific assessment publication, there were in excess of 600 registered stakeholders (Figure 8). This was a deliberate result of public outreach meetings over this period, where meetings were widely advertised through national and local radio stations, direct liaison with municipalities, the release of flyers to local communities, bulk sms distribution, newspaper adverts in provincial and local media houses, social media notices such as Facebook, dissemination of notice through government channels such as South African Local Government Agency and members of the PEC and PCG. Figure 9 provides the geographical distribution of stakeholders who participated in the process.

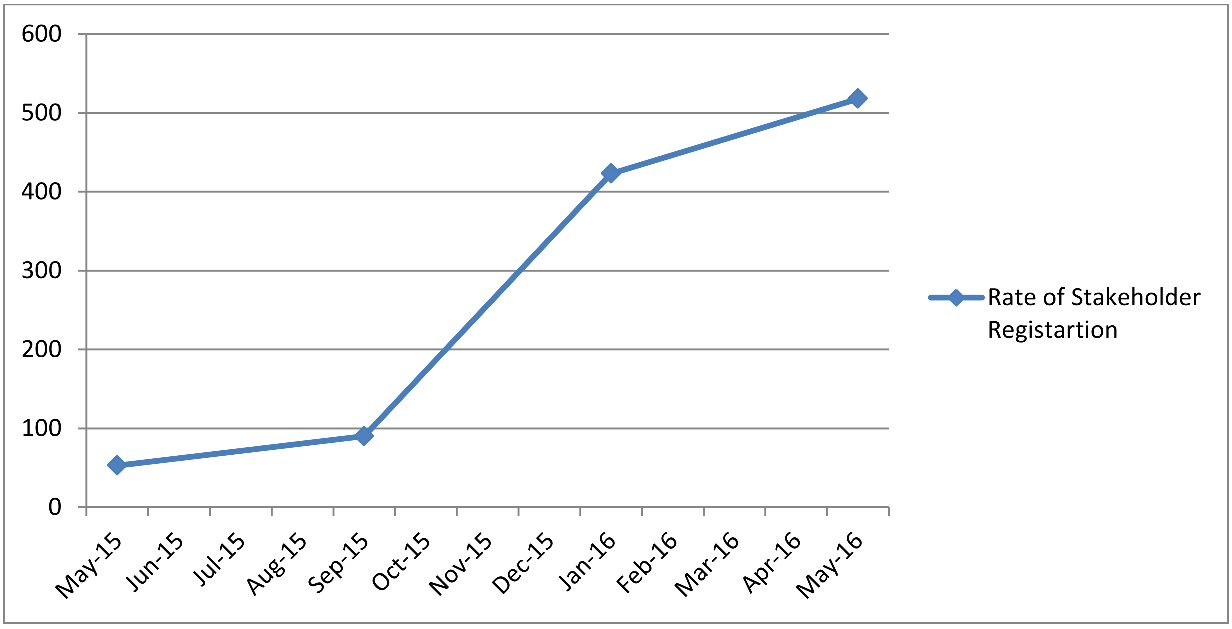


Figure 8: The rate of stakeholder registration over a 12 month period from May 2015 to May 2016. From the date of the launch until end-June 2015, the management team received 53 online registrations. During the period between early-July and end-September a further 37 online registrations were

received. During the period between early-October 2015 and end-Jan 2016 there was a substantial increase in online registration; the management team received 333 registrations.

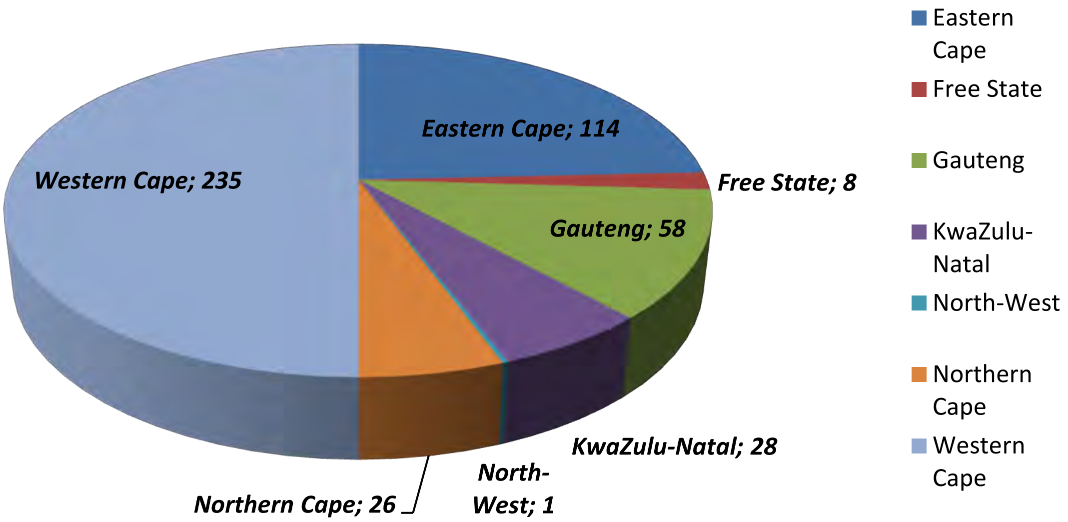
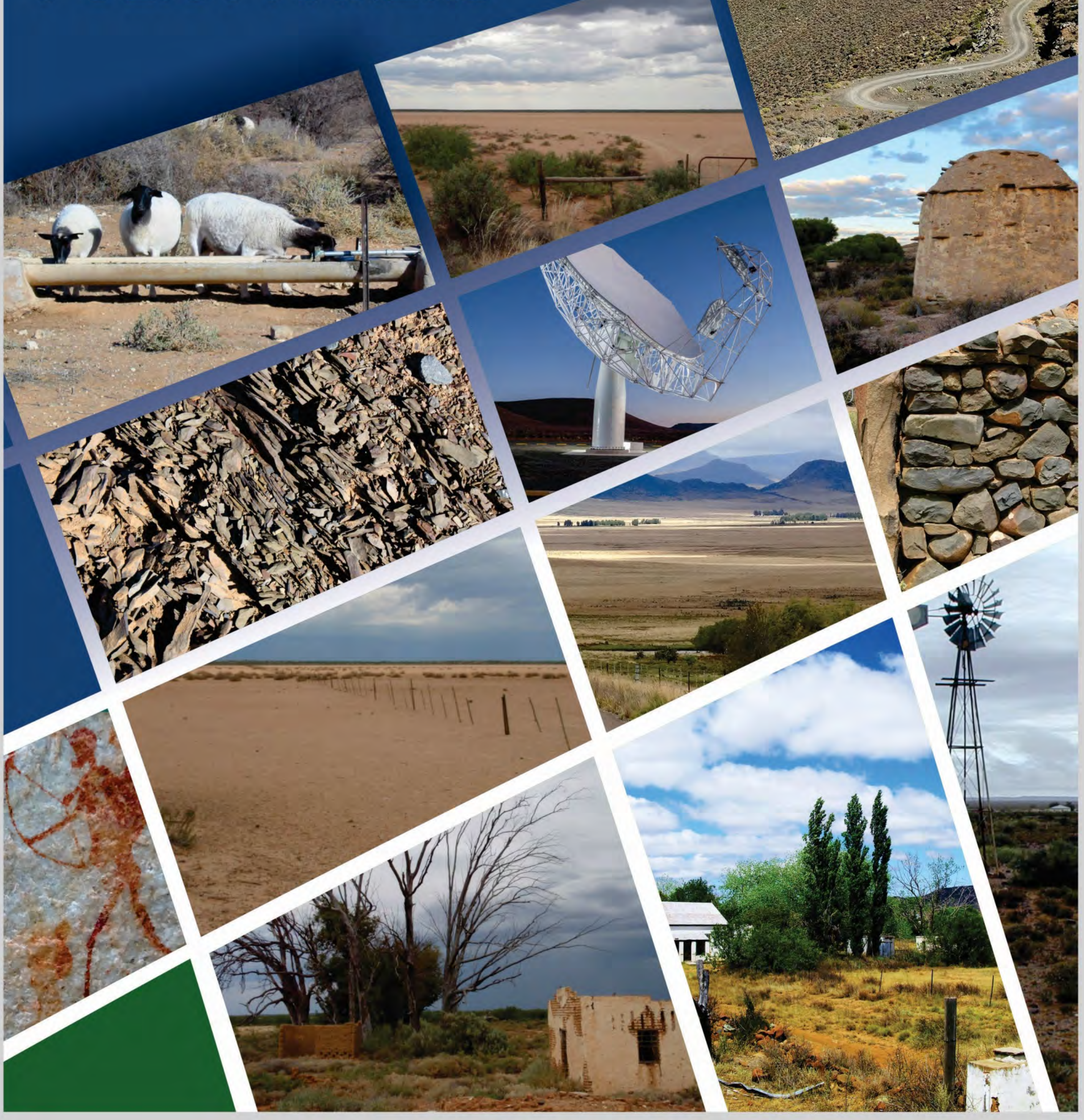


Figure 9: Registered stakeholders were resident in seven of the provinces, most of them based in the Western Cape. A number of online registrations did not indicate their province and cities therefore they have not been accounted for in the figure. In the Eastern Cape most of the stakeholders were based in Graaff-Reinet and Port Elizabeth, in the Free State the majority were from Bloemfontein, in Gauteng there is an equal split between Pretoria and Johannesburg. In KwaZulu-Natal the majority of stakeholders were based in Durban and a few in Pietermaritzburg. Victoria West had most of the stakeholders in Northern Cape, and the Western Cape was roughly equal between Beaufort West and Cape Town.

Shale Gas Development in the Central Karoo:

A Scientific Assessment of the Opportunities and Risks

SUMMARY FOR POLICY MAKERS



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SUMMARY FOR POLICY-MAKERS

Edited by Bob Scholes, Paul Lochner, Greg Schreiner,
Luanita Snyman-Van der Walt and Megan de Jager

Electronic publication

Authors

Selwyn Adams, Graham Alexander, John Almond, Katye Altieri, Megan Anderson, Emma Archer van Garderen, Doreen Atkinson, Karin Badenhorst, Dave Baldwin, Oliver Barker, Corinna Bazelet, Stephen Berrisford, Roger Bills, Tobias Bischoff-Niemz, Christy Bragg, Bill Branch, Peter Bruyns, Michael Burns, Clinton Carter-Brown, Albert Chakona, Matthew Child, Simon Clarke, Nicholas Clarke, Ralph Vincent Clarke, Henk Coetzee, Andrew Coetzer, Willem Coetzer, Jonathan Colville, Werner Conradie, Fahiema Daniels, Claire Davis, Elizabeth (Liz) Day, Jenny Day, Megan de Jager, Michael de Jongh, Richard Dean, Moctar Doucouré, Amanda Driver, Gerrie du Rand, Justin du Toit, Katie du Toit, Raymond Durrheim, Connal Eardley, Ismail Ebrahim, Dave Edge, Surina Esterhuyse, Justine Ewart-Smith, Saliem Fakir, Roger Fisher, Rebecca Garland, Dave Gaynor, Simon Gear, Caroline Gelderblom, Bettina Genthe, Cheri Green, Simon Hall, Michelle Hamer, Dai Herbert, Philip Hobbs, Danita Hohne, Stephen Holness, Liana Jansen, Adrian Jongens, Marthie Kemp, Mahlatse Kgatla, James Kinghorn, Menno Klapwijk, Gerrit Kornelius, Patricia Kramer, Kedibone Lamula, Quinton Lawson, Given Leballo, Anthony Leiman, Lehman Lindeque, Paul Lochner, Leslie London, Robin Lyle, Judy Maguire, Ashton Maherry, Antonia Malan, Norma Malatji, Mervyn Mansell, Sethulego Matebesi, Dave McKelly, Ian McLachlan †, Matthew Meas, Silvia Mecenero, John Midgley, Vunganai Midzi, Jolynn Minnaar, Musa Mlambo, David Morris, Muvhuso Mosetsho, Zainab Mowzer, Hlengiwe Mtshali, Bernard Oberholzer, Suzan Oelofse, Noel Oettlé, Mark Oranje, Jayson Orton, Anthony Osler, Braam Otto, Phil Paige-Green, Louwrens Pretorius, Domitilla Raimondo, Nick Rivers-Moore, Peter Rosewarne, Nigel Rossouw, Hanna-Andrea Rother, Melville Saayman, Igshaan Samuels, Catherine Schenk, Bob Scholes, Johan Schoonraad, Greg Schreiner, Roland Schulze, Leanne Seeliger, John Simaika, Andrew Skowno, Kate Snaddon, Luanita Snyman-Van der Walt, Barry Standish, Herman Staude, Maronel Steyn, Adrian Tiplady, Simon Todd, Daan Toerien, Krystal Tolley, Ikechukwu Umejesi, Les Underhill, Dewidine van der Colff, Paul van der Merwe, Elsona van Huyssteen, Wikus van Niekerk, Simon van Noort, Lize von Staden, Hugo van Zyl, Susi Vetter, Andrew Wade, Mieke Willems, Harald Winkler, Jarrad Wright, Graham Young, Owen Zinaman

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THE ORIGIN, PURPOSE AND METHOD OF THIS ASSESSMENT

The potential economic and energy security opportunities of a medium to large shale gas resource could be substantial for South Africa; as are both the potential social and environmental risks associated with a domestic gas industry in the Central Karoo. The development of shale gas using vertical and horizontal drilling and hydraulic fracturing or 'fracking' technologies, has been presented to the South African public and decision makers as a trade-off between economic opportunity and environmental protection. As such, it has become a highly divisive topic in South Africa, but one which has been, up to now, poorly informed by publically-available evidence.

To address this lack of critically-evaluated information, a Strategic Environmental Assessment (SEA) for shale gas development[1] (SGD) was commissioned in February 2015 by the Republic of South Africa, represented by the Department of Environmental Affairs with the support of the Departments of Energy, Mineral Resources, Water Affairs and Sanitation, Science and Technology, and Agriculture, Forestry and Fisheries; and the Provincial Departments of the Eastern, Western and Northern Cape Governments.

Phase 2 of the overarching SEA process - the contents of this published volume - was undertaken as a 'scientific assessment', guided by the principles of *saliency*, *legitimacy* and *credibility* (see Preface, Scholes et al. 2016). The 18 Chapters of the scientific assessment were drafted by 146 authors and peer reviewed by a further 25 local and 46 international independent peer review experts, and by a large number of stakeholders involved in the process. The key objective of the scientific assessment is to provide society with an evidence base, at a strategic level, which will assist South Africa in developing a better understanding of the risks and opportunities associated with SGD, if it occurs in South Africa. The geographical scope of the scientific assessment study area is provided in Figure SPM 0.2.

The Summary for Policy-Makers (SPM) is a concise compendium of the key findings of the scientific assessment[2]. The methodology for the assessment is based on the concept of 'risk', but this does not mean that the opportunities associated with SGD are not also assessed in a balanced fashion. The SPM begins with Chapter 1 (Burns et al., 2016) which provides, in as much detail as feasible, the

[1] The term "shale gas development" (SGD) refers to all exploration and production related activities, as well as downstream gas utilisation scenarios, encompassing the full life-cycle of impacts typical of a SGD programme. In Chapter 1 (Burns et al., 2016), clear distinction is made between the phases of SGD to distinguish the nature and extent of SGD activities which can be logically assumed across the scenarios.

[2] The symbol '§', which is located at the end of concluding statements or paragraphs in the SPM, denotes the location of the Chapter and sub-section where the evidentiary base for the summary statement/s can be traced to the specific reference source.

scale and type of activities which would logically be associated with three SGD scenarios; measured against a Reference Case scenario, where no SGD takes place. This includes introductory text explaining the current understanding of the petroleum geology of the Central Karoo.

Based on the information contained in Chapter 1, Chapters 2-18 undertake a rigorous and systematic risk assessment of the impacts relating to SGD based on a transparent expert judgement process. This allows for the consideration all impacts of an issue in a common way and where possible, within a spatial context. Risk is determined by estimating the *likelihood* of impacts occurring, in relation to their *consequences* i.e. *likelihood x consequence = risk* (Figure SPM 0.1). Risk is assessed for each significant impact, on different types of receiving entities e.g. the rural poor, a sensitive wetland, important heritage feature etc. It is qualitatively assessed into the following categories: *undiscernible, very low, low, moderate, high* and *very high.* The risk categories are predefined as a set of criteria which explain the nature and implications of the risk ascribed (Table SPM 0.1). For each topic, consequence levels have been determined by the individual chapter teams across the different disciplinary domains i.e. *slight, moderate, substantial, severe* and *extreme*. This means that all risk categories across the different topics are 'calibrated', which makes them comparable, both conceptually and within a spatial context.

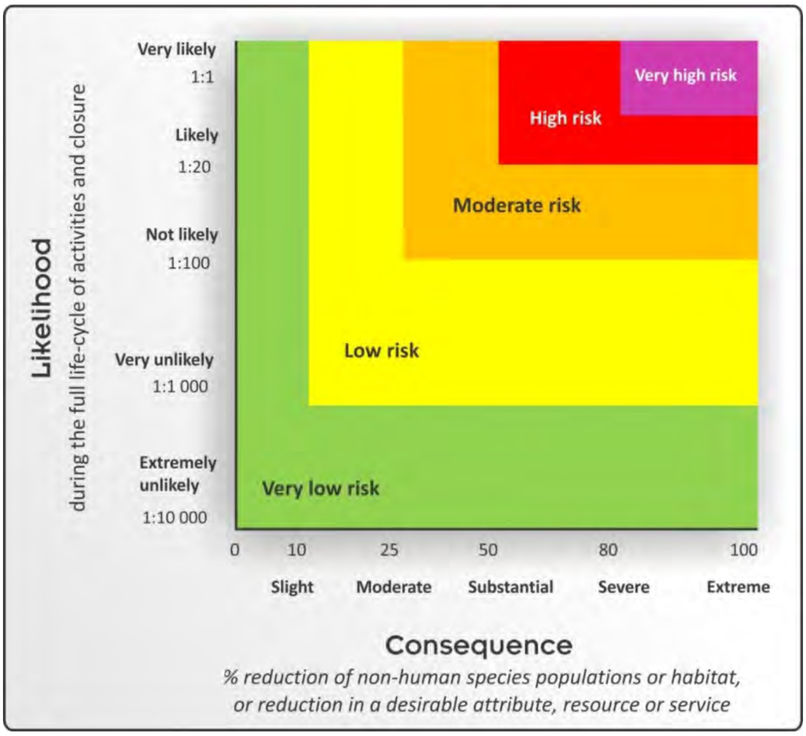

Figure SPM 0.1: Risk assessment diagram showing *likelihood x consequence* to determine risk. Risk is qualitatively measured by multiplying the likelihood of an impact by the severity of the consequences to provide risk rating ranging from very low, low, moderate, high and very high.

Table SPM 0.1: Predefined set of criteria applied across the Chapters of the scientific assessment.

Risk category	Definition
No discernible risk	Any changes that may occur as a result of the impact either reduce the risk or do not change it in a way that can be differentiated from the mean risk experienced in the absence of the impact.
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Low risk	Very unlikely (<1 chance in 100 of having a more than moderate consequence); or if more likely than this, then the impact is of moderate consequence because of one or more of the following considerations: it is highly limited in extent (<1% of the area exposed to the hazard is affected); or short in duration (<3 years), or with low effect on resources or attributes (<25% reduction in species population, resource or attribute utility).
Moderate risk	Not unlikely (1:100 to 1:20 of having a moderate or greater consequence); or if more likely than this, then the consequences are substantial but less than severe, because although an important resource or attribute is impacted, the effect is well below the limit of acceptable change, or lasts for a duration of less than 3 years, or the affected resource or attribute has an equally acceptable and un-impacted substitute.
High risk	Greater than 1 in 20 chance of having a severe consequence (approaching the limit of acceptable change) that persists for >3 years, for a resource or attribute where there may be an affordable and accessible substitute, but which is less acceptable.
Very high risk	Greater than even (1:1) chance of having an extremely negative and very persistent consequence (lasting more than 30 years); greater than the limit of acceptable change, for an important resource or attribute for which there is no acceptable alternative.

What follows in the sections below are the key ‘headline statements’, communicated in a common language, highlighting the most salient opportunities and risks emanating out of the full 18 Chapter assessment. Where appropriate the risk of an impact is provided without and with mitigation, providing the reader with an indication of how the risk profile of an impact changes with adequate mitigation employed. This is also spatially depicted as a composite risk ‘picture’, assessed across the scenarios, without and with mitigation in Section 19.

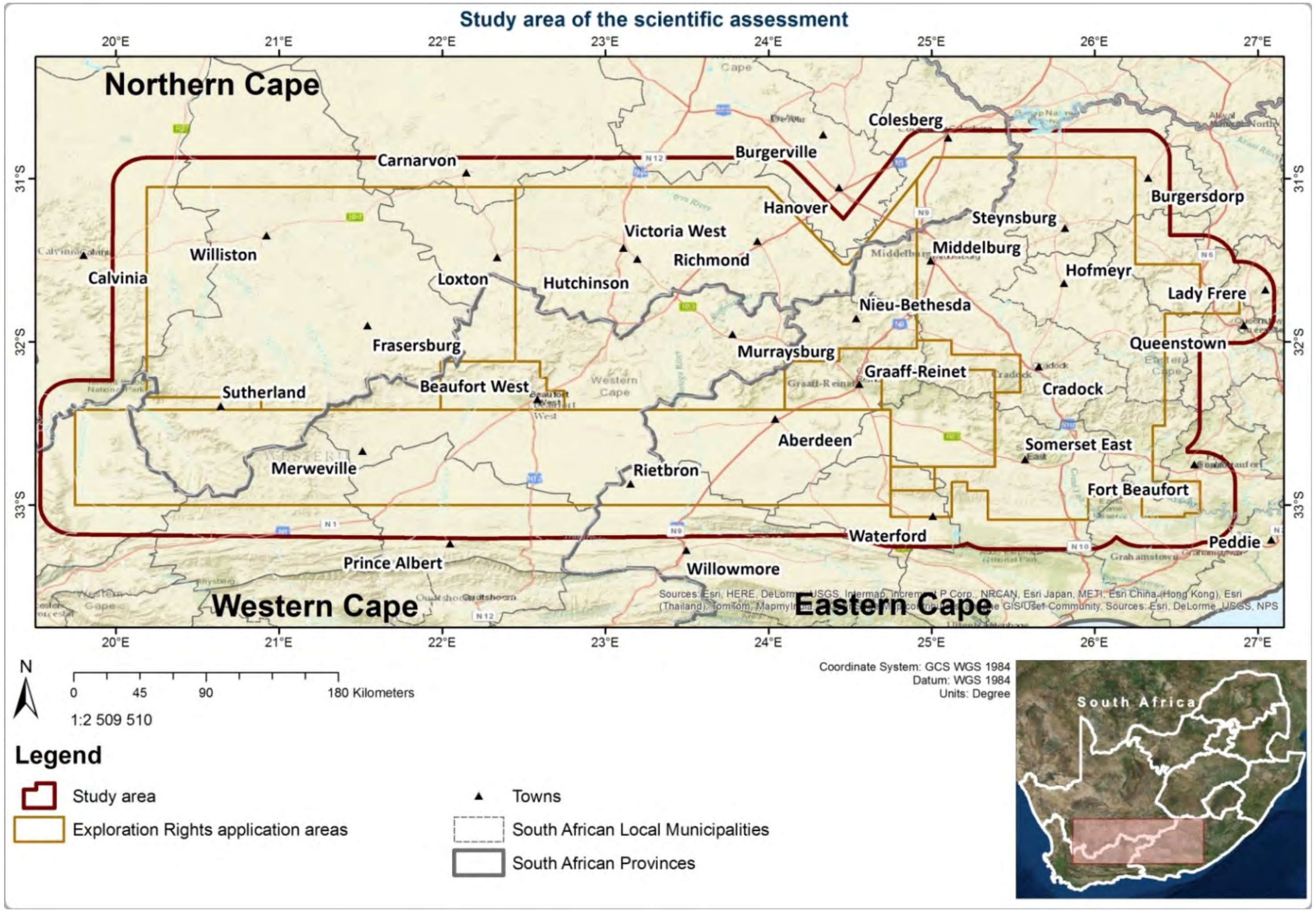


Figure SPM 0.2: Geographical scope of the scientific assessment study area.

The assessment considers SGD activities originating in a 171 811 km^2 region of the Central Karoo, delimited by the applications for Exploration Rights (for shale gas) which have been lodged by Shell, Falcon and Bundu, plus a 20 km buffer. The assessment follows the consequences of SGD in this region to the point of material impact, even if that is outside the study area – as may be the case of impacts on vectors such as air or water which are not spatially static.

1. THE PRESENCE OF NATURAL GAS IN THE CENTRAL KAROO

1.1 The geology of the Karoo Basin

The Karoo Basin is known to contain natural gas. This geological formation underlies 700 000 km^2 of South Africa (Figure SPM 1.1), including the scientific assessment study area, where ~87% of the surface area comprises sandstones, mudstones and shales of the Beaufort Group. From flat-lying structures in its northern part, the basin deepens and the sedimentary layers thicken towards the south-west, up to its interface with the mountains of the Cape Fold Belt. [§1.3.1]

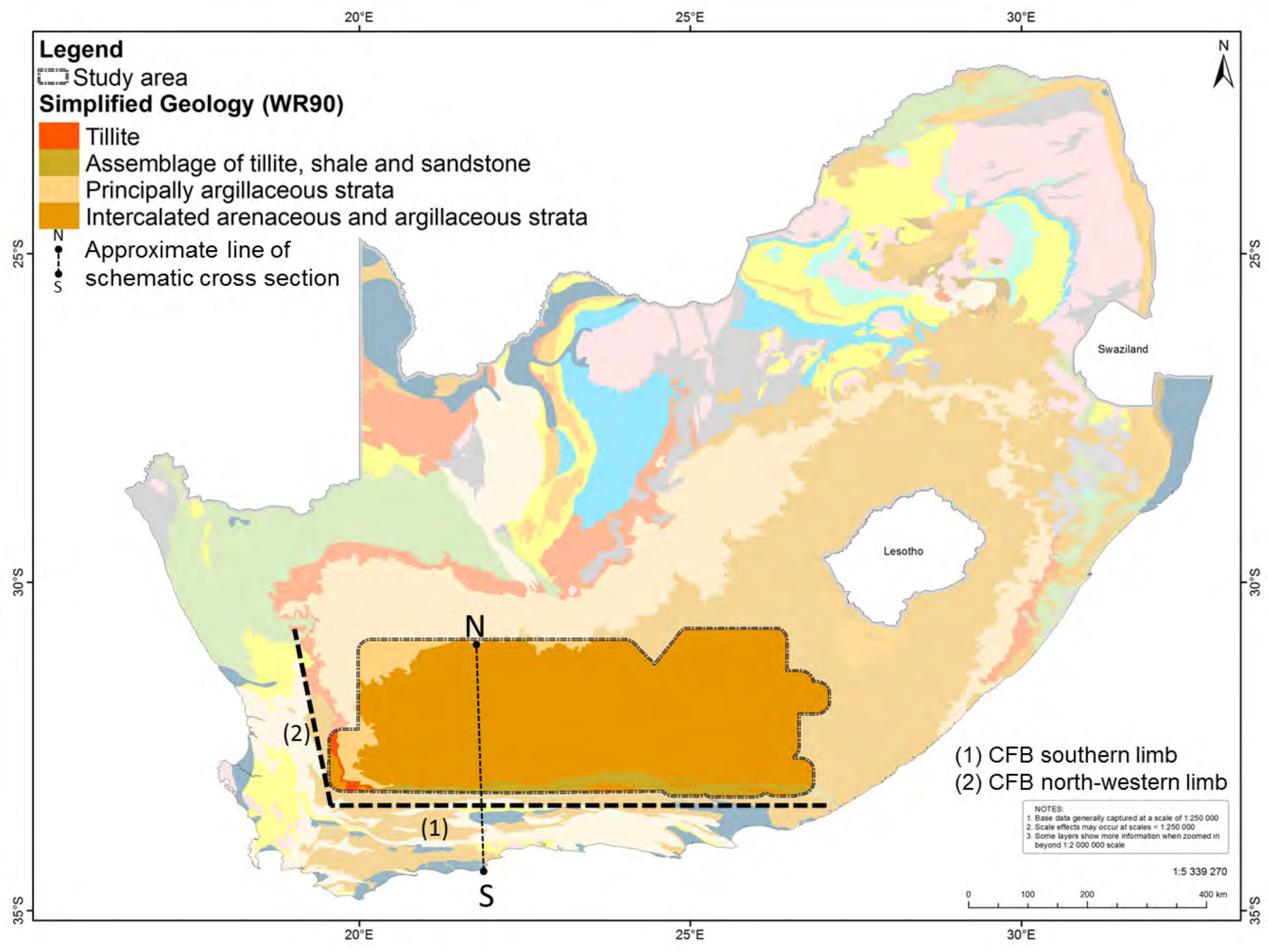


Figure SPM 1.1: Simplified geology of map of South Africa overlayed with the assessment study area. It shows the substantial extent of the main Karoo Basin (light brown areas) deepening from the north-eastern interior to the south-central interior where it abuts against the southern limb of the Cape Fold Belt (CFB); section line S-N through the study area marks the schematic profile in Figure SPM 1.3.

Natural gas in the Karoo Basin is said to be 'unconventional' in that it does not occur in pockets of porous rock (called "reservoirs"), from which it would flow without stimulation if penetrated by a well. Unconventional shale gas occurs as methane trapped in shale formations of low permeability, from which it can only be released by the process of hydraulic fracturing, popularly known as 'fracking' (Figure SPM 1.2). [§1.1]

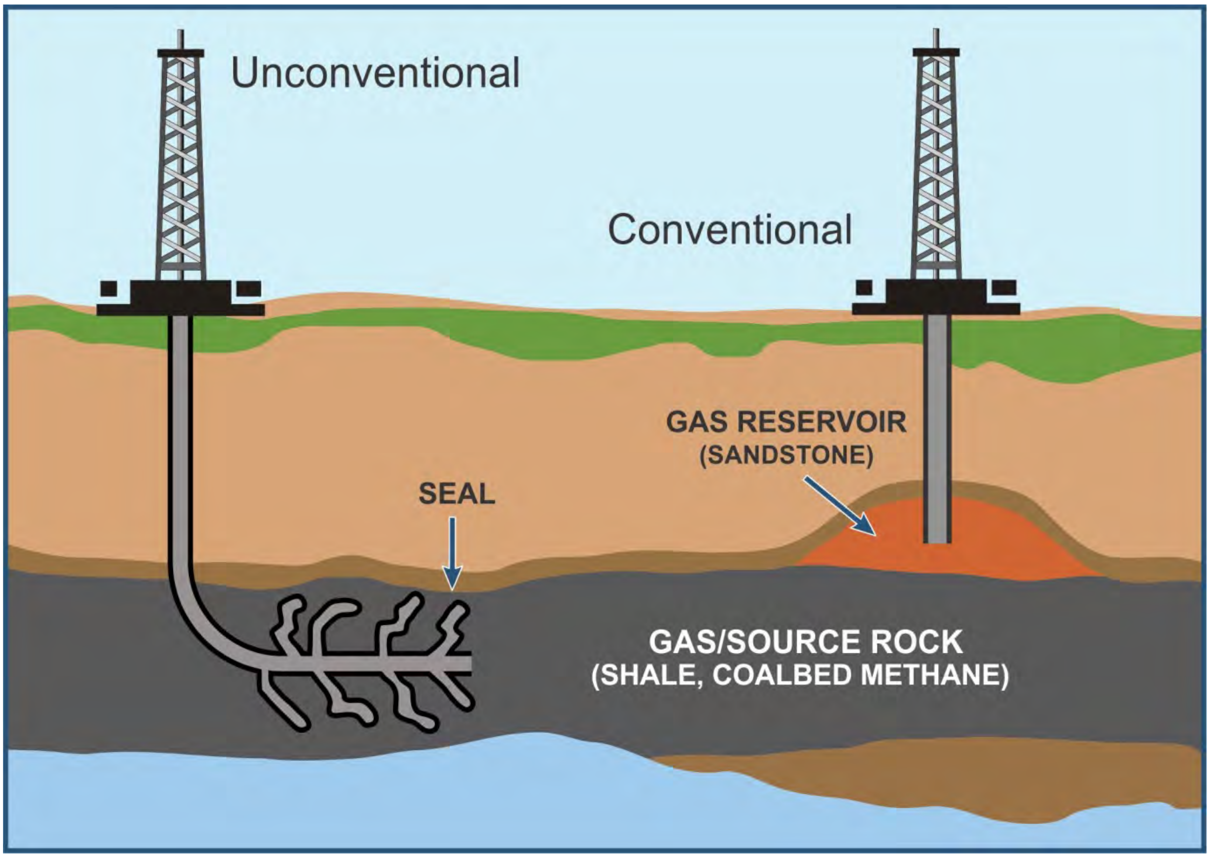


Figure SPM 1.2: Cartoon demonstrating the difference between 'conventional' and 'unconventional' gas reserves.
To extract conventional gas, a hole is drilled into the reservoir and the gas flows out by itself. For unconventional shale gas, such as that which occurs in the Karoo, the source rock lies very deep below the surface. The gas is tightly held and must be released by fracturing the rock around a wellbore, drilled horizontally for a long distance into the gas-containing shale layer
(adapted from http://worldinfo.org/2012/01/point-of-view-unconventional-natural-gas-drilling).

The total quantity of shale gas that occurs within the study area is uncertain, as is where exactly it may be concentrated. There may be no economically extractable gas. Geological upheavals hundreds of millions of years ago, specifically the intrusion of hot lava (dolerite) and the pushing-up of the Cape Fold Mountains are believed to have reduced the volume of gas originally in place. Indications are that remaining gas is most likely concentrated in the area between the Cape Fold Mountains to the south and the doleritic Nuweveld Mountains to the north, and at depths greater than 2 km below the surface (Figure SPM 1.3). [§1.3.1]

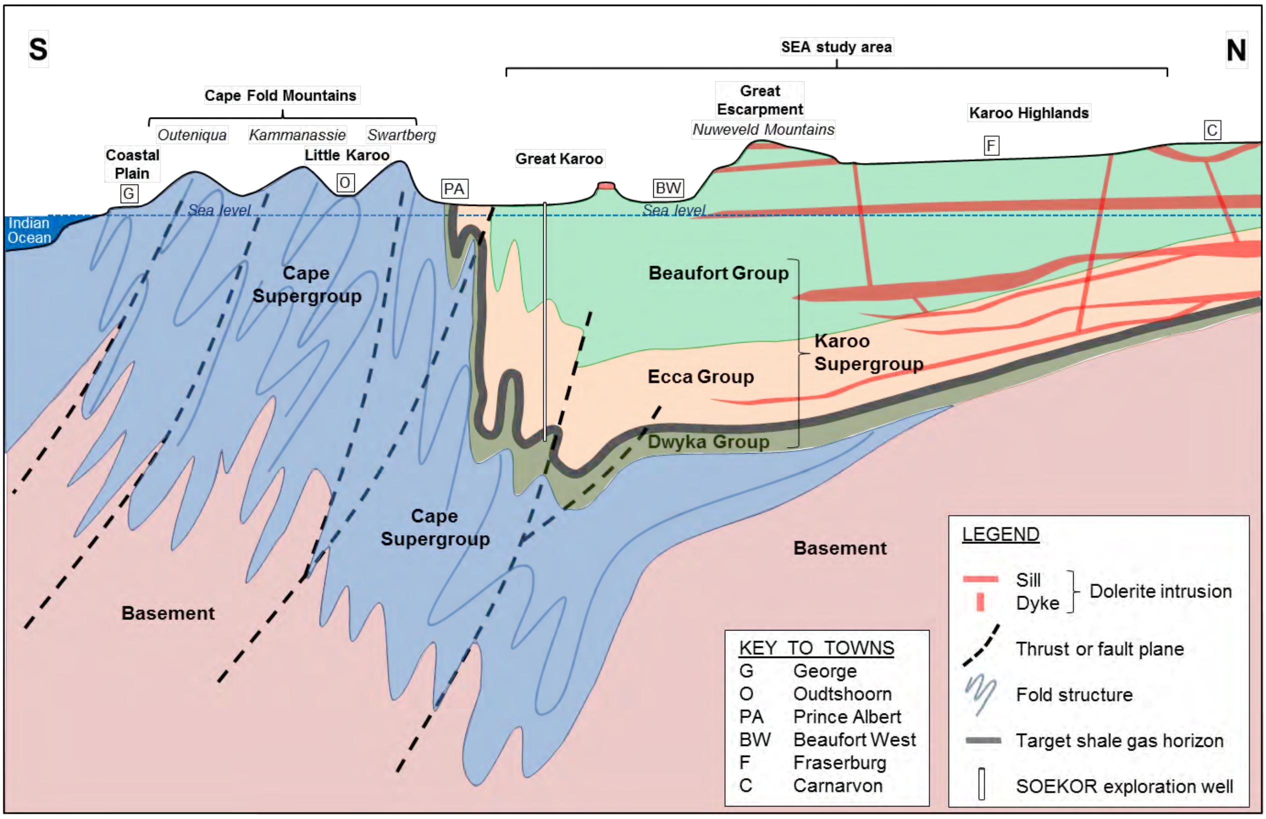


Figure SPM 1.3: Schematic geological profile across the study area.
The profile follows along the S-N section line in Figure SPM 1.1, illustrating the basin-like stratigraphic succession of Karoo Supergroup sedimentary strata in the main Karoo Basin north of the Swartberg Mountains, the Great Escarpment formed by the Nuweveld Mountains, and the underlying Cape Supergroup rocks that pinch out northwards against basement rocks (modified after Rosewarne et al., 2013).

1.2 Stages of shale gas development

SGD entails a broad range of activities which occur in different stages over extended periods of time, at various intensities and each with particular spatial footprints. This assessment covers all the main SGD activities, throughout their lifespan and after they have ceased, for the period during which impacts can be anticipated (Figure SPM 1.4). It addresses associated 'upstream activities' such as seismic surveys, wellpad and other site preparations and drilling deep vertical exploration boreholes. The assessment assumes that if initial exploration results are promising, these activities may be followed by deviated drilling to form horizontal wells that penetrate targeted shale layers, which would be 'fracked' to determine gas yields. Gas production activities could follow, involving the establishment of a wellfield(s), with repeated drilling and fracking exercises. There are a number of surface activities associated with this, such as waste management and transportation of equipment, materials and personnel to and from areas of operations. The assessment also considers 'downstream activities', focusing on how the produced gas could be used economically. [§1.4.2]

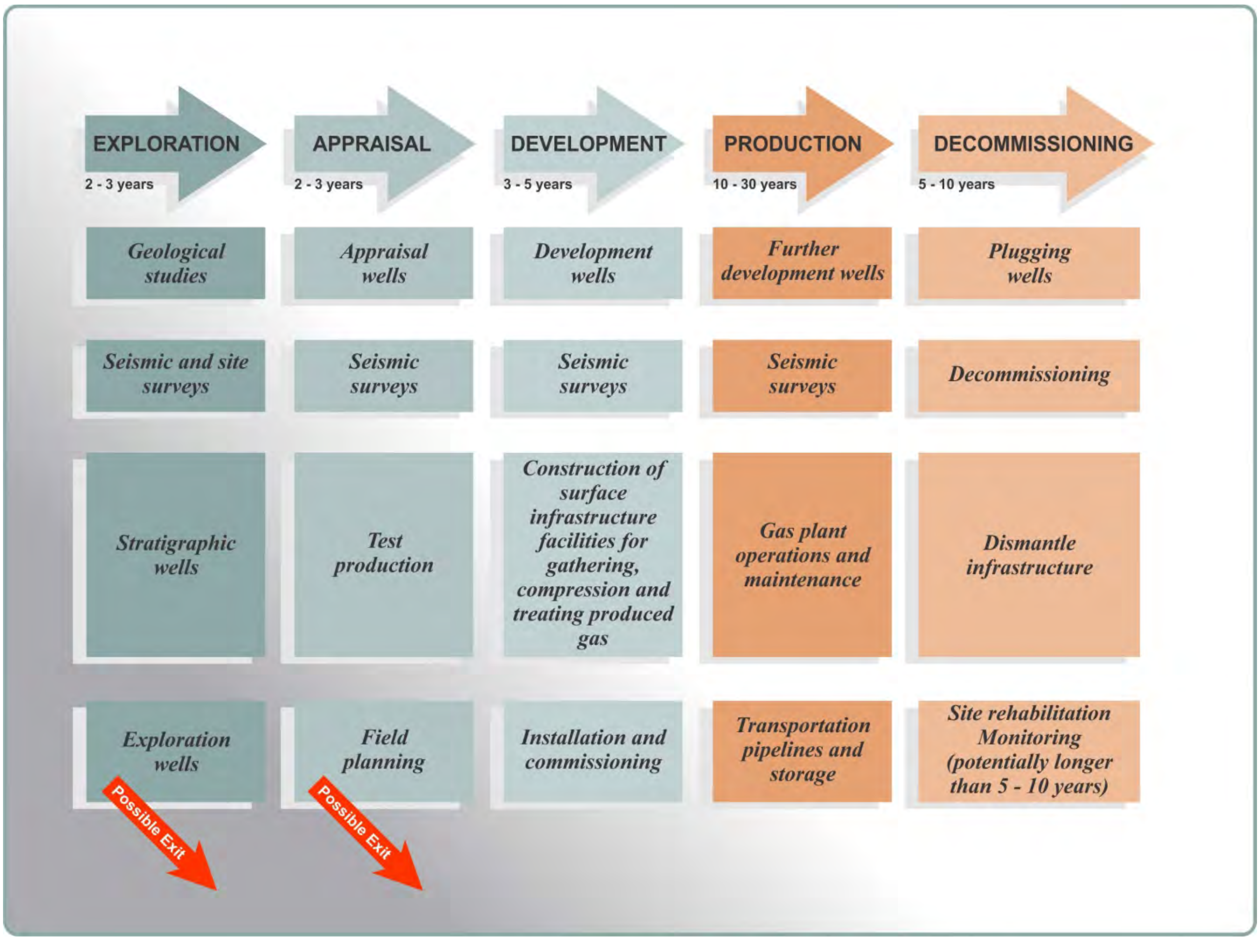


Figure SPM 1.4: Typical life-cycle of a shale gas development programme.
The process diagram shows the stage, timeframes and nature of activities, as well as the possible exit points if gas is not found in sufficient volumes or at flow rates that make production economically unfeasible. Note that this timeline does not account for permitting and regulatory processes that would need to be undertaken in the South African context such as site specific environmental assessments (adapted from National Petroleum Council, 2011).

Exploration is the first stage of the SGD life cycle, but it continues throughout. It is concentrated in the first few years of exploration and then continues into the production stage of the SGD life cycle to guide the location of ongoing drilling and fracking. Exploration involves geological studies, seismic surveys and drilling of vertical stratigraphic wells to obtain geological core samples for analysis. Exploration wells may also yield information on gas concentrations. The appraisal stage follows exploration, and for a single targeted area typically lasts about 2-3 years. It involves drilling appraisal wells, which have vertical and horizontal sections used to penetrate potential gas-yielding shale within the target formation. Appraisal scale fracking is undertaken. Equipment used for drilling and fracking, a range of materials and waste receiving facilities are contained within wellpad areas, each measuring around 2 ha. An area of similar extent to the wellpads is developed for temporary accommodation of drilling crews in the general area of activities. If, during the exploration or appraisal phase, it is revealed that technically recoverable reserves cannot be economically exploited, the wells and surface infrastructure are decommissioned. [§1.4.1]

The production stage of SGD operations might last 10-30 years, probably with the highest level of activity in the first 3-5 years. It involves the development of production wells (and access roads to the wellpads), the establishment of a gas pipeline network to convey produced gas to a central treatment processing, and the export of the treated gas by pipeline for the downstream uses. These would be located within the study area under the Small Gas scenario, or both within and outside the study area under the Big Gas scenario (Section 1.3). Once the production phase terminates, final decommissioning requires a further 5-10 years to be concluded. This involves plugging the wells, dismantling infrastructure and rehabilitating the sites. Monitoring and remediation interventions continue indefinitely. [§1.4.1]

During production, a typical shale gas wellfield occupies an area of about 900 km^2, which contains 50-60 wellpads, each supporting around 10 wellbores. Because the horizontal part of the wellbore extends several kilometres from the vertical part, the wellpads in a production wellfield are typically separated from one another by 3-5 km. While a production wellbore is yielding gas, new wellbores are drilled from the same wellpad, angled in different directions into the gas-containing shale layer. New wells maintain the planned rate of gas production as yields from wells drilled earlier diminishes. Wellpads are accessed by a network of unpaved roads, with the gathering network of buried gas pipelines mostly contained within the road reserves. At the conclusion of various operations, equipment and facilities (the drill rig, temporary structures, storage tanks, pumps, trucks, generators, etc.) are removed from the wellpads (Figure SPM 1.5Figure SPM 1.6). [§1.4.1]

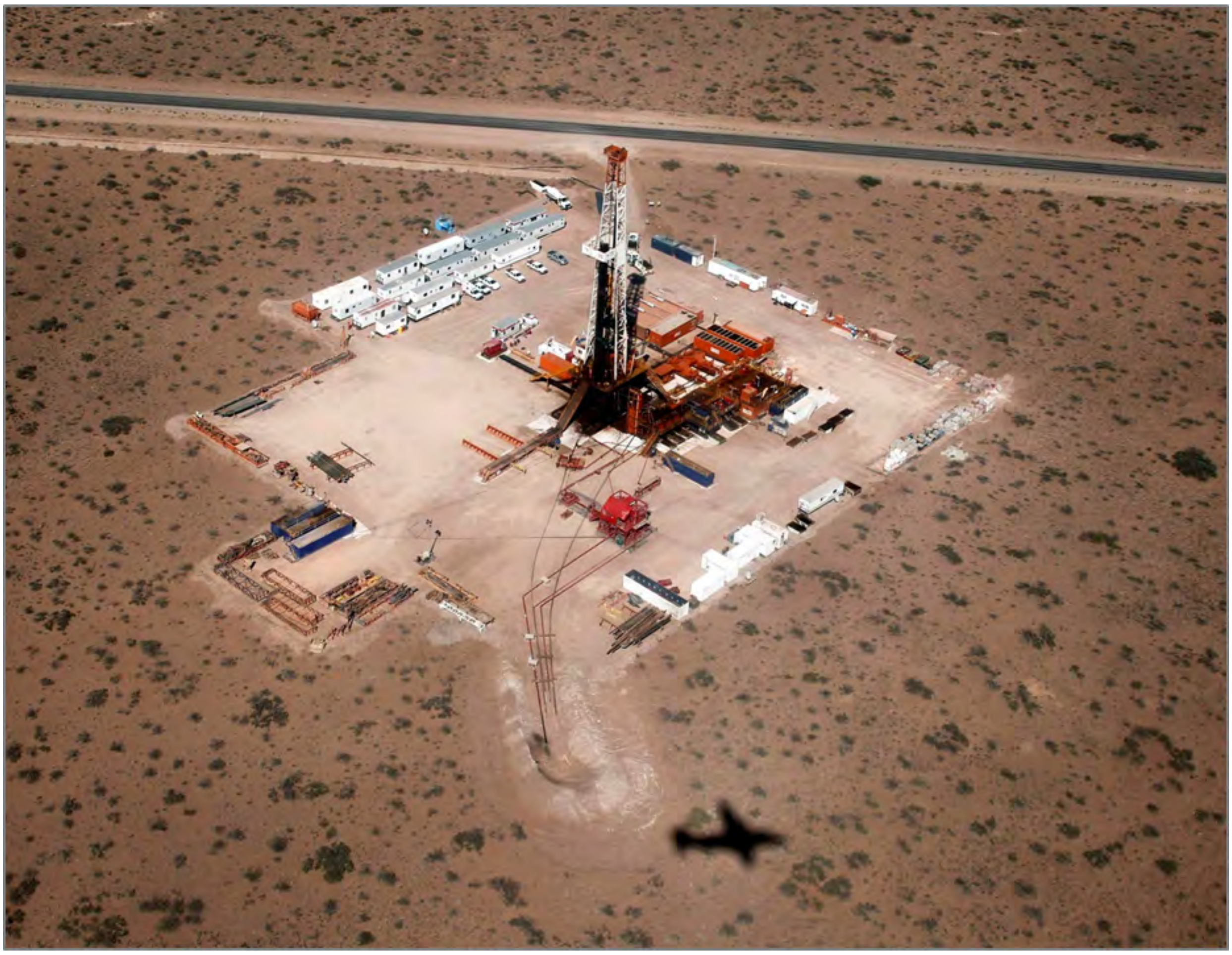


Figure SPM 1.5: Wellpad layout with a drill rig of about 40 m in height within an arid environment in Argentina.
(Source:REUTERS, http://www.vcpost.com/articles/5923/20120925/sidewinder-drilling-to-buy-union-drilling-for-139-mln.htm).

During fracking, 'fracking fluid' is pumped under high pressure into the gas-containing shale layers deep underground, via a horizontal well lined with a perforated steel casing. The high-pressure fluid causes tiny cracks to form in the shale, extending up to a few hundred metres from the well. When the pressure is released and the fracking fluid is pumped back to the surface, gas is released from the fractured shale (Figure SPM 1.7). The gas may flow for several years, at a declining rate.

Figure SPM 1.6: Production wellpad with supporting infrastructure in the United States (see annotations). In terms of current South African legislation, open water storage (impoundment) such as illustrated in this example from North America, would not be permitted. Image sourced from Range Resources Corporation.

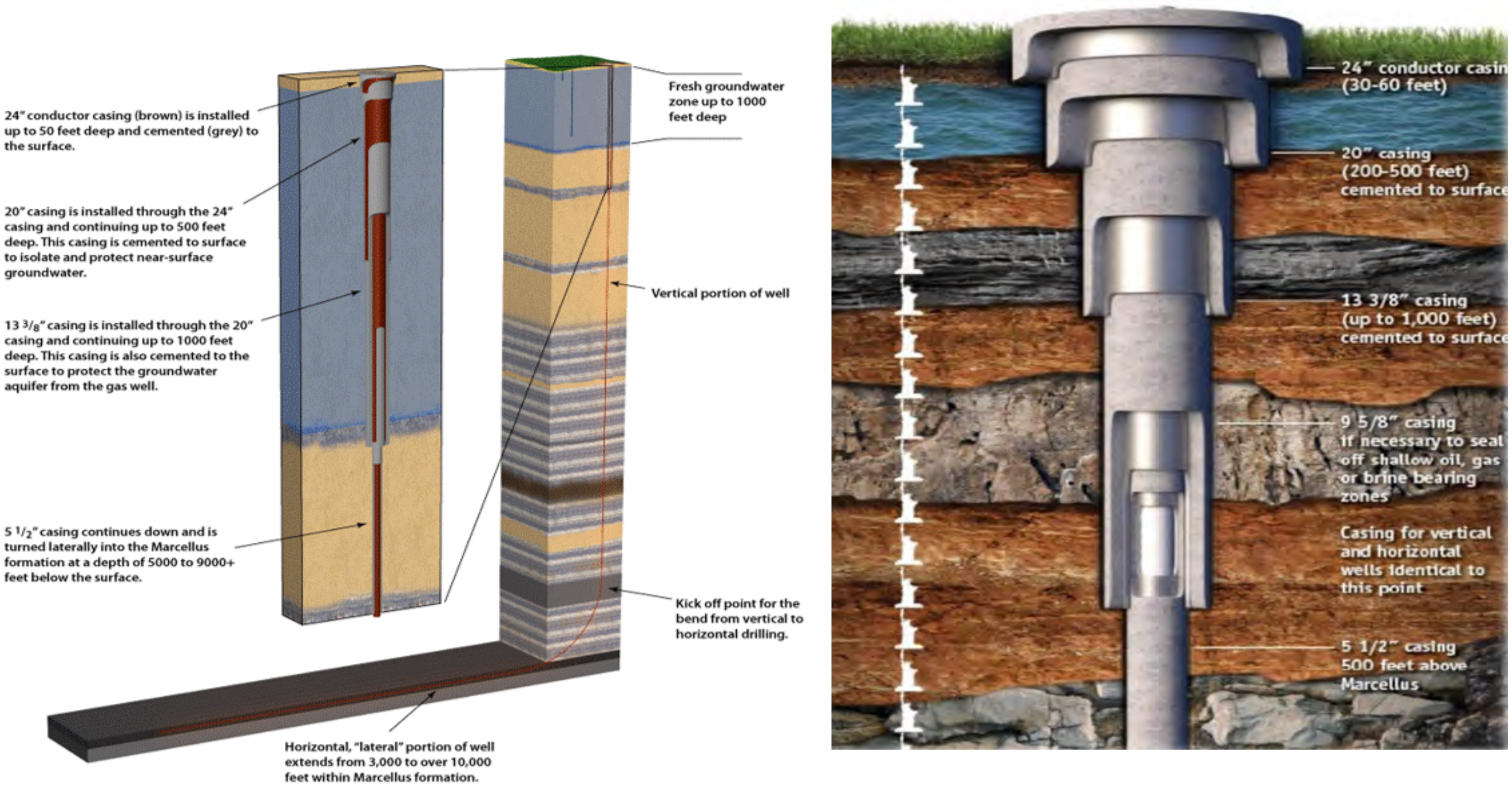


Figure SPM 1.7: Schematic demonstrating the vertical and horizontal drilling processes, typical of those in the Marcellus shale formation of Pennsylvania. The vertical section of the wellbore between the target shale formation and the surface is sealed with a steel casing and cement layers. In the upper sections of the wellbore, where it might pass through freshwater aquifers, multiple casing and cement layers are used. The near-horizontal section of the wellbore, which is 'fracked', runs along the shale gas-containing layer for up to several kilometres. It is lined with steel casing perforated with holes created by explosive charges. Source: Tom Murphy (n.d.), Pennsylvania State University, USA.

The fracking fluid consists of water and several additives, some of which are toxic or hazardous. The several tens of millions of litres of fluid are stored temporarily in tanks on the surface at each wellpad. Once used, the 'flowback' fluid that returns to surface consists of a mixture of the some of the original fracking fluid compounds, with a higher percentage of water and fine solids originating from the targeted shales. As much as possible of the flowback is re-used in later operations. The remnant water after fracking has ceased, is cleaned to a quality specified in legislation, with residual contaminants disposed of in a licensed site in an appropriate manner (SPM Box 1, Figure SPM 1.7). [§1.4.3.2.2.1]

SPM Box 1: The composition of fracking fluid

Over a thousand specific compounds are known to have been added to fracking fluids worldwide. The broad types and their relative quantities and properties are given below. A number of chemicals are currently prohibited from use in South Africa in any fracking activities.

Component	**%**	***Comments***
Water	95	Does not have to be freshwater, saline water can be used
Sand or ceramic proppant beads	4	Props open the cracks. Very fine, so silica in it can be a health hazard to wellpad workers if inhaled
Hydrochloric acid	1	Dangerous in concentrated form, for example, while being transported
Polyacrylamide		Non-hazardous, however breakdown products may be toxic & carcinogenic
Glutaraldehyde		Biocide (poison) used to eliminate corrosion-causing bacteria in water. Toxic and a strong irritant to humans
Polyethylene glycol		Toxic at high concentrations

Some of the fracking fluid injected into the well returns to the surface via the wellbore when the pressure is released. This is called "flowback" may contain compounds present naturally in the geological formation which is fracked. Some of the additional constituents in flowback, such as brine, heavy metals or radioactivity, may also be potentially hazardous. The most hazardous constituents of the flowback are separated and treated in the wellfield, concentrated and dispatched to an off-site disposal site. The remaining fluid can be re-used for further fracking operations. [§1.4.3.2.2.1]

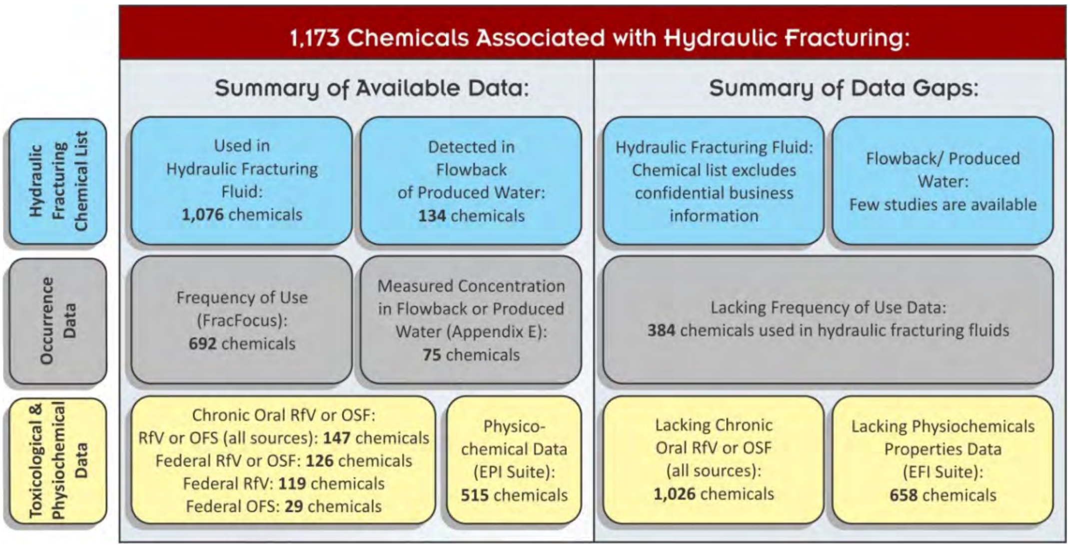


Figure SPM 1.8: Summary of information regarding chemicals used in fracking, highlighting gaps in knowledge.

RfV refers to Reference Value, an estimate of the exposure that is likely to be without an appreciable risk of adverse effects to humans over their lifetime. OSF is the oral cancer slope factor, a measure of carcinogenicity (Environmental Protection Agency, 2015). [§1.4.3.2.2.1]

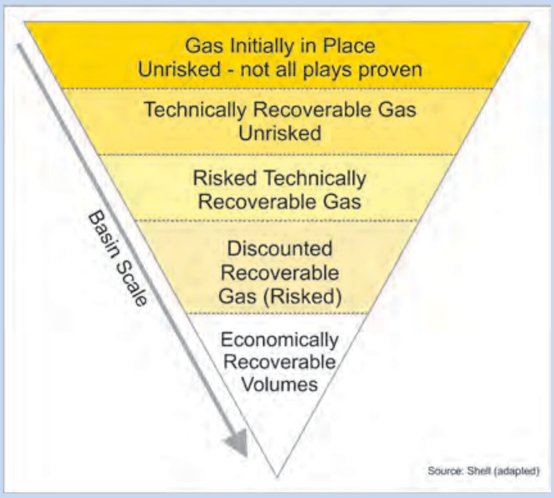
1.3 Shale gas development scenarios and activities

There is no history of production of shale gas in South Africa, so this description of potential scenarios and related activities is necessarily hypothetical. A summary of the main activities of SGD, for three scenarios, is provided in Table SPM 1.1. For detailed information, see Chapter 1 (Burns et al. 2016).

For the assessment, the *Reference Case* assumes shale gas exploration does not proceed. For this scenario (and the other scenarios included in the assessment), regional trends such as human migration, shifting economic activities and new development alternatives in the Central Karoo are assumed to continue. Climate change is assumed to have marked effects on ecosystems and the services they provide to communities. [§1.2.3]

In the *Exploration Only* scenario, exploration is assumed to take place, but not production. Exploration results reveal that production would not be economically viable. All sites are rehabilitated, drilled wells are plugged and monitoring of the abandoned wells is implemented. National energy needs, based on gas, are supported by imported gas product. [§1.4.3]

SPM Box 2: Economically recoverable gas volumes at the basin scale



Technically recoverable resources represent the volumes of natural gas that could be produced with current technology, regardless of petroleum prices and production costs. A large number of direct sub-surface measurements (depth, mineralogy, total organic content, thermal maturity, etc.) gathered by current drilling technology need to be undertaken to quantitatively calculate a technically recoverable gas reserve. Economically recoverable resources are those that can be profitably produced under current market conditions. The economic recoverability of gas resources depends on three factors: the costs of drilling and completing wells, the amount of gas produced from an average well over its lifetime, and the prices received for the produced gas. [§1.3.2]

Under the *Small Gas* scenario about 5 trillion cubic feet (Tcf) of gas are extracted. For comparison, the Mossel Bay offshore gas field will yield a total of about 1 Tcf. Downstream development in the Small Gas scenario results in a 1 000 MW combined cycle gas turbine (CCGT) power station located within 100 km of the production block. [§1.4.4]

The *Big Gas* scenario assumes a relatively large shale gas resource of 20 Tcf is developed. For comparison the offshore conventional gas fields in Mozambique contain about 100 Tcf. Downstream development results in construction of two CCGT power stations, each of 2 000 MW generating capacity, and a gas-to-liquid (GTL) plant, located at the coast, with a refining capacity of 65 000 barrels (bbl) of liquid fuel per day. [§1.4.5]

Certainty about what technically and economically extractable gas reserves may occur within the study area requires detailed exploration, including test fracking of the Karoo Basin shales. It is possible that no economically recoverable gas reserves exist at all in the study area. At the other extreme, the economically recoverable reserves may be greater than the Big Gas scenario considered here – in which case, associated impacts of SGD will be quantitatively larger, but not qualitatively different. Typically, only a small fraction of the total amount of gas present in a shale formation can actually be extracted at an affordable cost (SPM Box 2). The economic viability of SGD in the Central Karoo will depend on the gas price and production costs at the time when the gas is produced, which will be many years from now, if at all. In the interim, the extraction technology may advance, lowering the costs associated with production in the future. [§1.3.2]

Table SPM 1.1: Summary of the activities described in the three shale gas development scenarios.

Unit	Exploration Only	Small Gas	Big Gas
Trillion cubic feet (Tcf)	-	5	20
Production block/s [30 x 30 km well field]	-	1	4
Combined cycle gas turbine [1 000 MW]	-	1	-
Combined cycle gas turbine [2 000 MW]	-	-	2
Gas-to-liquid plant [65 000 bbl]	-	-	1
Number of wellpads [2 ha each]	30	55	410
New roads (km) [unpaved, 5 m wide]	30	58	235
Total area of wellpads and new roads (ha)	75	199	998
Percentage spatial coverage of study area	< 0.0001	0.0002	0.0009
Total number of truck visits	45 000	365 000	2 177 000
Industry water needs (m^3) [assuming no re-use of fluids]	*488 250	**9 212 625	***65 524 500
Industry water needs (m^3) [assuming re-use of 50% drill fluid + 30% frack fluid]	*319 110	**6 056 160	***43 087 235
Flowback waste (m^3) [sludge + brine + water]	*101 400	**5 573 900	***40 356 400
Other hazardous waste (t) e.g. oil, grease	*85	**635	***4 185

* For five exploration drilling campaigns, each with six exploration wells = total 30 wells over lifetime of Exploration Only
** For 55 wellpads, each with 10 wells, total 550 wells over lifetime of a Small Gas
*** For 410 wellpads, each with 10 wells, total 4 100 wells over lifetime of a Big Gas
Note: gas production pipelines assumed to be located within the road reserves
Note: data extracted from Burns et al. 2016 [§1.4, §1.5 and §1.6]

2. EFFECTS ON ENERGY PLANNING AND ENERGY SECURITY

The South African energy system is currently based mainly on coal mined in South Africa, complemented by imported oil and petroleum fuels with small quantities of natural gas. Smaller contributions from biomass, natural gas, nuclear and imported hydro-power make up the remainder of South Africa's primary energy supply. In recent years the contribution by 'renewables' (energy sourced from the sun and wind) has increased. Currently, natural gas is used only in small quantities. Most energy in South Africa is supplied as electrical power, about 90% of which is generated by burning coal. The portion supplied as heat is small. The transport sector uses liquid fuels, which are either imported (in both crude and refined form) or domestically produced using coal-to-liquid (CTL) and to a lesser extent GTL processes. [§2.1.2]

Energy planning in South Africa is performed at the national level, through several interrelated processes. The National Development Plan (NDP 2030) is the overarching planning document for the development of South Africa, and aims to reduce unemployment, eliminate poverty and reduce inequality by 2030. It has clear objectives and actions aimed at increasing natural gas use in the energy mix, irrespective of whether that gas is imported or sourced domestically. Actions proposed in the NDP 2030 include investigating shale gas opportunities and exploiting them in a sustainable manner should they be economically viable. The Integrated Energy Plan (IEP) takes its lead from the NDP 2030 and links the plans for the various energy sectors via a strategic energy planning framework into a plan for the entire South African energy system. The Integrated Resource Plan (IRP) is the electricity plan for the country. The draft Gas Utilisation Master Plan (GUMP) provides a long term roadmap for the strategic development of natural gas supply and demand. All these plans are led by the Department of Energy (DoE), in consultation with other government entities and non-governmental stakeholders. [§2.1.3]

Including more natural gas in South Africa's energy mix would make the energy system more resilient, efficient, cheaper and reliable. Natural gas, regardless of its source, has a desirable set of qualities that coal and oil do not possess. Natural gas can be used in almost all subsectors (power generation, heat, transport, chemicals manufacturing); is easily transported once a gas infrastructure is in place; is supported by a growing international market; is a more homogenous fuel than coal (thus more flexible and easier to handle); produces less carbon dioxide (CO_2) per unit of useful energy when burnt than coal (and is thus less climate damaging, provided leakage during production and transport is minimised); can be more efficiently used for power generation (more kWh per GJ); has high operational flexibility; and has an end-use cost structure that is relatively capital- light and fuel-intensive, making it more economically flexible than many alternative energy sources. [§2.1.2]

Table SPM 2.1: Summary of annual shale gas production over a 40 year period per scenario with associated estimated costs.

Based on accepted industry practice and notational energy planning resources. [§2.2.2]

Scenario	**Available shale gas**	**Annual shale gas production (40 years)**[1]	**Estimated cost of shale gas**[1]
Exploration Only	0 tcf	0 PJ/a	n/a
Small Gas	5 tcf ≈ 5 300 PJ ≈ 1 500 TWh	130 PJ/a ≈ 40 TWh/a *(≈50% of current natural gas supply in South Africa)*	6-10 US$/MMBtu = 20-35 US$/MWh
Big Gas[2]	20 tcf ≈ 21 000 PJ ≈ 5 900 TWh	530 PJ/a = 150 TWh/a *(2.5-3.0 times current natural gas supply in South Africa)*	4 US$/MMBtu = 15 US$/MWh

[1] *Estimated based on generally accepted industry practice and national energy planning resources.*
[2] *The "Big Gas" scenario of this book and the "Big Gas" scenarios of the IRP and GUMP are not the same scenarios and should be treated accordingly.*
Tcf = Trillion cubic feet; PJ = Peta-Joule; TWh =terawatt hours; MMBtu = equal to 1 million BTU (British Thermal Unit) ; MWh = megawatt hour

Gas is versatile in the national energy mix as it has a range of direct and indirect end-uses. In addition to generating electrical power, natural gas could be used for transportation, as feedstock to produce liquid transportation fuels, for fertiliser production, for industrial heat processes, for space heating and for residential cooking and water heating, if appropriately priced and secure in supply. [§2.2.2]

South Africa's three gas supply options are (1) pipeline gas imported from neighbouring countries, (2) Liquefied Natural Gas (LNG) imported by sea-going tankers and (3) produced in South Africa. South African sources include the possibility of offshore conventional gas fields within Exclusive Economic Zone on the West, South or East Coasts, or unconventional onshore sources such as shale gas or coal bed methane (CBM). South Africa will likely initially promote LNG imports to stimulate an anchor demand, supply initial power generation requirements, and establish a gas market. This would trigger investments into gas infrastructure and related investments into domestic conventional and/or unconventional gas exploration (including shale gas and CBM). These sources could be supplemented with increasing volumes of gas imported by pipelines. [§2.1]

Figure SPM 2.1: Power plant with three combined cycle gas turbines (CCGT) located in Algeria. Similar plants are planned as part of new CCGT capacity under the IRP 2010, regardless of whether exploitable shale gas is found in South Africa or not (Mubadala Development Company PJSC, 2016).

The availability of high volumes of shale gas at a competitive price could alter South African energy plans and further improve energy security. A likely outcome would be less use of coal. If the volumes of shale gas are high it is likely that the price will be relatively low. This will make gas-based power generation cost-competitive and cleaner than newly-constructed coal-based power stations, fundamentally altering planning assumptions and thus planning outcomes, especially in the IRP. [§2.2.2]

Use of shale gas enables the integration of more renewables into the mix and reduces the portfolio costs of power generation. Use of relatively low-cost shale gas would enable the creation of a network of gas-fired power stations under both the Small and Big Gas scenarios. These power stations have attributes complementary to solar photovoltaic and wind generation plants, which are inherently variable. Thus a portfolio containing all three is cheaper to build and operate than any one alone, for now and into the foreseeable future. Shale gas would not change the selected planning roadmap for the electricity sector, which already calls for more natural gas and renewables, but would likely make this path cheaper and cleaner. [§2.2.2]

Big Gas volumes extracted from shale in South Africa (or more) would make energy planning more integrated and resilient. Since the introduction of large quantities of relatively cheap natural gas creates links between previously de-coupled sectors, it would make energy planning slightly more complicated but at the same time would make it more integrated and resilient. Natural gas could act as the ‘pressure valve’ between sectors, allowing for adjustments between sectors if the planning assumptions are changed. [§2.2.2]

The risk to South African energy planning and security of not finding shale gas is very low. The IRP considers gas on the basis of its cost, not primarily on the basis of where it originates from. Gas demand could be supplied from imports if local sources are not viable. The risk relates to decisions on gas infrastructure investment, taken in anticipation of shale gas finds which subsequently do not materialise. This could result in energy infrastructure (including network infrastructure) that is not optimal for the energy future that occurs. This risk is low, as most of the planning decisions involving gas are ‘no-regret’ options with little risk of ‘lock-in’, and are based on rigorous infrastructure planning. The capital expenditure needed (for gas-fired power stations, gas-fired boilers, gas cooking, etc.) are small relative to alternative new-build options and therefore do not have a major effect on the overall costs of the energy system. [§2.2.2, §2.3.1]

Gas can assist historically disadvantaged populations to access modern energy sources. When complemented with energy access provided by a gas infrastructure, communities in the immediate area of SGD could benefit from the availability of natural gas and electricity as energy sources. Communities in the rest of South Africa would benefit indirectly via the broader macro-economic benefits anticipated from a local gas industry, reduced energy system costs and an environmentally cleaner power system. [§2.3.1]

3. AIR QUALITY AND GREENHOUSE GAS EMISSIONS

Without mitigation, the risk to shale gas workers of exposure to air pollutants is high, as is the risk to the climate from unintended methane leaks. With mitigation these risks can both be reduced to moderate. Many other risks related to air quality and GHGs are assessed as low or moderate without mitigation. Impacts depend on whether shale gas displaces a more or less emissions-intensive fuel. If actual methane leakage rates turn out to be at the high end of what has been seen elsewhere, they would negate the climate benefits of gas relative to coal as a low GHG-producing energy source. [§3.3.4]

There is insufficient information on air quality emissions and concentrations and GHG emissions in the Karoo to form a reliable baseline against which to measure the future impacts of SGD. There is no air quality monitoring stations within the study area. [§3.2.2.4]

Good practice guidelines are needed to minimise impacts on air quality and reduce GHG emissions in the event of SGD. The guidelines need to cover control technologies, effective legal regulation, early establishment of baselines, continuous monitoring and good governance enabled by coordination across several institutions. [§3.4]

3.1 Air Quality

SGD without mitigation would be associated with a high risk of occupational exposure to air pollutants. SGD activities that result in health risks at the wellpad are the emissions of diesel exhaust, nitrogen dioxide (NO_2), particulate matter (PM), volatile organic compounds (VOCs), silica and hydrogen sulphide (if present in the shale gas). Occupational exposure risk can be mitigated to moderate by decreasing respirable crystalline silica emissions using best practice. It is more difficult to mitigate risks from diesel exhaust and VOCs. [§3.2.4.2]

Under scenarios of Small and Big Gas development, in the absence of mitigation, there is a moderate risk of local community exposure to air pollutants. For communities within the study area, the risk of exposure to air pollution is driven by the increase in ambient PM concentrations, which already exceeds the National Ambient Air Quality Standards (NAAQS) at the one monitoring station closest to the study area, due to mineral dust of non-mining origin. SGD activities would dominate regional emissions of air pollutants other than dust, due to the currently low level of industrial activity in the study area. Even with these relatively large emission increases, ambient concentrations of pollutants other than PM should remain within NAAQS. With mitigation involving available technologies and best practice, the risk of local community exposure to NO_x, PM and VOCs can be reduced to low. [§3.2.4.3]

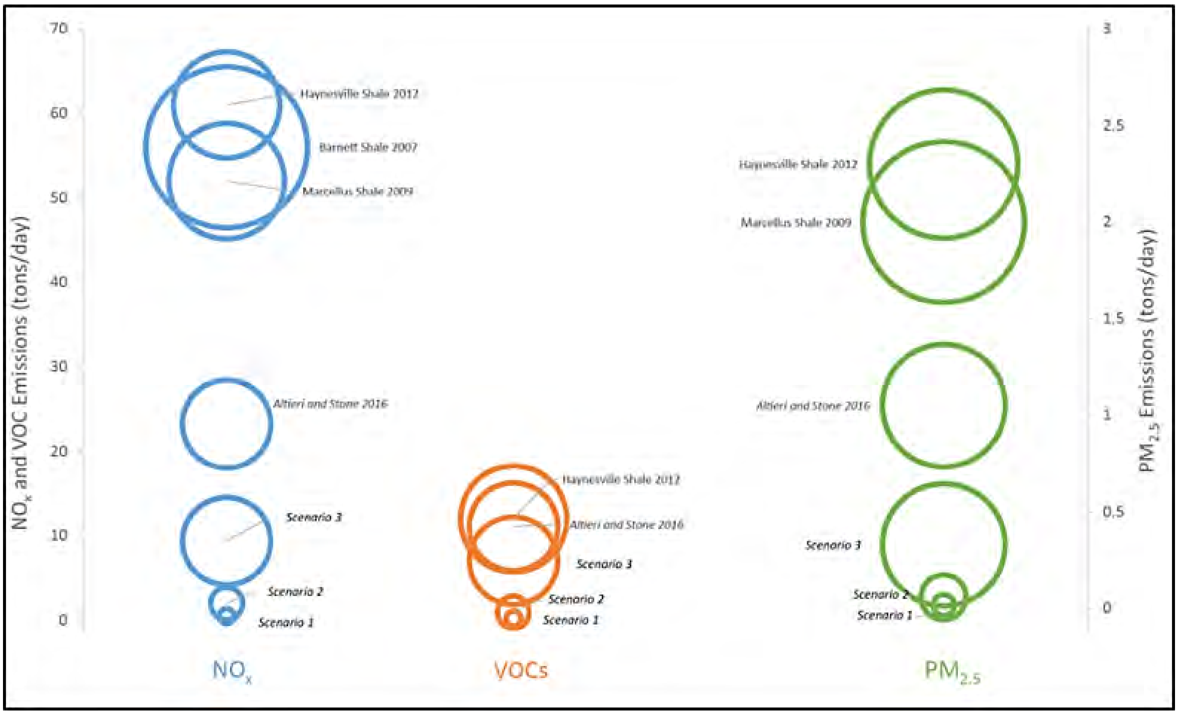


Figure SPM 3.1: Estimated air pollutant emissions resulting from shale gas development in the Central Karoo.

The data are from this assessment, Altieri and Stone (2016) and main shale plays in USA (Marcellus from Roy et al., 2014, Barnett from Armendariz, 2009 and Haynesville from Grant et al., 2009). The "bottom-up" South African estimates are much lower than the actual USA observations for three reasons: 1) the number of wells in the USA is larger than anticipated for South Africa (indicated by the size of the circles); 2) some states in the USA have weak regulatory regimes; and 3) the newer technology which would be applied in South Africa is anticipated to be less polluting. Scenario 1 = Exploration Only; Scenario 2 = Small Gas; Scenario 3 = Big Gas.

The extensive use of heavy diesel trucks during SGD exposes the entire study area to increased levels of air pollution. The risk is assessed as moderate for both Small and Big Gas development due to truck traffic associated with moving equipment to and from well sites, transport of water to the well sites, and the transport of waste and water from the well sites to regional waste centres. Routing trucks away from places where people live and treating road surfaces to minimise dust can reduce the risk to low. [§3.2.4.4]

It is plausible that SGD could improve indoor air pollution in both the study area and the country as a whole. This benefit depends on shale gas or electricity derived from it displacing "dirty" fuels such as wood, coal, and paraffin for domestic use, especially when those fuels are burned indoors without adequate ventilation. [§3.2.4.1]

3.2 Greenhouse gas emissions

Shale gas presents both a risk of increased national greenhouse gas emissions and an opportunity to reduce emissions. The opportunity for emission reductions depends crucially on whether gas displaces coal (the main fuel in South Africa) or low-carbon energy sources, and to the degree to which gas is used *in addition* to coal. Shale gas used in place of coal for electricity generation will reduce CO_2 emissions, but the scale of reductions is slight in relation to the magnitude of national GHG emissions now and as projected over the period of SGD. The worst shale gas use option is comparable in emissions-intensity to the best coal use option (Figure SPM 3.2). [§3.3.4.3]

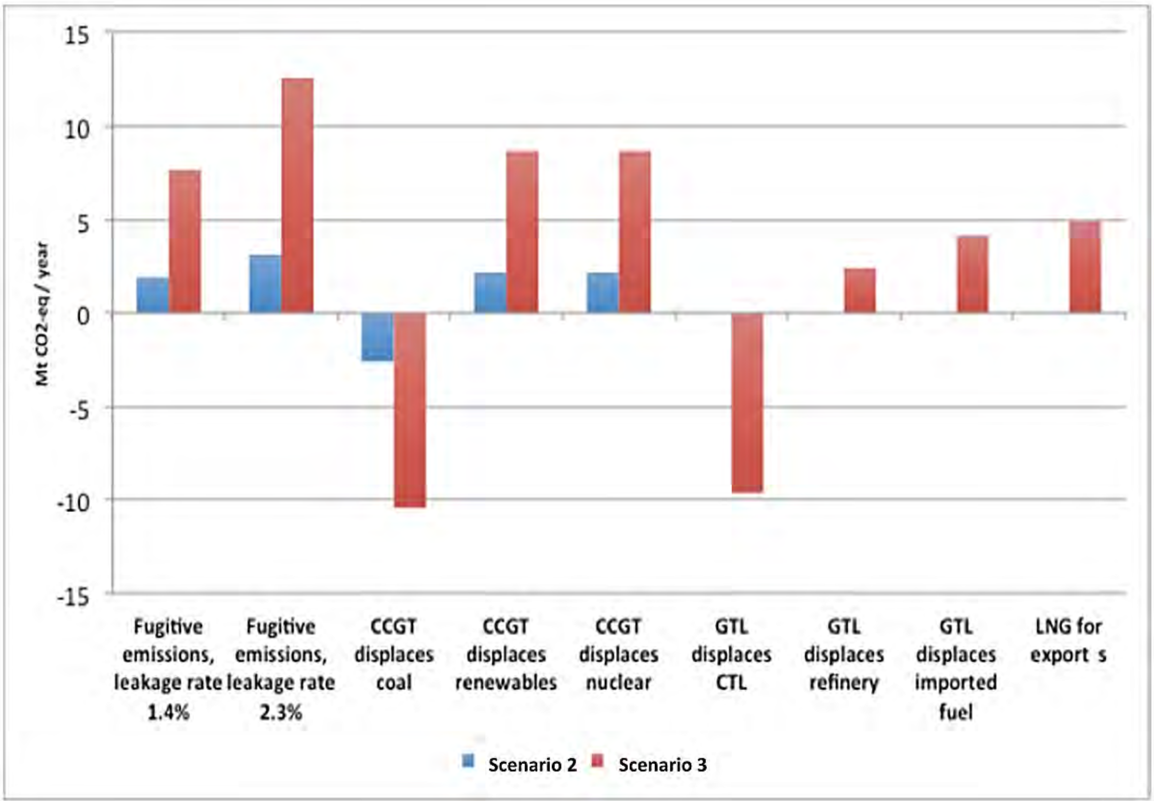


Figure SPM 3.2: Net change in national greenhouse gas emissions which would result from shale gas development under various assumptions.
The total South African emissions in 2010 were in the region of 400 Mt CO_{2eq}. Note that the outcome of SGD implementation could be either a small increase or a small decrease in national GHG emissions, depending on what is displaces and what fraction of the methane unintentionally leaks to the atmosphere in un-combusted form (‘fugitive emissions’). Scenario 2 = Small Gas; Scenario 3 = Big Gas.

For the Big Gas scenario with inadequate control of gas leaks, the risk that fugitive methane emissions will result in the GHG benefits being greatly reduced or even reversed is assessed as high. Methane has a greenhouse warming potential twenty to thirty times higher than CO2, so leaks amounting to a few percent can offset the benefit that accrues from the higher energy yield per unit

CO_2 emitted when gas is used in the place of coal. The GHG no-benefit threshold occurs at 1.9% leakage under the Small Gas scenario, and 3.2% under the Big Gas scenario. The estimates of leakage worldwide are in the range 1.5 to 2.3%, but recent literature showing that much of the emission comes from a few "super emitter" locations suggests that the true range may be 2.2 to 4.1%. This risk could be reduced to moderate with mitigation involving good practice and available control technologies [§3.3.4.1]

4. EARTHQUAKES

The natural occurrence of a damaging earthquake (M>5) anywhere in the study area is considered to be very unlikely. The level of risk depends on the exposure of persons and vulnerable structures to the hazard. In the rural parts of the study area the exposure is very low, the consequences of an earthquake are likely to be slight, and hence the risk posed by earthquakes is considered to be low. While it is considered to be very unlikely that a damaging earthquake will occur within 20 km of a town, the consequences of such an event could be moderate or even substantial. Lives could be lost, and many buildings would need to be repaired. Hence the risk in urban areas is considered to be moderate. Exploration activities associated with the Exploration Only scenario do not involve the large scale injection of pressurised fluids, the risk posed by earthquakes in the study area during the exploration and appraisal phase is considered to be low and not significantly different to the baseline.

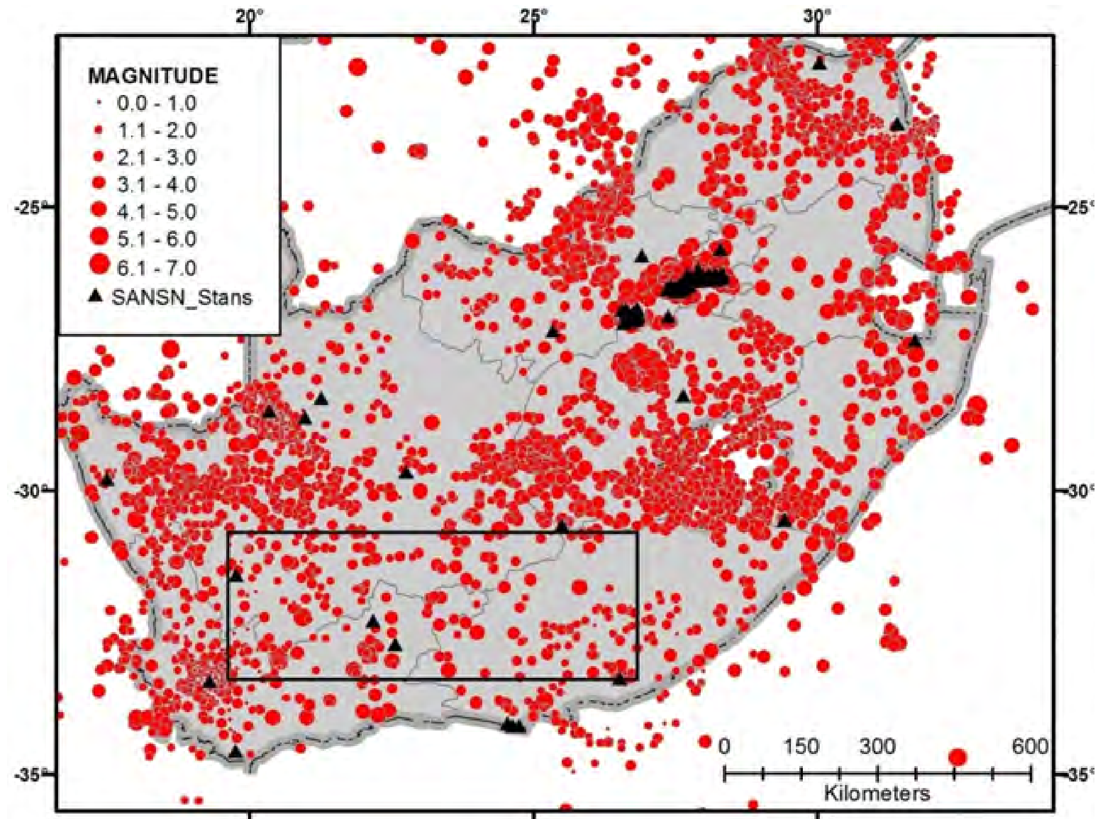


Figure SPM 4.1: Locations of recorded seismic events in South Africa between January 1811 and December 2014.

The black triangles are locations of seismic monitoring stations; the black rectangle is the study area. The study area is seismically quiet relative to other parts of South Africa and the world.

SGD by fracking increases the likelihood of small earth tremors near the well bores. Only a few such tremors are likely to be strong enough to be felt by people on the surface. Many studies, in several parts of the world, demonstrate an increase in small earth tremors during fracking. The possibility that fracking will lead to damaging earthquakes through triggering movement on pre-existing faults cannot be excluded, but the risk is assessed as low because the study area very rarely experiences tremors and quakes (Figure SPM 4.1). Damaging earthquakes associated elsewhere with SGD are almost exclusively linked to the disposal of large volumes of waste water into geological formations (a practice forbidden by South African legislation); rather than the development of shale gas resources using fracking. [§4.1.1, §4.1.3]

The risk to persons and assets close to fracking operations in rural areas, such as workers, farm buildings and renewable energy and Square Kilometre Array (SKA) radio telescope infrastructure, should be handled on a case-by-case basis. Vulnerable structures, including features of heritage importance, should be reinforced and arrangements made to insure or compensate for damage. Should particularly attractive shale gas resources be found close to towns, it is essential to inform local authorities and inhabitants of any planned fracking activities and the attendant risks; enter into agreements to repair or compensate for any damage; monitor the induced seismicity; and slow or stop fracking if felt earthquakes are triggered. [§4.4]

The authors cannot categorically exclude the possibility that an earthquake may be triggered by fracking. The Earth's crust is heterogeneous and physical processes are complex. Rock properties and geodynamic stresses are not perfectly known, and the seismic history is incomplete. It is thus important that seismicity is monitored for several years prior to any fracking, and that a seismic hazard assessment is performed to provide a quantitative estimate of the expected ground motion. Monitoring should continue during SGD to investigate any causal link between SGD and earthquakes. Should any such link be established, procedures governing fluid injection practice must be re-evaluated. [§4.3.2]

It is recommend that Council for Geoscience's seismic monitoring network be densified in the study area, and that vulnerability and damage surveys of buildings and other structures be carried out before, during and following any SGD activities. At the present time (August 2016) an additional six seismograph stations were being installed by the Council. Other mitigation measures to be considered should include: monitoring of seismicity during SGD and the slowing or stopping of fracking if felt earthquakes are induced, schemes to guarantee compensation in the case of damage, disaster insurance, reinforcement of vulnerable buildings (especially farm and heritage buildings, schools and hospitals), enforcement of building regulations, training and equipping of emergency first responders, and earthquake drills in schools and work places. [§4.2.4]

5. SURFACE AND UNDERGROUND WATER RESOURCES

Each well requires in the region of 10 500 m^3 of water to be fractured. The exact amount of water required depends on hole depth, geological conditions and the number of fracturing stages required. Assuming water re-use at 50% of drill fluid and 30% of fracking fluid, in the region of 6 000 000 – 45 000 000 m^3 would be required for the Small Gas and Big Gas scenarios respectively. The quality of the water does not have to be of a potable standard and can be salty or 'brackish'. [§1.4.3.2.2, §1.4.4.2, §1.4.5.2, §5.2.2.2]

There is not capacity to supply water for SGD from existing local sources. Water availability in the study area is severely constrained. Surface water availability is generally low, and in many areas over-allocated. Landowners rely mainly on groundwater resources for domestic and stock water. Groundwater recharge is typically low and sporadic. The use of groundwater is increasing, particularly during drought years. In many areas, groundwater already supplies 100% of the use. The availability of groundwater to meet the demand of even the Reference Case (where there is no SGD), is already seriously constrained. The additional demand under the Small and Big Gas scenarios could not be met from known local potable resources and would be considered a very high risk if local resources were utilised. [§5.2.2, §5.2.3, §5.2.4, §5.3]

There is potential to develop non-potable (brackish) groundwater within or near the study area, at a limited scale. This would need to take into account the potential risks associated with the transport and storage of brackish water, as well as potential risks associated with large water wellfield developments in the Central Karoo. [§ 5.2.2.2]

Surface spills on-site and along transport networks are the most likely source of water resource contamination. The risks of fracking fluids reaching near-surface waters by percolating upward from the fracking zone are considered very low. Risks of leakage from faulty wellbore linings in the top few hundred meters are higher, but manageable (moderate risk) if best practice techniques are utilised. The likelihood of spillages on the wellpad or during transport is near inevitable under both production scenarios. Spills, on average, are expected to have localised and short-term consequences (Figure SPM 5.1). [§5.5.1]

The most effective management action is to avoid high sensitivity water resources. These have been mapped, at a high-level, in as hypothetical 'set-backs' (see Figure SPM 5.2). The sensitive areas are deliberately conservative, considering the low confidence in scale and available data. Additional investigations will be required at an Environmental Impact Assessment (EIA) level to determine 'no-go' areas. It can be stated with reasonably high confidence that SGD activities located in areas of medium sensitivity will reduce the risk profile to low and very low for all direct water impacts. [§5.7.3]

Post-SGD legacy impacts will occur. There will be impacts following the completion of SGD from failed well linings or capping structures on spent production wells. It is highly unlikely that all decommissioned production wells will maintain their integrity indefinitely. The associated risk is constrained by the likely number of failures and localised zone of influence, and is therefore assessed as low in the Small Gas scenario and moderate in the Big Gas scenario with and without mitigation. Where monitoring data allows the impact to be traced, containment is feasible following site-specific assessments to identify appropriate mitigation. Contamination may only arise long after SGD has ceased. Systems for contamination detection and funding for remediation must be in place. [§5.5.1.4]

Water resources monitoring before, during and after SGD is an imperative. A comprehensive set of baseline water resource data for the study area must precede SGD. This must include establishment of water availability and verification of existing use, including the water resources needed to meet environmental requirements, the “Reserve”. The baseline must also include quantification of the quality of surface water and groundwater. The authority responsible for issuing water use licences (Department of Water and Sanitation) will not do so before comprehensive reserve determinations for groundwater, surface water and wetlands are completed. Ongoing water resource quality monitoring including general and SGD-specific determinants is essential during and after SGD. [§5.4.3.1, §5.8]

The capacity to undertake the analyses necessary for water chemistry monitoring in relation to SGD is currently inadequate in South Africa. Most accredited South African water quality laboratories are equipped to carry out routine water analyses; however, none are presently capable of analysing for SGD-specific determinants such as $\delta^{11}B$, $^{36}Cl/Cl$, ^{4}H, $^{3}H/^{4}H$, and CH_4. Sufficient lead-in time must be allowed for such facilities to be set up prior to SGD. Near-term baseline establishment may require the use of accredited laboratories elsewhere in the world. [§5.8.2]

Lack of infrastructure and institutional capacity for water management is currently a constraint in the Central Karoo and are considered a high risk which can be reduced to moderate with mitigation. The present institutional and human resource capacity is insufficient to implement a robust and effective water resource monitoring and management programme for SGD. This constraint applies especially to regulatory authorities, who often lack the necessary skills and the will to enforce regulations, and less so to the SGD industry, which it is expected will mobilise the necessary resources to meet regulatory requirements in this regard. The likelihood of environmental non-compliance is increased by poorly capacitated regulators, largely reliant on information supplied by the industry. [§5.5.3.2]

SGD provides a learning opportunity that can improve understanding of local water resources. The activities associated with exploration for shale gas would generate new geoscientific data and information which will advance the understanding of the geology, hydrogeology, geophysics and geochemistry of the study area. The discovery of, as yet, unknown groundwater resources is a possibility. This opportunity would however be realised whether SGD advances to production capacity or not, as the potential will be revealed mainly during the exploration phase. [§ 5.7.1]

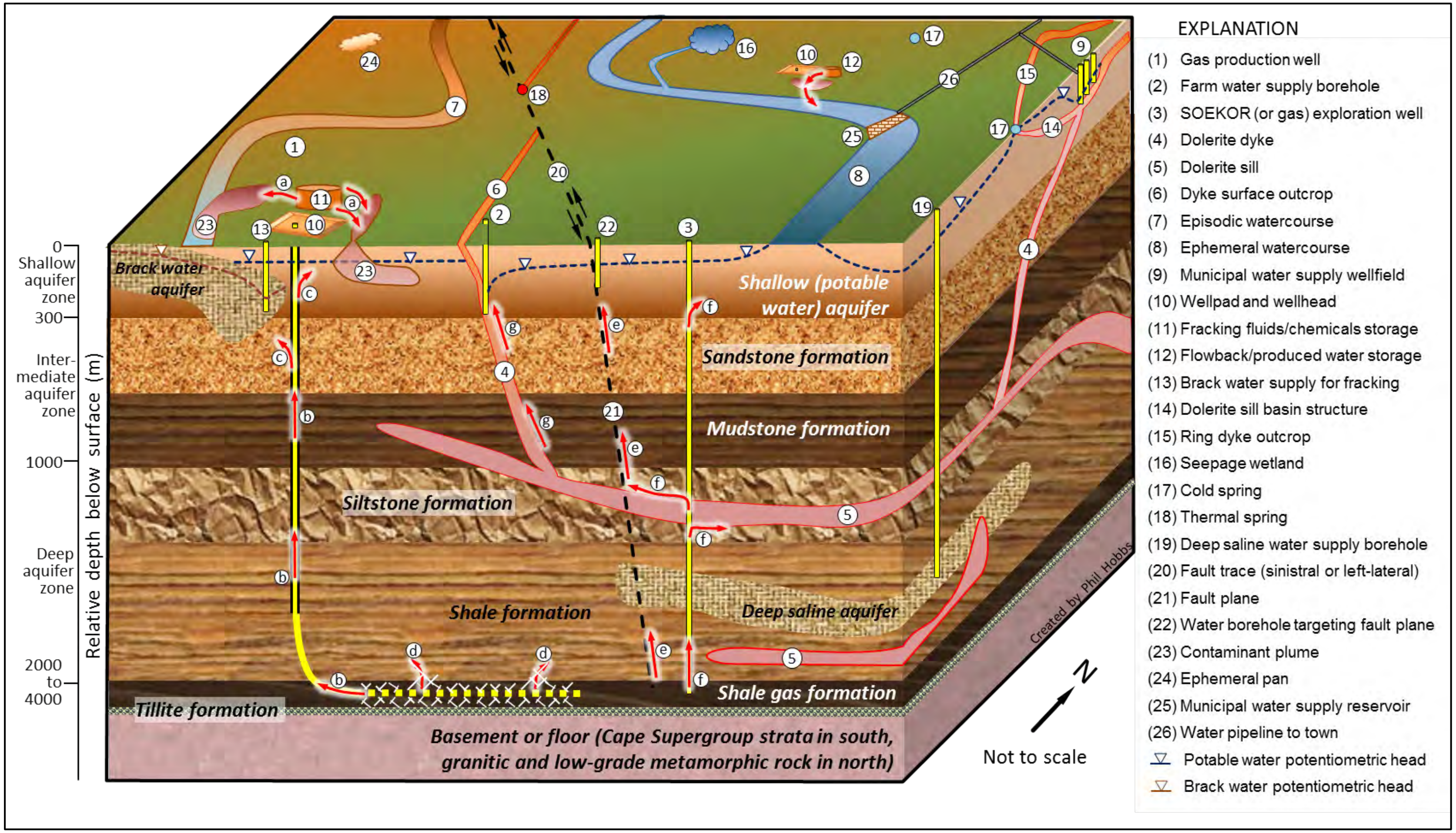


Figure SPM 5.1: Features associated with the surface water and groundwater environments in the Central Karoo as these relate to shale gas development activities. The possible contaminant pathways (red arrows) and plumes (feature 23) are conceptual and exaggerated for purposes of illustration. The thickness and types of rock layers is similarly illustrative only; in reality the various formations comprise a mixture of sedimentary rock types, and are not uniformly thick or necessarily horizontal. Features 3 and 19 might be artesian. The possible contaminant pathways are identified as (a) surface spills at the wellpad, (b) flowback and produced water via a production well, (c) leakage via faulty annular seals in production wells, (d) migration via hydraulic fractures, (e) preferential migration along fault planes, (f) leakage from old (possibly uncased) oil and gas exploration wells, and (g) preferential migration along dyke or sill contact zones.

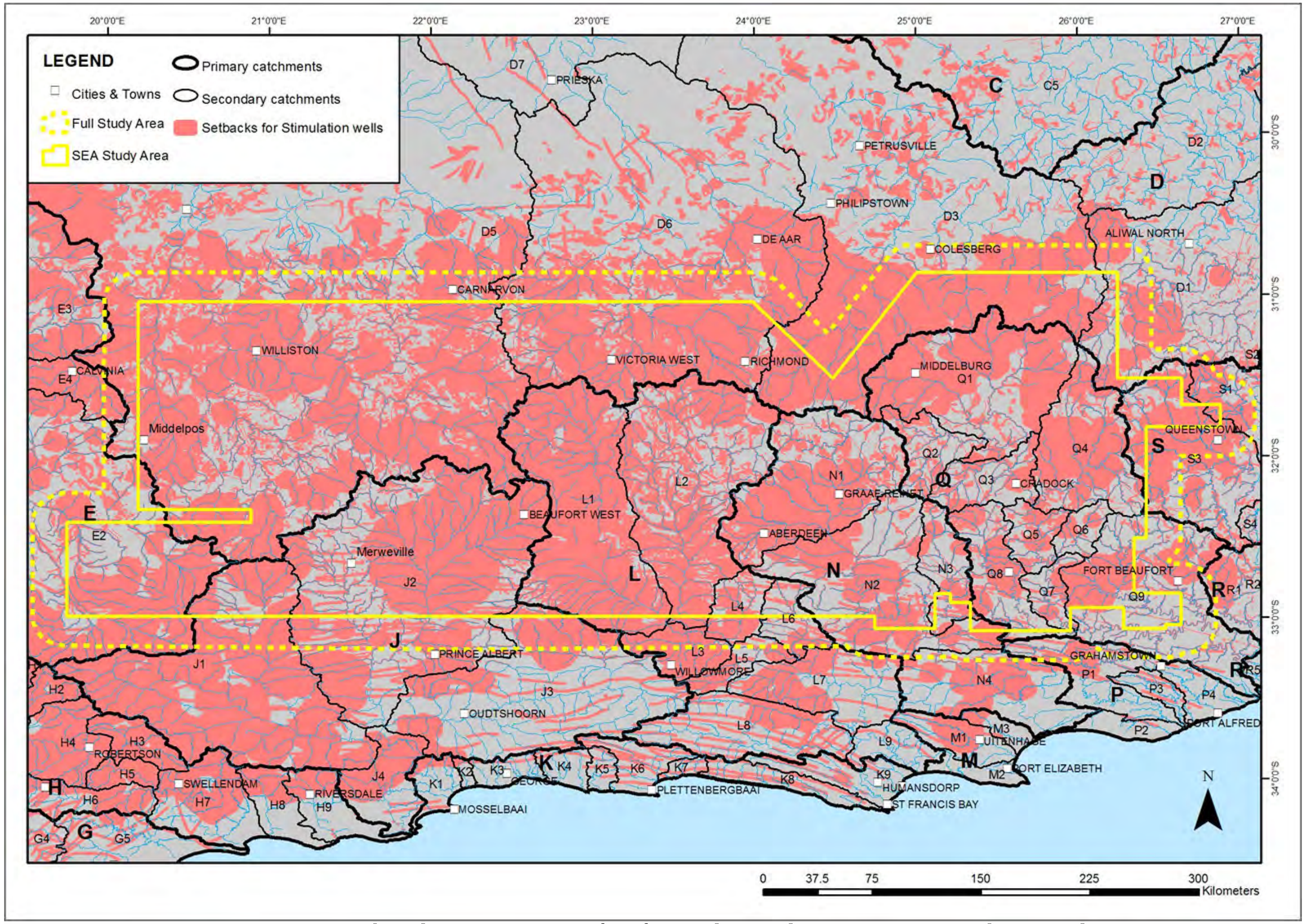


Figure SPM 5.2: Combined sensitivity map of surface and ground water resources in the Central Karoo.

The highlighted pink areas are of high sensitivity and are 'hypothetical set-back' areas. These comprise the areas in which impacts to water resources are possible, and if so, might have highly negative consequences (assessed with a medium-level of confidence). The grey areas are considered of medium sensitivity - in these areas, the risk to surface and groundwater resources can be significantly reduced to low and very low, assessed with a high-level of confidence. Additional investigations will be required at an EIA level to determine actual 'set-back' areas based on 'ground-truthed' site specific information.

6. WASTE PLANNING AND MANAGEMENT

SGD will generate substantial volumes and new types of waste. This includes liquid wastes such as flowback. Volumes of flowback will range from around 6 000 000 m^3 for the Small Gas scenario to around 40 000 000 m^3 for the Big Gas scenario (see Table SPM 1.1). Solid mining wastes such as bore fragments and cuttings, industrial wastes such as used machinery and supplies, as well as more conventional wastes such as sewage, domestic waste and construction waste will also be generated. [Table §1.4; §1.5 and §1.6 from Burns et al., 2016]

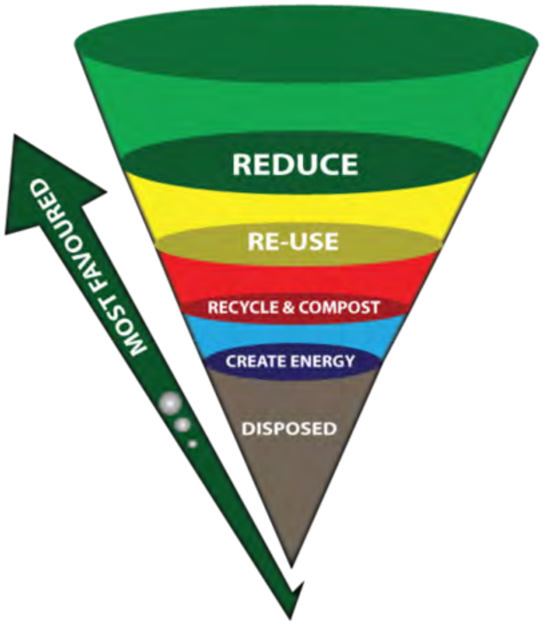


Figure SPM 6.1: Schematic of the Waste Management Hierarchy.
The hierarchy favours options for reducing waste wherever possible, re-using all types of waste related to SGD, recycling of materials such as flowback fluids and then disposal as a final step if none of the previous options prove feasible.

Under the Big and Small Gas scenarios the risks of exposure to waste streams is high. The risks of waste streams originating from exposure to hazardous and domestic waste streams; as well as the additional sewage load at already stressed waste water treatment works can be mitigated to low if waste from SGD is managed in line with the *waste management hierarchy* and the existing regulations and the principles for integrated waste management in South Africa. The emphasis is on minimising waste generation, promotion of the use of non-hazardous chemicals, re-use and recycling and minimisation of the impact of waste on water, the environment and communities. [§6.1]

Waste should be treated on site by the SGD industry. Municipal waste disposal sites are at jeopardy of receiving waste from SGD if an imminent amendment to the Waste Act, 2008 results in SGD waste being classified as general waste. Municipal landfills in the study are not designed or equipped to receive SGD waste and municipal staff do not have the skills or experience to manage it responsibly. The SGD industry, and not local municipalities, should be responsible for the treatment of waste streams onsite and safe disposal thereof emanating from exploration and/or operations.

There are five basic management options for contaminated waste water from SGD. These are: 1) Minimisation of produced water generation; 2) Recycling and re-use within operations; 3) Treatment; 4) Disposal; and 5) Beneficial re-use outside the operations (see Figure SPM 6.2). [§6.1.2]

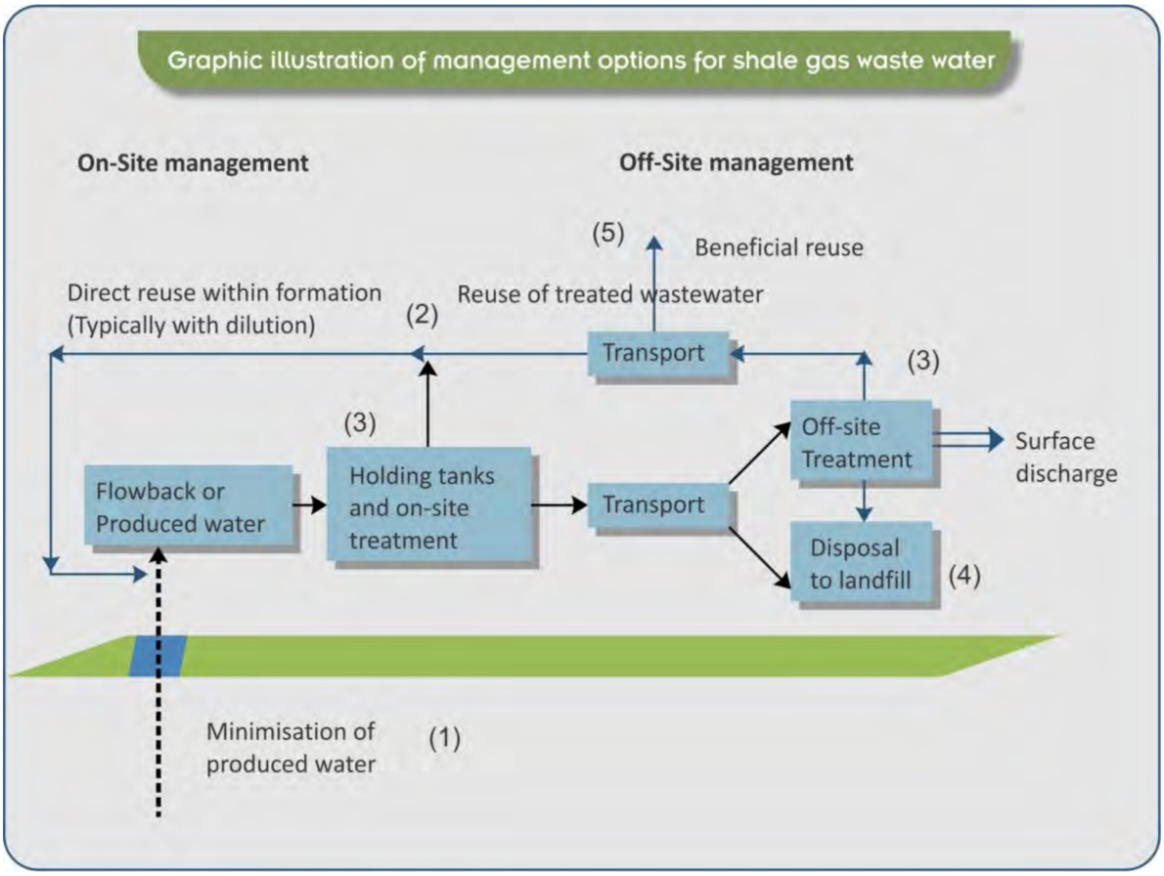


Figure SPM 6.2: Five management options for contaminated waste water from shale gas development.

The existing legislated waste management provisions in the Regulations for Petroleum Exploration and Production 2015 are largely adequate to reduce the waste-related risks of SGD to low, if rigorously enforced. This assessment has assumed that the Regulations for Petroleum Exploration and Production 2015 are mandatory and will not be relaxed by any future amendments. Recovery of drilling muds and fracking fluids will require a waste management license in terms of the Waste Act (2008). It is recommended that SGD wastes be added to the list of pre-classified hazardous waste streams in Annexure 1(2) of waste Regulation 634 (RSA, 2013). [§6.1.1, §6.3.1]

Norms and standards for waste classification and containment barrier system designs are prescribed, but the law is silent on landfill management, operational and groundwater monitoring requirements at facilities receiving waste from SGD. Development of norms and standards in terms of the Waste Act, 2008 specific for discharge of treated shale gas flowback and produced water may be required to ensure equal and adequate protection of all the water sources and associated ecosystems and communities in the study area. [§6.3.3, §6.4.5]

There is a current lack of staff, skills and expertise at all spheres of government to assess the increased volume of waste licence applications relating to SGD especially in the Big and Small Gas scenarios. The waste streams from SGD are new to South Africa and therefore capacity needs to be created to evaluate licence applications efficiently and responsibly. [§6.3.3]

There is insufficient laboratory capacity in South Africa able to perform the volume of analyses necessary for operational waste classification under the Big or Small Gas scenarios. The analyses must be undertaken at South African National Accreditation System (SANAS) accredited laboratories, very few of which have accreditation for the prescribed tests. Additional laboratory capacity will be needed to deal with the volume of analyses that would be required for SGD. [§6.3.3, §6.5.3.3]

Currently, no sites are licensed for Type 1, 2 or 3 hazardous waste disposal in the study area. This means that any *Type 1, 2 or 3* hazardous waste would need to be transported and disposed of outside the study area. Leach management and treatment is a pre-requisite for disposal of shale waste due to the presence of a range of toxic chemical additives, salinity and potentially radioactivity (leachable Naturally Occurring Radioactive Materials) in flowback water. These substances require particular handling for safe disposal. The institutional capacity, skills and knowledge to implement and enforce waste regulations, norms and standards is limited, especially at local level and will have to be strengthened before SGD is approved. [§6.2, §6.3.3, §6.4.3]

7. BIODIVERSITY AND ECOLOGICAL IMPACTS

The study area includes high levels of biodiversity by global standards, including sensitive and unique ecosystems and species. Seven different biomes and 58 vegetation types, 119 endemic or near-endemic plant species and 20 threatened animal species have been recorded from the study area. [§7.1.3]

The Karoo is characterised by ecological processes that operate over extensive areas. The aridity of the Karoo makes the ecosystems sensitive to disturbance. Recovery from disturbance is slow and generally not spontaneous. Active rehabilitation is often met with poor success. [§7.1.3]

A major concern is that the roads, pipelines and powerlines associated with SGD will result in fragmentation of the landscape. Loss of connectivity, edge effects and disruption of ecological processes associated with a network of linear structures are likely to undermine the biodiversity integrity of the study area. Impacts on species, ecosystems and ecological processes extend well beyond the physical footprint of the activity. For many species the impacts of noise, pollution, erosion and other disturbance can extend for hundreds of metres or kilometres from the source. Impacts on species and ecological processes are likely to have cascading effects on other species and processes. [§7.2.2, §7.2.3]

The assessment has identified areas of Ecological and Biodiversity Importance and Sensitivity (EBIS), from EBIS-1 (highest) to EBIS-4 (lowest). The primary mitigation for SGD with respect to biodiversity is avoiding and securing EBIS-1 and EBIS-2 areas. This effectively makes the EBIS-3 and EBIS-4 areas available for SGD. [§7.2.1, §7.3.1]

Strategic mitigation at the landscape level is essential, as the impacts of SGD cannot be effectively mitigated on site or at the operational level. EBIS-1 and EBIS-2 areas make up an estimated 50 % of the study area. Loss or degradation of habitat in these areas must be avoided and they should be secured through legal mechanisms. Securing these areas may lend itself to a fast-tracked, integrated protected area expansion strategy (Figure SPM 7.1,
Table SPM 7.1). [§7.3]

EBIS-1 areas contain extremely sensitive features and are irreplaceable. Impacts of SGD in these areas would undermine the ecological integrity of the study area (and more broadly, the Karoo). Activities related to SGD in EBIS-1 areas are must be avoided. It is not possible to minimise or offset impacts of SGD in these areas. [§7.3]

EBIS-2 areas contain highly sensitive features that are important for meeting biodiversity targets and/or maintaining ecological processes in the study areas. Where SGD activities in EBIS-2 areas are unavoidable, the impacts must be minimised and residual impacts must be offset by securing ecologically equivalent sites in EBIS-1 or EBIS-2 areas. In the case of such offsets, national and provincial offset guidelines should be applied to ensure no net loss (see Table SPM 7.2). [§7.3]

Environmental compliance in EBIS-3 and EBIS-4 areas is still required. This includes specialist-led assessment of local sensitivities and identification of appropriate mitigation. This is necessary to ground-truth desktop assessments and minimise impacts. [§7.3.4]

The cumulative and unforeseen impacts of SGD on biodiversity, as well as effectiveness of mitigation, must be monitored. The outcomes of the monitoring programme need to dynamically inform ongoing strategic and regional level decisions on SGD. [§7.4.2]

Figure SPM 7.1: Map of Ecological and Biodiversity Importance and Sensitivity in the study area. Protected areas (5% of study area) are legally protected. EBIS-1 areas (13% of study area) contain extremely sensitive features and are irreplaceable. EBIS-2 areas (37% of study area) contain highly sensitive features and/or features that are important for achieving targets for representing biodiversity and/or maintaining ecological processes. Protected areas, EBIS-1 areas and EBIS-2 areas collectively meet targets for representation of biodiversity and maintenance of ecological processes in the study area. EBIS-3 areas (44% of the study area) are natural areas that do not contain currently known sensitive or important features. In EBIS-4 areas (1% of study area) there is no remaining natural habitat (Figure SPM 7.1).

Table SPM 7.1: Extent of areas of Ecological and Biodiversity Importance and Sensitivity within the study area (percentage).

Ecological and Biodiversity Importance and Sensitivity	Extent (%)
Protected areas	5
EBIS-1	13
EBIS-2	37
EBIS-3	44
EBIS-4	1
Total	**100**

Table SPM 7.2: Strategic application of the mitigation hierarchy at the landscape level.

Based on map of Ecological and Biodiversity Importance and Sensitivity.

Ecological and Biodiversity Importance and Sensitivity (EBIS)	Primary focus of mitigation, based on the mitigation hierarchy
Protected Areas	**AVOID.** These areas are legally protected in terms of the Protected Areas Act.
EBIS-1 (highest)	**AVOID** – it is not possible to minimise or offset impacts of SGD activities in these areas. If possible, **SECURE** through legal mechanisms that limit habitat loss and degradation. These are first-tier receiving areas for biodiversity offsets.
EBIS-2	**Best option: AVOID** **Otherwise: MINIMISE, AND OFFSET RESIDUAL IMPACTS** by securing sites in EBIS-1 or 2 areas. If possible, **SECURE** through legal mechanisms that limit habitat loss and degradation. These are second-tier receiving areas for biodiversity offsets.
EBIS-3	**MINIMISE** SGD activities need not be avoided in these areas **IF:** • EBIS-1 areas are secured, AND • EBIS-2 areas are either secured or any residual impacts on these areas are offset.
EBIS-4 (lowest)	**MINIMISE**, especially in order to ensure that there are no negative impacts on protected areas, EBIS-1 or EBIS-2 areas.

8. IMPACTS ON AGRICULTURE

Agriculture functions on different levels or scales, including both a social subsystem and ecological subsystem. Decision-making within agriculture needs to consider both these subsystems, the agro-ecosystems agriculture depends on, as well as the governance systems organising and regulating agriculture in the Central Karoo. [§8.2.1]

The total Gross Farm Income (GFI) of the region is just over R5 billion/yr. Of which 48% is from the Eastern Cape, 10% from the Northern Cape, and 41% from the Western Cape. The sale of animals accounts for 39% of GFI, animal products 19%, field crops 4%, and horticultural crops 38%. The agricultural sector in the study area provides a direct source of income for 38 000 people. Considering the average size of families in the study area of approximately 4.5 persons; this translates to supporting the livelihoods of around 133 000 people. [§8.5.3.1, §8.5.3.2]

The biggest risk of SGD to agricultural production relates to the competing use and potential contamination of water resources. In the dryer central and western parts of the study area, farming communities rely exclusively on boreholes for water for humans and livestock consumption. Elsewhere, both surface and groundwater are used for livestock and irrigation purposes. SGD poses potential risks to both the quantity and agricultural usability of surface and groundwater resources. Opportunities may exist to use water produced as a by-product of SGD for agricultural production purposes or importing water from outside of the Central Karoo, which will significantly decrease the risks associated with local water competition. [§8.6.2, §8.8.1, §8.8.2]

SGD and agriculture are not mutually exclusive. SGD does not pose a significant risk to agricultural productivity in the long term if the risk to ground water resources is adequately addressed. The central and western parts of the study area are areas of low potential productivity in a national context. Nevertheless, they have made a relatively constant contribution to regional Gross Domestic Product (GDP) and sustained local livelihoods. The area offers limited options and opportunities. There is a trend towards alternative sources of land-based incomes, such as eco-tourism and hunting. [§8.5]

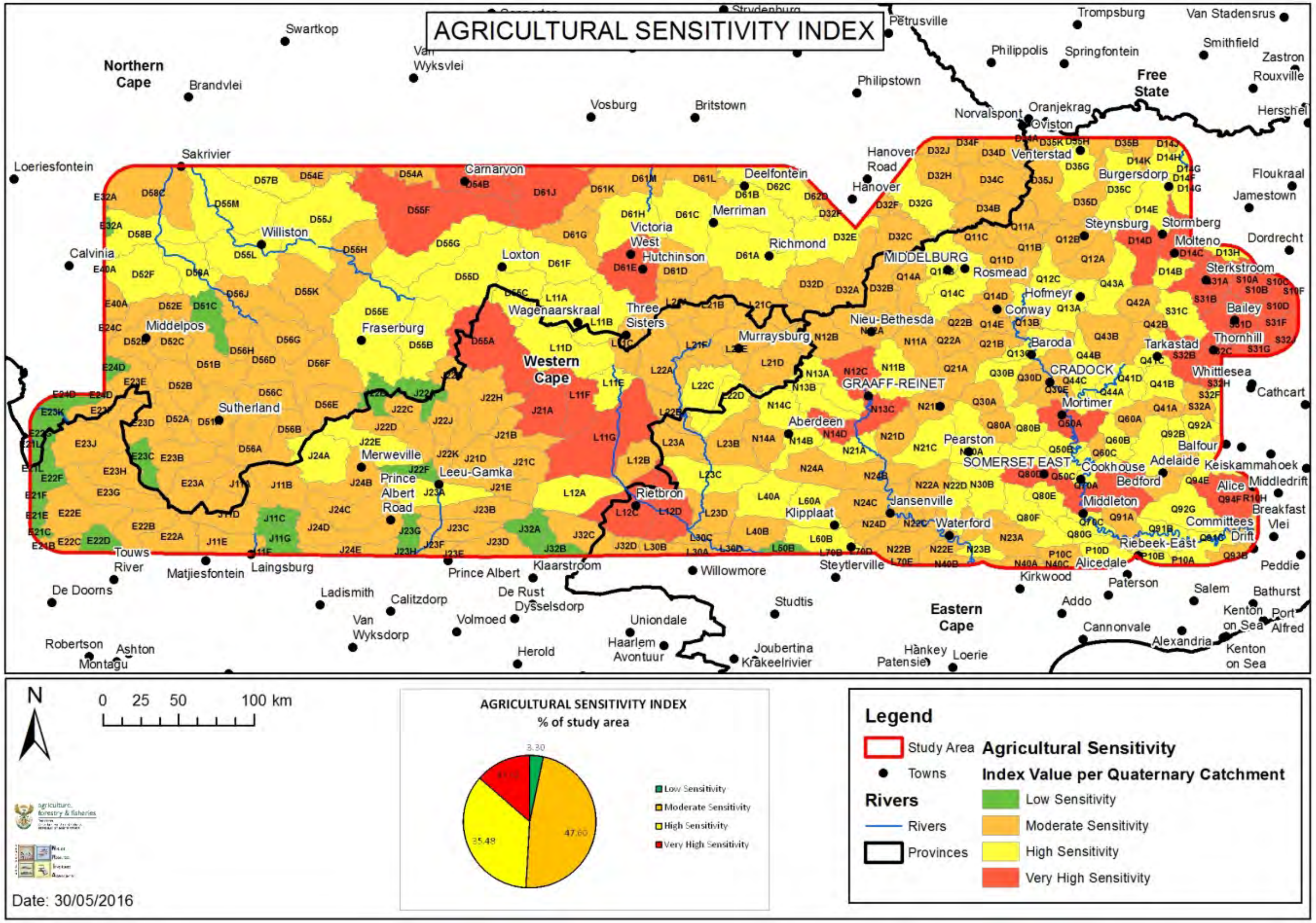


Figure SPM 8.1: Four tier agricultural sensitivity map focused on the study area within the Central Karoo.

The index considers land capability, grazing capacity, cultivated fields, irrigated areas and surface water features such as river and dams. The proportions of sensitive areas are provided as a percentage of the entire study area as follows: Very High Sensitivity = 22.14%; High Sensitivity = 33.8%; Moderate Sensitivity = 32.21% and Low Sensitivity = 11.86%. The sensitivity index rating was based per quaternary catchment located within the study area.

Any intervention that weakens current land-based livelihoods is likely to have a long-term impact on the resilience of both the area and its land users. Local land users draw on profound local knowledge to sustainably use vulnerable land-based resources. Fragmentation of the landscape to accommodate SGD must be carefully mitigated to minimise the negative impacts on the viability of agricultural enterprises. [§8.6.2, §8.8.2.1]

Some agricultural land may be taken out of production (leased or purchased) while SGD is underway, which could have a positive impact on the incomes of agricultural land users. This suspension of production would have a limited negative impact on long-term food security at regional scale as it would not be lost to production in the long-term, and may benefit from being rested from grazing. [§8.8.1]

Sufficient policy, legislation and regulations exist to protect the natural agricultural resources. The enforcement of these instruments remains a major stumbling block to sustainable agricultural resource use and prevention of their degradation. The institutional capacity, skills and knowledge to implement and enforce these measures are limited, especially at local level. [§8.3]

Local economic development associated with SGD will likely stimulate local markets for agricultural products. Significant numbers of locally-based staff of SGD companies will increase demand for agricultural products. SGD is likely to attract service enterprises that will also contribute to the local economy and consume agricultural products. [§8.8.1]

SGD will put the privacy and security of land users at risk. Currently land users enjoy high levels of control over the farm-based resources. This is in part a result of little through-traffic on most farms and relatively stable local populations. An influx new people associated with the Small and Big Gas scenarios may expose farm property and livestock to theft and increase vulnerability of local communities to crime and potentially violence. [§8.8.2.1]

Long-term monitoring and evaluation is essential to measure the effectiveness and efficiency of mitigation measures applicable to agriculture under all scenarios of SGD. The effective implementation of mitigation and rehabilitation measures is important to limit the negative impacts of shale gas operations and to ensure their continuous improvement. The effective implementation of a long-term monitoring programme depends on the availability of adequate resources, especially at the level of local implementation. The outcomes of these monitoring and evaluation processes must be fed back to relevant stakeholders to ensure continuous improvement. [§8.8.2]

9. TOURISM IN THE KAROO

Tourism adds over R2 billion to the economy of the study area annually. Tourism provides the largest number of enterprises in the study area: 828 in 2015/16, employing between 10100 and 16400 workers and annually adding R2.3 billion to R2.7 billion to the local economy. It is the fastest growing economic sector in most Karoo towns, thus its importance in the study area is expected to increase further in future, even in the absence of SGD. All towns in the study area are reliant on tourism, some (Nieu-Bethesda, Prince Albert, Sutherland, Loxton, Jansenville) more so than others (Figure SPM 9.1) [§9.1.2]. The rural Karoo landscape is an important resource for specialised tourism niches, such as eco-tourism, agri-tourism, hunting and adventure tourism, which disperse tourism activities beyond the towns. Negative impacts on the Karoo tourism brand poses risks to different tourists and industries in different ways (see Table SPM 9.1).

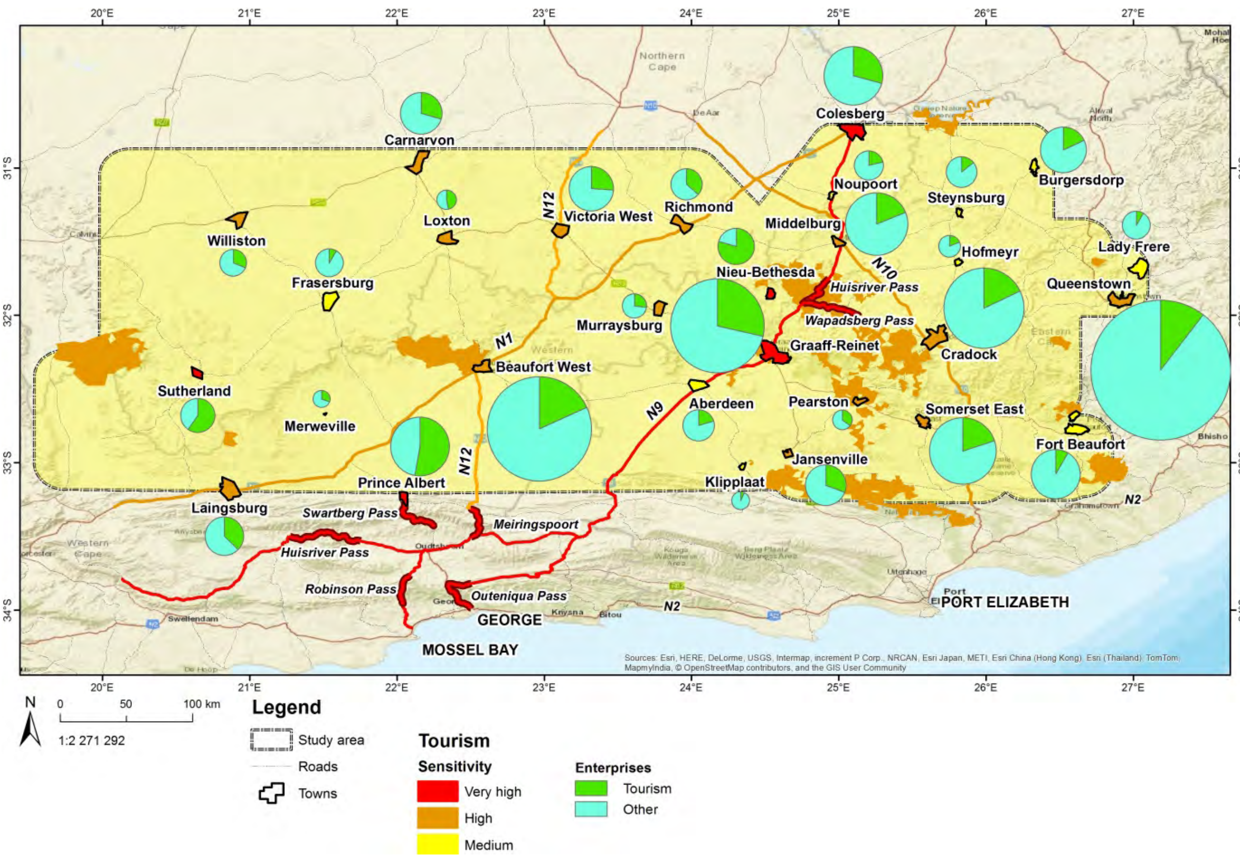


Figure SPM 9.1: Estimates of tourism sensitivity in the study area based on the number of enterprises. The estimate is determined based on the negative impacts on tourism and tourism enterprise numbers relative to the total number of enterprises of towns in the study area. Circle sizes indicate the total number of enterprises in each town.

The three broad tourist groupings identified in the study area have distinct requirements and different sensitivities with regard to SGD. The groups are: business tourists and those visiting friends and relatives (VFR); people travelling through the region; and niche tourists who actively seek out the Karoo as a destination for its landscapes, stillness, biodiversity, heritage, experiences, food and stargazing. Business and VFR tourism is expected to increase under SGD but might experience crowding out if shale gas workers use tourist facilities for accommodation in the towns, especially those of the N1, N6 and N9 routes. Tourists passing through the study area would experience an increase in traffic and, also possibly, competition for facilities in the towns. Niche tourists are most sensitive to disruption by SGD of the sense-of-place, biodiversity, and darkness and quietness of the Karoo. They are also the most dependent on rural areas (Figure SPM 9.1). [§9.2.1]

The most likely risk of SGD on tourism is expected to be an increase in traffic and its associated noise pollution. This would result from slow-moving trucks continuously ferrying materials needed for SGD, hindering traffic flows and traffic noise disturbances of tourists in towns and rural areas of the study area. It will start should exploration be initiated ca. 2018 and will escalate and endure should the Small or Big Gas scenarios happen from about 2025 to beyond 2050. Other risks include the visual disruption of scenic landscapes, a loss of sense of place, perceived or actual pollution (especially of water) and small earth tremors. All of these changes could impact on the value of the Karoo brand, which is associated with an undeveloped rural landscape. In regions of very high, high and medium sensitivity for the Small and Big Gas scenarios risks range from high to very high without mitigation. With mitigation, these risks can be slightly, although not substantially, reduced. [§9.2.3; §9.3]

Negative impacts on the tourism sector would increase the risk of losses of employment and value addition to local economies. The loss in employment and Gross Value Added (GVA) associated with various degrees of tourism impairment are provided in Table SPM 9.1. [§ 9.2.2] Negative impacts on tourism could endure for a decade or more after all SGD activities have ceased and full rehabilitation has been achieved.

Table SPM 9.1: Quantified losses in tourism enterprises, employment and value addition which could be experienced.

These may be associated with increasing levels of negative impacts caused by SGD.

Loss in tourism enterprises	Tourism employment	Loss in GVA R million
	Loss	
< 4%	<530	<100
4 - 8%	531 - 790	100.1 - 200
8.1 - 12%	791 - 1580	200.1 - 300
12.1 - 16%	1581 - 2110	300.1 - 400
16.1 - 20%	2111 - 2660	400.1 - 500
>20%	>2660	>500

Mitigating the risks on tourism requires active cooperation between the mining and tourism industries. Mitigation actions could include: (i) Protecting key tourism access routes, for instance the N9, from the heavy truck traffic associated with SGD; (ii) Limiting shale gas traffic on mountain passes (such as the Swartberg, Outeniqua, Wapadsberg, Lootsberg, Huisrivier and Robinson) that provide access to the area and enhance tourist experiences; (iii) Minimised heavy traffic on local tourist routes;. (iv) Protecting Karoo towns from impacts of SGD, especially those highly dependent on tourism; (v) Reduction of noise and visual disturbances in the study area through the use of appropriate buffers around sensitive tourism assets, such as tourist facilities, protected areas and heritage sites in the rural landscape; (vi) best practice mitigation of air, water and light pollution. [§9.3]

Integrated tourism management would be required to deal with the complexities resulting from SGD. Management of tourism in the study area is currently fragmented between three provinces and many municipalities, each with its own approach. A government-led or endorsed partnership with the mining and tourism industries to collaboratively protect and promote tourism in the Karoo is an example of an integrated approach. This could lead to the establishment of an appropriate institution to achieve integrated tourism management and to support the Karoo tourism brand. This institution could be funded by a levy on gas production earmarked to offset the negative impacts on tourism. [§9.3.4]

10. IMPACTS ON THE ECONOMY

SGD could deliver highly significant economic opportunities, but its extractive nature could also bring economic risks. In both respects SGD is little different to other types of mining. The opportunities include an increase in the national and local economic activity and employment. The principal risks relate to the 'boom and bust' nature of extractive industries, and to the effects of large new inward investments on increasing the value of the South African Rand, which can make exports less competitive. [§10.2]

Positive macro-economic impacts particularly on the balance of payments can be expected from SGD. Shale gas at prices at or below imported gas would in the medium term substitute for imported gas, which would improve the trade balance and shield the country from price volatility and exchange rate risks associated with imported natural gas. If the Big Gas scenario is assumed, gas revenue could be equivalent to between 8% and 16% of the current account deficit thereby making a potentially substantial contribution to deficit alleviation. The economic risk associated with exchange rate appreciation is considered manageable for the scenarios considered. [§10.2.1.2]

The achievement of long-term macro-economic benefits will necessarily depend on the uses to which the proceeds of SGD are put. Concerted efforts will need to be directed at ensuring that the majority of proceeds accruing to government are invested so as to enhance the long-term prospects of the country. [§10.2.1.1, §10.2.1.2]

Measures focused on ownership/shareholding, purchasing, hiring and training are the key ways in which the benefits of SGD can be maximised, both in the study area and nationally. These could include, for example, applying rules similar to those required in the enhanced Social and Labour Plans (SLP) in the mining industry and local community development requirements of the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP). [§10.4]

Shale gas development would increase employment opportunities. The Big Gas scenario would be associated with approximately 2 575 direct operational jobs in drilling, trucking and power generation with residents of the study area probably able to fill 15% to 35% of these positions initially, increasing over time as training proceeds (

Table SPM 10.1). It should not be assumed that indirect and induced impacts in terms of jobs in the study area would reach the same level as direct impacts. [§10.2.2.2]

Table SPM 10.1: Preliminary estimate of direct employment opportunities resulting from shale gas development per scenario.

	Seismic exploration	**Exploration and appraisal drilling**	**Small Gas**	**Big Gas**
Size or recoverable reserve (tcf)	N/A	1	5	20
Use of gas resource	N/A	Potential movable modular power plants (1-2 MW each)	One 1 000 MW CCGT power station in the study area	Two 2 000 MW CCGT power stations in the study area and a 65 000 bpd GTL plant at the coast
Duration of activity (years)	1	5 to 10	35 minimum	35 minimum
Number of rigs/areas	5	5	3	20
Jobs per rig/area	100 to 150	100	100	100
Exploration and drilling jobs*	500 to 750	500	300	2 000
Transport/trucking jobs**	N/A	20	40	275
Power station jobs (by 2050)***	0	0	80	300
Total eventual jobs (regardless of where employees are from)	500 to 750	520	420	2 575
Initial percentage of employees from within the study area	20%	15% to 35%	15% to 35%	15% to 35%
Initial number of employees from within the study area	100 to 150	80 to 180	60 to 145	390 to 900

* Total exploration and drilling jobs were estimated in Burns et al. (2016)
** Transport/trucking jobs based on truck trip numbers in Burns et al. (2016) (these are substantially greater for the Big Gas scenario given the larger number of wells), assuming two drivers per truck and two return trips per eight-hour shift.
*** Power station jobs based on current jobs at larger Eskom power stations which are gas-fired or could be gas-fired such as Ankerlig and Gourikwa.

SGD would be a new economic activity in the study region of a potentially similar magnitude to the emerging renewable energy sector. Table SPM 10.2 provides a comparison of SGD impacts on jobs and value generation to those associated with the agriculture and tourism sectors and the renewable energy projects in the study area. It provides broad context for evaluating potential impacts. It shows, for example, that the Small Gas scenario for SGD should result in roughly half the direct jobs expected from the currently approved renewable energy projects, while the Big Gas scenario should exceed these jobs by a factor of at least three. [§10.2.2.2]

Table SPM 10.2: Estimates of direct operational employment and economic contribution by the main economic sectors in the Central Karoo. Also included are the approved renewable energy projects relative to SGD.

Sector or project	**Direct operational jobs for people from within the study area**	**Broad indicators of economic value within the study area**
Agriculture*	38 000	Total Gross Farm Income (GFI) of R5006 million/yr. Contribution of activities directly related to hunting equalling R189 million/yr
Tourism*	10 100 to 16 400 jobs	R2.3 billion/yr to R2.7 billion/yr contribution to annual study area Gross Value Added
Shale Gas Development	Initially 60 to 145 for the small scale production or 390 to 900 for the Big Gas scenario	R3.5 billion/yr to R7 billion/yr turnover for small scale production scenario or R14 billion/yr to R28 billion/yr turnover for large scale production
Renewable energy projects**	Initially 115 to 270 assuming that the portion of jobs that go to local residents is same as for SGD	R3.75 billion/yr to R4.75 billion/yr turnover

* From Oettle et al. (2016) [Agriculture] and Toerien et al. (2016) [Tourism].

** Jobs estimates based on capacity (totalling 1 500 MW) of 14 preferred bidders/projects approved for the study area under the REIPPPP multiplied by jobs/MW averages for wind and solar power projects contained in the 'Green Jobs' report (Maia et al., 2011). Turnover estimates based on capacity per project multiplied by capacity factors for wind and solar published by NERSA and by contract prices per bidding round published by DoE.

The risk that SGD could 'crowd out' other economic sectors in the study area, such as agriculture and tourism, by causing rises in the prices of labour and other inputs, is low for the scenarios considered. An important proviso is that SGD should not seriously compete with local water users or pollute local water supplies. [§10.2.2.2.2]

Local government finances are likely to be put under significant strain particularly under the Big Gas scenario. Appropriate mechanisms will be needed to effectively alleviate this strain. [§10.5]

For the Big Gas scenario, there is a high risk that the residual costs associated with SGD become the responsibility of society. With mitigation this can be reduced to moderate. Mitigation includes the implementation of financial mechanisms to ensure that developers make adequate financial provisions to allow the state to deal with remediating remaining impacts in the event of pre-mature closure and longer term risks associated with the post-closure period. [§10.2.3]

Adequate and unambiguous compensation mechanisms are needed for landowners to cover the use of their land and for other affected parties where environmental and other damages cannot

be mitigated. Property values on farms near where drilling occurs are likely to decrease – the risk is assessed as moderate without mitigation. This applies to places exposed to water supply or quality deterioration, and to places whose amenity value is reduced by visual, noise, traffic or security risks. This loss can be balanced by adequate compensation. Property values in towns, on the other hand, are likely to increase due to increased economic activity assuming key externalities such as those associated with increased truck traffic can be managed. [§10.2.4]

11. THE SOCIAL FABRIC

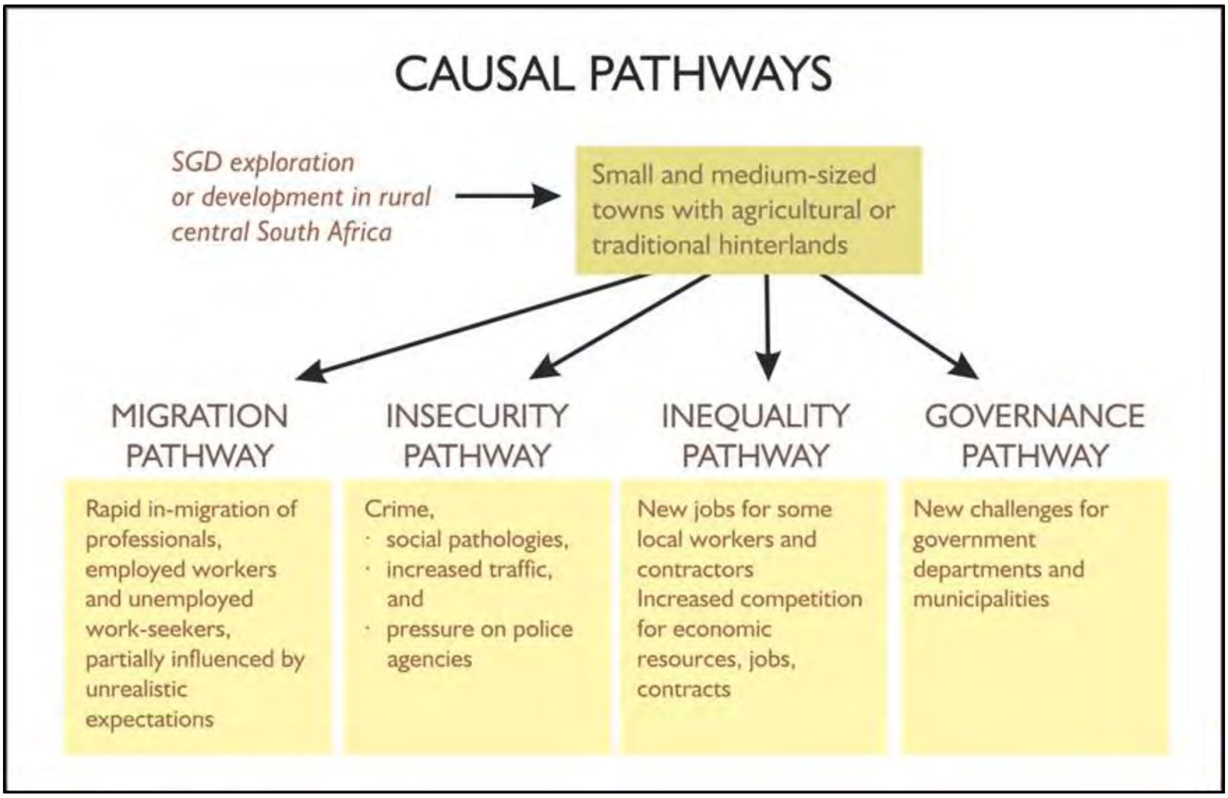


Figure SPM 11.1: Four main casual risk pathways of shale gas development which may affect social fabric. These are (a) human migration; (b) safety and security; (c) social institutions / inequality; and (d) governance. These are all interrelated in various ways, so they should not be considered in isolation.

For human migration, assuming the Small and Big Gas production scenarios, the risks will be high to very high respectively. This can be somewhat reduced to high with mitigation, for both scenarios. Mitigation efforts will include housing provision, training programmes and transparent employment practices. Municipal planning processes are typically slow and cumbersome, and therefore unable to respond timeously to these demographic fluxes. Towns in the study area already experience housing backlogs, due to inter-town and farm-town migration trends. Human in-migration to the affected environment can trigger inter-community conflict in competition for scarce resources, such as employment. If the Exploration Only scenario phase does *not* move on to the Small and Big Gas scenarios, there will be a sudden reduction in housing demand, and very likely an outflow of population. [§11.2, §11.3]

As regards physical security, assuming the Small and Big Gas scenarios, the risks are considered very high and high respectively. Various mitigation strategies are possible, depending significantly on the capacity of policing and social support agencies. Small towns in the study area will have to expand their traffic management capability significantly due to much greater traffic pressure caused by SGD trucking. With mitigation, risk can be reduced, but it is still considered to be high. [§11.2, §11.4]

There is a high risk without mitigation that benefits may not be equitably distributed, thus reducing the strength of local social institutions. For the Small and Big Gas scenarios, these risks can be reduced to moderate with mitigation. There may be more jobs and wages in the local community, stimulating new economic multipliers. This may be associated with increased competition for resources and xenophobia in a multi-racial society, disruption of local employment patterns, alienation, conflict and greater social inequality. Mitigation would include assisting communities in become more resilient and adaptable over time; however it is not clear how much institutional effort will be required by other government agencies, to promote resilience. Furthermore, proactive company initiatives may well strengthen local social institutions. [§11.2, §11.3.3, §11.3.6, §11.6.5]

Opportunities through large investments in small town areas create boomtown conditions in the local economy. SGD especially in the Big Gas scenario will create a significant mining sector in the study area. This will be associated with increases in construction, trade (wholesale and retail) and business services, which are likely to have extensive multiplier effects in the local economy, as well as job creation in these sectors. [§11.5]

In terms of governance and power dynamics, the risks associated with the Small and Big Gas scenarios are high. SGD, while anticipated to raise the mean social welfare at national and local level, may perversely simultaneously accentuate social inequalities and schisms. With mitigation in the Big Gas scenario, this risk can be reduced to moderate, but remains high for the Small Gas scenario. There may be increased pressures on already inadequate municipal governments to meet the growing demand for basic services, and new political tensions. Municipalities will be subjected to a wide range of demands for new or expanded services, and the administrative capacity, staffing levels, equipment, and outside expertise needed to meet those demands may be beyond anything that has been budgeted. The mineral leasing process typically involves experienced business people on one side and inexperienced farmers and municipalities on the other. This raises the risk that energy speculators will take advantage of local people, or that such perceptions are created, thereby detracting from municipalities' legitimacy. [§11.6]

12. IMPACT ON HUMAN HEALTH

The health status of the local population in the study area is currently below the national average, making them more vulnerable to adverse human health effects from SGD. This is despite the perception of the Karoo as a healthy environment, and is largely related to poverty, inadequate housing, unsafe water and sanitation, and insufficient health infrastructure. Investment in health infrastructure and improving socio-economic status, arising from SGD or other sources, could improve the health outcomes in the communities (Figure SPM 12.1). [§12.5]

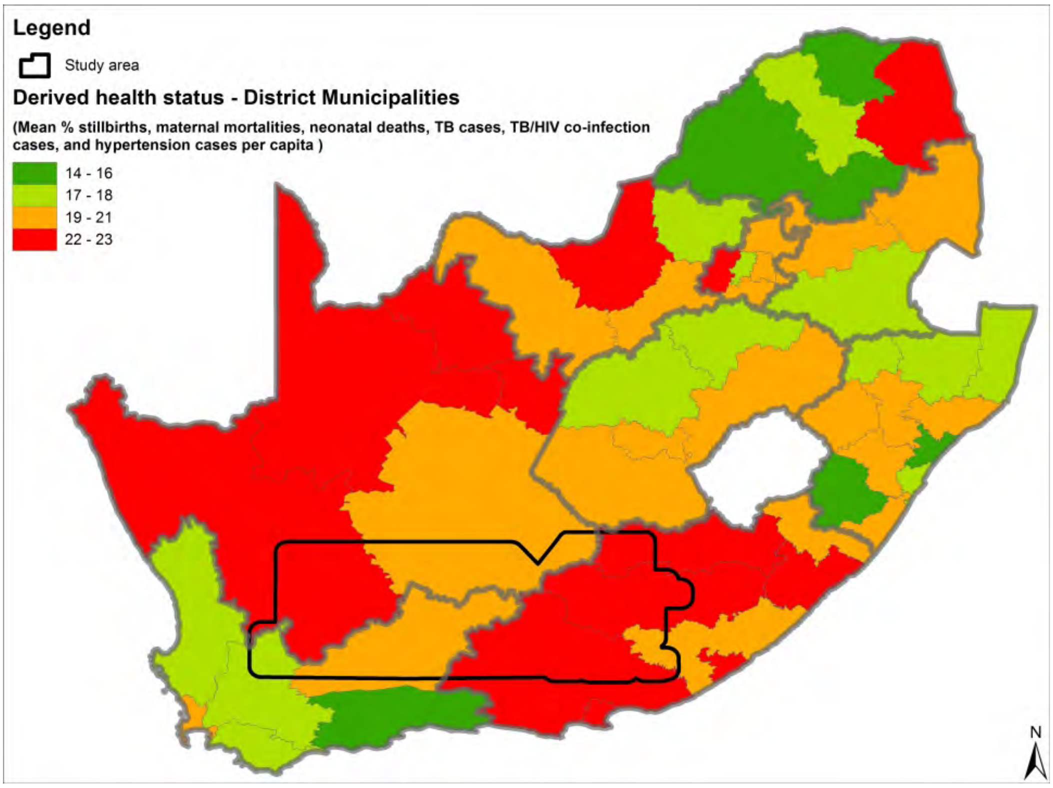


Figure SPM 12.1: Current health status of people in the Central Karoo compared with the national average. Based on numbers of still births, neonatal deaths, maternal mortality rates, TB and TB-HIV co-infection rates and hypertension per capita with red indicating highest percentage health issues.

People living close to shale gas infrastructure (wellpads and roads) are at risk of negative health impacts through air, water and noise pollution. Through on-site mitigation and keeping SGD operations at a safe distance from population centres, the potential human health risks on communities can be reduced to moderate, but some reduction in air quality will nevertheless be experienced at regional scale. [§12.2, §12.3, §12.19]

There is a high risk that SGD workers can be directly exposed to toxic substances for extended periods. Short-term dermal and respiratory symptoms are common among SGD workers. Some cases of death have been reported in countries with a history of SGD. Airborne silica exposure at the wellpad is an important cause of respiratory issues. Mitigation options, such as engineering solutions and personal protective equipment, conforming to the Hierarchy of Pollution Controls (Figure SPM 12.2), can substantially reduce the workers' exposure to moderate. [§12.10, §12.14]

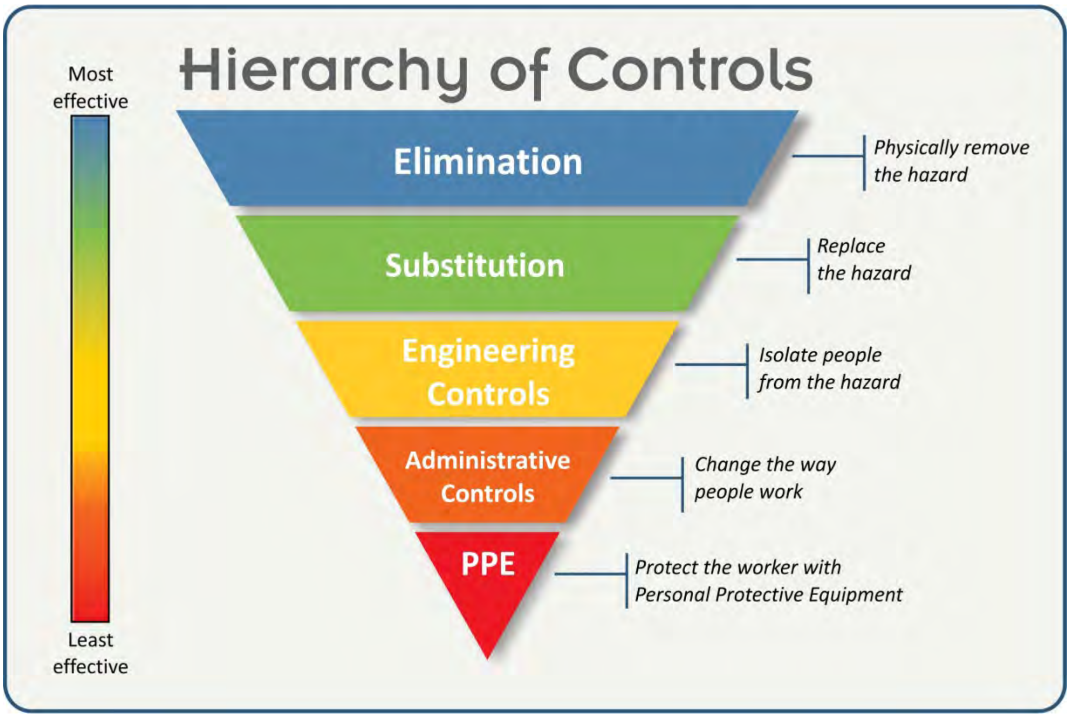


Figure SPM 12.2: Hierarchy of pollution controls for occupational health and safety for workers at sites of shale gas development.
This is particularly relevant to production sites associated with the Small and Big Gas production scenarios. (Source: NIOSH, 2015)

Baseline monitoring is crucial to attribute a future negative or positive impact of SGD on human health in the study area. Currently the available information on health issues in the study area is inadequate to form a baseline. Metrics such as incidence of asthma and other respiratory problems, dermal irritations (rashes), cardiac, cancer, birth weights, birth defects, APGAR scales, kidney and liver, infertility, neurological impairment need to be monitored. [§12.20]

Uncertainties in the chemicals to be used and their health consequences are the major limitation to assessment of the likely risks of SGD on health. This assessment is based on international data and experience. Many of the chemicals used in SGD do not have adequate health data associated with them to make an assessment. Since the activity of fracking worldwide is relatively new in relation to the time needed to assess long-term health effects, including trans-generational effects, robust scientific evidence is scant. Some of the chemical used are known to have long-term health effects. [§12.8]

Detection of health impacts resulting from SGD will require baseline and ongoing monitoring of air and water quality and health. A focus should be the health symptoms associated with SGD. A baseline will need to be established prior to initiating SGD activities in to enable unambiguous attribution of change to specific causes. Health issues should be included in the Regulations for Petroleum Exploration and Production, which currently do not consider them directly. [§12.7, §12.20]

13. SENSE OF PLACE VALUES

There is insufficient underlying research and documented evidence for this assessment to comprehensively evaluate the issue of sense of place. The assessment describes the key concerns and determinants with respect to sense of place, and is able to infer some limits of acceptable change for particular senses of place, based on the existing landscape and its land use. Sense of place has strong links to visual and noise impacts, social fabric and heritage and biodiversity issues, but also contains subjective elements which are not fully captured or measurable by those approaches. If these subjective elements are not researched and included in future SEAs or EIAs and other development processes then the risk of social disruption through SGD would increase.[§13.1, §13.2, §13.8]

There is not one, but are several, 'senses of place' in the Karoo. Some of them have local significance, while others are sensed by people living outside the area (for instance, by tourists), and perhaps even by people never visiting the area (for instance, the senses of place resulting from elements of scientific significance or artistic representation). The multiplicity of senses of place in this assessment have been identified in a generalised way from publicly available literature or media and potential areas of conflict or sensitivity highlighted .While this is not best practice or conclusive, it provides an indication of the range of sense of places that have been expressed in the public domain (Figure SPM 13.1). [§13.3, §13.5].

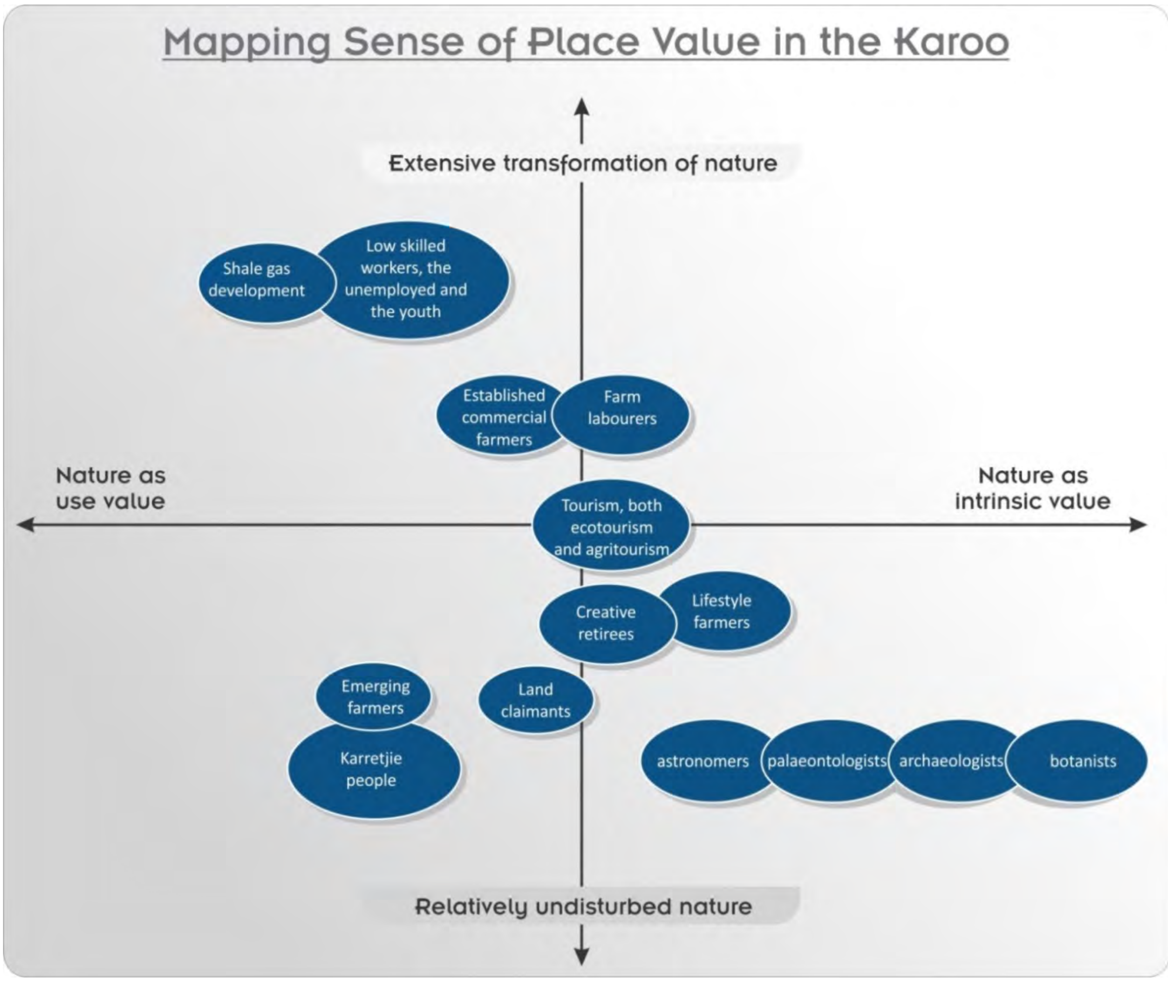


Figure SPM 13.1: Matrix of 'sense of place' values experienced in the Central Karoo.
Two of the key dimensions of the variation in sense of place in the study area are whether the sense of place is based on a human-transformed environment, such as towns or farmland, or on a minimally- disturbed landscape; and the priority which human extrinsic needs (such as employment and income) are given relative to intrinsic values such as aesthetic or spiritual appreciation.

SGD in the Karoo will affect values associated with sense of place, in some cases positively and in others negatively, and in some cases irreversibly. The loss of sense of place for farmers, farm labourers (including the Karretjie People), emerging farmers and land claimants ranges from moderate to high across the scenarios without mitigation and low to moderate after mitigation. The loss of sense of place to lifestyle farmers, creatives, retirees, tourists and scientists ranges from high to very high across the scenarios without mitigation and high to moderate with mitigation. The loss of sense of place to people associated with SGD, low-skilled workers and unemployed youth is considered very low with and without mitigation. [§13.5, §13.7]

Some senses of place are in conflict with one another whereas others are more compatible. It could be argued, for example, that shale gas developers employ a sense of place that is in conflict with the average Karoo tourist's sense of place that usually involves a sense of nothing or remoteness. Should SGD occur, a significant measure of this remoteness or "Niks" of the Karoo could be lost forever. However, for example, the tourism industry's sense of place and the farming community's sense of place are far more compatible and even supportive of each other. They both encourage low levels of noise, open space and limited numbers of people. [§13.1, §13.3.14, §13.5, §13.7.1]

Senses of place are not equally valid or justifiable within all contexts and some senses of place may have greater legitimacy than others. Senses of place are often shared by people who either live in a place or those who value it as a destination for work or holidays or who view it from an outsider's perspective. They may be regarded to have more value because they are shared by a greater number of people or potentially create value for a larger number of people. Others have more impact because it is the majority view of the people who own land and/or pay taxes and still others carry more weight because they are compatible with a diversity of senses of place. [§13.1, §13.7.2]

Sense of place values are seldom adequately addressed in public participation processes such as in EIAs, although they often turn out to be major issues. For them to be adequately addressed would require detailed empirical research to elucidate the specific sense of place values in particular contexts. One way to fill this critical gap would be to include such investigations in processes such as SEAs, EIAs, Spatial Development Frameworks (SDFs) and Environmental Management Frameworks (EMFs). It is recommended that both quantitative (Likert type surveys) and qualitative (ethnographic type fieldwork) research methods be applied to establish sense of place values within communities. This information would enable monitoring of change in senses of place and determination of the limits of acceptable change. [§13.6, §13.8]

14. VISUAL, AESTHETIC AND SCENIC RESOURCES

Without mitigation across the SGD scenarios, it is likely that visual fragmentation of Karoo landscapes, and transformation of its pastoral or wilderness character to an industrial connotation will occur. With mitigation which generally requires avoiding visually sensitive areas identified in Figure SPM 14.1; these risks can be reduced. Not all risks related to visual impact are mitigatable and very high residual risk may remain even with mitigation, especially in the high sensitivity areas and under the Big Gas scenario. [§14.4.4]

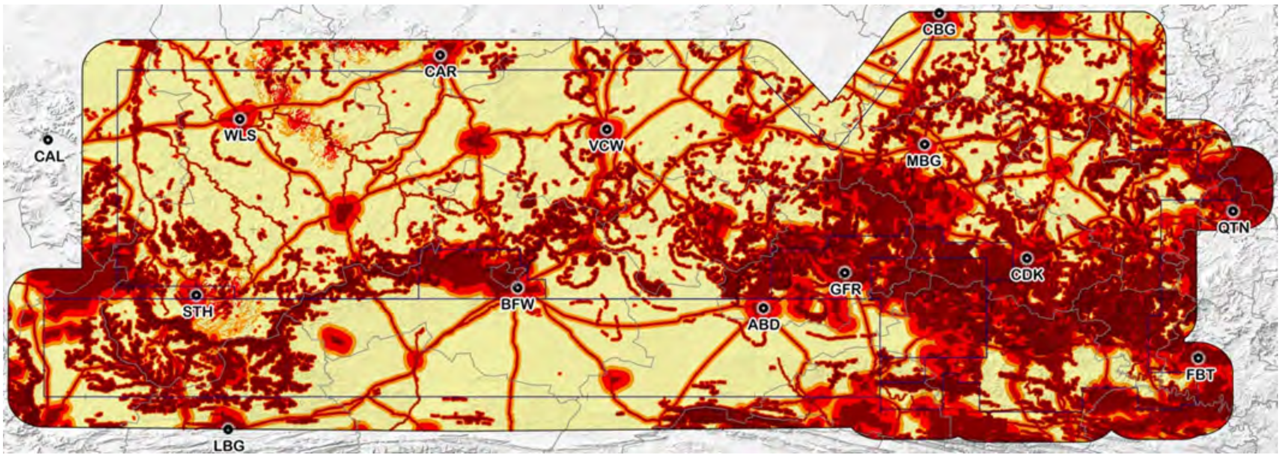


Figure SPM 14.1: Composite map of all scenic resources and sensitive receptors in the study area. This includes visual buffers, indicating visual sensitivity levels from dark red (the actual feature or receptor), red (high visual sensitivity) orange (moderate visual sensitivity) and yellow (low visual sensitivity). These are not necessarily exclusion zones, but indicate visual sensitivity at the regional scale.

Potential visual impacts resulting from the proposed SGD can be managed to a limited degree through a range of avoidance, mitigation and offset measures. Avoidance measures involve the protection of valuable scenic resources, including the use of visual buffers. Mitigation measures are mainly project-related, such as the control of construction activities and minimising the visual intrusion of structures in the landscape (Figure SPM 14.2). Finally, offset measures involve compensation in one form or another for the visual intrusion caused by SGD and possible loss of scenic resources. A possible offset is the creation within the study area of a scenic wilderness corridor forming a linked system of protected landscapes. [§14.4.1]

Cumulative impacts in the Central Karoo may pose a compounding risk. The visual risks of SGD must be considered in conjunction with visual risks resulting from associated secondary developments and from other unrelated developments in the study area, for instance the roll-out of wind and solar energy and possible uranium mining. Mitigation consists primarily of restricting SGD activities in visually sensitive locations [§14.4.1]

Scenic 'hotspots' in the Karoo that are particularly sensitive to SGD can be identified. These need to be taken into account in EIAs and other permitting processes. Currently, visual resources have no specific legal protection in South Africa, except under the definition of the National Estate in the

National Heritage Resources Act. It is advisable that national, provincial and local authorities enact legislation or by-laws to prepare for the effects of possible shale gas activities on visual resources (Figure SPM 14.1). [§14.4.2]

National, Provincial and Local Government need to prepare for future possible SGD in South Africa in order to conserve scenic resources and protect visually sensitive receptors. Best management practices to minimise potential visual impacts have been gleaned from similar activities in South Africa and from overseas studies on SGD. [§14.5]

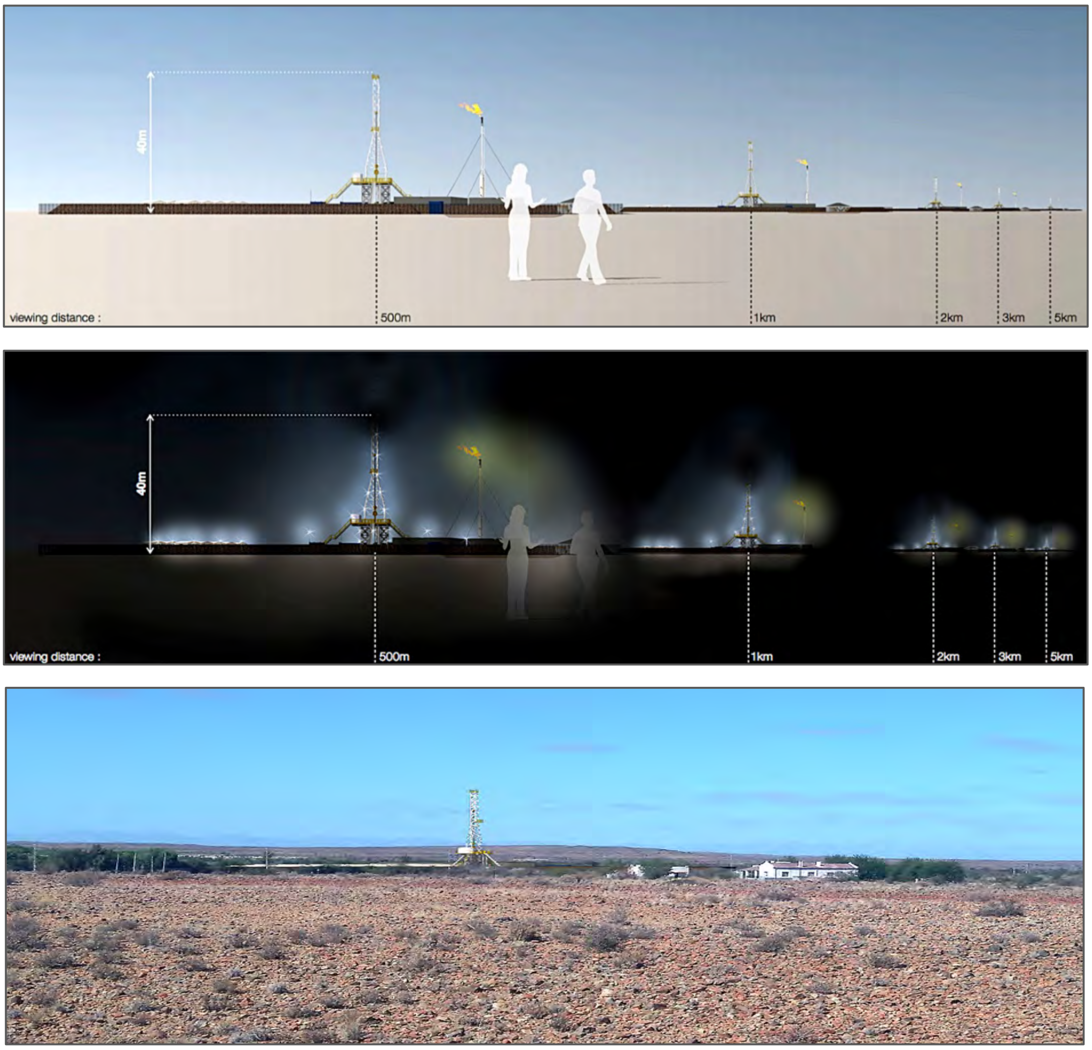


Figure SPM 14.2: Visual simulations of a wellpad located in the Central Karoo landscape.
During the day (top) and at night (middle) indicating visibility at a range of distances from 500 m to 5 km, before mitigation. The flatness and low vegetation in the Central Karoo enhances visibility. Night time visibility of lights would tend to be pronounced in the dark rural landscape of the Karoo. A visual simulation of a wellpad in a Karoo landscape at a distance of about 300 m (bottom). The adjacent farmhouse gives an indication of the scale of the drilling rig.

The level of information relating to scenic resources needs to be addressed; there being no comprehensive or standardised baseline or grading system currently in South Africa, nor fine-scale mapping for the study area. Additional information is required in particular for cultural landscapes and for private reserves, game farms and resort or tourism-related amenities that could be affected. An assessment of cumulative impacts would require information on the location and density of proposed SGD in relation to other existing and proposed activities, such as wind and solar energy developments, as well as uranium mining. [§14.6]

15. IMPACT ON HERITAGE RESOURCES

The risk to heritage resources from SGD varies markedly from place to place within the study area. It depends on the type of heritage resource, the specific locations of wellpads, access roads and related infrastructure, and the amount of induced seismic activity that occurs. There is no part of the study area where there is no risk to heritage resources. Heritage resources representing all levels of significance are distributed in variable densities throughout the study area, but because of generally low survey coverage the actual distribution of resources is poorly known. Living heritage, which is ubiquitous, binds the physical resources together and contributes to the character of a region that is so highly valued by a wide community of South Africans. [§15.1.1]

Heritage resources in the study area are part of the National Estate and thus belong to the people of South Africa. While most are of relatively low heritage significance, there are numerous sites of high sensitivity scattered across the region. Towns and villages, river valleys, rocky ridges and the undulating uplands tend to be more sensitive than the open plains for some categories of heritage, largely because of access to water. In these regions the risks to heritage resources is considered high but can be reduced to low by appropriate micro-siting of SGD infrastructure during EIA processes [§15.3.1]. Seismic activity could negatively affect heritage resources to varying degrees depending on the fragility of the resource, but built heritage within 10 km of fracking sites is considered a high risk without and with mitigation. [§15.2.1, §15.2.2]

The risk to heritage resources in the study area during the Exploration Only scenario is considered high. The exploration phase may be associated with intensive and widespread seismic lines and 3D surveys in the region. The Small and Big Gas production scenarios would be confined to designated 30 x 30 km production blocks, thereby reducing the risks associated with widely dispersed and diverse heritage resources. Although it will not be possible to choose the exploration and/or production areas based on heritage resources, micro-siting of the infrastructure and the implementation of management and mitigation measures during all phases will help reduce risks. The most difficult aspects with which to deal in terms of mitigation are aspects relating to the cultural landscape and, along with minimising the amount of landscape scarring that occurs, effective closure phase rehabilitation will be key to mitigating risks. [§15.4]

The risk to cultural heritage assuming the Big Gas scenario is considered very high without mitigation. For the Small Gas scenario it is high without mitigation. Avoiding the sensitive visual hotspots identified in the Visual Chapter by Oberholzer et al. (2016) will decrease the risk to high and moderate for the Big and Small Gas scenarios respectively (see Figure SPM 14.1). [§15.3.2.5, §15.3.2.7]

16. NOISE GENERATED BY SHALE GAS RELATED ACTIVITIES

Acoustic noise has a marked impact on the physical health of people and on their psychological wellbeing. The Karoo area is a quiet area. Residual day- and night-time noise levels are approximately 33 dBA and 25 dBA respectively (LAeq). This is 10 dB quieter than the typical levels published in standards for rural areas, a significant difference since an increase of 10 dB is perceived as a doubling of 'loudness'. [§16.1.2]

Exploration phase noise impact is likely to be localised and of short duration with very low risk with and without mitigation. Noise would be generated predominantly by trucks, and would only be noticeable in the immediate vicinity of exploration activities, for the duration of the activities. [§16.2.4, §16.2.5]

The Big Gas scenario will likely have very high noise risks for humans and animals within 5 km of the sites. Noisy activities during the operational phases are expected to run constantly (day and night) for six to eight weeks at a time, repeated every six months at every wellpad, for a period of a decade or two, with quieter activities between. Night time noise impacts are therefore most likely, when residual noise levels are at a minimum. [§16.2.4, §16.2.5, §16.3.3] For receivers within 5 km of drilling activities, the risk can be mitigated to high by implementing best practice management technologies. [§16.4]

For all scenarios, risk is reduced to very low once receivers are located a horizontal distance of 5 km away from drilling activities on wellpads. That being said, proposed sites of noise generating activities will need individual Noise Impact Assessments in accordance with SANS 10328 to determine the likelihood and severity of impacts at a site specific level. Noise control, attenuation and monitoring will likely be required for all sites. The extent of the required measures will be determined by the Noise Impact Assessment undertaken as part of an EIA process. [§16.5]

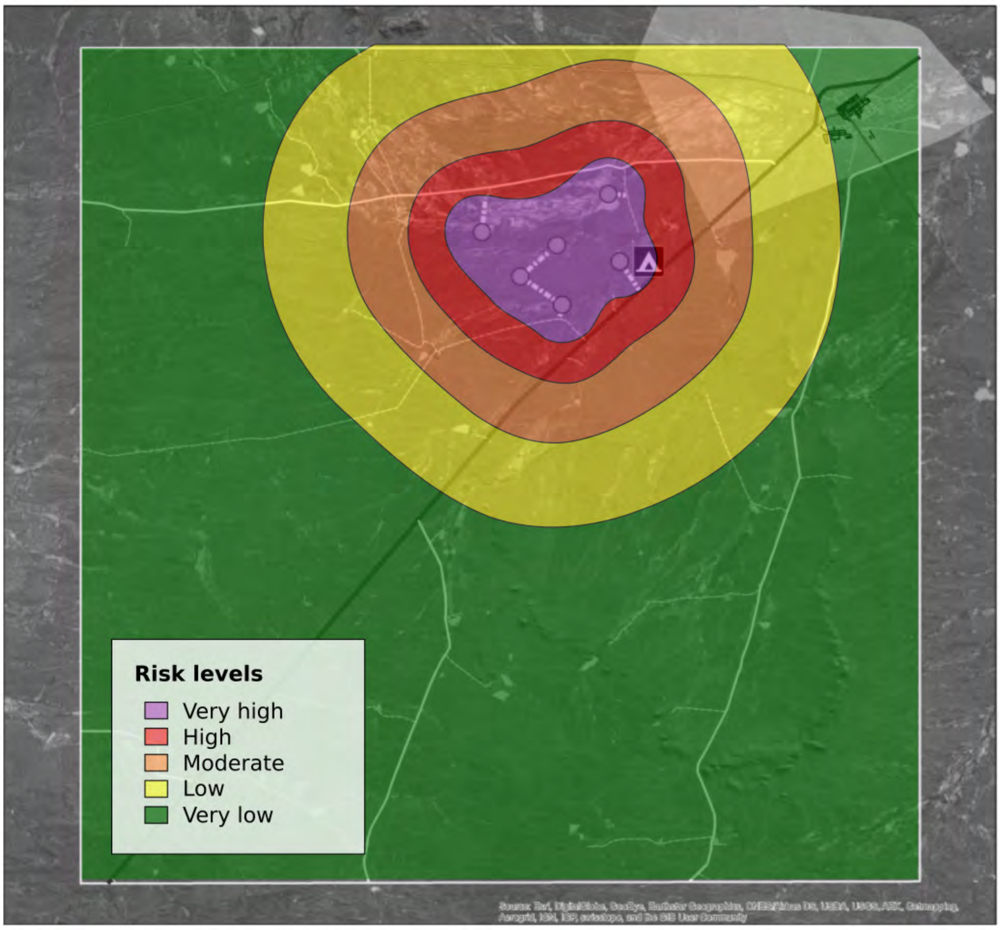


Figure SPM 16.1: Notional schematic showing the risk profile of noise impacts from wellpad activities. Risk reduces to very low once approximately 5 km from the wellpad. The figure does not include potential disturbance due to increased road traffic noise if roads are otherwise quiet.

There is additionally a risk of noise impacts emanating from the surrounding roads due to increased heavy goods vehicle road traffic. This will be especially prominent assuming the Big Gas scenario wellfield is located in the vicinity of quiet and seldom used roads. [§16.2.4] Under the Big Gas scenario, this risk is considered high without mitigation and moderate with appropriate traffic noise control mitigation applied. [§16.2.6. §16.4]

17. ELECTROMAGNETIC INTERFERENCE WITH THE SQUARE KILOMETRE ARRAY

The permissible electromagnetic interference (EMI, 'noise' in the radio frequencies) is regulated for those parts of the study area which can affect the performance of the Square Kilometre Array (SKA) radio telescope. The SKA will be the largest and most sensitive radio telescope in the world and constitutes a multi-billion Rand, multi-decadal investment, centred near Carnarvon, just north of the study area. The array forms a spiral with several arms, with receivers at increasing spacing on each arm (Figure SPM 17.1). Three of the spiral arms penetrate the study area. In terms of the Astronomical Geographic Advantage Act and its regulations, EMI at each of the distributed receivers may not exceed certain limits. [§17.1.1]

Electrical motors, switchgear, spark-ignited engine motors and communication devices are the types of equipment used in SGD which can potentially cause EMI. [§17.3.4] The first mitigation action is to reduce the number of such sources, and to select the equipment or shield it in such a way to minimise the EMI. Testing of all equipment for compliance is necessary prior to SGD. The EMI produced depends on both the specific equipment and its use. It cannot be assessed in detail at the strategic level, but when specific proposals are considered in an EIA phase, an inventory must be made, including where, how often and how many of each type will be used and the EMI characteristics of the proposed equipment must be determined. Radio propagation models can then be run to confirm that the specified limits are not exceeded at the receivers. [§17.3.7]

The key mitigation is to exclude EMI-generating sources for distances up to 40 km for the most sensitive parts of the SKA. Within sensitivity class 5 and within the Karoo Central Astronomy Advantage Area (KCAAA), no SGD activity is permitted (Figure SPM 17.1). If SGD activities are located beyond the KCAAA, but still fall within sensitivity classes 1-5, any activity would require detailed site specific EMI assessments. If mitigation actions are followed, the risk of EMI with the SKA originating from SGD is very low. [§17.3.5, §17.3.6]

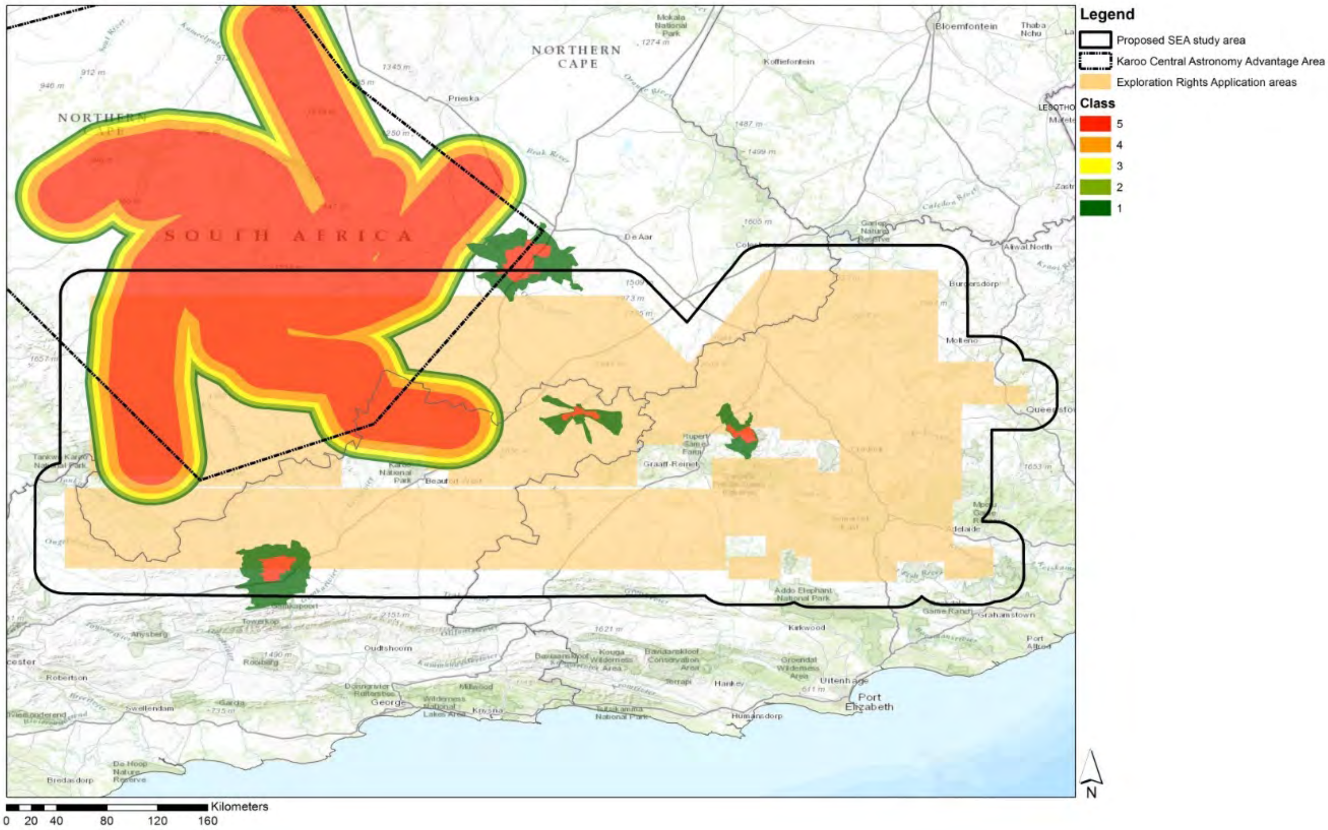


Figure SPM 17.1: Map showing the sensitivity classes of the Square-Kilometre Array.
The sensitivity classes are categorised from 1 – 5, where each class is informed by a specific separation distance. The KCAAA is shown as the black polygon around the SKA spiral arms, overlayed with the study area. The isolated polygons occurring outside of the core spiral arms and KCAAA are future planned antenna. Fracking activities beyond the pre-identified buffer zones do not represent a risk of detrimental impact on the SKA as a result of EMI. Within each sensitivity class, a particular level of EMI mitigation is required, which may make certain SGD activities unfeasible within sensitivity class 5. [§17.3.7]

18. SPATIAL AND INFRASTRUCTURE PLANNING

Towns in close proximity to SGD activities will experience growth exceeding projections based on past trends. For the Big Gas scenario, the risk is assessed as high, but can be mitigated to moderate. Enhanced resource and institutional capacity to plan for and address increased service delivery demand for housing, water provision, social services, electricity and roads will be required. [§18.2.3; §18.3.1, §18.4.5, §10.4]

Around 45 000 to 2 117 000 truck visits may be required for the Exploration Only and Big Gas scenarios respectively. For the Small Gas scenario the range will be somewhere closer to 370 000. The risks associated with the increased traffic volumes and new network of geographically scattered private local access roads and wellpads is considered high without mitigation. Mitigation will be required to source construction material and identify and approve local sites for extraction of raw materials. The risk can be reduced to moderate with mitigation. This would include adequate road rehabilitation prior to SGD, avoidance of certain routes; and improved safety and emergency response capacity. [§18.2.1, §18.2.4, §18.3.1]

There may be a need to develop pipelines and re-establish rail infrastructure in the sub-region to relieve the pressure on the road infrastructure. There is thus a critical need to audit and establish the current baseline condition and usage of national, regional and local roads to inform mitigation responsibilities in future. The current state of road infrastructure is generally poor and the financial and human capacities to address the issue are currently limited. [§18.2.2, §18.3.1, §18.4.2, §18.4.4]

Regulatory uncertainties and limited municipal capacity to facilitate ongoing processes of land use and land development applications associated with SGD poses a high risk without mitigation. This risk primarily relates to the already limited municipal governance capacity and regulatory bottlenecks. With mitigation, this risk can be reduced to moderate. Clarification of legal and implementation practices in the land use and land development regulatory framework, as well as provincial support to municipalities is required. [§18.2.4, §18.4.6]

The primary option for mitigation of risk is to enhance integrated spatial planning. This will be essential to deal with the multi-scaled and inter-sectoral issues that result from activities of magnitude and duration of SGD. SDF and IDP plans in the area will require updating. Given a number of other activities proposed in the area such as renewable energy projects, the SKA, uranium mining, transport corridors etc., the preparation of a Regional Spatial Development Framework could contribute to pro-active intergovernmental planning between the respective local and district municipalities, provinces, relevant provincial and national sector departments and other role players (Figure SPM 18.1). [§18.1.4, §18.4.1, §18.4.6, §18.4.7]

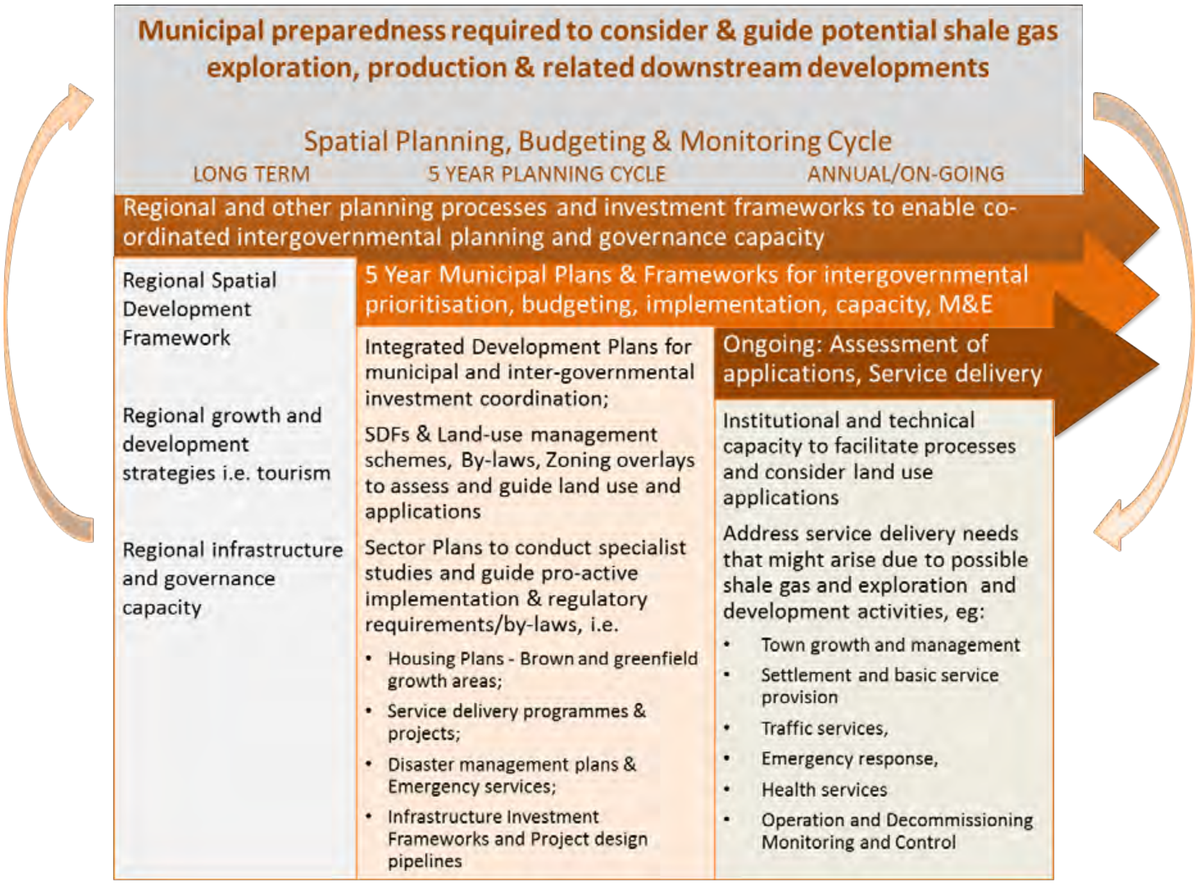


Figure SPM 18.1: Proposed system for developing enhanced municipal preparedness required to consider and guide land use applications, manage municipal impacts and service needs.

19. AN INTEGRATED 'RISK PICTURE'

Risks are assessed across the scenarios, with and without mitigation. Without mitigation assumes inadequate governance capacity, weak decision-making and non-compliance with regulatory requirements. With mitigation assumes effective implementation of best practice principles (including avoidance of key sensitive features), adequate institutional governance capacity and responsible decision-making. Based on the risk assessment approach described in the introductory text, risks are predicted in a consistent manner across the Chapters, ascribing a risk category to a specific impact, within a particular spatial setting (see Table SPM 0.1).

Some impacts assessed have spatially explicit risk profiles which have been integrated. For other Chapters, the impacts assessed do not have a specific spatial profile, such as those concerning social fabric, sense of place, energy planning, economics and others. This does not make the information contained therein any less relevant or important for decision-making.

An integrated 'risk picture' was developed (see Figure SPM 19.1). This picture spans the three scenarios (considered against the Reference Case) and assessments are made without and with mitigation applied. Spatially explicit risk profiles were merged, and are depicted using the 'maximum rule' to prioritise the highest risk areas over those of lower risk in the cumulative spatial overlay (see Table SPM 19.1).

The risk picture is not a detailed reflection of 'reality'. The purpose of the risk mapping exercise is to demonstrate the potential evolution of the risk profile across the scenarios considered, which accounts for the full life-cycle of SGD activities, from cradle-to-grave, and to test the efficacy of mitigation actions in reducing risks. The purpose of the risk picture is not to determine areas which should be excluded from SGD activities in the future, although more localised sensitivity mapping processes may reveal this with relatively high degrees of confidence in the future.

Table SPM 19.1: Chapter topics with spatially explicit risk profiles used to develop the integrated risk 'picture'.

Topic	Impact	Spatial unit
Air quality and Greenhouse Gas Emissions	Local community exposure to air pollutants	Sensitive areas identified as being within 10 km of towns
Earthquakes	Damaging earthquakes induced by fracking	Sensitive areas identified as a being within 20 km of towns
*Water**	Contamination of groundwater resources through surface spills and discharge	Water resource sensitivity maps developed based on legislated and proposed setbacks from surface and groundwater resources and associated geological structures
	Contamination of groundwater resources caused by a loss of well integrity and via preferential pathways caused by fracking	
	Physical disturbance of watercourses and contamination of surface water resources through flowback discharge and contact with contaminated groundwater	
*Biodiversity and ecology***	Ecological and biodiversity impacts	EBIS classes defined at habitat to landscape scales generally utilised in spatial biodiversity planning
Agriculture	Alteration of agricultural landscape and impact on agricultural resources base	Agricultural sensitivity classes defined at the quaternary catchment scale
Tourism	Tourism impacts	Tourism sensitivity classes defined at town, protected area, and tourism route scale
Visual	Visual intrusion into the landscape, altering the rural character	Visual sensitivity classes defined at the regional scenic resource scale
Heritage	Impacts on built heritage, monuments and memorials	Sensitive areas identified as being within 10 km from towns
	Impacts on archaeology and graves	Archaeology and graves sensitivity classes defined at the landscape scale.
	Impacts on palaeontology, meteorites and geological heritage	Palaeontology, meteorites & geological heritage sensitivity classes defined at a landscape scale
*Electromagnetic Interference****	Electromagnetic interference impacts on radio astronomy receptors (SKA)	EMI sensitivity classes defined at the scale of separation distances from the SKA development footprint

* The primary mitigation measure assumed for the 'with mitigation' assessment for water resources is that SGD activities do not occur within the areas mapped as being of high sensitivity (see Figure SPM 5.2). The spatial risk assessment must be interpreted in the light of known mapping constraints, with particular regard to scale.

** For biodiversity and ecosystems, 'with mitigation' assumes the following: 1.) That proclaimed protected areas are 'no-go' areas 2.) That EBIS-1 areas are avoided 3.) That EBIS-2 areas are avoided, or at a minimum, utilised but only following securing suitable offset sites in EBIS-1 or 2 areas (see Figure SPM 7.1).

*** 'With mitigation' assumes that no SGD activities are permitted within sensitivity class 5 and within the Karoo Central Astronomy Advantage Area (KCAAA) (see Figure SPM 17.1).

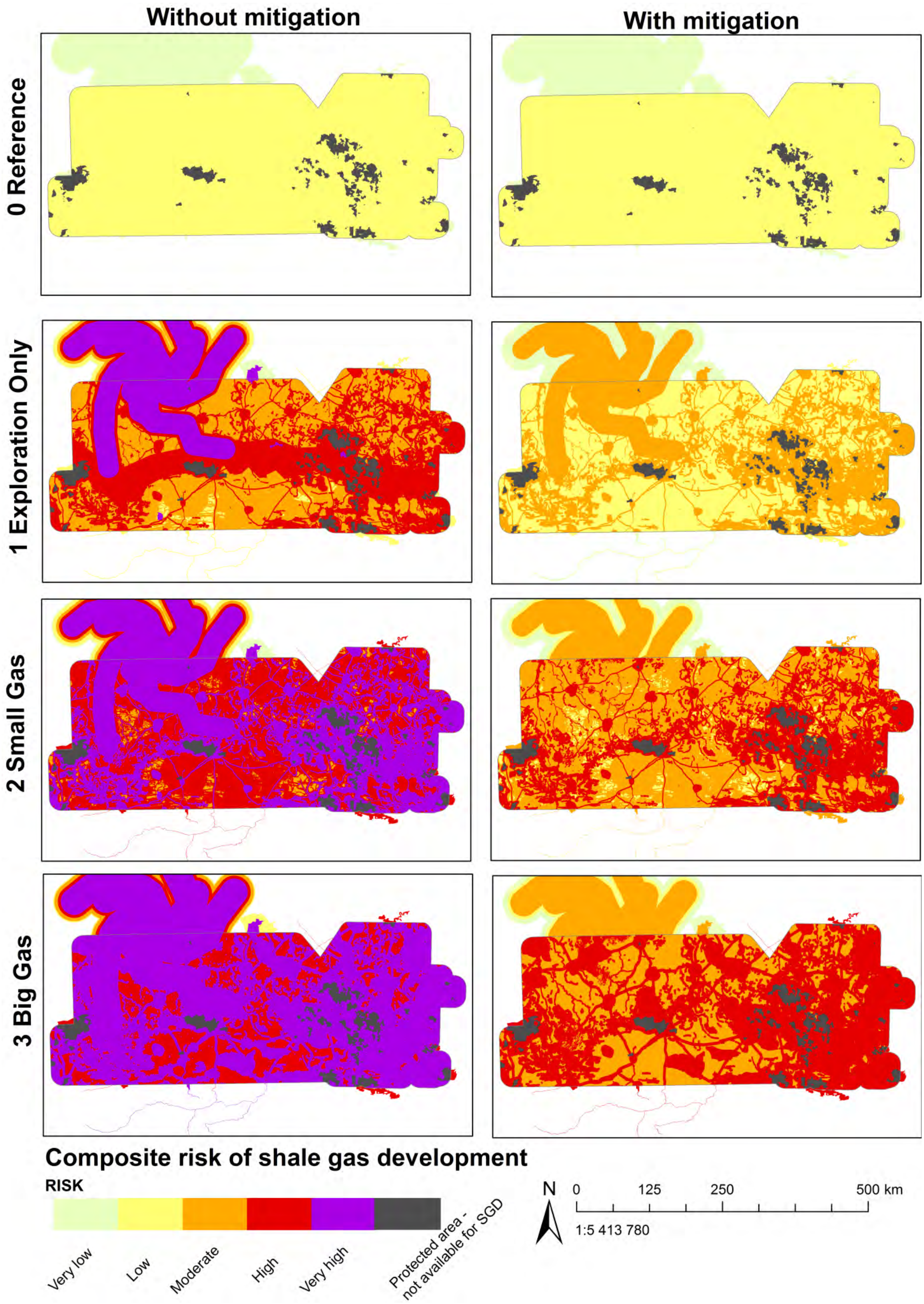


Figure SPM 19.1: Composite map of spatially explicit risk profiles within the study area, depicting the risk of SGD across four scenarios, without-and with mitigation.

The risk picture presents a mosaic of cumulative risk, evolving across the scenarios. Risks range from low to very high in the study area, with higher risk areas prevalent towards the eastern portion of the study area (Figure SPM 19.1). This may be attributed to more variable landscape features in the east which are characterised by a denser distribution of towns (Burns et al., 2016), more diverse habitats and a greater concentration of protected and sensitive areas (Holness et al., 2016), higher agricultural production potential (Oettlé et al., 2016) and an increased concentration of scenic resources and landscapes (Oberholzer et al., 2016).

Without mitigation, the risks associated with SGD from the Exploration Only to Big Gas scenarios increase incrementally from moderate-very high to high-very high. Effective implementation of mitigation and best practice principles may reduce the risk profile to low-moderate for Exploration Only, and overall moderate-high for the Small- and Big Gas scenarios.

There is major uncertainty regarding the nature and extent of a shale gas resource. Modern exploration, in its various forms, is the only way to increase the understanding of the resource and whether shale gas should be considered further in the country's energy planning and national discourse.

At the strategic-level of assessment, the risks associated with Exploration Only could be mitigated to low-moderate (considering both spatial and non-spatial risks). Good practice mitigation is reliant on the veracity of the future decision-making processes. These should be guided by evidence-based policies, robust regulatory frameworks and capacitated institutions in a manner that is ethical, responsible and transparent.

In the Exploration Only scenario, there are some moderate risks even after mitigation is applied. These include impacts to physical security and altered local social dynamics [§11.7]; occupational exposure to air pollutants on drilling sites [§3.2.5, §12.19]; EMI within sensitivity class 5 of the SKA [§17.3.5]; local road construction and regional pressure on road infrastructure [§18.3.2]; spatial and development planning and governance capacity [§18.3.2]. The impact of altered power dynamics is the sole impact assessed as high after mitigation within the Exploration Only scenario. [§11.6]

Application of the mitigation hierarchy will help to significantly reduce risks. The mitigation hierarchy prescribes avoidance as the most efficient manner to minimise impact exposure and hence to reduce the risk profile. Avoidance is most commonly applied within a spatial context to delimited areas that are unacceptable for development for one reason or another (sometimes many). Avoidance can also mean the prohibition of certain development activities if more suitable, less consequential alternatives exist.

Through effective project planning, many of sensitive features of the Central Karoo can be avoided. This includes high sensitivity water resources, EBIS-areas 1 and 2, high sensitivity agricultural land, heritage features, important tourism areas or routes, vulnerable people living in towns or rural communities, high sensitivity visual resources and the footprint of the SKA development phases.

All data, including spatial information, should be further tested and augmented during site-level assessments. This applies to specific development applications, where the nature, location and extent of SGD activities are clearly defined. Even though the most recent existing spatial data available were utilised for this strategic-level assessment, it must be recognised that information may be incomplete and/or contain inaccuracies. Most of the features mapped at the scale of this assessment will require additional project-level assessment processes to ground-truth sensitive features on-site.

The decision regarding SGD is not a binary *'yes'* or *'no'* question. There are a number of decisions which are made through multiple decision-making processes spanning all spheres of government and civil society (including the industry); potentially over an extended period time. Most of these decisions will be conditional rather than absolute decisions, meaning that certain activities may be permitted in one location and not another, or with a given set of requisite monitoring or management actions. This will depend on the specific nature of the activities and the location within which they are proposed.

Decisions regarding SGD should be considered in a 'step-wise' manner. If South Africa does choose to proceed with exploration, and an economically and technically suitable reserve is discovered in the future, due assessment of regional and cumulative impacts should inform decision-making prior to commencing with production of gas in the Central Karoo at a significant scale.

Baseline and ongoing data should repeatedly be collected and fed back into the evidentiary base to critically test decisions, the efficacy of management actions and scientific assumptions. As a starting point, South Africa is in the advantageous position of being able to accumulate a baseline dataset and start building or supporting the institutions capable of collecting, managing and analysing that data in a responsible manner.

CHAPTER 1

Scenarios and Activities

CHAPTER 1: SCENARIOS AND ACTIVITIES

Integrating Author:	Mike Burns[1]
Contributing Authors:	Doreen Atkinson[2], Oliver Barker[3], Claire Davis[4], Liz Day[5], Surina Esterhuyse[7], Phil Hobbs[4], Ian McLachlan†, Nigel Rossouw[7], Simon Todd[8], Luanita Snyman-Van der Walt[1] and Elsona van Huyssteen[9]
Corresponding Authors:	Selwyn Adams[10], Megan de Jager[1], Zainab Mowzer[10] and Bob Scholes[11]

1 Environmental Management Services, Council for Scientific and Industrial Research, Stellenbosch, 7660

2 Centre for Development Support, University of the Free State, Bloemfontein, 9300

3 Banzi Geotechnics cc, Johannesburg, 2193

4 Natural Resources and the Environment Unit, Council for Scientific and Industrial Research, Stellenbosch, 7600

5 Freshwater Consulting Group, Cape Town, 7800

6 Centre for Environmental Management, University of the Free State, Bloemfontein, 9300

7 Shell South Africa: Integrated Gas Ventures, Bryanston, 2021

8 South African Environmental Observation Network Arid Lands Node, Kimberly, 8306

9 Built Environment Department, Council for Scientific and Industrial Research, Stellenbosch, 7660

10 Petroleum Agency SA, Cape Town, 7536

11 Global Change and Sustainability Research Institute, University of the Witwatersrand, Johannesburg, 2000

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Executive Summary

There is no history of exploitation of shale gas in South Africa, so this description of potential scenarios and related activities is necessarily hypothetical and based on experience elsewhere, interpreted in the light of what is known about the Karoo petroleum geology, its ecology and social environment. Shale gas, the "unconventional resource" targeted by the petroleum sector, is methane gas trapped in shale formations which have low permeability[1]. The gas is stored or "trapped" under pressure in pore spaces, in existing fractures, and adsorbed on the shale particles. Hydraulic fracturing is the process of applying hydraulic pressure to the shale until that pressure exceeds the formation fracture gradient or fracture pressure. The hydraulic pressure is created using surface equipment to pump hydraulic fracturing fluid through perforated well casing into the target shale formation. When the hydraulic pressure exceeds the formation fracture pressure the rock breaks resulting in millimetre (mm)-scale fractures. The fractures are kept open by solid particles (typically sand) which is included in the hydraulic fracturing fluid. The trapped methane gas flows out of the shale through the well casing perforations into the wellbore, as long as there is a pressure differential between the source formation and the surface. Produced natural gas has a number of downstream uses, including fuel for electricity generation and for refining to fuels and other hydrocarbon-based products (including diesel, petrol and plastics).

Economically recoverable gas in the study area could range between 5 and 20 trillion cubic feet (tcf). It is also possible that no economically recoverable gas reserves might exist. The shales of South Africa's Karoo Basin are known to contain gas. It is uncertain what the magnitude and distribution of the gas reserves are. Igneous dolerite intrusions and the effects of Cape fold processes are believed to have reduced the quantity of gas relative to what originally might have been contained within the shales. Based on limited exploration data, there is reasonable agreement between several assessments that have been made of the presence of shale gas in the Karoo Basin. Indications are that gas is most likely concentrated in the area between the Cape Fold and the Nuweveld mountain ranges.

Three shale gas exploration and development scenarios of increasing magnitude are explored in this chapter, relative to a Reference Case with no shale gas activities. The three shale gas scenarios are: (i) *exploration proceeds, with results indicating that production would not be economically viable* (i.e. all sites are rehabilitated, drilled wells are permanently plugged and monitoring of the abandoned wells is implemented) *(referred to as the 'Exploration Only Scenario')*; (ii) *a relatively small but economically viable shale gas discovery is made, with downstream development resulting in a 1 000 MW combined cycle gas turbine (CCGT) power station (referred to*

[1] Shales are classically defined as "laminated, indurated (consolidated) rock with >67% clay-sized materials" with grain size of <.004mm on the Wentworth Scale (Jackson, 1997).

as the 'Small Gas Scenario'); and (iii) *a relatively large shale gas discovery is made, with downstream development resulting in construction of two CCGT power stations (each of 2 000 MW generating capacity) and a gas-to-liquid (GTL) plant located either at the coast or in Gauteng (referred to as the 'Big Gas Scenario').* This chapter describes both the Reference Case and the main shale gas exploration and production activities (or impact drivers) through which the three defined shale gas scenarios would materialise.

The Karoo is changing in response to a number of historic and current influences, independently of shale gas development (SGD), and the resilience to further change varies across the study area. Changes in climate are expected to increase the vulnerability of ecosystems and thereby affect ecosystem services that contribute to social well-being. The effects of this and other change factors will be offset, to varying degrees, by entrepreneurial economic and institutional responses.

The description and quantification of the shale gas-related activities presented in this Chapter informs the assessment of ecological and social risk addressed in other Chapters. For the Exploration Only scenario, activities that will manifest as key impact drivers (i.e. those with greatest influence on risk) include the operations of seismic exploration vehicles along networks of survey transects across the study area, clearing of drilling wellpads and crew accommodation sites, the construction of access roads and traffic (especially heavy-duty vehicles using these and public roads throughout operations), rail and road transport of equipment and materials, water use, noise, light and gas emissions, visual impact, generated waste and employment. These activities, plus the installation of gas reticulation and processing infrastructure, will also manifest as key impact drivers for both the Small and Big Gas scenarios; however, their scale will increase significantly relative to exploration, particularly in the case of the Big Gas scenario.

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CHAPTER 1: SCENARIOS AND ACTIVITIES

1.1 Shale Gas: Introducing the unconventional

Shale gas is a hydrocarbon that consists mainly of methane (CH_4). It is commonly used as fuel for generating electricity, heating and cooking; it can also be converted to liquid fuels, polymers, and other products (Holloway and Rudd, 2013). In order to assess the strategic implications of shale gas development (SGD) within the study area it is necessary to understand what the SGD process life cycle entails, what the main activities are that characterise each stage of the life cycle and how these present as impact drivers that could pose risks to the receiving environment[2]. In turn, an understanding is required of the ecological and social characteristics of the environment in which SGD could materialise. Insight is also required of the petroleum geology of the study area in order to understand where and in what amounts shale gas might occur. It is the aim of this Chapter to provide this foundational context for the 17 chapters which follow in this scientific assessment.

In the sub-surface, hydrocarbon reserves are accumulated or trapped in reservoirs. These reserves are commonly classified by the petroleum sector as either ‘conventional’ or ‘unconventional’. The ‘unconventional’ reserve designation is not strictly a function of geology, but may also be a function of cost to exploit, development and production technology challenges (e.g. requirements for horizontal drilling, hydraulic fracturing) and a suite of determinants of economic feasibility.

Hydrocarbon reserves require four basic components in order to accumulate in the sub-surface: (i) source rocks (e.g. organic rich shales); (ii) migration pathways from the source rock; (iii) reservoirs into which hydrocarbon product migrates; and (iv) trapping mechanisms. Conventional hydrocarbon reserves are trapped within interconnected pores and/or fractures in sandstone and limestone rock formations (i.e. the reservoir) with a confining or impermeable boundary that prevents hydrocarbon migration (i.e. the trap). In response to exploration and development operations, the interconnectivity of the pores, or permeability, allows the hydrocarbons to typically flow from the reservoir into a wellbore, without the need for fracture stimulation (Figure 1.1).

Shale gas formations act as a source, a reservoir and a trapping mechanism. The gas is generated from organic material in the shales and trapped within micro pores and existing fractures and adsorbed on the individual particles of shale. Vertical and horizontal drilling of wells and hydraulic fracturing are employed to exploit the shale gas. Unconventional gas is also contained within ‘tight’ or less porous

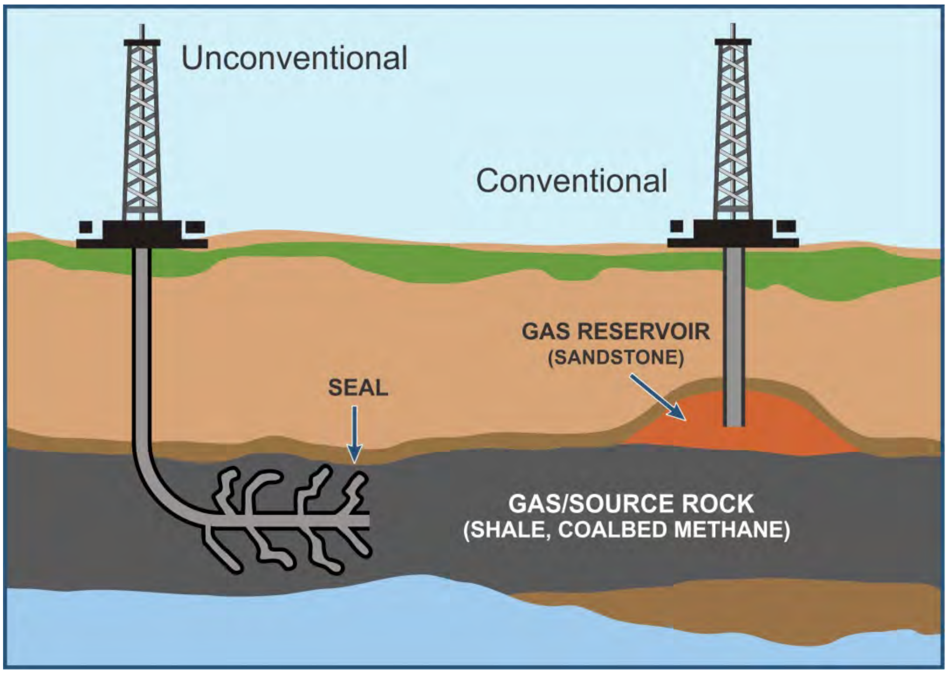
[2] In the Scientific Assessment, the focus is on key activities that present as potential *top order* impact drivers; i.e. those that warrant assessment at the strategic level. It would be the purpose of project level Environmental Impact Assessment to address the many other activities that present as lower order impact drivers.

rock formations that include some sandstones and carbonates (US Energy Information Administration (EIA), 2013). Gas incorporated into coal seams (coal seam gas) also qualifies as an unconventional hydrocarbon product.

Shales may have relatively high porosity but low permeability; therefore, the formation with associated shale gas is stimulated to produce the trapped gas using a technique termed hydraulic fracturing (popularly called ‘fracking’). This process entails typically drilling a well with vertical and horizontal (lateral) sections into a gas-bearing shale formation to achieve maximum exposure of the wellbore to the shale. Sections of the lateral well bore are selectively isolated; fluid pressure in these sections is then increased using surface pumps until the pressure exceeds the shale formation's fracture gradient. Millimetre-scale fractures are created whilst any existing fractures are enhanced within the shale as a result of this hydraulic pressure. The fractures act as pathways for gas to flow out of the shale and into the drilled well (House of Commons Energy and Climate Change Committee, 2011; Holloway and Rudd, 2013). Sand and other materials included in the fracturing fluid prop the fractures open allowing the gas to flow to the surface via the vertical well bores (US EPA, 2012).

Many countries across the globe have gas-rich shale formations (Figure 1.2). In Europe, countries have applied a range of policy approaches towards SGD. For example, France and Bulgaria have banned fracking, whilst Poland and the United Kingdom have an ongoing programme of exploratory drilling and testing of fracking (European Commission, 2015). SGD has occurred widely in the United States of America (USA) where shale gas ‘plays’ such as the Barnett and Marcellus formations are important targets for the sector. The onshore USA is unique in that a surface owner may also own the mineral estate (or hold an exclusive development license), unlike most other countries where national governments own the minerals (Kulander, 2013). SGD activities are prescribed, regulated, and enforced at the local, state and federal levels (Williams, 2012). In South Africa the Mineral and Petroleum Resources Development Act (MPRDA, 2002, as Amended in 2008) vests the ownership of the country’s mineral resources, including petroleum, with its citizens. The State acts as custodian of the resources, granting rights to third parties for exploration and exploitation whilst securing benefits for the nation through fiscal arrangements (Norton Rose Fulbright, 2015). The gazetted MPRDA Regulations for Petroleum Exploration and Production (2015) include specific regulations for shale gas exploitation.

Figure 1.1: Schematic comparison between conventional and unconventional gas reserves and extraction techniques (http://worldinfo.org/2012/01/point-of-view-unconventional-natural-gas-drilling). Note: conventional gas extraction often involves the establishment of horizontal well sections; also, unconventional gas extraction may involve vertical wells only. It is mainly the fracking process that differentiates the product extraction technique (unconventional versus conventional)



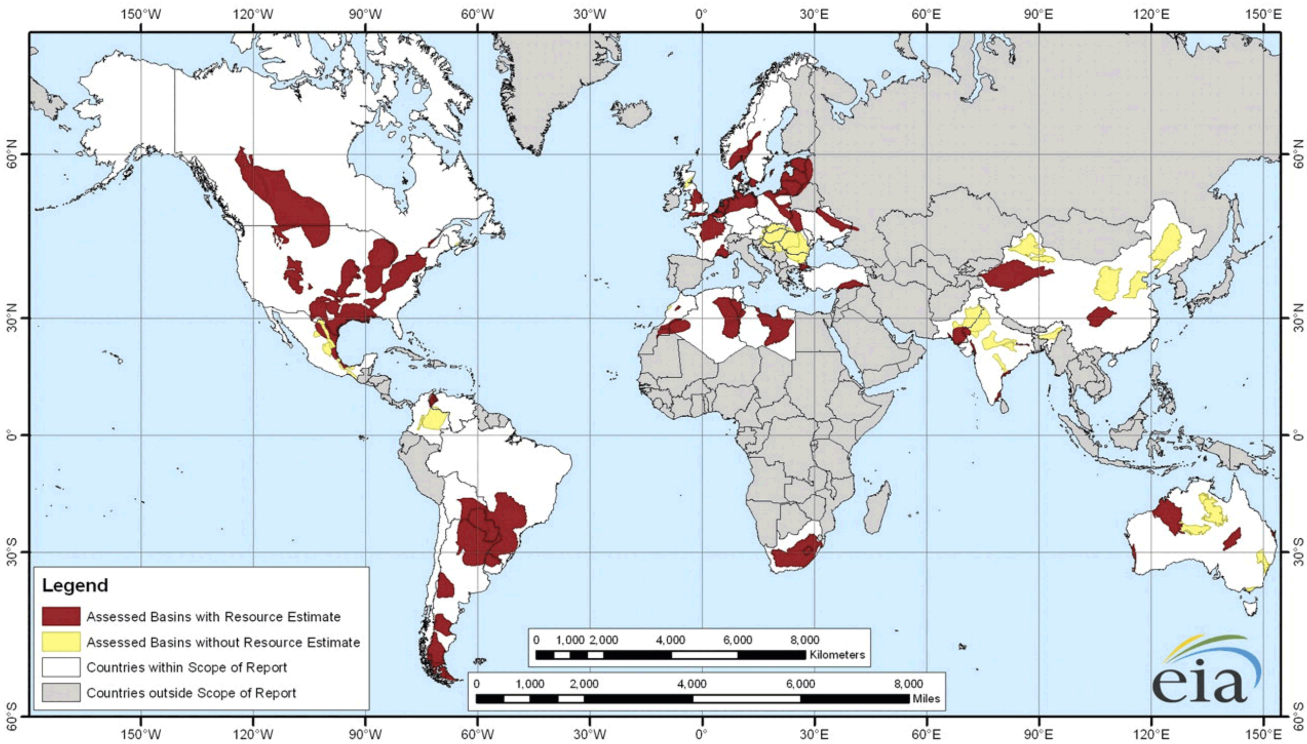


Figure 1.2: World shale gas and oil resources estimated by the US EIA (2013).

As indicated in Figure 1.2 South Africa's shale gas reserves are likely to be concentrated in the sediments of the Karoo Basin. With the exception of the Southern Oil Exploration Corporation's (SOEKOR's) regional oil exploration program in the 1960's (Cole and McLachlan, 1994) there have been no onshore shale gas exploration or production operations undertaken in the country. This implies that the social (including economic) and biophysical attributes of the Karoo are currently unaffected by SGD.

Box 1.1. The geology of the Central Karoo

The geology of the study area comprises a succession of sedimentary strata (mainly sandstone, siltstone, mudrock and shale) that attain a maximum combined thickness of some 5 000 m in the south of the main Karoo geological basin. The sedimentary strata represent material deposited by rivers draining into an inland sea over a period of approximately 120 million years, between roughly 300 and 180 million years ago. Much of this timespan brackets the periods in geological time known as the Permian and the Triassic. To the north-east into Lesotho, these strata are overlain by lava intrusions that form the Drakensberg Mountains. Except for an area along the southern margin of the study area, dolerite intrusions are widely present elsewhere. The sedimentary and intrusive strata together form the geological Karoo Supergroup.

1.2 The Karoo: Its coupled ecological and social characteristics

1.2.1 Ecological characteristics of the study area

1.2.1.1 Broad-scale ecological context

The areas in which the Karoo shale gas reserves may be concentrated are centred on the Nama Karoo Biome (Figure 1.3). About 62% of the study area consists of Nama Karoo and the remainder is made up of Grassland, Succulent Karoo and Albany Thicket biomes. The Succulent Karoo and Fynbos elements are in the west of the study area, Grassland Biome occurs in the eastern part, while Thicket occurs in the south-east. These patterns in biome distribution are explained largely by climatic gradients, especially rainfall seasonality and amount. Geology and soil characteristics serve as secondary local determinants of biome distribution and some of their distinguishing characteristics. According to Cowling and Hilton Taylor (1999), 2 147 plant species, including 377 endemics (plants which grow nowhere else), occur within a core area of 198.5 km^2 within the Nama Karoo Biome. This is less than half the reported total for the less extensive Succulent Karoo Biome, indicating that the broad-scale species richness of the Nama Karoo is relatively poor compared to at least some of the adjacent biomes. Endemism is also relatively low and many species are shared with adjacent biomes.

Within the study area the presence of areas of Thicket Biome in the east and Fynbos in the west increase the total species richness, and it is likely that these areas hold a disproportionate share of the total diversity.

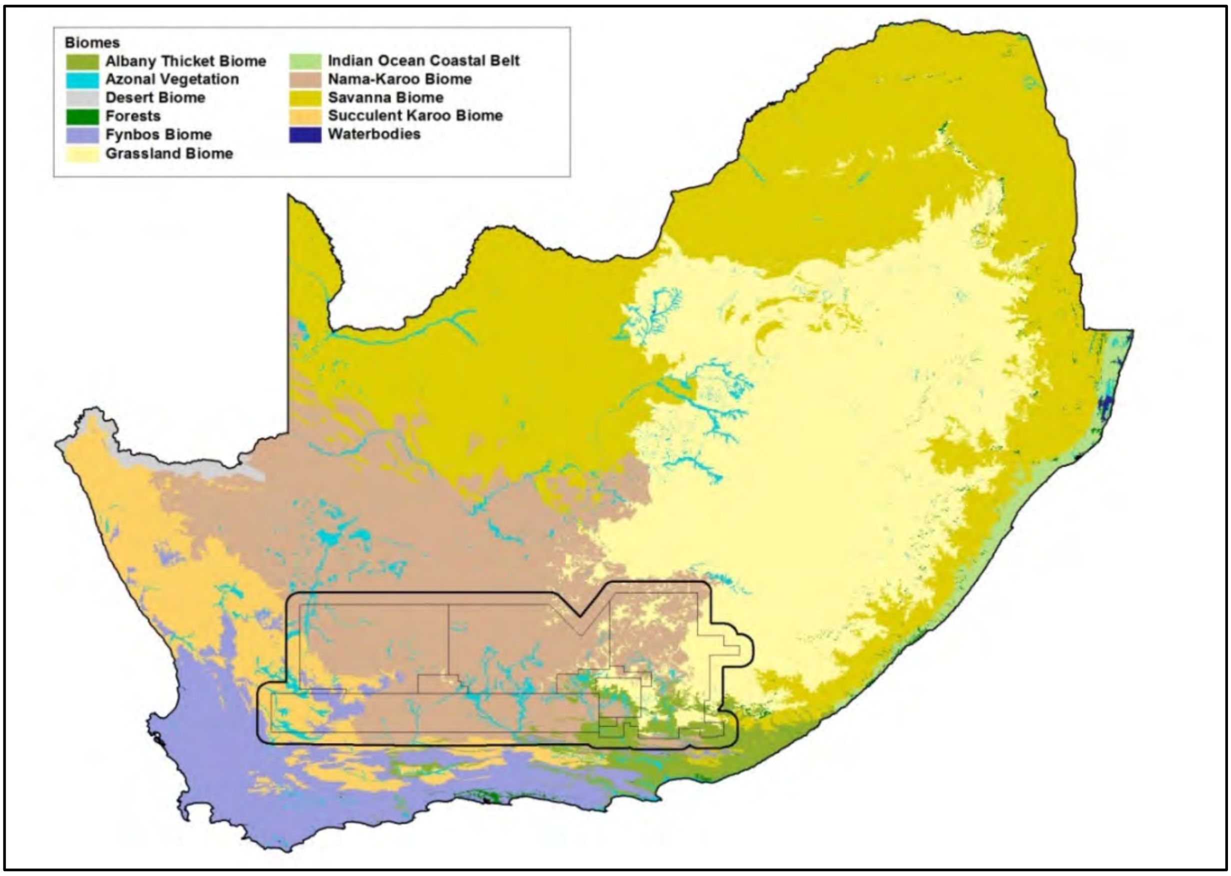


Figure 1.3: Biomes of South Africa (Mucina and Rutherford, 2006), with the study area (including buffer zone) indicated.

1.2.1.2 Surface water

The Karoo is a semi-desert environment, with a mean annual precipitation (MAP) that ranges from 100 mm in the west to 400 mm in the east (Figure 1.4). The median annual runoff is less than 60 mm over most of the study area and falls below 10 mm for much of the western half (Schulze et al., 1997). This assigns a premium value to freshwater resources that are critical, for example, for sustaining local communities and their livelihoods. The western and south-western portions of the study area are not only more prone to extreme but erratic rainfall and associated floods, but also to drought (Figure 1.5 and 1.6).

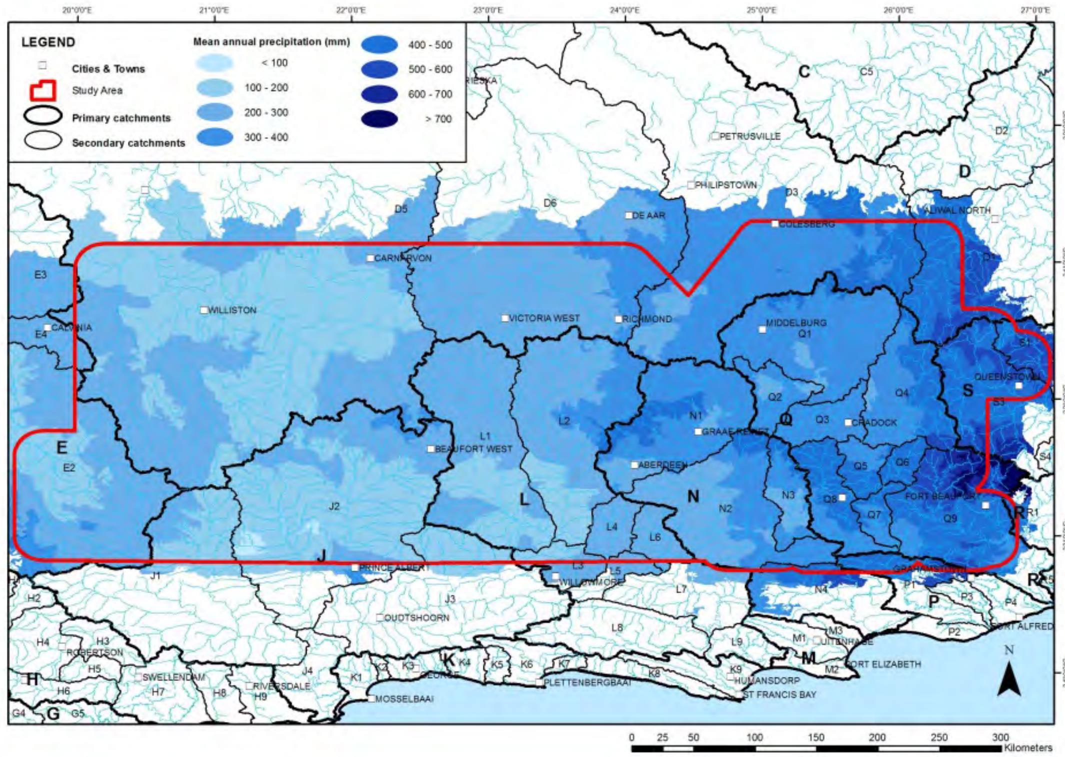


Figure 1.4: Mean Annual Precipitation (MAP) (mm) is the 50 year (1950-1999) average rainfall per Quinary, determined from a 1.7 x 1.7 km grid of MAPs developed by Lynch (2004) with Quinary catchments rainfall determined by techniques described in Schulze et al. (2010)

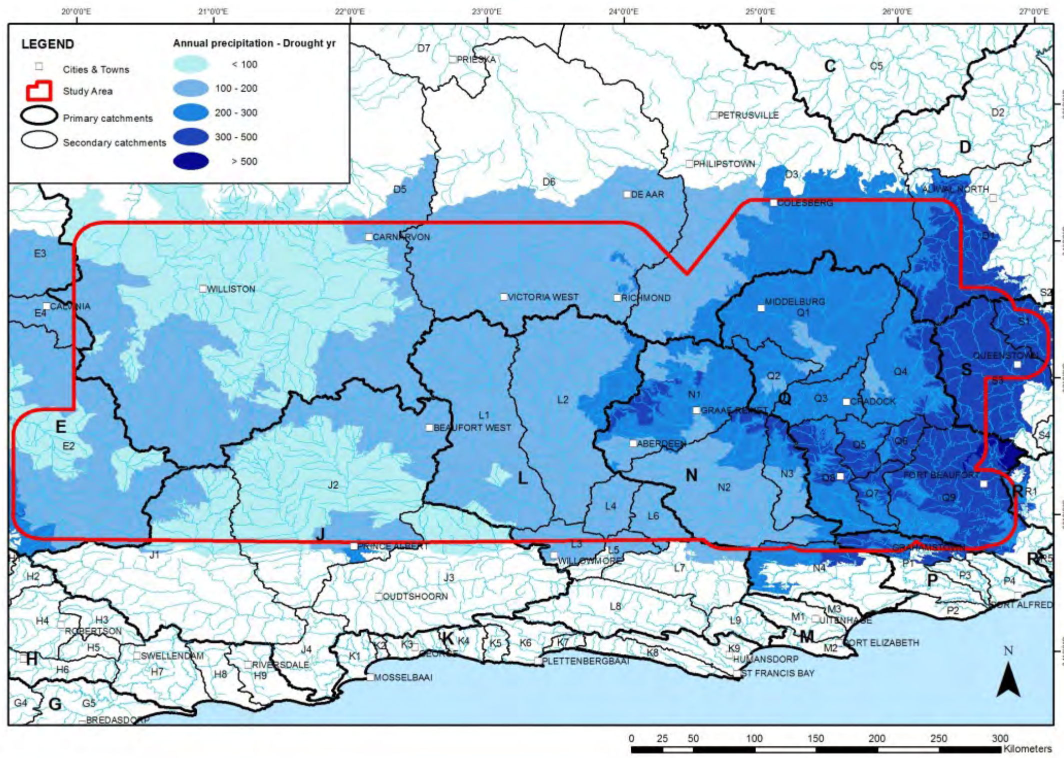


Figure 1.5: Annual Precipitation in a Year with Drought. A year with drought is defined here as one standard deviation below the mean annual precipitation. The map shows a decreasing rainfall gradient from east to west from around 500 mm to below 100 mm per year.

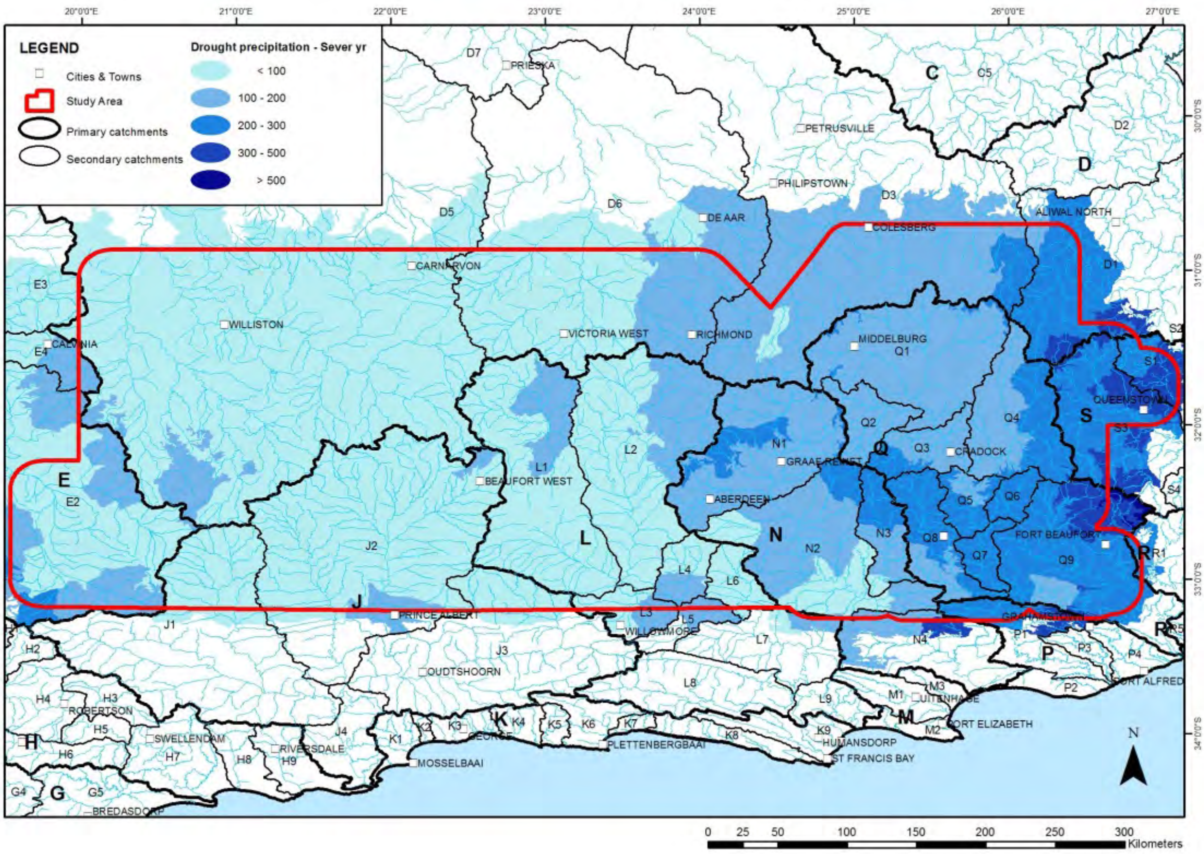


Figure 1.6: Annual Precipitation in a Year with Severe Drought. A severe meteorological drought is defined as 1.5 standard deviations below the mean annual rainfall, and the map shows around 60% of the study area receiving less than 100 mm in such a year – indicative of the harsh climatic conditions existing in this region.

Set against rainfall data are evaporation rates that also show strong east-west gradients. Large portions of the hotter, western part of the study area experience evaporation rates in excess of 1 800 mm per annum. This reduces toward the cooler eastern part of the study area, although rates are still well in excess of MAP (Figure 1.7).

The Great Escarpment (represented here by the Nuweveld Mountains) divides the study area into the Lower Karoo in the south, at an elevation of less than 1 000 m, and the Upper Karoo in the north, at an elevation above 1 000 m. The majority of the area north of the escarpment drains northwards via the Riet, Sak, Ongers and Seekoei river systems into the Orange River (and then the Atlantic Ocean), while those areas to the south of the escarpment contribute to the Gouritz, Gamtoos, Sundays and Great Fish River systems that drain into the Indian Ocean. Surface water drainage systems in the study area range from mainly perennial (flowing 11-12 months per annum) in the eastern portion of the study area, to a mixture of ephemeral (flowing for 2-10 months) and episodic (flowing for 0-2 months) interspersed with perennial systems in the western portion.

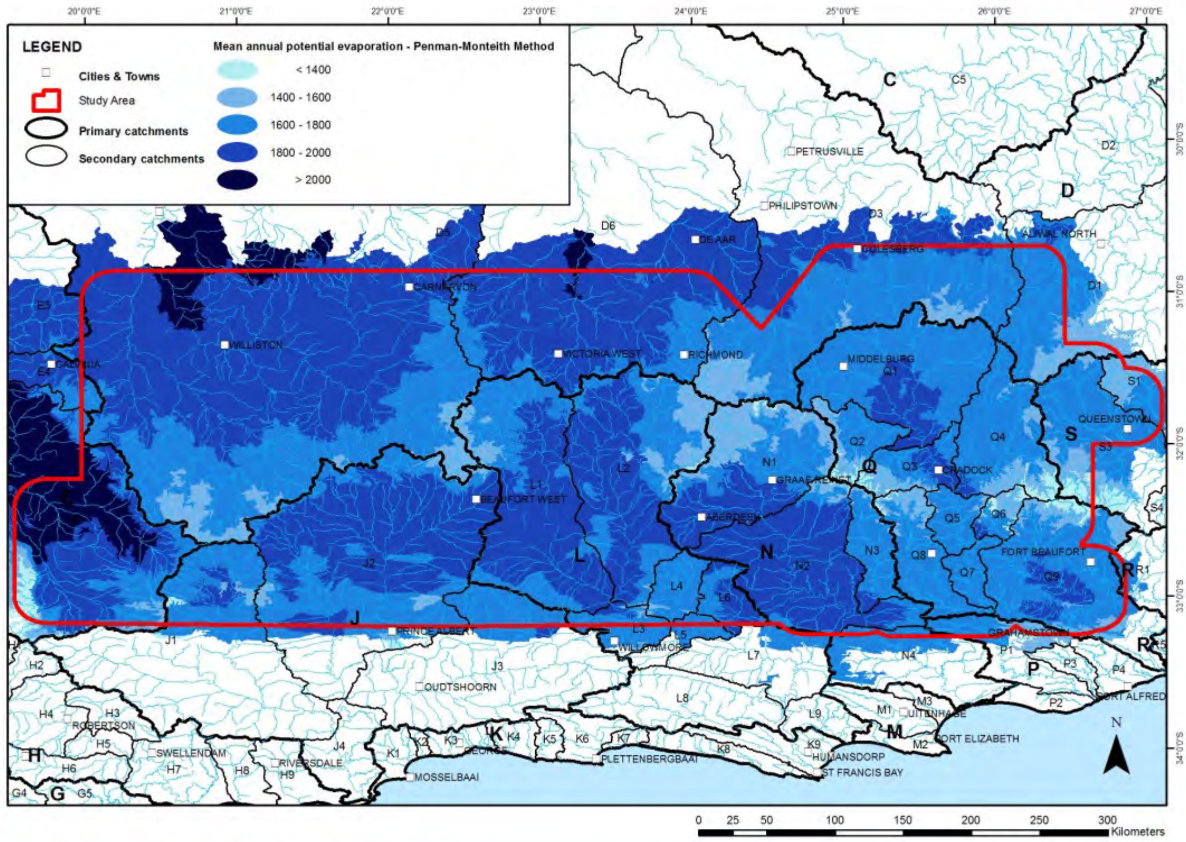


Figure 1.7: Potential Evaporation (PE) is an index of the atmospheric demand of water from a vegetated surface that contains sufficient soil water. PE is directly related to solar radiation and wind, and inversely related to relative humidity. Annual values are high, at generally over 1 600 mm and in parts of the arid west (even > 2 000 mm). The band of relatively lower PE running through the centre occurs over the cooler higher lying east-west mountain range.

Although probably less than half of their extent has been mapped, surface water-associated ecosystems account for about 5% of the study area. These are largely riparian ecosystems, although there are also some wetlands associated with the endorheic pans of the Bushmanland and Upper Karoo areas.

The sporadic rainfall events result in unreliable and unpredictable surface water runoff to rivers and dams. Soil erosion results in sediment entrainment in runoff and accelerated siltation of dams, with consequent reduction in storage capacity. These factors, coupled with the generally low MAP rates, substantially raise the value of underground water resources, which are relied on for agricultural, domestic and other uses over much of the study area.

1.2.1.3 Groundwater

Groundwater occurs in saturated sub-surface strata. The water derives from various sources such as rainwater that infiltrates downward through the unsaturated zone to the water table (rainfall recharge), lateral or vertical inflow from adjacent groundwater systems (sub-surface recharge) and inflow drawn from adjacent surface water bodies (induced recharge). Rainfall recharge represents the principal mechanism of groundwater replenishment in the Karoo. In this environment, it is typically assigned a value of 3% of the average annual rainfall (Van Tonder and Kirchner, 1990)[3]. This water is referred to as meteoric water, indicating that it is derived from atmospheric sources.

In the Karoo, there is a critical dependence of farming and human settlements on groundwater. The development and exploitation of groundwater resources for purposes of water supply require the sinking of a borehole into sub-surface strata. Where conditions are favourable, shallow groundwater is typically encountered in weathered strata near the surface. At greater depth, groundwater is associated with fractured strata. The influence of dolerite intrusions on the occurrence of groundwater makes these structures the primary targets for the positioning of a successful borehole. The mineralogical composition of dolerite is detectable by means of geophysical techniques. The shallow aquifer (<300 m depth) is well researched and fairly well understood. It supplies local wellfields and farm boreholes. Deep groundwater, including its connectivity with shallow aquifers, is only poorly understood. Methane occurs naturally in groundwater penetrated by a number of boreholes in the study area.

The presence of deep groundwater sources in the Karoo (i.e. far below the usual drilling depth of farm water supply boreholes) is inferred from thermal springs and data collected from a few very deep wells drilled by SOEKOR.

The considerable pressure of the overlying rock mass has the potential to drive some relatively deep groundwater to surface, where there is a pathway for this to occur, resulting in hot springs. If released, the flow of water might reduce over time as the pressure in the deep-seated host strata dissipates through loss to the atmosphere. In instances such as at Aliwal North there is no evidence of a reduction in such flows to the surface over time.

Deep groundwater is referred to as connate (fossil) water if it was trapped in the rock strata when the rock formed millions of years ago, in which case it typically has a high dissolved mineral content and is not replenished naturally. If the deep groundwater derives from meteoric sources, it is referred to as formation water and could be replenished naturally often over long distances from a distal recharge area, which generally makes it less saline than connate water. The temperature of deep groundwater generally increases with the depth from which it rises. Groundwater from the carbon-rich strata of the Whitehill Formation also contains hydrogen sulphide.

Uranium occurs quite commonly in the south-western part of the Karoo Basin as shallow tabular ore bodies in association with sandstones of the Adelaide Subgroup of the Beaufort Group (Cole,

[3] There will be considerable variation in replenishment factor (%) from place to place and between years, see Hobbs et al. (2016).

1998). The combined extent of these occurrences is sufficient to define the so-called Karoo Uranium (metallogenic) Province, described by Cole et al. (1991) as extending from the north-eastern part of the Western Cape Province across the south-eastern part of the Northern Cape into the southern Free State. Four orebodies were subject to feasibility studies in the late-1970s. One of these, located 42 km west-southwest of Beaufort West, showed an average ore grade of 1.5 kg /t at a depth of 13 m (Cole, 1998). Steyl et al. (2012) report that the results of various geochemical studies of fine-grained sedimentary rocks of the Karoo Supergroup show that the shales are not enriched in possibly ‘dangerous’ elements, including uranium. In the context of SGD these authors do, however, recommend further geochemical characterisation of the shale gas-bearing strata.

Murray et al. (2015) report concentrations in the range 0.002 to 0.041 mg /l in shallow Karoo groundwater. These authors identified higher uranium and radon concentrations in the ‘shallow’ groundwater than in warm spring-waters rising from a maximum depth of ~1000 m. In a study focussed specifically on the incidence of naturally occurring hazardous trace elements in groundwater nationally, Tarras-Wahlberg et al. (2008) report concentrations of up to 0.539 mg /l in groundwater sampled from old uranium exploration boreholes around Beaufort West and Sutherland and concentrations of <0.016 mg U/l in water supply boreholes in the same area.

1.2.1.4 Ecological patterns and drivers

The study area is characterised by low (<1 m tall) woody shrublands with a variable grass layer. The latter may become dominant on sandy soils or on cooler and wetter landscape units such as mountain plateaus. Trees tend to be restricted to drainage lines and other localised moist habitats (Cowling and Hilton Taylor, 1999). There has been considerable speculation regarding the proportion of grass in the vegetation before European colonisation (Hoffman et al., 1995); however, it is clear that this varies seasonally and over decadal time-scales according to cycles of drier and wetter summer rainfall conditions; which are key drivers of vegetation patterns (Bond et al., 1994; Hoffman et al., 1990).

A key driver of vegetation patterns in South Africa, and especially within the more arid parts of the country, is rainfall (Figure 1.8). The majority of the study area is arid and receives an average of around 250 mm annual rainfall. Some areas such as the Tanqua Karoo, in the rain-shadow of the Cederberg, receive less than 100 mm per annum. Rainfall seasonality is also important. Most of the study area receives the greater proportion of its rainfall in summer, with some winter rainfall-dominated areas occurring along the western margin (Figure 1.8).

Despite the large increase in game farming in recent years, the largest area of the study area is still used for domestic livestock grazing. Grazing by livestock or game is the primary determinant of rangeland condition across the study area (O'Connor and Roux, 1995; Todd, 2006).

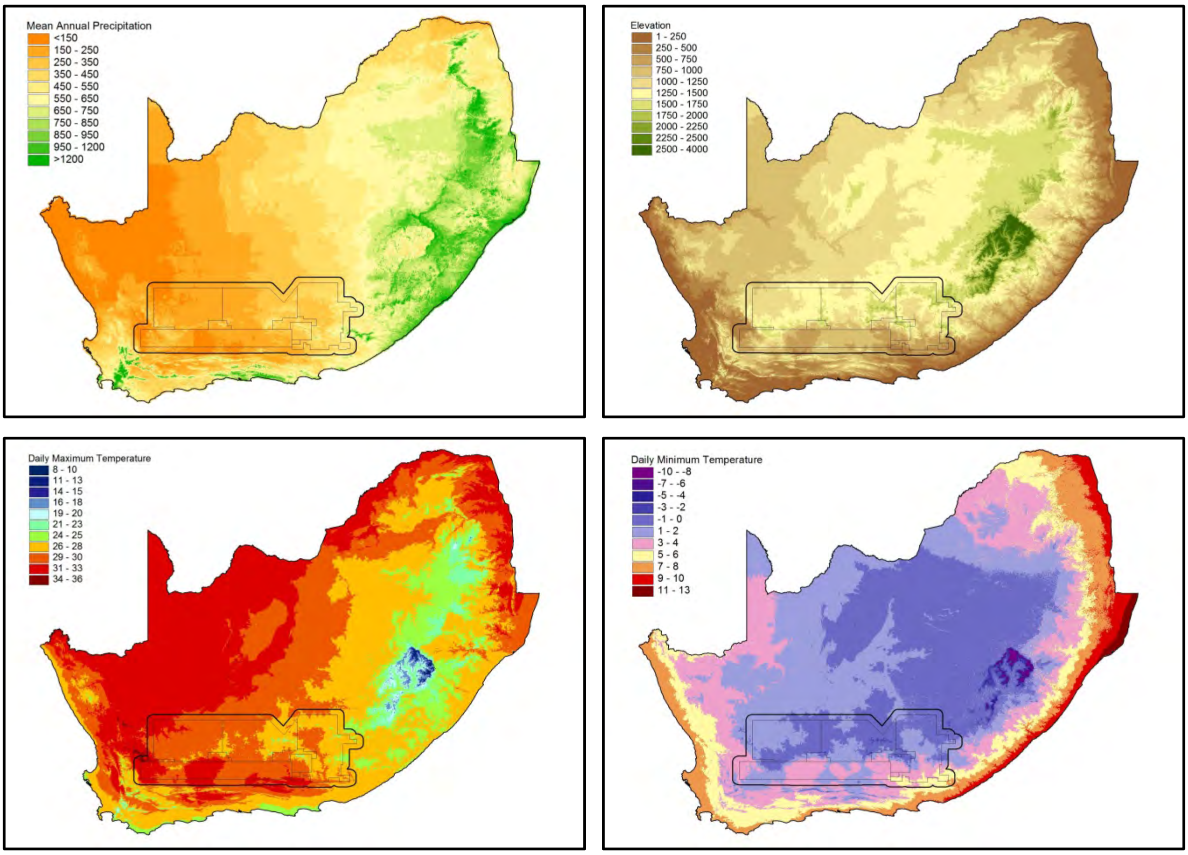


Figure 1.8: Dominant climate and physical drivers of ecological patterns and processes across the Karoo: Patterns of MAP, elevation, daily mean maximum temperature for February and daily mean minimum for July (the hottest and coldest months respectively).

1.2.1.5 Land use effects on ecosystems

Most vegetation types are still more than 98% intact in terms of structure and composition. The total extent of intensive agriculture is less than 1% of the total area, restricted to the vicinity of the major rivers (which are typically dry) including the Sundays, Buffels, Gamka, Kariega, Great Fish and Groot Brak. The areas of intensive agriculture are, however, of disproportionate importance to farming enterprises due to their high productivity compared to the surrounding landscape.

Concerns over the degradation of the study area as a result of agricultural practices have strongly influenced agricultural policy over the past century (Hoffman et al., 1999). Game farming has grown rapidly over the past 20 years. Many farming enterprises are mixed, with both game and livestock managed on the same property; and in many cases tourism is an important farming enterprise.

1.2.2 Social and economic characteristics of the study area

1.2.2.1 <u>Social and economic responses to a challenging biophysical environment</u>

Remarkably, the relatively harsh biophysical environment of the study area does not appear to be a major obstacle to social and economic development[4]. Although the causal factors of current development cannot be stated with a high degree of certainty, an initial suggestion would include: inherited infrastructure and diverse business services; investment capital and creative skills (Ingle, 2010a); land tenure arrangements that facilitate land sales, purchases, investment and consolidation; public sector capacity, whether in provincial departments or municipalities; and human ingenuity in turning local conditions into marketable assets (such as the "space, silence and solitude" of the Karoo (Ingle, 2010b)) through entrepreneurial experience and skill.

1.2.2.1.1 Urban development and planning

The discussion that follows applies to the following geographic sub-regions of the study area (Figure 1.9):

- *Great Karoo*: the arid areas of the Central Karoo District Municipality (CKDM), Pixley ka Seme District Municipality (PKSDM), the western part of Cacadu District Municipality (CDM) and the western part of Chris Hani District Municipality (CHDM); typical towns include Beaufort West, De Aar, Graaff-Reinet, Middelburg and Cradock;
- *Eastern Cape Midlands:* Towns located within commercial agricultural areas, but which are not in the "Karoo proper"; here the environment is less arid and often quite mountainous; the area includes towns such as Sterkstroom, Queenstown, Bedford, Grahamstown, Somerset East and Fort Beaufort (these straddle the eastern parts of CDM, the western part of CHDM and the western parts of Amathole District Municipality (ADM));
- *Eastern Cape Traditional*: Towns located within communal areas, such as Peddie, Lady Frere, Alice (these straddle the eastern parts of CHDM and the central parts of ADM); and
- *Sundays River Valley*: *The* intensive agricultural areas near Kirkwood in the southern part of CDM.

[4] Naturally, there are limits on development imposed by the capacity of key ecosystem goods and services (e.g. water availability; see Sections 1.2.1.3 and 1.2.1.4)

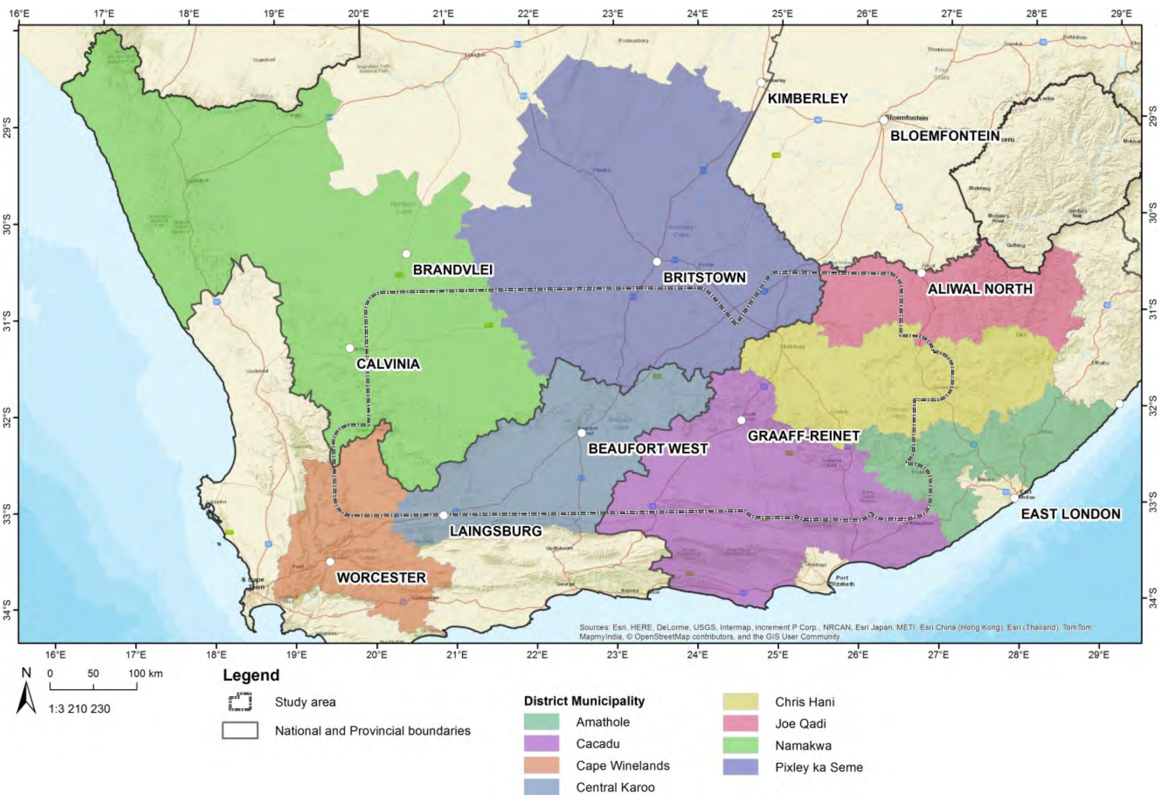


Figure 1.9: Geographic sub-regions included in the study area.

The gross domestic product (GDP) in the study area is generally low when compared to towns and cities located outside the region. Nevertheless, the Great Karoo has shown an increasing economic growth rate (around 4% per annum, albeit from a low base) and the economic growth rate of the Central Karoo District is now consistently higher than the Western Cape Province (CKDM, 2012: 39). The Central Karoo District, which is classified as a rural development “poverty node”, performs significantly better than other poverty nodes elsewhere in the country over a range of indicators (Business Trust, 2007:39). The study area has seen several towns growing in population and economic resilience, while the economies of other towns have dwindled; this is due to a range of dynamics, including new patterns of transport, markets, government services and entrepreneurial innovation (Nel et al., 2011).

Economic strengths vary significantly from the extreme eastern parts of the study area towards the west. In the Great Karoo, commercial agriculture, tourism and commerce are relatively well developed (Lawson et al., 2013). Local economies are more diversified and infrastructure is generally good, including banking, communication and roads. In the Cape Midlands and Traditional Eastern Cape, the towns are generally less developed, with high transport costs, poorly developed markets and poor telecommunications (CHDM, 2010:57). The share of government services as a proportion of regional GDP is relatively low in the Great Karoo (around 10%) while in the extreme east it is much higher[5]. Levels of unemployment also vary along a west-east axis. In Central Karoo the unemployment rate is about 31%, whereas in Chris Hani District it is pegged at about 57% (CKDM, 2012:45; CHDM, 2013:29).

A very high-level generalisation relating to urban development and planning is as follows: *western areas* - more developed and economically diversified, higher levels of employment - contrast with *extreme eastern areas* - less diversified, higher unemployment.

1.2.2.1.2 Population shifts

The Great Karoo has experienced population growth between 1996 and 2011, which in itself is not so remarkable; however, an important phenomenon is that the annual population *growth rate* has increased significantly during this period. This is most likely due to in-migration. From census data gathered in 1996, 2001 and 2011 the population of the study area is estimated to be around 600 000 people, although this subject to fluctuations due to migration patterns (stepSA Regional Profiler, 2016).

In the extreme east, the study area borders on, and partly encompasses, areas of the Eastern Cape with higher population densities. These areas (part of the former Transkei, with a proportion of land still under tribal authority ownership) have higher densities in terms of settlements. Over the period 1996 – 2011 towns such Queenstown, Alice and Grahamstown (all on the border of, or just outside, the study area) have shown relatively high population growth accompanied by significant out-migration into surrounding rural areas (Department of Science and Technology (DST), Council for Scientific and Industrial Research (CSIR), and Human Sciences Research Council (HSRC), 2015). Some of these trends are depicted in Figure 1.10.

Pixley ka Seme District (De Aar area) had a negative growth rate between 1996 and 2001, which became a positive growth rate between 2001 and 2011 (Atkinson, 2015). In contrast, the population in Eastern Cape Traditional Areas is declining in absolute terms, largely due to out-migration, but also possibly due to HIV/AIDS mortalities (CHDM, 2010:37; ADM, 2015:21).

[5] Data in Chris Hani and Amathole District Municipalities do not differentiate between government and private community services.

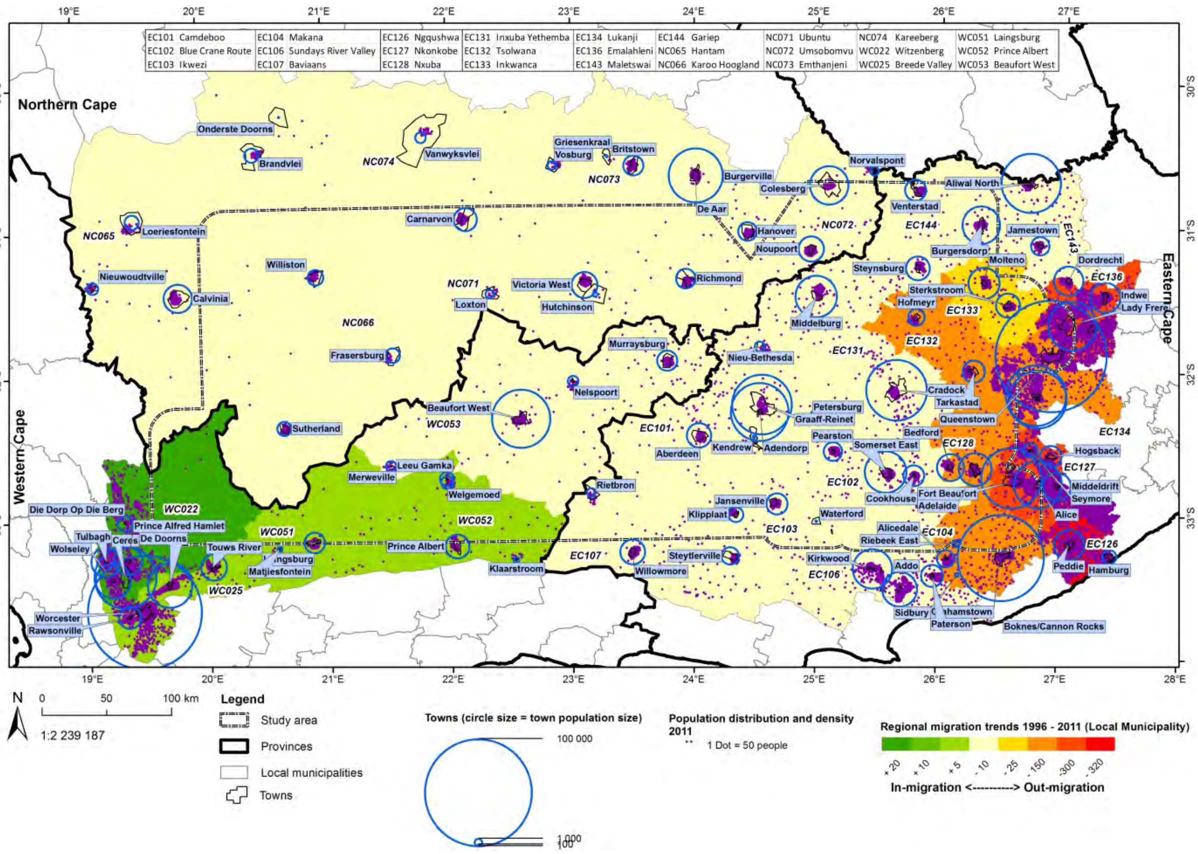


Figure 1.10: Population density, distribution and regional migration trends for Local Municipalities within the study area (Population Distribution Indicator, CSIR (2014))

1.2.2.1.3 Tourism

There are many indications that the Great Karoo is increasingly providing tourism product and growing tourism demand, in terms of ecotourism, interest in historical arts, cultural attractions, astro-tourism, cuisine and other niche markets (Gelderblom, 2006; Saayman et al., 2009; Toerien, 2012; Ingle, 2010b; Table 1.2). Overnighting by people travelling through the Karoo and business tourism also add to the tourism demand. Although not limited to these centres, the Karoo Midlands towns of Cradock and Somerset East have developed significant tourism sectors (Atkinson, 2012). Towards the extreme east of the study area, tourism activity becomes much more isolated (e.g. Hogsback and Stutterheim in ADM) and contributes much less to economic development and diversification.

Tourism is dependent on investment and marketing. In the Great Karoo and Karoo Midlands sub-regions there is significant in-migration of investors (often retirees, or urbanites seeking an alternative quality of life (Ingle, 2013)). This phenomenon is less pronounced towards the eastern extreme of the study area.

1.2.2.1.4 Agriculture

The western areas of the study area are primarily oriented to small livestock (goats, sheep, Angora goats) producing a variety of meat, wool and fabric products. Stud farming is also well established, with various regions presenting as hotspots for different stud farming foci (e.g. Middelburg) often with associated business tourism (e.g. buyers attending auctions). In the Karoo Midlands cattle-holding is increasing in scale (Development Partners, 2009:87). Farm sizes are increasing and more efficient farming practices have maintained levels of productivity. There has been a renewed focus in South Africa, and more specifically in the Karoo, on the re-innovation, transformation and lengthening of agricultural value chains for the purposes of more equitable job creation. A shift is underway from agricultural jobs to agri-processing jobs, such as with the wool value chain and the manufacturing of wool products rather than exporting the bulk of raw wool. Also, there has been exploration and introduction of crop types that thrive in arid and semi-arid areas such as the Karoo. A successful example of this is the small rooibos tea farmers case study in the Northern Cape (China and South-South Scoping Assessment for Adaptation Learning and Development (CASSALD), 2013).

There appears to be significant agricultural capital for investment in the Great Karoo and Karoo Midlands with many farmers diversifying into game farming or privately owned game parks. Hunting is providing increasing levels of revenue to farmers (Development Partners, 2009:118). There is growing mutual support between agriculture and tourism due to farm-stays, ecotourism and hunting.

1.2.2.1.5 Economic sectors compared in key municipalities

The study area is largely defined by an agricultural economy (from a production perspective) and characterised by commercial farms, interspersed with a variety of local and regional service towns, nature reserves and conservation areas (Figure 1.11). For reasons of financial feasibility, farms are quite large. Smaller farming units with intensive agriculture, sustained by irrigation, are established next to major rivers. Towns such as Beaufort West, Graaff-Reinet, Middelburg, Colesberg and Cradock are important regional service towns, accommodating the bulk of the population (DST, CSIR and HSRC, 2015).

More than half of the towns in the study area include around 20% of households living in poverty, a relative decline in working age population and a decline in formal economic production. This results in increased levels of socio-economic vulnerability (DST, CSIR and HSRC, 2015). Within this context, even though service delivery improvements have been made in many towns, municipal functioning is jeopardised by diminishing economic production and financial viability.

Although the study area is not a key national economic production zone, it is crossed by important networks of national and inter-regional transport routes carrying a large volume of road and rail freight. It is also crossed by a number of high voltage electricity corridors, with more planned. The economic significance of this is likely to increase in response to the following:

- Large parts of the region fall within areas identified as ideal in terms of horizontal radiance and annual mean wind power for potential solar and wind energy generation (a significant number of green energy projects related to wind and solar energy are under consideration in the area (Economic Development Department (EDD), 2014));
- Tourism through-traffic will continue to contribute to the economy given the range of natural and cultural heritage and tourism attractions in the region;
- The N1 freight corridor will continue to increase in strategic economic importance; and
- The government’s Strategic Infrastructure Programme (SIP), which includes plans to upgrade the road/rail/port elements of the Manganese Corridor linked to one or more Eastern Cape ports, and support for greater connectivity between urban and rural areas and between major centres for manufacturing and agri-processing.

These initiatives are expected to provide local job creation and enable regional economic growth (EDD, 2014).

1.2.2.2 Municipal capacity and economic development

There is a difference between municipalities in the western/central and extreme eastern parts of the study area, which is influenced by both a legacy of underdevelopment and current challenges with regard to revenue sources and other factors. For example, Camdeboo Local Municipality has been described as an effectively run municipality with one of the strongest balance sheets of all Eastern Cape municipalities (Development Partners, 2009:153). The Integrated Development Plan (IDP) for municipalities in Amathole District, for example, conveys that they face challenges in areas such as infrastructure maintenance (ADM, 2015:108).

Municipal capacity as a determinant of development will be critical in future as many types of investment (including mining, manufacturing, tourism and potentially shale gas development) depend on municipal capacity. Critical municipal capacity required to implement, monitor and manage complex investments include: waste water treatment, water pollution control, environmental pollution control, air quality management, environmental risk assessments, occupational health and safety assessments, infrastructure safety, including pipelines and tankage, disaster management and noise control (CHDM, 2013:73).

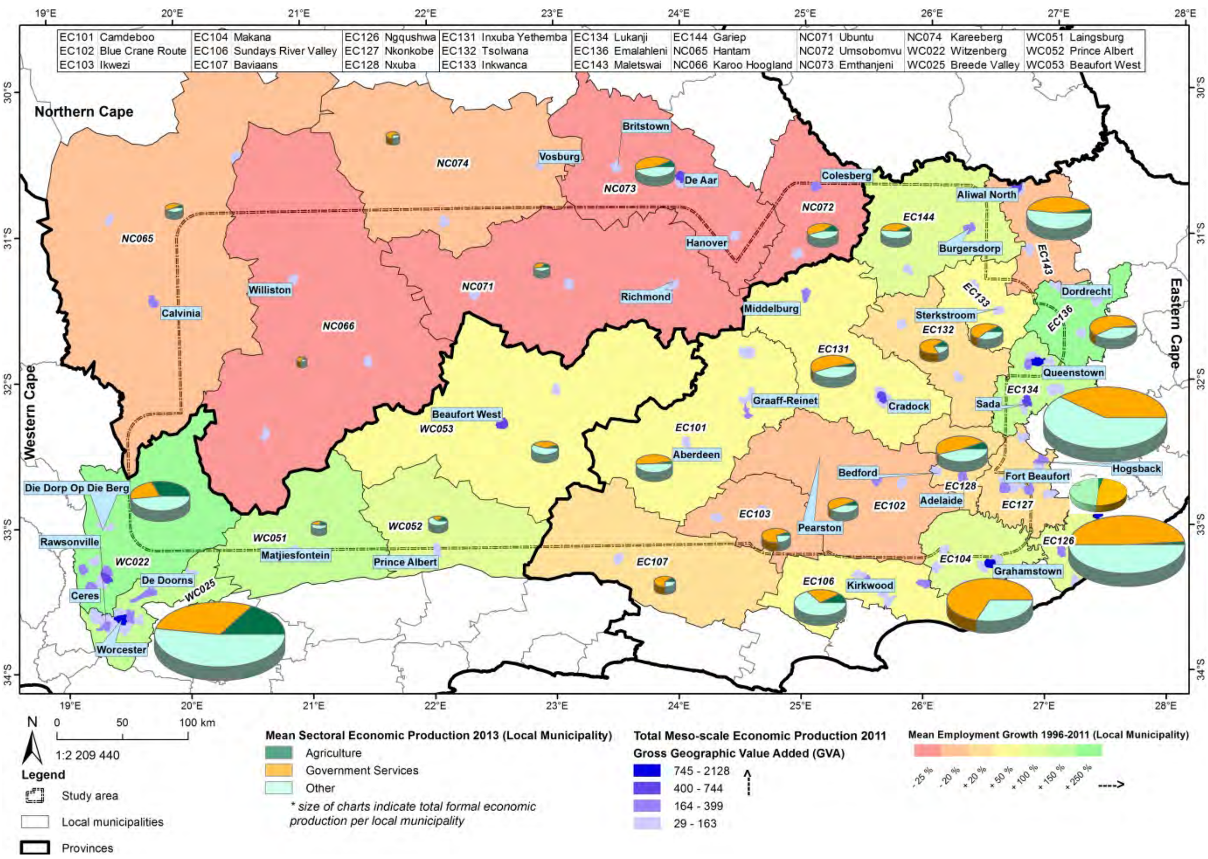


Figure 1.11: Sectoral- and meso-scale economic production and mean employment growth for Local Municipalities within the study area (Economic Production Indicator, CSIR (2014)). Note, although agriculture does not present as making the highest contribution in terms of economic production, it plays a major role in job creation and livelihoods within the study area.

1.2.2.3 The social fabric

Social fabric is a collective term for numerous complex and subtle social relationships. A few proxy variables can be used to suggest the strengths and weaknesses of the social fabric in different towns and rural areas in the study area.

One proxy variable is municipal-business collaboration. In some towns, such as Beaufort West and Cradock, a relatively high level of collaboration can be found (Atkinson, 2012); however, this cannot be generalised to other towns. One of the most successful towns is Somerset East where a vibrant Local Economic Development Agency has attracted considerable capital and projects by working closely with the Blue Crane Local Municipality. In contrast, frustration is expressed in the Amathole IDP regarding public apathy in municipal IDP planning processes (ADM, 2015:118). These factors are highly complex and no easy comparisons or generalisations can be made; however, it is highly likely that effective local leadership alliances can strongly boost the fortunes of a town or district.

A second proxy variable is the density of civil society organisations that provide opportunities and support for local people (including the poor). In Beaufort West, for example, numerous local organisations are active, with community membership and participation in church/religious and sports structures being high (Wyeth and Webb, 2002:21, 47).

1.2.3 Reference Case - Imagined future without SGD

In the absence of SGD, which is defined for the assessment as a Reference Case scenario, the most significant drivers of *ecological change* in the Karoo over the next 30 years will be climate change and land use dynamics. Apart from an increase in average temperature, climate change is likely to result in an increased frequency of extreme events such as drought and floods. These events are deleterious to farming activities and either directly or in concert with land use and temperature increase will ultimately have negative impacts on biodiversity. There are four land use effects that are expected to exert most influence on ecosystem integrity: increased game farming, implementation of land reform (not necessarily negative)[6], renewable energy development and uranium mining.

Water resources are sensitive to the impacts of climate change. In the case of surface water, as rain intensities increase, this will translate into greater degrees of flooding, erosion, sediment transport, and therefore higher siltation rates within water impoundments. Groundwater resources are likely to benefit from higher intensity episodic rainfall events, which can allow for above average recharge conditions (Van Wyk, 2010). It is likely that the value of groundwater resources in an increasingly arid Karoo environment will become greater compared to surface water.

In the Great Karoo and Midlands, private land ownership will enable access to finance and associated investment in agriculture, tourism and other rural activities, which in turn stimulate economic multipliers in towns. Cultural and ecological tourism in the Great Karoo and Eastern Cape Midlands will grow steadily, giving rise to further economic diversification. In the extreme east, tourism is expected to remain underdeveloped.

[6] Land redistribution will be relatively limited in the existing commercial farming areas. It is uncertain to what extent land tenure reform may materialise in the traditional areas in the extreme east of the study area.

Box 1.2: Projected climate changes for the Karoo

Projections of temperature and rainfall for the Karoo are presented here based on the median (50th percentile) of an ensemble of six dynamically downscaled Global Climate Models (GCMs) (Engelbrecht et al., 2013; Engelbrecht et al., 2009; Malherbe et al., 2013)[7, 8]. Change is expressed as an anomaly, which is the difference between the average climate over a period included within the last several decades (1971-2000) and the projected climate in the short- to medium-term (2021 to 2050). The projected changes are based on Representative Concentration Pathways (RCPs), specifically RCP 8.5 and RCP 4.5 Wm-2 scenarios[9], which assume different paths of development for the world (Intergovernmental Panel on Climate Change (IPCC), 2013). RCP 4.5 describes a future with relatively ambitious emission reductions, whereas RCP 8.5 describes a future with no reductions in emissions. Emissions in RCP 4.5 peak around 2040, then decline; in RCP 8.5 emissions continue to rise throughout the 21st century (Meinshausen et al., 2011; Stocker et al., 2013).

Temperature

Temperatures are expected to increase between 1 and 1.5 °C (RCP 4.5) and between 1.2 and 1.8 °C (RCP 8.5) over the Karoo region. The increase in temperature is projected to occur in association with an increase in the number very hot days (number of days when the maximum temperature exceeds 35°C).

Rainfall

Projected changes in rainfall are typically harder to detect than that for temperature, but it is likely that South Africa will experience a reduction in annual rainfall amounts and an increase in rainfall variability. Rainfall is expected to decline over the Karoo region, with possible slight increases along the north-eastern border. Some areas of the Karoo may experience a slight increase in extreme rainfall events in the future but this change needs to be interpreted in conjunction with evidence from historical trends in extreme rainfall events. The number of dry days is also expected to increase further indicating a drying trend in the region.

Commercial agriculture will become more sophisticated to ensure access to national and international markets. The marketing of Karoo produce will become more effective, generating higher returns to farmers. Many farmers will diversify into game farming, agri-tourism, hunting and other activities to increase their economic resilience. It is possible that as tourism develops, more labour-intensive services (such as restaurants and accommodation) will materialise. Importantly, towns will continue

[7] A projection is a statement of a possible future state of the climate system, dependent on the evolution of a set of key factors over time (e.g. carbon dioxide emissions).
[8] An ensemble of models refers to a set of individual climate models used to project different (but equally plausible) climate futures.
[9] Cumulative measure of human Greenhouse Gas (GHG) emissions from all sources; expressed in Watts per square meter (Stocker et al., 2013).

to grow as long as social grants are paid. Any reduction or elimination of social grants (e.g. due to fiscal difficulties) will reduce growth in rural towns. It would reduce spending power and thereby undermine local businesses.

Renewable energy solutions have become an affordable technology (South Africa International Renewable Energy Conference (SAIREC), 2015). Apart from the larger renewable energy national grid extensions, the beyond the grid smaller renewable energy opportunities have made isolated rural communities more self-sustainable.

Information and communications technology (ICT) interconnectivity will become a significant socio-economic development enabler. It will address many of the problems of remoteness as distance becomes irrelevant. The advances in eHealth, eAgriculture, eEducation and even eGovernment (*inter alia*) have the potential of turning around the declining economies of dying towns, potentially reducing the numbers of youth migrating to cities (ITWEB, 2015).

Those towns within effective municipalities are likely to steadily grow their economic base. This will stimulate further rounds of investment. Where municipalities are under capacitated, investment and growth will be less pronounced. Commercial farmers will become primarily urban-based (in terms of where they live), but are expected to develop their farm infrastructure in response to agricultural diversification, also targeting rural tourism. These trends will be less marked in the extreme east of the study area.

For the communal farming areas, there are two sources of economic promise: First, producer organisations will empower local farmers to become more profitable with their current land holdings; and second, that prosperous local farmers will gain access to more land (through a variety of rental or collaborative schemes) and gradually become commercial farmers. There are significant economic prospects for the arid Karoo, the more temperate midlands and for the communal extreme eastern areas. In some cases, these potentials will be largely achieved if sufficient government and private sector energies can be locked in. In some towns, economic development is likely to remain patchy and vulnerable to economic shocks.

1.3 Petroleum geology in the Karoo

1.3.1 Geological features of the Karoo Basin

The main Karoo Basin is filled with sedimentary formations of the Karoo Supergroup, and covers an area of approximately 700 000 km^2, representing more than half the surface of South Africa. Within the study area, ~87% of the surface area comprises intercalated arenaceous and argillaceous strata of the Beaufort Group (Figure 1.12 and 1.13). From a flat-lying morphology in its northern part, the basin deepens and the sedimentary succession thickens towards the south-west, up to its interface with the northern margin of the mountains of the Cape Fold Belt (CFB) Mountains.

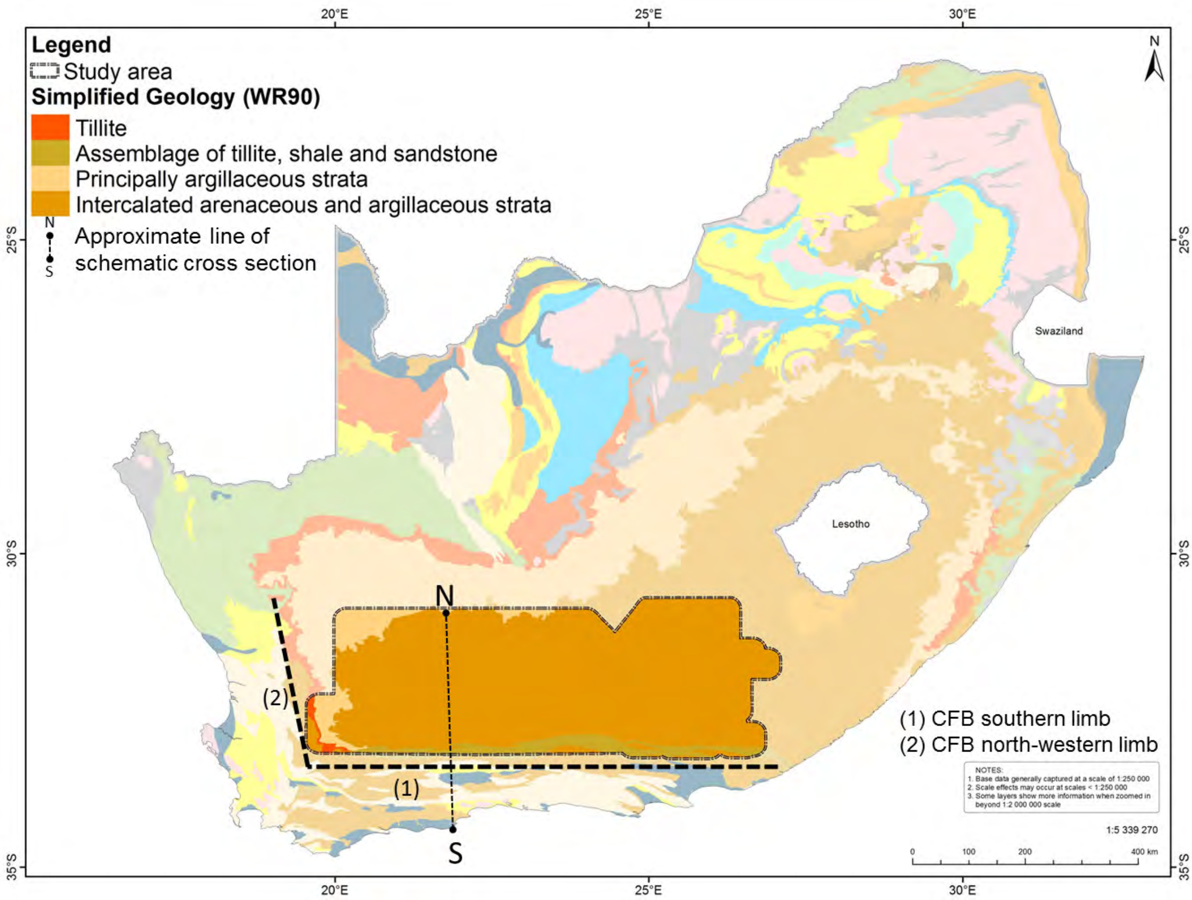


Figure 1.12: Simplified geology of South Africa showing the substantial extent of the main Karoo Basin (light brown areas) deepening from the north-eastern interior to the south-central interior where it abuts against the southern limb of the Cape Fold Belt (CFB); section line S-N through the study area marks the schematic profile in Figure 1.13.

Sedimentary rocks of the Karoo Supergroup

The sedimentary formations are subdivided into groups that reflect variations in depositional environment, rock type (lithology), position in the geological record (stratigraphy) and age (chronology). At the base of the succession, and therefore the oldest, is the glacial deposit (tillite, diamictite) of the Dwyka Group. This is overlain in turn by mainly fine-grained sediments (mudstone, siltstone, shale) of the Ecca Group and, with the inclusion of subordinate sandstone, the Beaufort Group.

The South African Committee on Stratigraphy (SACS, 1980) recognises six distinguishing features between the Ecca and Beaufort groups that collectively are "……. considered to reflect a major change in environment, from deposition in a large body of water, possibly marine, in the case of the Ecca, to generally terrestrial, river-dominated conditions in the case of the Beaufort". Periodic and cyclical deposition is evident in much of the sedimentary column throughout the Ecca and Beaufort groups. Such strata are collectively referred to as rhythmites.

The Ecca and Beaufort groups are themselves subdivided into formations on similar grounds that define the groups. Of direct relevance to this study are the carbon-rich shales of the Prince Albert, Whitehill and Collingham formations at the base of the Ecca Group, which is why they are also referred to as lower Ecca strata.

Middle to Lower Ecca Group

The Prince Albert, Collingham and Whitehill formations comprise the (Middle to Lower) Ecca group. The formations include carbon-rich shales ranging range in depth below surface from about 300 m to over 3 000 m. They include deep water carbonaceous sediments, with the organic content thereof originating from biological matter that settled out of suspension in a low oxygen environment. The reducing (anoxic) conditions assisted in preserving the organic matter – which explains the origin of the shale gas contained, in places, within the sediments.

Box 1.3. History of petroleum exploration in the southern Karoo Basin

The Southern Oil Exploration Corporation (SOEKOR) was established in 1965 with the mandate to prove or disprove the existence of economic amounts of oil and gas in South Africa. Seismic surveys were initiated in the southern part of the Main Karoo Basin, and between 1965 and 1972 a total of some 13 000 km of data was acquired (Fatti and Du Toit, 1970). Exploration drilling that was undertaken in the same period demonstrated the presence of gas within the Ecca shales, with minor high pressure, low volume gas shows having been encountered in most of the 12 wells drilled in the southern part of the Karoo Basin (Rowsell and De Swardt, 1976).

In 1976 a comprehensive study was initiated by the Council for Geoscience (CGS) to investigate the oil-shale potential of the Whitehill Formation on the western flank of the Karoo Basin (Cole and McLachlan, 1994). Sixteen cored boreholes were drilled in the area between Strydenburg and Hertzogville. The study was subsequently extended to include all available borehole logs and cores over the whole extent of the Whitehill Formation, with the logs of 48 borehole and petroleum exploration wells that intersected the Whitehill Formation having been considered. It is these data that form the basis of the majority of shale gas resource estimates for the Karoo that have been made to date.

The Petroleum Agency SA (PASA) acts as regulator for exploration and production activities and is also the custodian of the national petroleum exploration and production database. In 2006 PASA focused on locating and assembling the geological and geophysical data relating to the southern part of the main Karoo Basin. In 2012 the agency also provided an assessment of the potential shale gas resource with a view to determining the reliability of the USA Energy Department's 2011 estimate of 485 trillion standard cubic feet of Technically Recoverable gas; an estimate of a best and a lowest gas resource case was also presented (Decker and Marot, 2012).

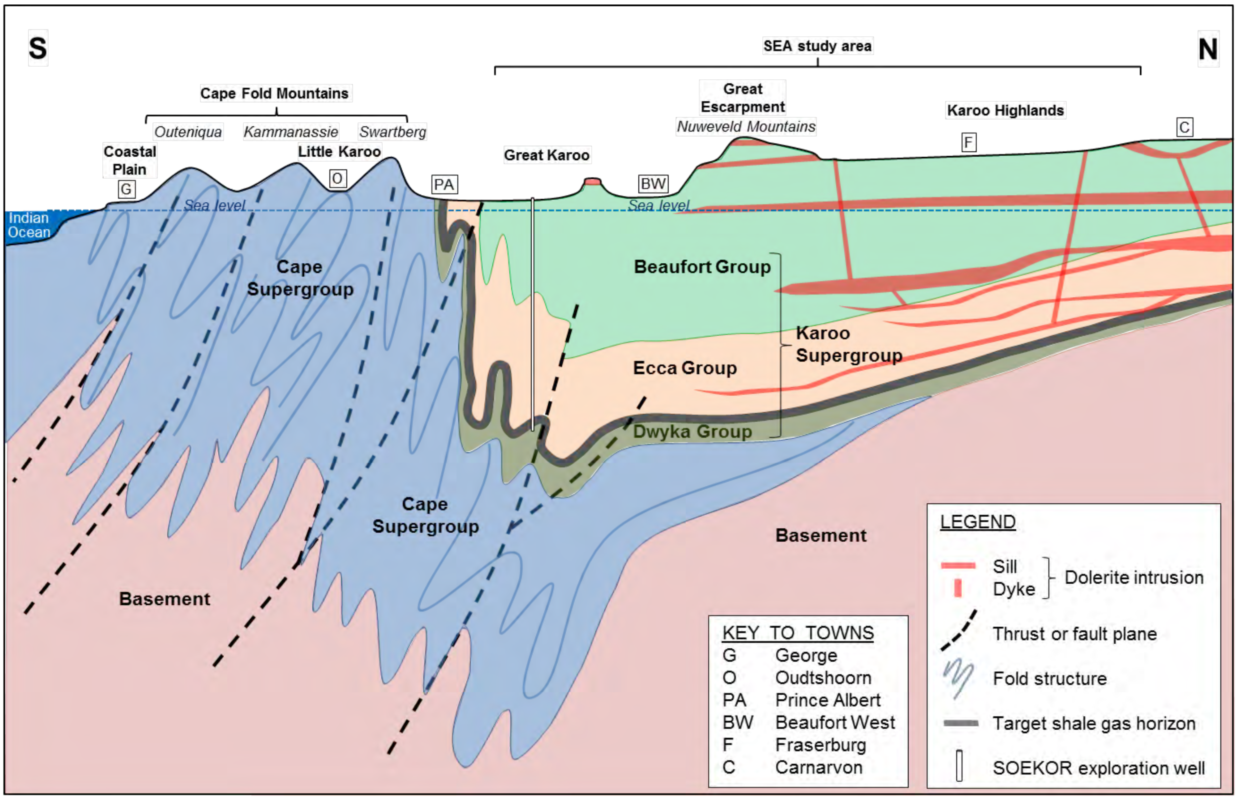


Figure 1.13: Schematic geological profile across the study area along the S-N section line in Figure 1.12, illustrating the basin-like stratigraphic succession of Karoo Supergroup sedimentary strata in the main Karoo Basin north of the Swartberg Mountains, the Great Escarpment formed by the Nuweveld Mountains, and the underlying Cape Supergroup rocks that pinch out northwards against basement rocks (modified after Rosewarne et al., 2013)

The shales have been severely affected by intense thermal maturation associated with deep burial, the Cape Fold Belt tectonic folding processes and, in a large portion of the southern part of the basin, by intrusion of igneous dolerite. An effect of these factors has been to severely reduce the capacity of the shales to generate gas. The Collingham Formation overlies the Whitehill Formation and forms the top unit of the shale gas target sequence. It varies in thickness from 30 to 70 m and comprises thin hard bands of dark-grey siliceous mudrock that alternate with very thin beds of yellow weathering tuff. Although it has been regarded as contributing to the potential shale gas reserve of the Karoo Basin, Decker and Marot (2012) and Cole (2014a,b) exclude it due to insufficient data to substantiate the presence of large areas of thick carbonaceous shales expected to incorporate organic carbon at levels greater than 2%. The formation may, however, have some potential for localised gas development if targeted in tandem with the underlying formations, such as the Whitehill Formation.

The Whitehill Formation directly overlies the Prince Albert Formation. It is black in colour and is thinly laminated highly carbonaceous pyritic shale, which varies in thickness over its entire area of distribution from 10 to 80 m. In the study area its thickness range is less extreme (35 to 43 m).

Organic carbon values are consistently high, with up to 17% total organic carbon and averaging more than 2% over large areas. It covers an area of 260 000 km^2 of which 66% (171 811 km^2) lies within the study area. It represents an attractive shale gas exploration target.

The Prince Albert Formation which overlies the Dwyka Group basement to the Ecca Group is highly variable in thickness (35 to 150 m) and in the study area is characterised by dark grey carbonaceous, pyritic splintery shale or mudrock. Organic carbon values are high enough over a large enough interval to warrant its consideration as a shale gas target.

Intrusive rocks of the Karoo Supergroup

Development of the Karoo Basin terminated with eruption of the basaltic lava that would form the present-day Lesotho Highlands. Some of the magma rising via vertical fractures and fissures did not reach the surface, finding easier pathways through the horizontally bedded pile of sedimentary strata to solidify as dolerite sills. Dolerite dykes represent solidification in the sub-vertical to vertical pathways. The presence of these intrusions is recognised internationally as unique to the Karoo (Norton Rose Fulbright, 2013), and collectively define the Karoo Large Igneous Province.

Radiometric dating indicates that the sills and dykes were intruded very rapidly within a period of approximately 0.47 million years, or maybe even as a single event. While dykes manifest on the surface as long sinuous bodies forming relatively narrow ridges or depressions, sills form the capping of hills throughout the region (the Three Sisters hills being an example of this). Dolerite is absent along the southern limit of the Karoo Basin within the compressive zone of the Cape Fold Belt where this formative process has prevented the intrusion of sills and dykes. The concentration of dolerite within the study area is illustrated in Figure 1.14 whilst the thickness contours of the percentage of dolerite affecting the Whitehill Formation are indicated in Figure 1.15.

The dolerite structures represent the main targets for scientific groundwater exploration. Dykes in particular are the feature most commonly targeted by landowners for successful water borehole siting, whereas more prominent sill complexes are typically targeted for larger-scale municipal water supply to towns such as at Victoria West (see Hobbs et al., 2016). One of the overriding factors used in defining the potential reserves of the Karroo shale gas province has been the perceived negative effect on gas retention of dolerite sills and dykes, especially in the Whitehill Formation. This is a function of both contact metamorphism and gas escape via breccia pipes relating to the intrusion of dolerite sills. These effects are additional to the loss of shale gas that will have occurred along faults during periods of rebound and decompression associated with the Cape Fold structures. In places, the dolerites may provide secondary traps for gas that has migrated out of their source rocks during uplift of the basin and the fall in pressure resulting from the opening up of escape pathways.

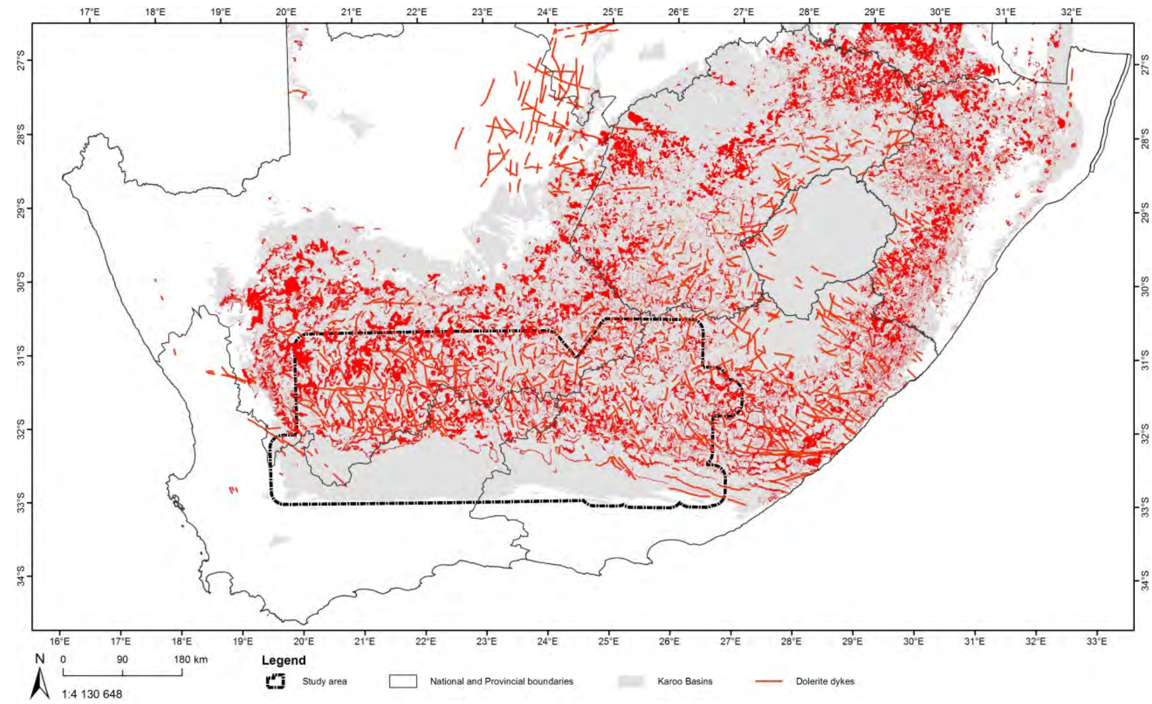


Figure 1.14: Distribution of dolerite dykes and sills in the main Karoo Basin (CGS, 2013).

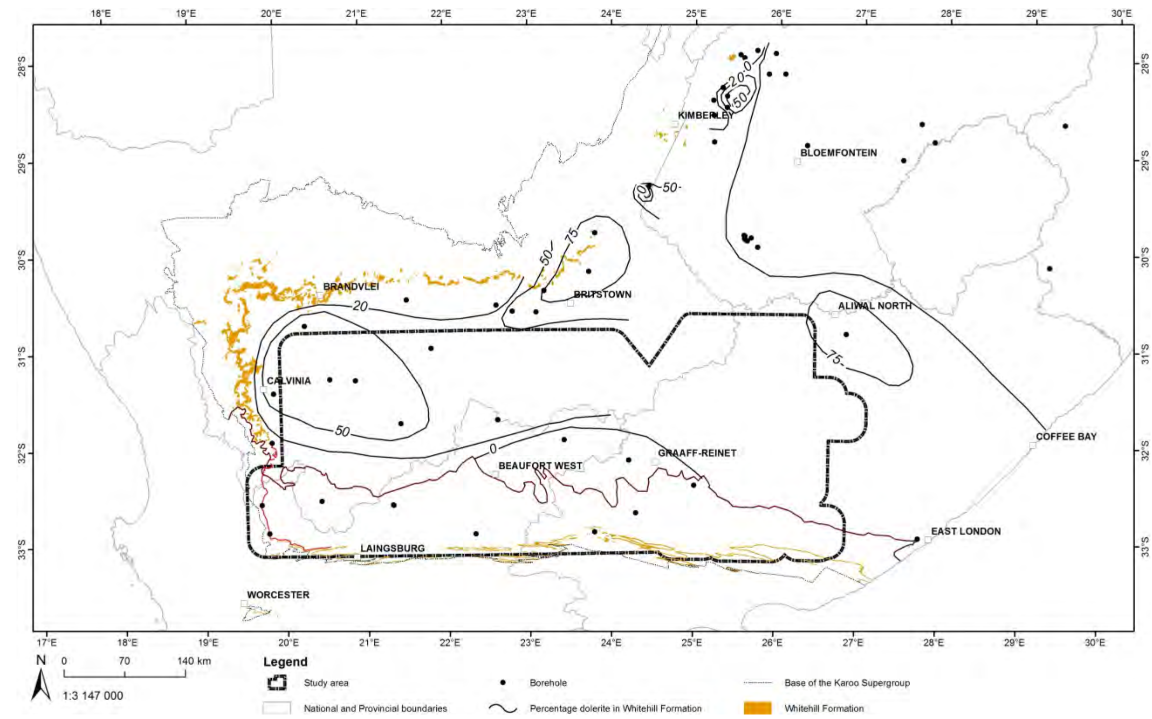


Figure 1.15: Contours of the percentage of dolerite in the Whitehill Formation (CGS, 2013).

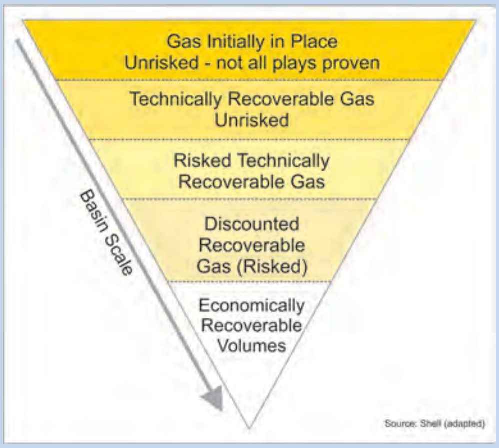
1.3.2 *Shale gas reserve models*

A number of attempts have been made to assess the shale gas or petroleum potential of the Karoo carbonaceous shale sequences. In recent years seven different assessments have been made, originating both locally and from the USA. The most significant results of these assessments are outlined here.

With the growing success of the shale gas industry in North America, the US Department of Energy commissioned a world-wide inventory of shale gas reserves. The results, which were reported by Kuustraa et al. (2011, 2013), are summarised in Table 1.1.

In 2012 PASA was tasked with providing an assessment of the shale gas reserve of the lower Ecca group of shales within the southern part of the Karoo Basin (Decker and Marot, 2012). In the assessment, account was taken of key geological risk factors (e.g. the implications of dolerite intrusions). The PASA assessment considered three scenarios. Scenario 1: that gas was producible from all three of the target zones (Prince Albert, Whitehill and Collingham formations); Scenario 2: that the Collingham Formation would not be prospective; and Scenario 3: that only the Whitehill Formation would contain sufficient gas to be productive. The results of the assessment are summarised in Table 1.2, which presents estimated shale gas volumes that have been adjusted to include only the study area. The areal extent of the three scenarios is shown in Figure 1.16, with the study area superimposed.

Box 1.4. Technically recoverable resources versus economically recoverable resources



Technically recoverable resources represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs.

A large number of direct sub-surface measurements (depth, mineralogy, total organic content, thermal maturity, etc.) gathered by current drilling technology need to be undertaken to quantitatively calculate technically recoverable gas reserves (McGlade et al., 2013).

Economically recoverable resources are those that can be profitably produced under current market conditions. The economic recoverability of oil and gas resources depends on three factors: the costs of drilling and completing wells, the amount of oil or natural gas produced from an average well over its lifetime, and the prices received for oil and gas production (US EIA, 2013).

In 2014 the South African Council for Geoscience (CGS) conducted a shale gas reserve assessment as part of a study dealing with the potential impact of hydraulic fracturing on groundwater (Cole, 2014b). The approach used was based on contoured values of shale gas variables derived from petroleum exploration wells. For a preferred area of 21 815 km^2, accounting for various limiting criteria (e.g. dolerite content < 20%), the shale gas reserve estimates provided for the Whitehill and Prince Albert formations are 13 and 72 tcf, respectively.

Table 1.1: US Department of Energy assessment of South African shale gas reserves, reported by Kuustraa et al. (2011, 2013).

US Dept. Energy Report Date	Main Karoo Basin Risked Gas in-Place (tcf)	Main Karoo Basin Technically recoverable gas (tcf)	World ranking of estimated RSA Reserve
2011	1 834	485	4^{th} largest
2013	1 559	390	6^{th} largest

Notes: tcf = trillion cubic feet of gas; the estimates are cumulative for the Prince Albert, Whitehill and Collingham formations; the lower estimate of shale gas reserve reported in 2013 accounts for the potential negative effects of dolerite intrusions, which were excluded as an influencing variable from the 2011 assessment; the area to which the analysis is applied is considerably smaller than used in estimates made by PASA.

Table 1.2: Different estimates provided by PASA for shale gas reserves contained within the lower Ecca Group of shales (Decker and Marot, 2012). The estimates presented here reflect volumes adjusted to correspond with the study area.

Target formations of the Ecca Group	Prince Albert Whitehill & Collingham formations	Prince Albert & Whitehill formations	Whitehill Formation Only
Risked gas in place (tcf)	1 722	1 408	159
Technically recoverable gas (tcf)	455	377	32

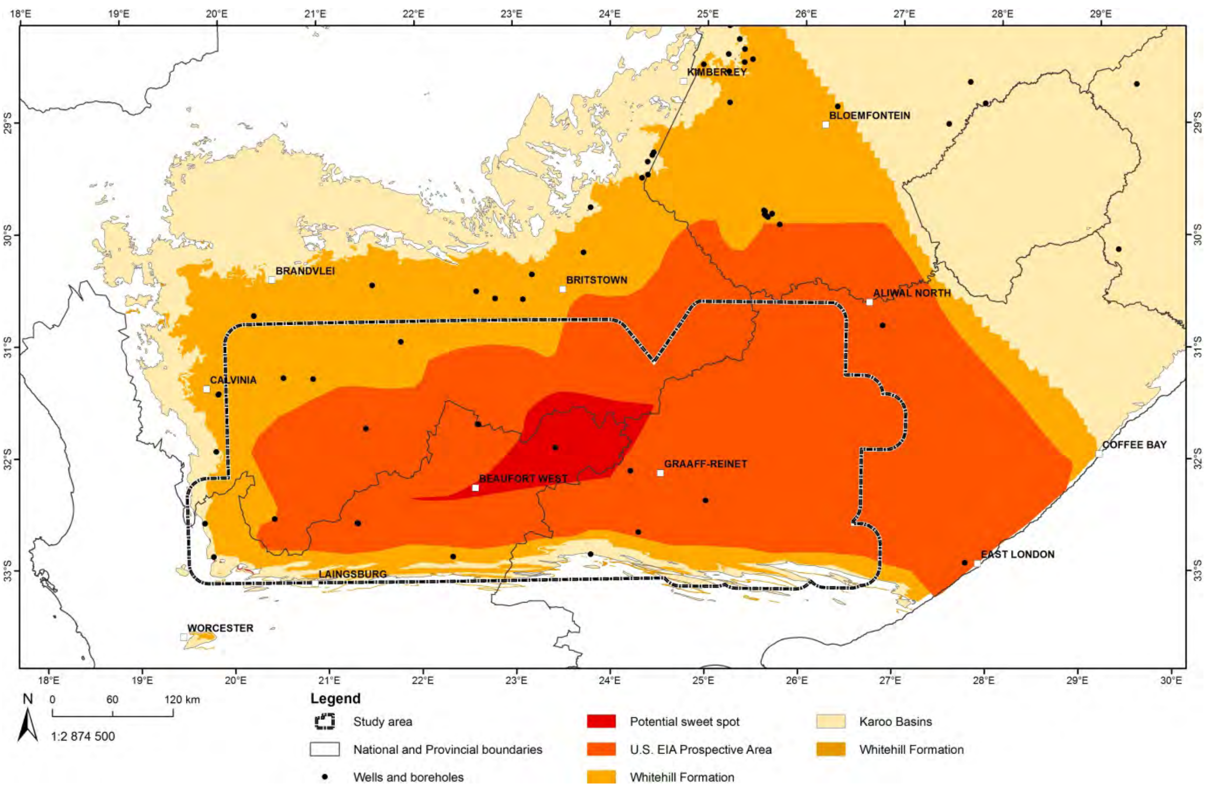


Figure 1.16: Areal extent of the reserve estimates considered by PASA contained within the lower Ecca Group of shales (Decker and Marot, 2012).

Drawing from various sources, Geel et al. (2015) prepared a shale gas reserve map for South Africa. Accounting for factors such as reserve maturity and depths and thickness of the Whitehill Formation, the authors define prospective shale gas areas and estimate potential recoverable free gas volumes in the Karoo Basin of between 19 and 23 tcf, with the latter volumes based on gas recovery success factors of 30 and 50% respectively[10].

[10] In the USA, with maturing shale gas technologies, a 20% gas recovery rate from shale is generally assumed, with the number slowly trending higher (Tom Murphy (n.d.) Penn State University, review comment). Recovery rates of between 30 and 50% may be feasible accounting for expected technological advances between now and when shale gas exploration and production could materialise in the study area.

An assessment of shale gas reserve potential was undertaken by PASA as a specific contribution to this Chapter (Mowzer and Adams, 2015). The authors provided both deterministic and probabilistic shale gas reserve evaluations. A distribution curve was generated, with several defined value points identified. In Figure 1.17, P50 is presented as the “best” area of prospectivity, with an estimate of the reserve potential for this area ranging between 36 and 44 tcf.

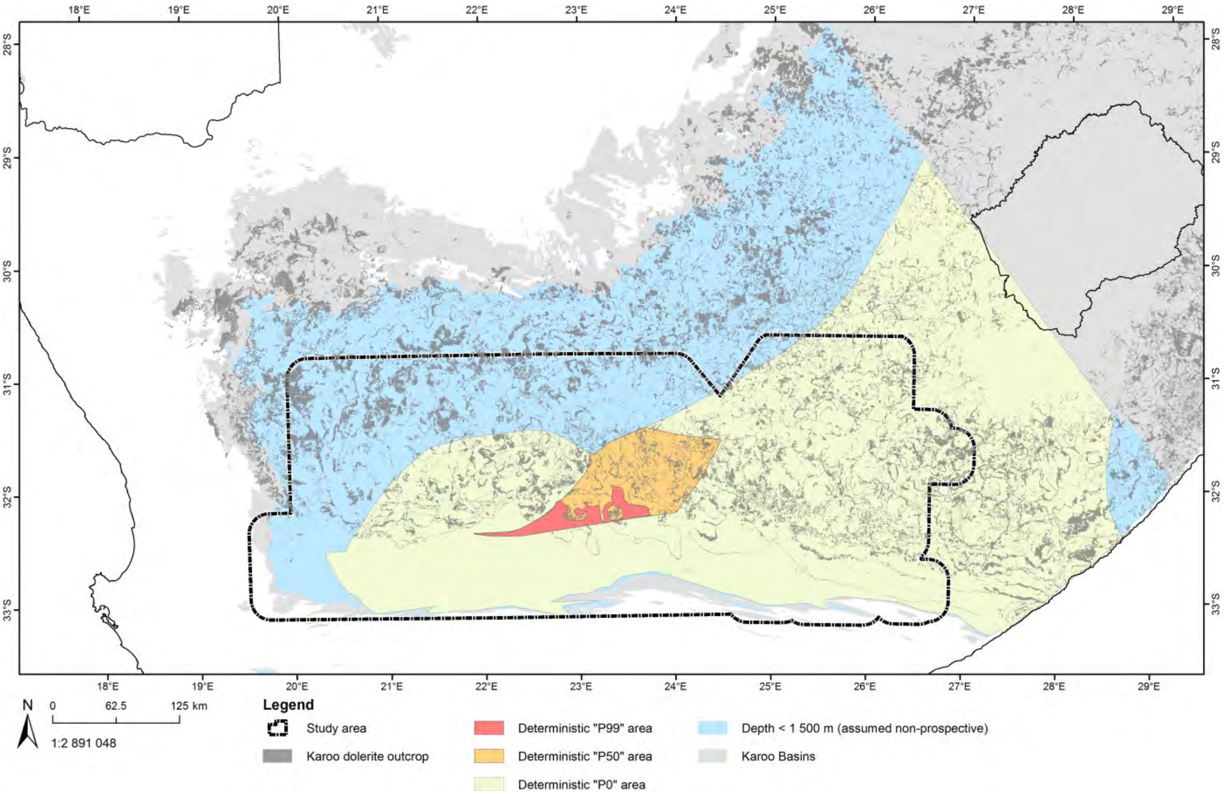


Figure 1.17: Prospectivity map for the Whitehill Formation (after Mowzer and Adams, 2015)[11].

The different approaches adopted for the reserve assessments outlined above make direct comparison of the results difficult. However, to the extent that this is possible, there is reasonable agreement between the results, in that much the same range of ‘shale gas in-place’ and ‘technically recoverable’ reserve quantities are presented. Accounting for the study area, where the depth to the top of the Whitehill Formation is at least 1 500 m a reserve estimate can be made for this formation, ranging between 17 tcf and 81 tcf. To this volume of gas can be added what might be contained within the underlying Prince Albert Formation for the same area, which Cole (2014 b) suggests could range between 54 tcf and 72 tcf.

[11] In this context, prospectivity refers to *mineral potential* - based on mineral exploration data - often depicted graphically in map format.

For both formations within the study area, where the depth to the top of the Whitehill Formation exceeds 1 500 m, the total technically recoverable shale gas reserve could range between 71 and 153 tcf. Taking a conservative approach regarding estimates of *economically viable* volumes of shale gas that might be available for downstream development and production, the Small Gas and Big Gas scenarios considered for the scientific assessment are 5 and 20 tcf, respectively[12].

According to the Onshore Petroleum Association of South Africa (ONPASA) (based on information provided for this assessment) approximately 10% of the total study area could yield technically recoverable concentrations of shale gas. It is further contended by the companies involved that only a fraction of this 10% is likely to be targeted through relatively few economically viable SGDs that proceed from exploration to production. The area most likely to be targeted includes the central and eastern/north-eastern parts of the study area, roughly indicated in Figure 1.18. It is considered most likely that the economically recoverable shale gas reserve quantified above would be contained within the beige- and red-shaded areas indicated in the figure. The red-shaded area within the central part of the study area is considered to have the highest probability of yielding the greatest volume of shale gas, whilst the blue-shaded areas offer the lowest probability.

Box 1.5. Economically recoverable gas in context

To put into context the magnitude of economically viable shale gas assumed for the scenarios included in this scientific assessment, reference can be made to recent discoveries of conventional gas in Mozambique and Tanzania.

Mozambique holds over 100 tcf of proved natural gas reserves, up from 4.5 tcf a few years ago. This positions the country as the third-largest proved natural gas reserve holder in Africa, after Nigeria and Algeria.

There have been several major natural gas discoveries made in offshore southern Tanzania since 2010. The country has proven reserves totalling about 50 trillion cubic feet of gas.

The volumes of economically viable shale gas assumed for this scientific assessment are considerably lower than for the above examples (of conventional gas).

Sources: Oil and Gas Journal. Wood Mackenzie. US Energy Information Administration. Oxford Institute for Energy Studies.

[12] South Africa’s draft unpublished Gas Utilisation Master Plan (GUMP) suggests a conservative estimate for recoverable reserves of Karoo shale gas of 9 tcf. The range assumed for this study (5 – 20 tcf) spans the GUMP estimate.

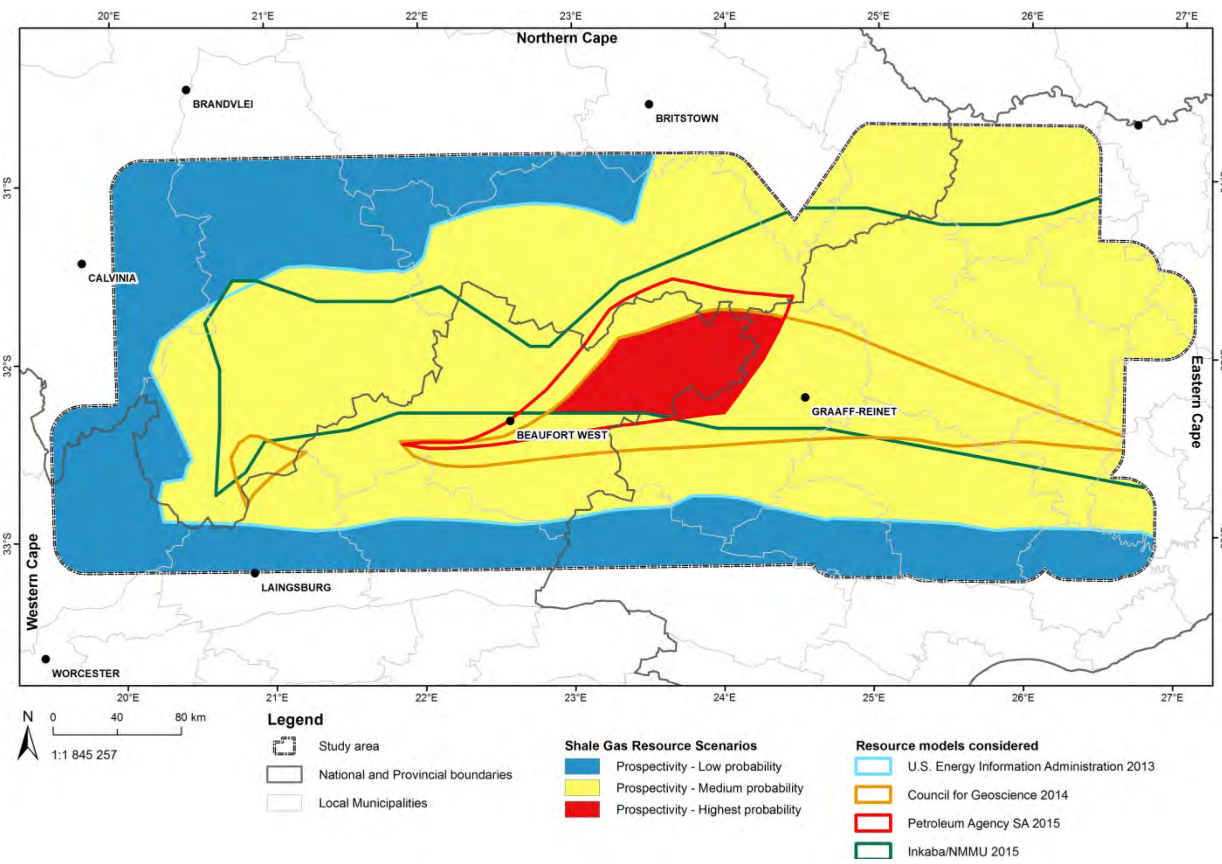


Figure 1.18: SGD prospectivity map for the study area generated by overlaying 4 existing reserve models generated by the U.S EIA (2013), the CGS (2014), the PASA (2015) and Geel et al. (2015). Based on this overlay approach, the solid red polygon, followed by the yellow/beige-shaded area, is considered most likely to yield technically recoverable shale gas. In stating this, it is acknowledged that the reserve models that are used each draw from a very limited data set.

1.4 Shale gas exploration and production scenarios

1.4.1 Typical shale gas project life cycle

Five distinct stages are recognised in a typical life cycle for a shale gas project (Figure 1.19)[13]. These stages progress from geological studies to discovering hydrocarbons to installing infrastructure for producing gas (National Petroleum Council, 2011). Also included is decommissioning at the conclusion of exploration and production, addressing all aspects of environmental rehabilitation.

[13] These stages are preceded by permitting and authorisation phases. For example, the MPRDA (Section 5A of Act 28 of 2002/2008) requires Environmental Authorisations for seismic, exploration, development and production operations (in the form of an Environmental Management Programme (EMPr)). Other permits and authorisations also apply.

Certain stages lead to a decision, where investment choices are made about whether or not to proceed to the next stage[14]. Decisions are informed by technical and economic criteria, among other factors. Exploration is the first stage in the search for hydrocarbons (shale gas, in the case of this assessment). Amongst other activities, it involves mapping and imaging the sub-surface geological structures, primarily through seismic surveys. Seismic surveys are typically conducted in a phased manner during exploration and also in stages during development of gas fields for production. Regional seismic surveys, usually comprising two-dimensional (2-D) seismic acquisitions, are normally conducted during initial exploration campaigns with the aim of furthering understanding of the sub-surface geological structure and identifying prospective zones for the next phases of exploration. More sophisticated three-dimensional (3-D) seismic surveys are typically commissioned during subsequent stages of exploration and/or development and production planning[15]. The intensity of the surveys (e.g. density of seismic lines that are surveyed on a per km^2 basis) tends to increase for each subsequent stage of seismic exploration, especially as areas are prioritised for drilling.

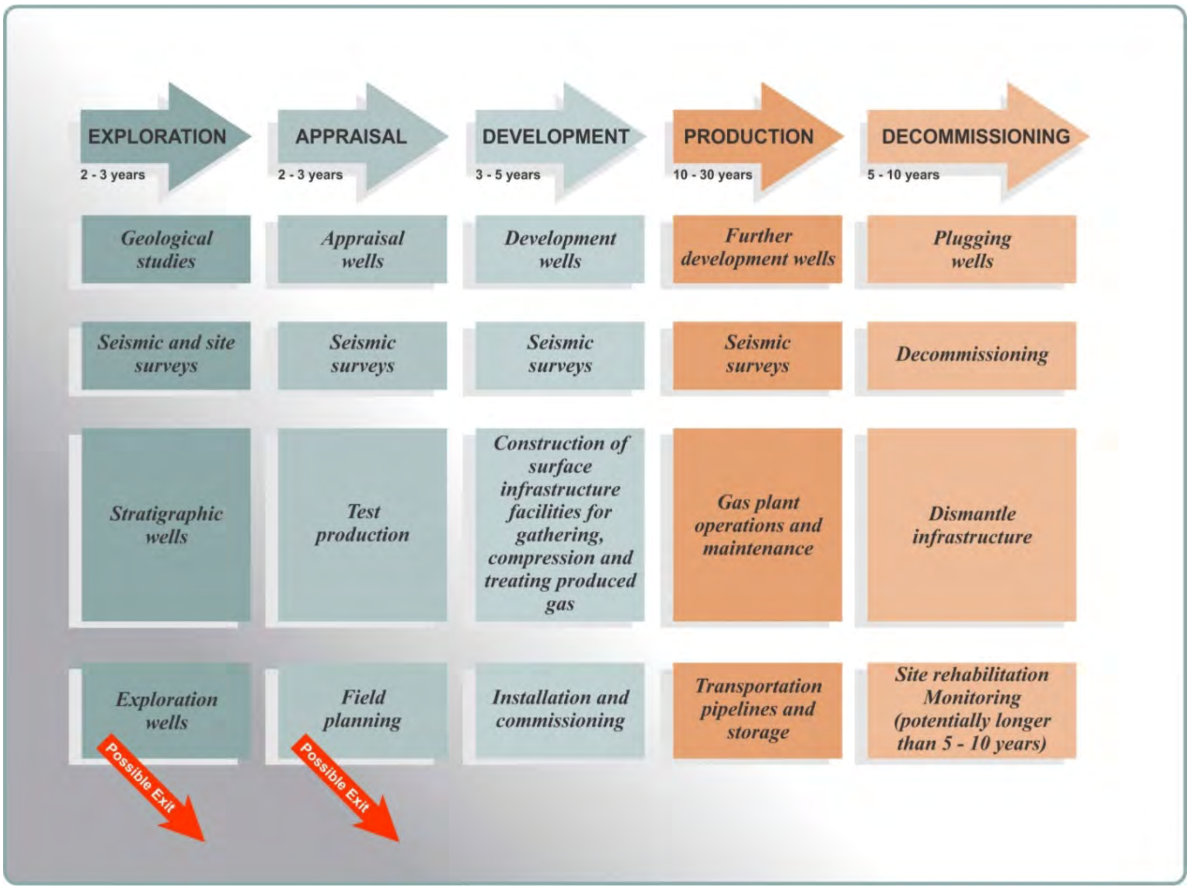


Figure 1.19: Typical life cycle of a shale gas project (adapted from National Petroleum Council, 2011)

14 Internationally, license conditions often impose minimum operational commitments (e.g. a certain number of wells to be drilled), which can require a license holder, for example, to proceed with operations beyond the exploration phase.
15 3-D seismic can also be used as the initial approach to seismic investigation.

1.4.2 Imagining SGD scenarios

There are a number of constraints to knowing whether, to what extent and in what form SGD might materialise within the study area. Most significant in terms of responding to these constraints is the limited understanding of the magnitude and distribution of potential technically recoverable shale gas reserves that could be targeted for exploration, development and production. It is clear that if exploration does not reveal technically recoverable reserves that can be exploited economically, activities will not proceed further and decommissioning will be implemented. If the converse materialises, development may occur, and it could take several alternate forms.

Although there is no way of knowing what SGD developments will actually materialise at this stage, this does not diminish the need for strategic assessment of plausible possibilities to guide future planning. To deal with high levels of uncertainty regarding fundamentally important, but currently unknown determinants of future outcomes of SGD, the use of scenarios provides a platform from which to proceed with the assessment[16]. Three SGD scenarios are proposed, which are additional to the Reference Case scenario already described. The Exploration Only scenario identifies the study area as having no potential for SGD and production, as might be revealed through extensive exploration and the results of appraisal that do not indicate economic breakeven possibilities. The Small Gas scenario identifies modest downstream SGD potential in the central region of the study area where current understanding of the petroleum geology suggests there is greatest probability of a technically recoverable reserve that could be exploited economically. The Big Gas scenario, also located in the central region of the study area, identifies large-scale downstream SGD potential, extending beyond the development considered for the Small Gas scenario. An important aim of the scientific assessment report is to consider the risk implications of these scenarios compared to the Reference Case scenario described in Section 1.2.3.

The scenarios outlined above provide the basis for the description and quantification of SGD activities that will be presented next. In this regard the prologue to the description of each suite of SGD activities that is described captures the essence of an imagined situation within the SGD sector operating within the study area, playing-out in the future in 2050. The 'run-time' of approximately 35 years from present (2018) allows for the anticipation of plausible established states that might be achieved for the scenarios under consideration.

[16] According to Illbury and Sunter (2001) scenarios, which deal with uncontrollable determining variables, anticipate *plausible* future situations. Based on current knowledge of the petroleum geology of the study area, the three SG exploration and production (E&P) scenarios presented here are considered sufficiently plausible to warrant assessment. Largely due to the probable effect of intrusive dolerite on compromising the integrity of gas that might have been previously been contained within the shale formations (i.e. before the intrusions), it is considered implausible that SGD could materialise beyond what is stated as the Big Gas development scenario (see below).

In the following sections, description of the 'upstream' (i.e. prior) SGD activities associated with each of the three scenarios is structured in a 'cumulative' format: the Small Gas scenario assumes all the activities that took place in the Exploration Only scenario, and the Big Gas scenario assumes all activities in the Small Gas scenario (and thus the Exploration Only scenario). Through this approach, the activities are presented as an exploration, development and production continuum (Figure 1.19). This approach avoids unnecessary repetition in the description of activities that are common to different scenarios.

Certain SGD activities described are fundamental to this scientific assessment and are expressed and quantified as impact drivers in the sections in which each of the individual scenarios are described. Although the quantification of many of the impact drivers can be anticipated with a relatively high degree of certainty, it is inevitable that assumptions need to be made. Where applicable, these assumptions are expressed in the form of ranges in the quantification of activities. The information that is presented is structured to allow for appreciation of the strategic implications of the SGD activities, both individually (e.g. in the context of a specific scenario) and cumulatively through their association with activities that could follow one after the other across a typical SGD continuum.

1.4.3 Exploration Only

1.4.3.1 Scenario statement

A scenario that could result from shale gas activities proceeding only as far as the exploration phase can be expressed as follows:

Box 1.6. Exploration Only scenario

In 2050 all shale gas activities in the study area have ceased. This follows a period of relatively intensive exploration that was initiated in 2018, which continued until 2025 when it was concluded that the shales within the area contained no economically viable gas reserves. Exploration activities included a limited seismic survey campaign followed by drilling activities, with some fracking, at five targeted locations. Since 2020 a primary focus of South Africa's electricity and petrochemical sectors has been on the use of liquefied natural gas (LNG) imported as feedstock for power generation and liquid fuel production. Also since this time, wind and solar energy projects in the Karoo have continued to make an important contribution to meeting the country's electricity demand. An environmental audit of all shale gas exploration activities in the study area, undertaken in 2048, showed that rehabilitation has fully achieved the targets specified in the project Environmental Impact Assessments and accompanying Environmental Management Programmes. Environmental monitoring will, nevertheless, continue for at least another decade.

The suite of exploration activities contributing to this scenario is discussed below. The discussion is structured to describe the main activities that would be involved, the various assumptions regarding when and where the activities might be scheduled and their quantification as impact drivers.

1.4.3.2 Exploration activities

Exploration activities within a shale gas licence area would be preceded by a number of permitting and authorisation requirements. Important in this regard is the securement of Environmental Authorisation to proceed with exploration projects based on the outcome of Environmental Impact Assessments (EIA) and accompanying Environmental Management Programmes (EMPr) aimed at identifying and ensuring the achievement of impact avoidance or mitigation and benefit-enhancements to which project proponents commit and are legally bound. These processes address social, health, economic and biophysical issues of relevance to all exploration projects that are undertaken[17]. With the necessary permits and authorisations in place, a Rights Holder will undertake the scope of exploration that is required. Typically, a considerable lead time is scheduled for mobilisation of contractors and equipment to site.

Exploration field activities within the SGD sector can be broadly differentiated into *seismic acquisition* and *exploration drilling*, which are discussed below.

1.4.3.2.1 Seismic surveying

1.4.3.2.1.1 What seismic surveying entails

The overall objective of a seismic acquisition programme is to identify drilling targets (Robinson and Coruh, 1988; Busanello et al., 2014) with a primary focus on formations expected to yield hydrocarbon product (Nolen-Hoeksema, 2014). Other objectives are to identify the depth and thickness of the shale target, drilling and other hazards (dolerite dykes, faults, breccia pipes), fractures and their density, direct hydrocarbon indicators, (estimate) minimal hydraulic fracture pressure, and to inform the design of additional seismic acquisition and drilling programmes.

A seismic survey is in effect an echo sounding technique (Short, 1992). An acoustic pulse is initiated from a surface location, with reflection occurring at the boundaries of rock layers. This results in the seismic pulse traveling upwards as a reflected wave front. The sub-surface response is recorded by an array of receivers placed on the land surface. Travel time to the reflectors and the velocity of

[17] Application also needs to be made for various licenses pertaining to planned activities; e.g. a Water Use License.

propagation of the reflected acoustic pulse are analysed to develop a picture of the sub-surface geology.

There are four basic components of land seismic survey operations (Box 1.7):

- *Location*: planning the location and configuration of a seismic programme.
- *Source*: the means of transmitting sound (acoustic) energy into the sub-surface.
- *Receivers*: gathering the sound energy as it is reflected by changes in rock properties in the sub-surface (typically using geophones).
- *Recorder*: a device for storing received data, which is then downloaded for processing.

Box 1.7: Main components of seismic survey operations
(drawing mainly from information provided by Short (1992)).

Location:

Seismic surveys are typically performed on a pre-determined set of accurately geo-referenced 'seismic lines'. These lines are established for an initial regional seismic survey. For areas of specific interest, they are supplemented in follow-up surveys. 'Line-clearing' is the generic term used to describe the process of defining and making accessible the corridors (seismic lines) along which the survey is carried out. The aim is to provide for access of pedestrian and vehicular traffic along the lines and, where necessary, to provide line-of-sight between geo-referenced survey control points and the series of locations where seismic data acquisition is planned. The seismic lines tend to be straight and regularly spaced, although some deviational tolerance can be accepted in gaining access to the data acquisition point (e.g. to avoid a particular landscape feature). In forested and densely vegetated environments, line-clearing can be an intrusive operation with considerable scarring of the vegetated landscape; however, in open environments, where access and line-of sight considerations are not significant constraining factors, there is minimal actual clearing (if any) of vegetation along the lines. In open terrain, the seismic lines tend to bear relatively light loads of traffic involving vehicles used to deploy and retrieve equipment and crews. Where possible, data acquisition points are accessed using existing roads and paths. Specific vehicular driving techniques are employed, such as reversing versus turning around, to minimise environmental disruption.

Mapping is carried out (e.g. in the form of an overlay of the planned seismic lines on cadastral and land use maps) in advance of seismic survey operations. Account is taken of factors such as impassable terrain, restricted access areas (e.g. conservation areas, wetlands) and other obstructions (built areas, rough terrain). Amongst other authorisations involved in planning the location of a seismic survey, land access permission is secured and road-use permits are obtained from the surface owner along with provincial, district and local traffic authorities.

Seismic Sound Source:

During surveys, seismic waves are generated at or near the Earth's surface and travel though the rock formations, potentially up to a maximum depth of 10 km (Nolen-Hoeksema, 2014). In the study area the maximum depth of interest would extend to about 6 km. Land seismic surveys rely primarily on two types of seismic sources: explosives and mechanical sources of vibration (most commonly produced by 'vibroseis' trucks). Surveys may be conducted using one or both approaches to seismic sound source generation, with the choice depending on several factors including geophysical objectives, cost and environmental constraints (Bagaini et al., 2010).

The choice of energy source is critical in data acquisition because resolution quality is largely determined by the source characteristics. A geophysicist would select the seismic source based on the following criteria:

- Penetration to the required depth: a source is selected that produces adequate energy to illuminate the target horizon/s at their particular depths.
- Bandwidth for the required resolution: if high resolution reflections are required to delineate subtle geological features, the source must transmit a broad range of frequencies, from high to low. For shallow targets, explosive sources possess adequate energy and frequency bandwidth; for deeper targets, the longer travel path to a deep reflector requires the selection of a source that has enough energy at the higher frequencies to maintain a broad reflection bandwidth.
- Environment: Areas with sensitive receptors will dictate the buffer and safety requirements and the selection of the source.

There are other technologies that could be used in parallel with seismic surveys (e.g. gravity surveys, magnetic prospecting, magneto-tellurics and passive seismics). The geological information derived from these surveys, some of which are done from aircraft (including drones), is typically complementary to the seismic information derived from conventional methods.

Seismic Receivers:

Seismic waves propagate from the source and travel through geological layers. At the contact from one type of rock to another there is a change in physical properties and it is at these interfaces that some seismic energy reflects back to the surface where seismic receivers (electromechanical devices called geophones) detect the reflected energy (Nolen-Hoeksema, 2014).

Individual geophones are wired together and configured in arrays along a cable. There are two basic types of geophone cable systems: analog- and telemetry-based. The analog systems have a pair of wires for each geophone group and several additional pairs of wires for 'roll-along', which allows for setting of the pulses and recording to proceed efficiently (i.e. geophones that have finished recording are picked up behind the shot and moved into position in front of the rolling data acquisition process). If the cables are too long the signal may be attenuated through various causes. These problems are overcome using telemetry systems, which have an analog connection from the geophone group to a processor. The processor or station box amplifies, filters, digitises and transmits the signal to the recording facility by wire, optical fibre or radio. Hybrids of these two systems can be used to accommodate varying field conditions (Stoker et al., 1997). New wireless systems are evolving and being used, which require little or no need for cabling. In terms of managing environmental impacts, this diminishes the need for clearing lines to lay cables.

The seismic source that is triggered and reflected propagates in a pattern that interweaves with the array of receivers. Where the geophone arrays are set up in line with the sound source, this allows for a 2-D profile of the sub-surface geological structure to be generated (i.e. a 'slice' through the rock strata). If the source moves around the receiver line, causing reflections to be recorded out of the plane of the in-line arrangement of receivers, generation of a 3-D image is possible (the third dimension being distance, orthogonal to the in-line receiver line; Stoker et al., 1997). For 2-D surveys geophones are deployed in multiples of 100s; for 3-D surveys, deployment is in multiples of 1 000s.

Seismic Recorders:

Once a seismic signal is transmitted and received it is recorded. This trace data along with metadata (e.g. the geographic co-ordinates of the seismic sound sources and receivers) is then transferred to processing centres.

Personnel setting up a seismic data collection system which includes a small recording box, a battery, and an array of geophones. Fibre optic cables laid out in a grid pattern over the survey area transmit the signal from the recording box to the recording truck (Source: Shell).

For the areas in which seismic surveys are undertaken, the activities about which insight is necessary for the purposes of this assessment are those related to the generation of the *seismic sound source*[18]. In this regard, the assumed main approaches that would apply to the study area include the shot-point method and the use of vibroseis trucks. Factors that come into consideration when deciding on the energy source include: (i) required energy to obtain adequate information for desired depths; (ii) produced reflection pulse; (iii) convenience and safety; (iv) signal-to-noise ratio; (v) repeatability; and (vi) total costs (Suarez and Stewart, 2008).

The shot-point method of creating shock wave energy is used, amongst other reasons, in areas where the deployment of vibroseis trucks (see below) is not an option. It would probably be considered for use to some extent within the study area.

The vehicles used for a shot-point seismic programme include a number of truck- or track-mounted drill rigs, a recording truck and several light pickups or stake-bed trucks for transporting crew and light equipment[19]. The drilling rigs create small-diameter holes up to several metres deep (between 3 and 8 m)[20]. Different shot hole depths are associated with different charge sizes that are used. Drilling water, when needed, is obtained from the nearest approved source. To avoid contamination potentially attributable to the explosives that are used, water-bearing zones are sealed with bentonite gravel that is either poured directly down the hole or is placed down-hole in biodegradable cardboard tubes. A light helicopter is often used to move cabling, data boxes, geophones and other light equipment to workers on the ground.

An explosive charge is placed in the hole, which is back-filled with drill cuttings (the material excavated from the shot hole). Before the charge is detonated the fill is tamped down to secure the charge. A ground crew is tasked to work through the area and set off the sources in sequence and retrieve equipment such as geophones, markers, etc. Detonations are often triggered (and/or effects measured) using a radio-controlled unit located in a nearby recording truck. Detonations are contained within the hole to force the generated energy downward through the rock strata. As a result, the only sound heard above ground is a dull thud. There is strict adherence to regulations and safety requirements regarding handling and detonation of the explosives that are used.

Vibrator or vibroseis trucks are mobile seismic sound sources (Figure 1.20) designed to do away with the need to drill shot holes and the complex process of detonating explosives, and to reduce safety and security risks relative to the shot-point method. These advantages are, however, offset by other

[18] Other activities associated with geophysical surveys impinge relatively less on the environment.
[19] In some situations, hand augers are used to drill the shot holes.
[20] In rugged topography a portable drill may be deployed by light all- terrain vehicle (ATV) or by helicopter.

impacts on the environment (e.g. vehicle passage width, which exceeds that of vehicles used for the shot-point method). The trucks can be equipped with special tyres or tracks for deployment in a range of environments; although terrain can impose limits to their operation (e.g. they can't work in steep mountainous areas). They would probably be used at least as extensively as the shot-point method within the study area.

During operations, the vehicle moves into position and lowers the baseplate to the ground. Seismic vibrators fitted to the trucks produce ground motion that propagates into the sub-surface (Bagaini et al., 2010). The vehicle operator can make the piston and baseplate assembly move up and down at specific frequencies thereby transmitting energy through the baseplate and into the ground.

Vibroseis trucks can be employed individually or as a group, often with four or more trucks operating simultaneously. After the prescribed number of sweeps is completed, the baseplates are raised and the vehicles move to the next location, typically a distance of 10-50 m. Productivity, or the number of seismic traces recorded in a given time, is increased by using more than one fleet of vibroseis trucks.

Figure 1.20: Seismic vibration (vibroseis) truck (*Source*: Shell).

1.4.3.2.1.2 Key impact drivers of seismic exploration

The objective of an initial seismic acquisition programme in the study area would be to contribute to the understanding of the sub-surface geology of the Karoo Basin including its depositional environment, the tectonic activity that it has been subjected to and the presence of igneous intrusions including dykes, sills, breccia pipes and hydrothermal vents. The objective would also be to gauge the presence and distribution of potential shale gas plays. Subsequent seismic surveys would support, minimise or eliminate further exploration, including drilling programmes.

Figure 1.21: Ground impression left by the vibrator pad of a vibroseis truck (*Source*: Shell).

Initial seismic operations would likely be completed in the first 3 years following the issuance of exploration rights (Figure 1.19). This could be followed by subsequent surveys conducted over a number of years, throughout the development and production cycle[21].

The areas where seismic surveys might be undertaken in the study area are indicated in Figure 1.22 (derived from the information presented in Section 1.3.2). Only a small fraction (< 1%) of this area would be impinged upon directly through surveys conducted along quite widely spaced grids (e.g. 10 km spacing for a regional 2-D survey) of seismic lines (< 5 m wide, which is the width of the vehicles that traverse the lines). Exclusion areas indicated in the figure (solid grey-shaded) include municipal areas, conservation areas, wetlands and riparian zones, restricted activity zones and topographically complex landscapes, for example, where slopes exceed 10°[22]. There are likely to be other exclusion areas within the study area, additional to those indicated in Figure 1.22. A closer grid spacing (e.g. 1 km or narrower) would be used for targeted areas, where 3-D surveys are commissioned.

Various towns distributed across the study area would be used to support the seismic survey activities, including offices for project administration, accommodation of personnel (100–200 personnel per campaign), equipment storage and staging areas for equipment destined for deployment in the field

[21] Companies generally complete the majority of spatially extensive seismic work relatively quickly so that drilling options can be determined early in the SGD process. They usually commission additional concentrated seismic work later when there is need to focus on a specific area/region.

[22] Slopes in excess of 10° would practically be extremely difficult to traverse in the course of seismic operations.

and pre-processing and temporary archiving of seismic data. For a proportion of operations, in isolated areas, mobile camps in the immediate vicinity of operations might serve as operational bases for the seismic teams.

As described in Section 1.4.3.2.1.1 the most likely approaches that would be employed to generate the sound source used in a seismic campaign within the study area would include the shot-point method and the use of vibroseis trucks. Although many activities would be associated with seismic exploration, those to which the status of being key impact drivers can be assigned include the following:

- Clearing of seismic lines (minimal, in the case of the study area; also, minimal if wireless technology is used optimally);
- Vehicle and pedestrian traffic traversing the seismic grid;
- Noise emissions.

Quantification of key impact drivers is presented in Table 1.3.

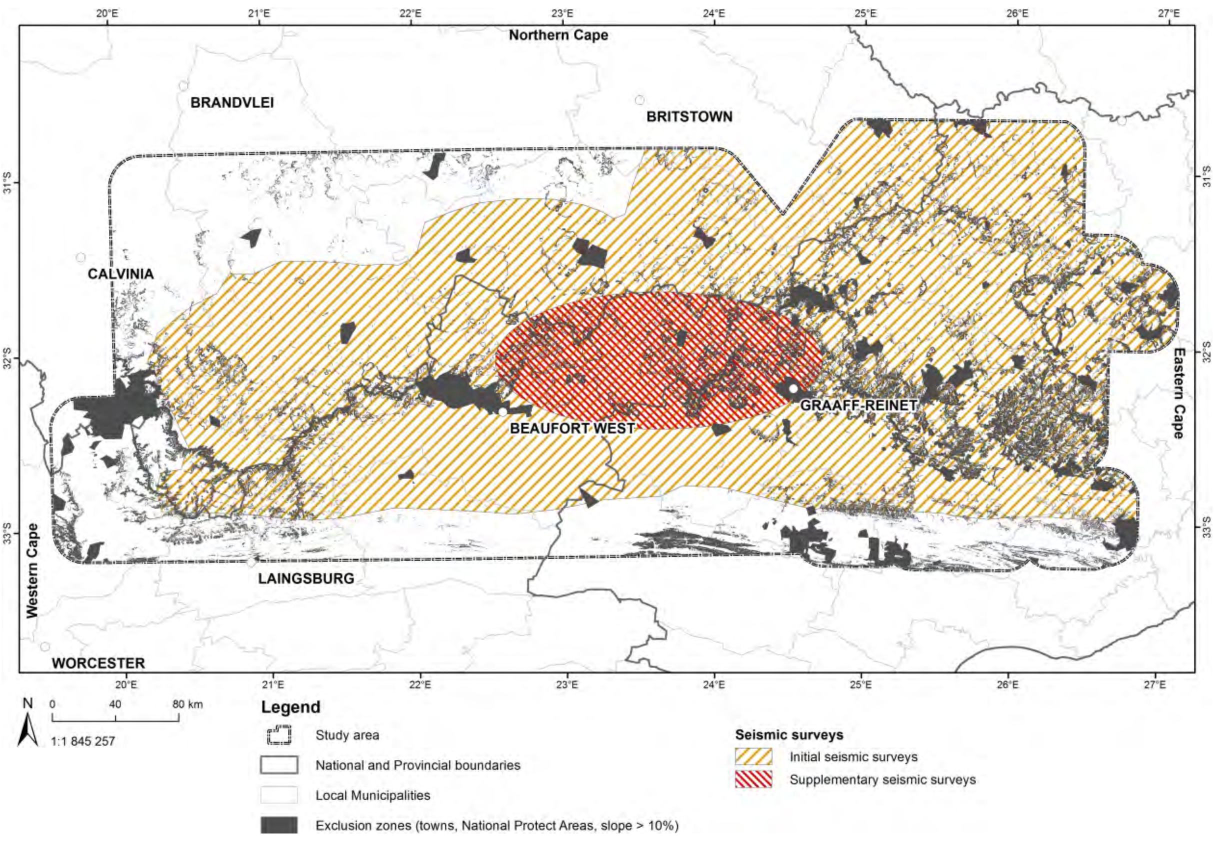


Figure 1.22: Extent of the study area that might be affected by exploration activities. There is the possibility that exploration activities may be restricted to identified 'sweet spots' and not cover the majority of the area during the initial phases of exploration. Note: supplementary seismic surveys could also occur outside the red-shaded area.

1.4.3.2.2 Exploration and appraisal drilling

1.4.3.2.2.1 What exploration and appraisal drilling entails

Following seismic exploration, establishing the presence and potential yield of hydrocarbon reserves is achieved through drilling, evaluation of drill cuttings and cores, downhole logging and, for some operations, measurement of hydrocarbon flow through extended well testing (e.g. measurement of gas flow following trial fracking).

A typical drilling campaign involves a number of operations. The first entails drilling vertical stratigraphic wells; the next entails appraisal wells, accompanied by fracking and test production.

In terms of drilling location, the first phase of drilling one or more stratigraphic wells is informed by regional geological studies and the results of seismic exploration. For the appraisal phases of drilling, well locations are determined by the combined results of seismic exploration and the results derived from stratigraphic wells. The overall sequence of stages and activities for exploration and appraisal drilling include:

- Site and logistics planning including drilling water supply (if needed) and establishment of groundwater monitoring wells;
- Site preparation including drilling of a mousehole (if needed)[23];
- Rig mobilisation: move-in, rig up;
- Drilling and evaluating vertical exploration wells (to derive key stratigraphic, structural, petro-physical and reservoir information), potentially drill stem testing or possibly conventional well testing;
- Drilling, evaluating and completing appraisal wells, fracking and, potentially, production testing;
- Demobilisation: drilling rig and ancillary equipment, site restoration, monitoring of wellhead and groundwater well(s).

[23] In industry terms, a “mousehole” refers to a hole that is established at the wellpad in order to store pipe joints for quick connection to the drill string. If a shallow aquifer is present, this could be penetrated by the mousehole, and associated environmental risks therefore need to be managed.

Site and logistics planning

Detailed baseline information (e.g. regarding surface and shallow groundwater, soils, vegetation and infrastructure) is collected and interpreted in the course of project planning. This typically involves the use of high resolution aerial photography and/or satellite imagery. At this stage, water wells may be drilled for baseline sampling and testing and for subsequent monitoring of potential future contamination of soils and groundwater.

Using this and other information sources, early planning activities include the identification of traffic routes, site access and haul roads. Assessments are also made of road pavement conditions, background traffic volumes, the history of road accidents on the planned project road network and related implications for and attributable to the project traffic volumes. This information is important since drilling programmes involve the transport of personnel and haulage of significant quantities of heavy construction vehicles and equipment and materials to the drill site (some part-distance by rail, but ultimately by road). Examples of equipment and materials include: drilling rigs and ancillary equipment; casing used to line drilled wellbores; chemicals (solid and liquid); compounds used to prepare drilling mud; cementing equipment and material; mobile electricity generators; fuel and lubricants; and temporary accommodation and field office units for crew.

An exploration well site (wellpad) typically occupies an area of up to 2 ha, which contains the drilling rig, portable offices, storage space (for chemicals, fuel and drill muds), plant and equipment areas, parking space for trucks, laydown areas (for drilling pipe and well casing), equipment to process and measure gas produced by the well and water storage tanks and treatment facilities. Additional space may be required for storing excavated sub- and top-soil that would later be used for site rehabilitation.

Separate from the wellpad, approximately 0.5 ha of land is developed for temporary accommodation of the drilling crew[24]. This area is designed and managed as a self-contained temporary development with sleeping and catering facilities and other amenities and services. The camp is typically located a few hundred metres to a few kilometres away from a wellpad (or cluster of wellpads) where impacts on the local population and environment can be managed effectively (e.g. with due cognisance of project vehicles using public roads for travel between the camp and wellpads).

Gravel access roads are constructed to link the wellpads and crew accommodation to existing road networks, most likely with some upgrades to carry heavy loads and project-related increases in traffic.

[24] In the event that operations are located close to towns, the need for temporary accommodation (i.e. camps) diminishes; i.e. staff can be accommodated in the town/s.

Site preparation

Wellpad areas are levelled or shaped to the minimum extent required, for example, to provide for drainage and for positioning temporary site offices, laydown areas and equipment storage. Unless a truck-mounted drilling rig is used (probably only for stratigraphic wells), a re-useable drilling mat will be laid, on which the drilling rig is set up. Above-ground tanks will be positioned for containing water and waste fluids/solids, most likely configured in closed loop format in order to separate solids and fluids – the latter either for re-use or disposal (in the case of waste). Closed loop systems minimise the risk of spills and/or leakage of waste. The areas underneath liquid storage facilities (chemicals, fuel, bulk water and drilling mud containment areas) are lined with impermeable material, the properties of which are in compliance with international best practice standards. Portable containment structures are installed around all tanks in order to contain any accidental spills. The layout of a typical drilling pad is illustrated in Figure 1.23.

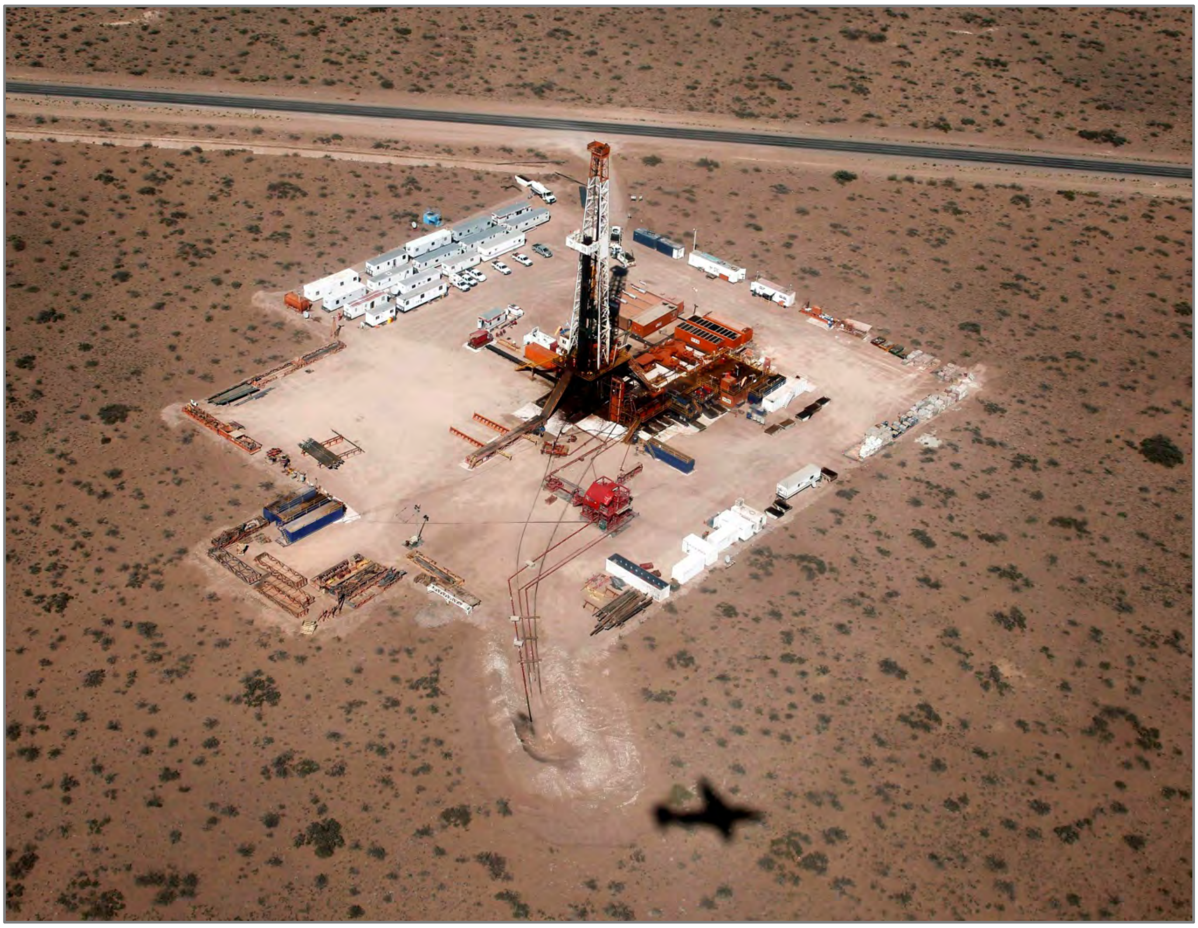


Figure 1.23: A typical wellpad layout with drilling and supporting infrastructure in place within an arid environment in Argentina, similar to what may be encountered in the Central Karoo (*Source*: REUTERS, http://www.vcpost.com/articles/5923/20120925/sidewinder-drilling-to-buy-union-drilling-for-139-mln.htm).

Drilling of vertical stratigraphic wells

The objectives of drilling a vertical stratigraphic well or set of wells (X-wells in Figure 1.24) are to:

- Correlate stratigraphic and structural records to seismic interpretations;
- Identify freshwater aquifers, drilling hazards and hydrocarbon-bearing zones;
- Confirm predicted organic-rich shale formation packages that might be anticipated, identify new potential target zones and identify existing fractures;
- If encountered, evaluate the thermal maturity, presence/absence of fractures, gas content, gas saturation (free and adsorbed), gas composition, mineralogy, porosity and permeability of the hydrocarbon-bearing shale unit/s (using cores, electric logs and other means).

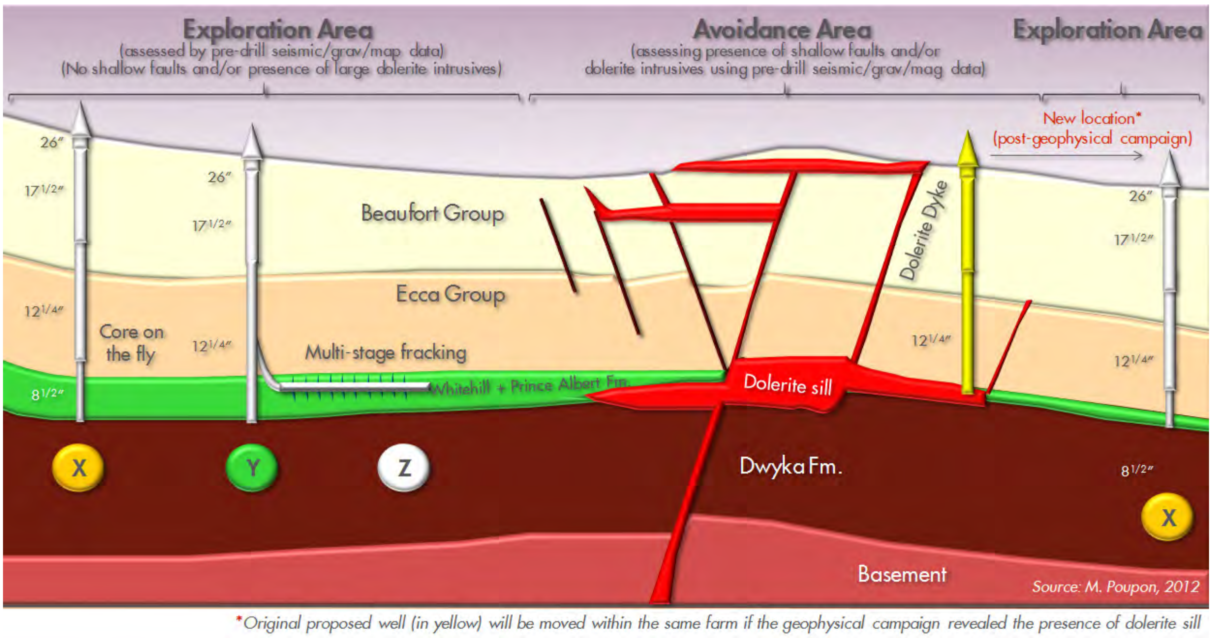


Figure 1.24: A stratigraphic well (indicated by “X”) is a vertical well drilled to obtain geological core samples, ideally from the target formation. An appraisal well is a vertical well (indicated as ”Y”) that is drilled some distance away from the stratigraphic-well so that the characteristics of the formation can be further evaluated and delineated. If the evaluation is positive, a side track may be drilled through the wall of an appraisal well on a curved trajectory, ending with a horizontal section of well bore within the target formation. The horizontal well (indicated as “Z”) is subjected to fracking (*Source*: Shell).

Drilling units (rigs) are powered by either diesel- or gas-fuelled internal combustion engines. For exploration operations, and during the early stages of production operations, diesel-fuelled rigs are used; however, as field gas is produced locally, with the necessary permitting in place, drilling operations can transition to the use of this energy resource (alternatively, any produced gas is flared). Apart from cost considerations (field gas is cheaper than diesel), there are considerable benefits in terms of atmospheric emissions attributable to gas- versus diesel-combustion (Table 1.3).

Table 1.3: Comparison of atmospheric emissions from gas- and diesel combustion.

Emitted compound	Diesel-fuelled engine Emission kg/day	% reduction gas vs diesel	Gas-fuelled engine Emission kg/day
CO	10.38	4.3	9.94
NOx	160.13	78.6	34.27
Particulates (< 10 micrometers)	1.675	95.0	0.08
Hydrocarbons	2.345	78.6	0.5

Emissions based on a Caterpillar C32 (or 3512) engine (Source: CAT documentation)

Drilling is initiated by lowering a drill bit through a conductor pipe installed at the surface and by rotating the drill string to which the bit is attached. The rotating bit crushes the rock into small particles or 'cuttings'. These cuttings are flushed from the well as the drilling mud is pumped down inside the drill pipe and back up the outside of the drill pipe in the annular space between the drill pipe and the open hole. The chemical and physical properties of drill cuttings reflect the properties of the geological formations from which they originate (e.g. sandstones, shales); generally, cuttings are relatively inert. The damp cuttings, with residual drilling fluid, are stockpiled temporarily within the drilling works area in impermeable containment facilities. They are subjected to systematic sampling and laboratory analysis with the aim of determining their chemical properties prior to later disposal[25].

Drilling fluid, often termed 'drilling mud', is used to perform a number of functions including providing hole stability, the entrainment and transport of drill cuttings to surface and circulating drill gas out of the hole. The mudlogger and the mud engineer are responsible for monitoring and analysing the mud as it is filtered to remove the cuttings and any entrained gas. The mud engineer will measure various mud properties such as its density, fluid loss, rheology, solid content, pH, plastic viscosity and other important variables. The engineer supervises treatment of the mud to meet required specifications before it is circulated back downhole to lubricate and cool the drilling bit and to continue the process of transporting the cuttings to surface. Drilling fluid is prepared through the addition of various compounds and chemicals to water that is supplied to site[26]. The additive used in

[25] For example, it may be necessary to adjust the pH of drill cuttings, which may be increased as a result of the chemical properties of the drilling fluid coatings (sodium hydroxide is one of the additives used to increase the pH in order to prevent biological activity within the drilling fluid).

[26] To minimise the risk of environmental pollution potentially attributable to the uncontrolled release of drilling fluid into the environment, industry best practice is to use additives that comply with standards such as those specified in the OSPAR Commission's list of substances considered to pose little or no risk to the environment (PLONOR; OSPAR Commission, 2008). Another example, with specific reference to fracking, is the set of standards applied in Australia (ACOA, 2013).

greatest bulk is barite, which serves primarily as a weighting agent to balance downhole pressure in a well. Other drilling fluid additives fulfil a range of functions such as pH control, corrosion inhibition and de-foaming. For a well drilled, for example, to a depth of 3 500 m (a typical depth assumed for the study area) approximately 1000 m^3 of drilling fluid would be prepared. This would incorporate approximately 300 tonnes of compounds and additives used to formulate the drilling fluid, with water comprising the balance.

In the case of back-to-back drilling of a number of wells in close proximity, drilling fluid would typically be re-used for a number of wells that are drilled. A top-up of approximately 25% (by volume) of water and drilling fluid compounds would be required for each subsequent drilling operation to account for fluid coatings that remain on stockpiled cuttings and other operational losses. When the drill bit reaches key depths drilling is stopped and steel casing is run into the open hole and centred within the hole using centralizers. Cement is then pumped down inside the casing and forced out of the bottom and up into the annular space between the casing and the borehole wall until there is a "show" at the surface. The cemented casing then undergoes a mechanical integrity pressure-test to ensure that there is adequate structural integrity at the bottom of the casing or casing shoe. Subsequently, a cased-hole cement bond electric log is run to verify cement bonding along the cemented the casing string[27]. Casing involves setting a series of casing strings of decreasing diameter at increasing depths (Figure 1.25). The purpose of the casing is to provide structural support and integrity to the borehole, allow for deep drilling into high pore pressure formations and to isolate water- and hydrocarbon-bearing formations to prevent cross-contamination. The casing ultimately allows for the safe production of any hydrocarbons found.

[27] Where they penetrate groundwater zones, wells typically have double, triple, or more overlapping strings of casing, which are bonded with cement, to provide not only structural integrity to a well but to effectively isolate the well bore from the water-bearing formations.

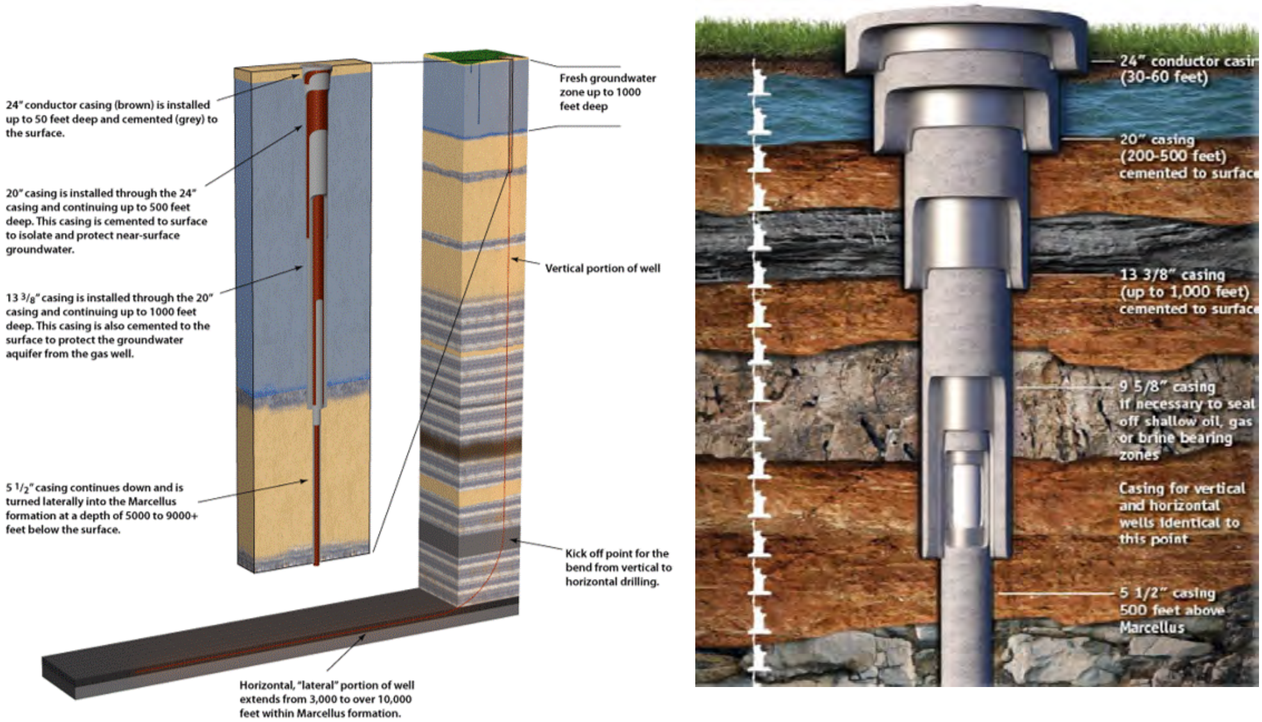


Figure 1.25: General well casing design for SGD operations. Multiple strings of overlapping casing are used to isolate the wellbore from aquifers that are encountered during drilling; these are bonded with cement (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA).

Petro-physical evaluation of the formations penetrated by the well is carried out during the course of drilling operations. This evaluation involves the services of wellsite geologists and mudloggers and the deployment of techniques such as logging while drilling (LWD) and open-hole wireline electric logging. Mudloggers keep a detailed record or log of specific data while drilling that includes: rate of penetration; measurements of mud gas content and type; analysis of drill cuttings to establish formation changes, chemical and physical properties (e.g. rock type and description, apparent porosity, cementation, fluorescence, odour, grain size and friability); pore pressure; drill bit records; mud weight; and hydrocarbon shows. LWD tools are electrical devices installed as part of the drill string and mounted near the drill bit. They are used to record data relating to formation petro-physical properties (porosity, density, resistivity, gamma ray), which are transmitted to the surface in real-time.

Open hole wireline logging involves lowering diagnostic tools on an electric cable into the uncased hole. There are a suite of these tools, including calipers; temperature recording devices; density/neutron/sonic for porosity, gamma ray/Spontaneous Potential/resistivity recorders to indicate rock type and fluid content; Nuclear Magnetic Resonance meters (NMR) for fluid differentiation and gauging production permeability; sidewall core tools for collecting rock samples; formation test tools that record pressures and collect fluid samples; and dipmeters that provide structural information and seismic profile data relating to rock velocities. The ultimate goal is to determine the fluid/gas content in the rock along with the quality and quantity of a hydrocarbon reservoir. This data is key to determining if further well evaluation is necessary and to inform future exploration, development and production decisions and activities.

Appraisal wells

If the results of tests from stratigraphic wells invite further investigation, additional wells are drilled nearby. These wells are planned to yield increasingly detailed information on the properties of the target formation. An appraisal well is created in a similar way as a stratigraphic well with vertical and, typically, horizontal sections. In order to drill horizontally, directional drilling methods are used. A number of horizontal laterals can be drilled from the same vertical wellbore.

On completion of drilling, the rig is removed and the site is prepared for fracking. Well perforating guns, employing directional explosive charges, are lowered into the cased wellbore by tubing or wireline. Once the guns reach the predetermined depths along the section(s) of the target formation they are discharged to perforate the casing (Figure 1.26). Detonation of the charges punches holes through the well casing and surrounding cement layer into the reservoir rock in the sections of the well bore where gas is expected to be extracted. The perforating guns are then pulled out of the hole to surface where the pumping unit and other equipment are attached to the wellhead; pumping of fracking fluid to increase the hydraulic pressure then begins. This is done in multiple stages in the horizontal component of the well, with each stage measuring 75 to 100 m in length on average.

The fracking fluid is made up of more than 90% water, with the balance comprising proppant (sized particles, normally sand) and other additives (Figure 1.27)[28]. The holder of a right is required to disclose the fluids, chemicals and other additives used in fracking to the competent authority (MPRDA Regulations for Petroleum Exploration and Production, 2015: Chapter 9, Subsection 113). The use of Material Safety Data Sheets is a common means of communicating this information.

[28] Some theory-based research has recently been published, which focuses on the implications of changing the method of fracturing targeted shales using carbon dioxide as an alternative, or additive, to water (Chandler, 2016). The capacity of the gas to penetrate CO_2-philic nanopores within shales in order to force out lighter petroleum molecules, such as methane, is being investigated. If proven to be implementable in practice, CO_2-based fracturing technology would have significant implications for water use and related waste management.

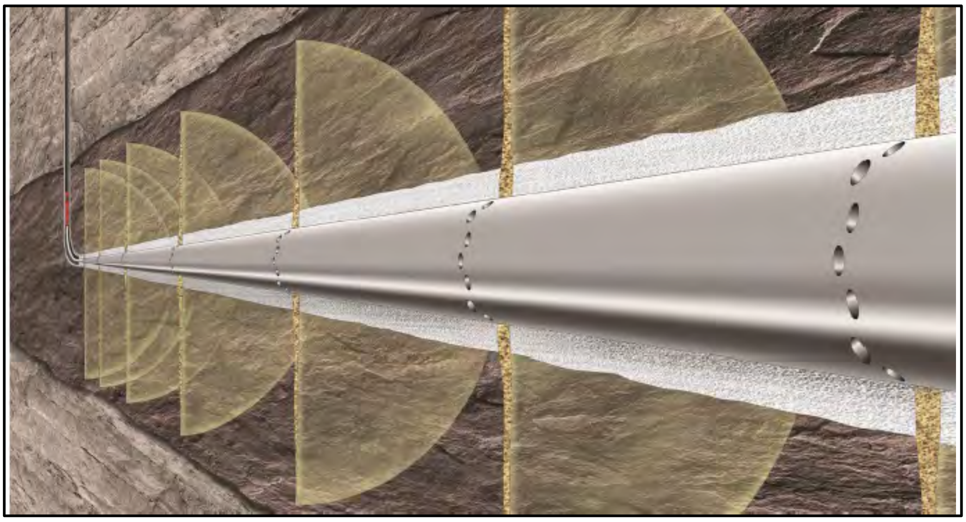


Figure 1.26: Schematic illustration of a horizontal wellbore with perforations through which fracking fluid is transmitted into the surrounding shale (*Source*: Shell).

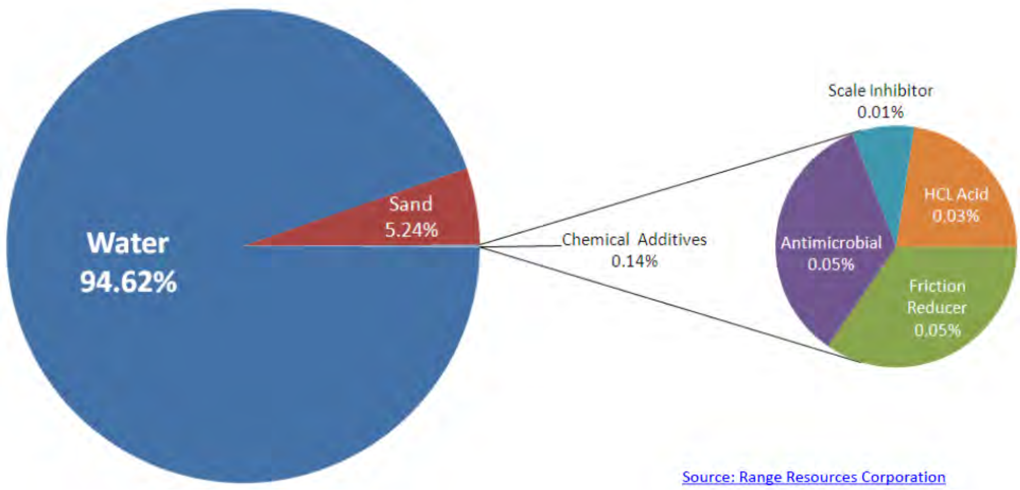


Figure 1.27: Example of the relative composition (% contribution to total volume) of compounds comprising a typical batch of fracking fluid (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA, citing Range Resources Corporation); as outlined below, other additives may be included.

Chemical contaminants associated with SGD

Much of the following section is based on a draft document written by the Environmental Protection Agency of the USA (EPA, 2015) on the potential impacts of fracking on drinking water. Note that all of the data used in the EPA document were derived from peer-reviewed papers of government origin, to ensure that they were not influenced by the industry.

Available information indicates that many hundreds of chemicals have been associated with drilling and fracking. Assessing the likely effects of any particular chemical “cocktail” is difficult for the following reasons:

- Most of the information on fracking materials comes from the USA. While laws in most states require disclosure of the content of fracking fluids, this is not true for all US states, since the composition is considered to be a trade secret.
- At least 1 173 different chemicals are known to have been used in fracking in different parts of the world. There is no indication as to which combinations might be used in the area of interest in the Karoo, although a broad listing of possibilities has been provided.
- Toxicological data are limited or unavailable for the vast majority of the organic chemicals that are known to be used, or to have been used, in fracking. Thus, the potential effects on human health are very poorly understood (Finkel et al., 2013; Colborn et al., 2011) but have been discussed by McKenzie et al. (2014) and Kassotis et al. (2014). Furthermore, very few published, peer-reviewed epidemiological or toxicological studies are available and the veracity of some publications is questionable.
- Data that are available are almost all for individual chemicals, while the effects of chemicals in combination may be greater or less than the effects of each alone.
- EPA (2015) notes that more than 10% of the chemicals (134 of 1 173) have also been detected in flowback or produced water.

It is not feasible to describe or even list the hundreds of chemicals involved in the fracking process. Figure 1.28 provides a summary of existing information regarding chemicals used in fracking, highlighting gaps in this regard. A table is also presented in the digital addendum to this Chapter (Digital Addenda 1A) describing the major uses for which chemicals are employed and, where appropriate, their toxic effects. Unless otherwise indicated, the information contained in the table is taken from EPA (2015).

A number of chemicals are considered so noxious or otherwise problematic that they are currently prohibited from use in South Africa in any fracking activities. These are listed in a second table in Digital Addenda 1A.

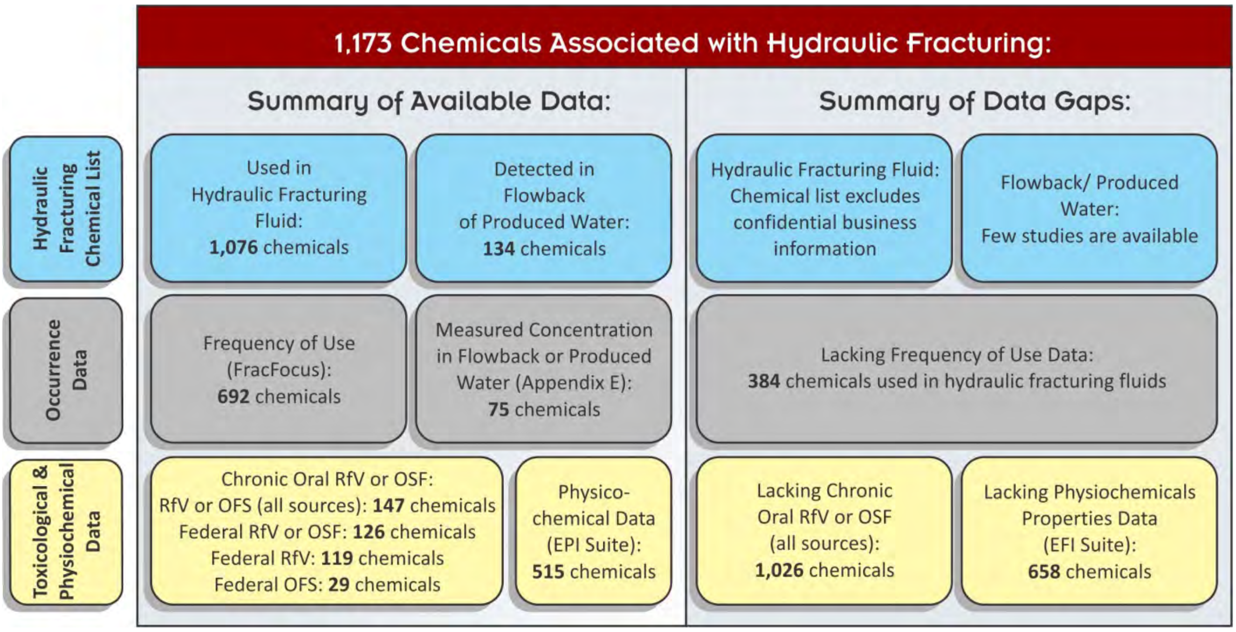


Figure 1.28: Summary information regarding existing data and information gaps regarding the state of knowledge about chemicals involved in fracking processes in the United States (from EPA, 2015): RfV = Reference Value, an estimation of an exposure [for a given duration] to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse effects over a lifetime: OSF = oral cancer slope factor, a measure of carcinogenicity.

According to an estimate provided by ONPASA, the volume of water used to effect fracking within the study area, for example, within a well comprising a 3 000 m vertical and 1 000 m horizontal section would amount to about 6 000 m^3. Water requirements for fracking can be much higher, with Kargbo et al. (2010) reporting that the volumes used in wells drilled within the US Marcellus formation, with a 1 500 m vertical section and a 980 m horizontal section, ranging from 7 700 to 38 000 m^3. Broomfield (2012) reports that vertical shale gas wells typically use approximately 2 000 m^3 of water, whereas horizontal wells typically use between 10 000 and 25 000 m^3 per well. Water requirements reported in the literature for fracking of individual wells range from 10 000 to 30 000 m^3 (Grant and Chrisholm, 2014; Rahm et al., 2012, 2013; Warner et al., 2013; NySDEC, 2015). The volume of water used depends, amongst other factors, on well characteristics (depth, hole sizes and conditions, horizontal lateral length) and the number of fracturing stages within the well.

Box 1.8. Water supply alternatives for SGD

ONPASA has not published information on water supply options to support fracking within the study area. Supply options that could be investigated include:

- *Local groundwater in the proximity of wellpads or within shale gas license areas (shallow aquifer or deep fossil water).*
- *Groundwater/surface water outside the shale gas licence areas.*
- *Seawater.*
- *'Grey' water sourced either within or outside the shale gas licence areas.*

Although oil and gas developers aim to reduce freshwater consumption through water re-use and use of waste water from other sources, in current practice freshwater still comprises 80-90% of the water used for fracking. For example, NySDEC (2015) reports that between only 10 and 20% of fracking water use comprises recycled waste water. Re-use involves either straight dilution with fresh water of the flowback waste water (see below) or the on-site introduction of treatment processes prior to flowback water re-use.

Proppant is high specification aggregate, usually sand, which is treated and coated with a resin. It can also be produced as ceramic nodules. Sand in the southern Karoo is largely unsuitable for use as proppant because of the high clay content of the local soils, which are derived from shales and mudstones. For this reason, it unlikely that proppant would be sourced locally within the study area for SGD operations. For the scenario considered here, entailing exploration operations only, it can be assumed that proppant would be imported to South Africa and transported to the sites of fracking by road or rail. For the Small- and Big Gas scenarios outlined in Sections 1.4.4 and 1.4.5, importation of proppant at the scales required would be uneconomical and it is likely that the product would be manufactured at a location where suitable aggregate can be sourced, for example where sandstones define the local geology, and transported to the study area.

The fracking fluid is injected down the wellbore at a pressure of between 400 and 600 bar (40 – 60 MPa)[29]. The fluid migrates through the perforations in the well casing and cement into the reservoir rock to create fractures that are typically 2-7 mm in width, close to the wellbore. The fractures become narrower as they extend outwards for distances of up to about 300 m from the wellbore. The proppant that is pumped into the fractures holds them open when the hydraulic pumping pressure is reduced. The creation of open fractures has the effect of significantly increasing the surface area of rock connected to the main wellbore; gas that is released in the process flows out of the reservoir rock to the surface via the wellbore.

[29] The injection pressure required to create fractures depends on the rock's fracture pressure. Normal pressure gradient is about .456psi/ft (1.4941 psi/m) or 0.1013 bar/m. The Whitehill Formation (12 045 ft) at the SOEKOR Cranmere 1/68 well location was drilled with 10.2 ppg mud weight with no reported loss of returns (i.e. no formation breakdown). Based on this depth, the calculated mud hydraulic pressure gradient is 0.53 psi/ft, and the minimum fracture pressure at this depth can therefore be inferred to be 6389 psi or 440. bar. The Whitehill Formation should be encountered at greater depths south of the 1/68 Cranmere well, so the fracture pressure should increase.

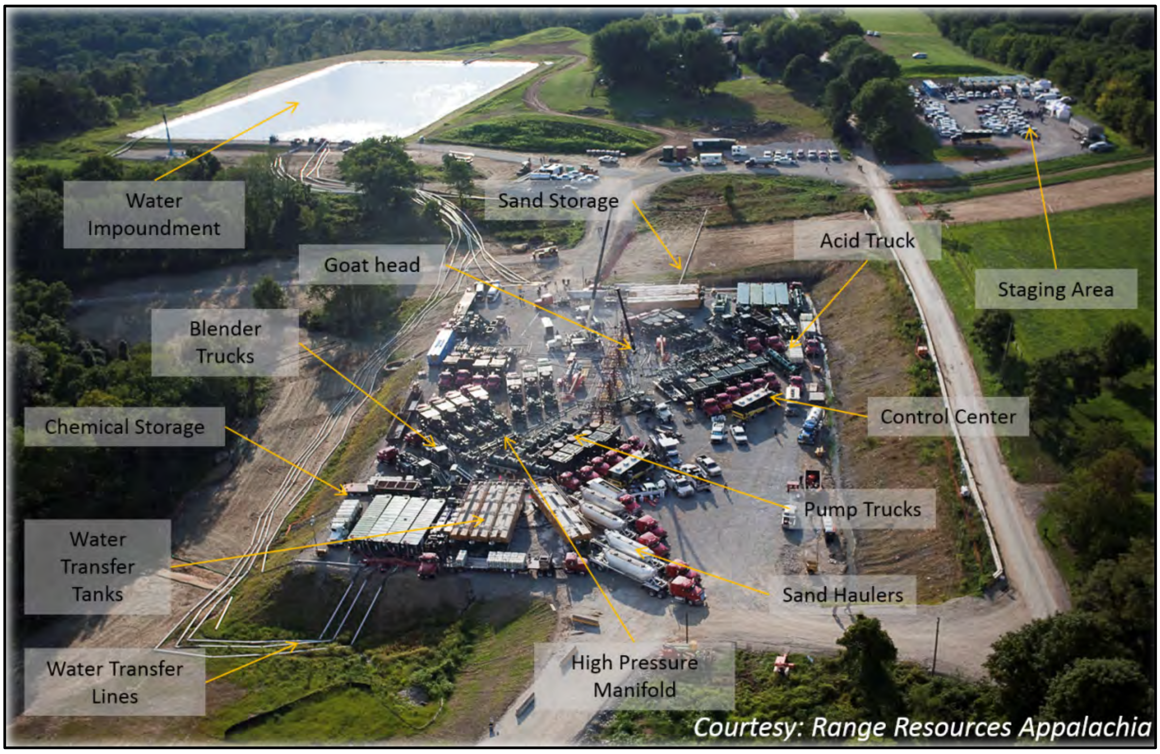


Figure 1.29: Example of a fracking process underway in Appalachia, with the main equipment and facilities involved indicated (*Source*: Range Resources Corporation).

Figure 1.30: Example of a fracking operation underway, involving a series of wellheads (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA).

Following fracking, surface equipment is installed on the well in order to allow it to be ‘produced’. During initial production, some of the fracking fluid and other entrained material returns to the surface as "flowback". This includes water, fracturing chemicals and gas. Solids are separated from the liquids and gas at a treatment facility on site. This process can also be carried out at a central location to which the flowback is transported, often by road tanker. Graphic illustrations of a produced fluid management system are presented in Figure 1.31 and 1.32. Typically, there is recovery of about 30% of the volume of fracking fluid originally injected into the well as flowback; however, recovery volumes can range widely depending on shale characteristics (e.g. between 0 and 80%) (Broomfield, 2012; Grant and Chrisholm, 2014). Sludge (proppant, shale dust, other solids and chemical residues), which can account for around 3% of the flowback volume, is disposed of at designated approved material waste sites.

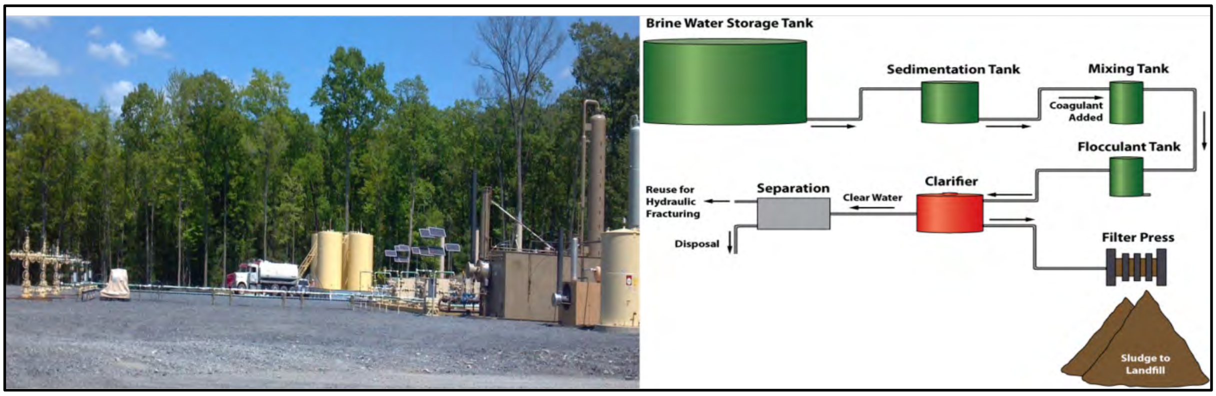


Figure 1.31: Schematic illustration of a produced fluid management system (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA).

Figure 1.32: Example of a closed loop fluid management system (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA).

Flowback fluids are typically saline, with reported total dissolved solids (TDS) values ranging from 10 000 mg/l to 300 000 mg/l (Rahm et al., 2012, 2013). High TDS values indicate that the flowback fluids contain "connate water" trapped in pores of the rock during its geological history. Such water is recovered and treated on surface. The production of connate water can persist for the operational lifetime (5-20 years) of a well (Grant and Chrisholm, 2014), with volumes ranging from 1-2 m^3 per day (Rahm et al., 2013; NySDEC, 2015). Volumes do, however, decline as the well production exhibits the characteristic exponential decline in gas yield as reservoir pressure depletes over time. Since the water has been in prolonged contact with the shale from which it originates, chemical characteristics of the target formation dominate its chemistry, which can also reflect radiogenic properties (Section 1.2.1.3). The quantity and chemical characteristics of produced water and flowback fluids persist as key uncertainties in terms of management, even in plays where unconventional oil and gas have been produced for a while (Rahm et al., 2013).

In the course of initial well-testing, the produced gas may be flared. Well testing is normally conducted for 30 to 60 days, with flaring undertaken for 30 days or less.

The typical shale gas formation is a pressure depletion reservoir with a characteristic exponential production rate decline over time (Figure 1.33). Production rates and pressure data obtained during well testing are used to calculate an Estimated Ultimate Recovery (EUR) of the well and the field.

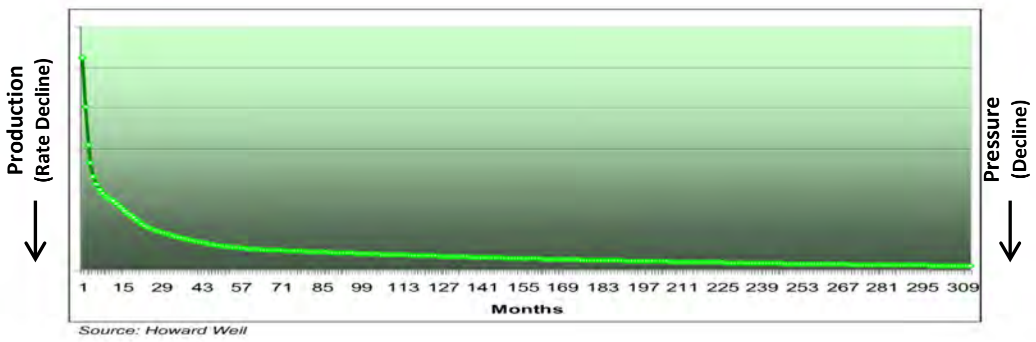


Figure 1.33: Typical Shale Gas Decline Curve (after Benedetto, 2008)

On completion of production testing, gas-flow is suspended, surface equipment is disconnected and demobilisation proceeds. The decision to either suspend or permanently decommission (plug and abandon) is based largely on test results. The production test data are, therefore, crucial for decision-making in this regard. Well suspension is affected by closing the valves on the wellhead to prevent product flow to surface (Figure 1.34); gauges are installed to detect possible changes in pressure that could be indicative of a leak. For final decommissioning, cementing of the well bore is undertaken from the furthest point to surface. This aims to ensure that all hydrocarbon- and water-bearing zones are isolated to prevent cross contamination or communication with shallow aquifers or the surface. The issue of well closure/decommissioning is critical and is implemented in accordance with industry best practice as described, for example, by American Petroleum Institute (2009).

Figure 1.34: Surface equipment in place for a suspended well (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA)

If there is full decommissioning, in addition to well plugging, the wellhead and testing and production facilities are removed. Wellpad areas and access roads are rehabilitated to achieve pre-disturbance landform states, with vegetation re-established in accordance with EMPr specifications and relevant prescribed regulations (e.g. regarding species diversity, vegetated ground-cover targets). Baseline environmental studies undertaken in advance of exploration and production provide reference standards to be achieved through rehabilitation. The decommissioned well, along with one or more monitoring wells, are routinely inspected in accordance with prescriptive rules and EMPr and EIA commitments to ensure there is no sub-surface communication and subsequent groundwater contamination. In this regard, the period of operator liability extends as long as might be necessary (potentially several decades) in order to achieve compliance.

1.4.3.2.2.2 Key impact drivers associated with exploration and appraisal drilling

It is likely that the bulk of the exploration or appraisal drilling activities would be initiated immediately following the completion of seismic surveys and that the activities would be concluded between 5 and 10 years after initiation of SGD operations in the study area (Figure 1.19).

Exploration and appraisal drilling would be undertaken within a small fraction of the area in which the seismic surveys are undertaken (< 5% in terms of surface area footprint), where information on the petroleum geology indicates there is the greatest potential for encountering technically and economically viable shale gas reserves. Given that such possibilities could extend across a number of license areas, several separate drilling campaigns might be launched. For the purpose of this report, it is assumed that five campaigns in total will be completed. The notional distribution of these drilling campaigns shows their greater concentration in the central region study area, where current knowledge of the shale gas prospectivity suggests the largest reserves of gas might be encountered (Figure 1.35).

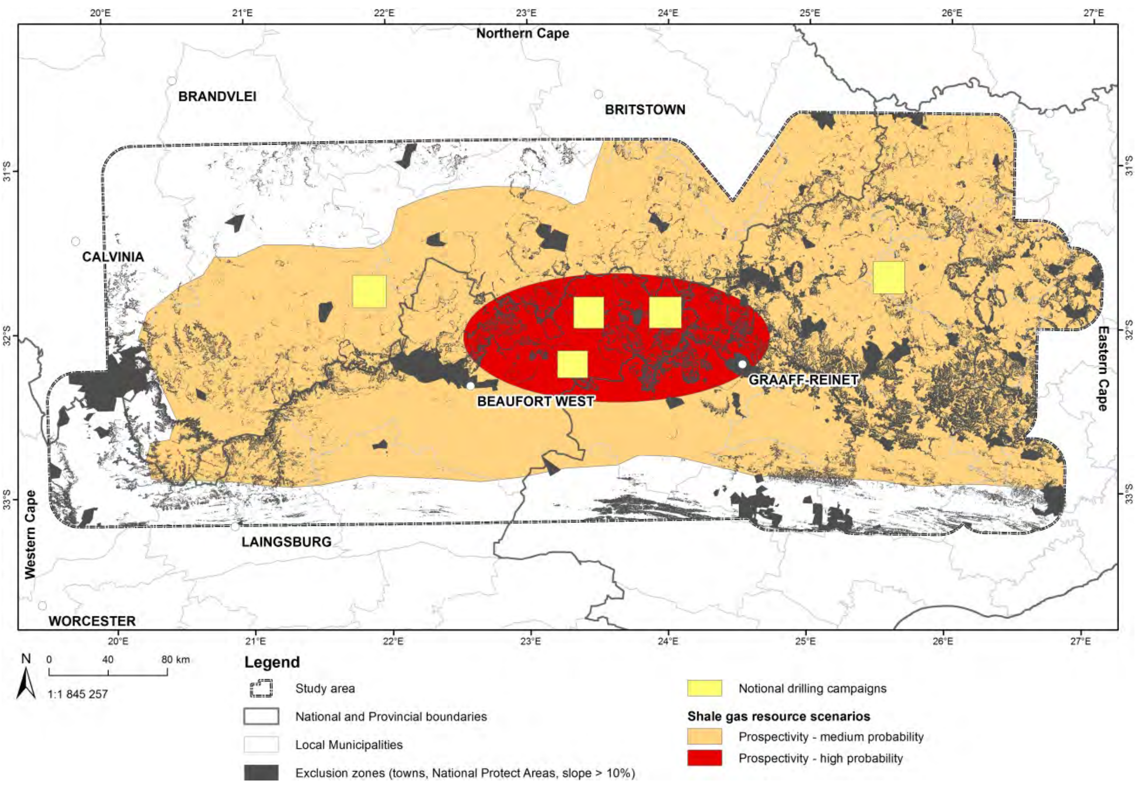


Figure 1.35: Notional distribution of five exploration drilling campaigns that might be commissioned within the study area. The figure simply indicates approximately how large a general target area might be in the case of a drilling campaign; it is currently not known where any campaign might be located. Within each square, only a very small fraction of the actual land surface is directly impacted (<5%), though a larger area would be exposed to noise, visual and light disturbance.

For each drilling campaign, it is assumed that six stratigraphic wells would be drilled from their own individual wellpads. For each campaign, two of the already established wellpads would be used for additional drilling to create two sets of three horizontal wells for fracking; i.e. a total of six horizontal wells drilled from two wellpads, replicated for each of the five exploration campaigns. A schematic indication of how the wellpads associated with these wells might be distributed in an area targeted for exploration drilling is presented in Figure 1.36. Also schematically indicated in this figure are access roads to the wellpads and a facility for crew accommodation. Provision would be made for treating flowback and produced water, entailing modular, contained equipment capable of treating the relatively low volumes of fluid waste generated during operations.

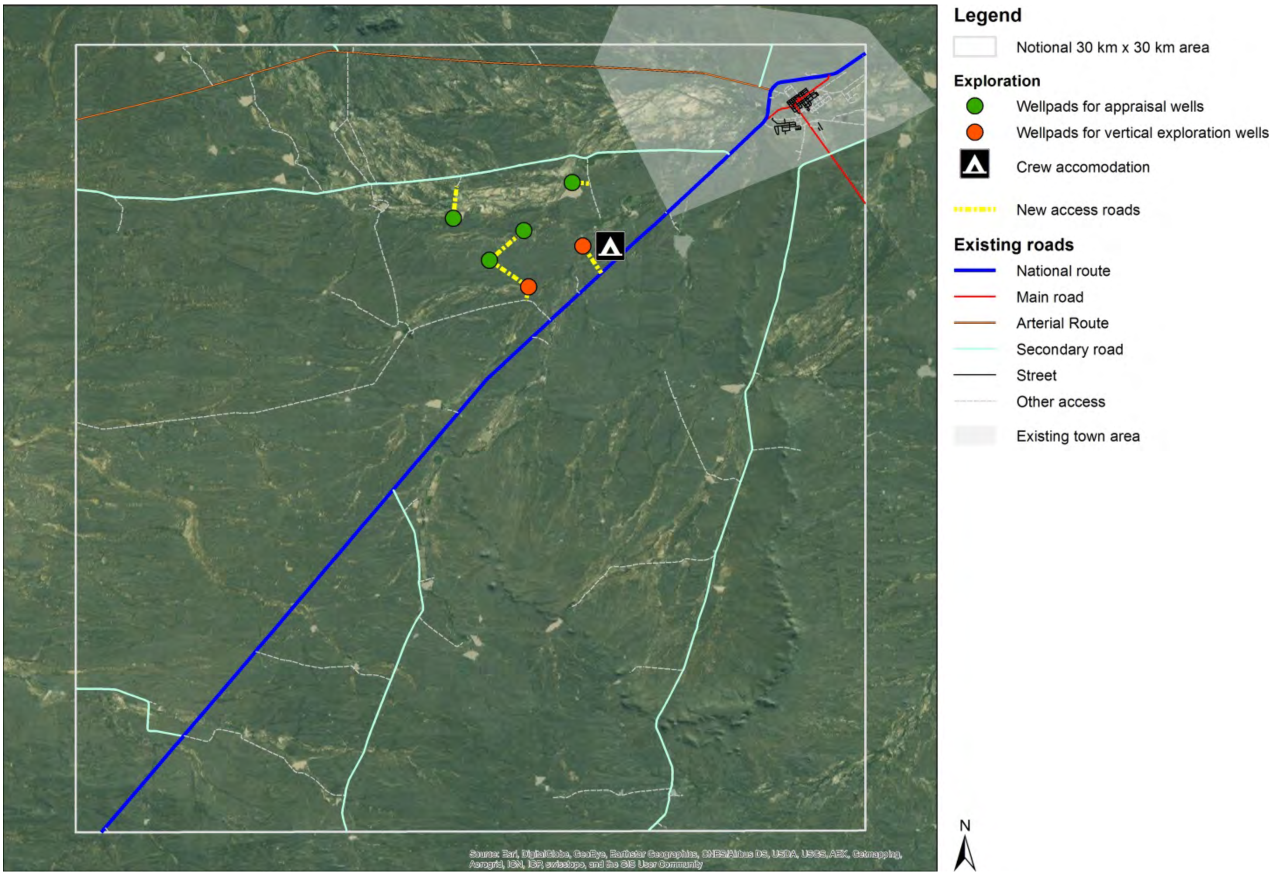


Figure 1.36: Notional schematic depiction of the location of six wellpads (two would be used to drill two sets of three horizontal wells for hydraulic fracturing) and a crew accommodation facility. An area of approximately 30 x 30 km is indicated as being targeted for exploration. It is assumed that throughout the study area there could be five such initiatives.

Planning, site preparation, drilling, fracking and flow-testing would proceed for each exploration and appraisal drilling campaign, as described in Section 1.4.3.2.2.1. Although many activities would be associated with each of these project elements, those to which the status of key impact drivers can be assigned include the following:

- Clearing of wellpad areas and the crew accommodation sites.
- Construction of new access roads to wellpads.
- Rail plus road transport to site of drilling fluid compounds (mostly containerised).
- Rail plus road transport to site of well casing.

- Road transport to the site of the drilling rig components (power unit, derrick, etc.)[30].
- Road transport to site of ancillary equipment supporting drilling operations at the wellpads.
- Road transport to site of temporary infrastructure and equipment used to establish crew accommodation.
- Transport to site of a truck-mounted drilling unit for creating shallow aquifer water monitoring wells. This unit would probably be mobilised to site during the phase of establishing environmental baseline conditions.
- Sourcing and supply of potable water for domestic use.
- Sourcing and supply of process water to prepare drilling mud and for fracking[31].
- Process water treatment for recovery (re-use as drilling and fracking fluid) and disposal of process waste (e.g. sludge recovered from flowback) and produced water.
- Drill cuttings disposal.
- Domestic and solid waste management.
- Hazardous waste management (additional to waste process water and solids).
- Flaring of gas during drilling and well-flow testing.
- Noise and light emissions.
- Decommissioning, including removal of equipment and infrastructure from site (primarily by road).
- Employment, personnel logistics, and labour negotiations.
- Management of safety, security and medical/health.

Quantification of the main activities comprising seismic exploration and an exploration and appraisal drilling campaign, to which the status of key impact drivers is assigned, is presented in Table 1.4

[30] It is possible that a single drilling unit could be used for the various exploration campaigns that are undertaken (i.e. shared equipment); alternatively, separate drilling units would be sourced for each campaign.
[31] The volume of water needed for preparing drilling mud and for fracking for an exploration campaign (Table 1.4) would be relatively small compared to a production programme (Table 1.5andTable 1.6).

Table 1.4: Quantification of key activities/impact drivers associated with seismic survey and exploration and appraisal drilling within the study area (Note: for some quantifications, ranges of values are provided to provide for uncertainties regarding assumptions; e.g. the possibilities that there may or may not be re-use of drilling fluid compounds and water used for both drilling and fracking).

Impact driver	Unit	Factor	Total	Comments
Seismic exploration				
Employment provided: Vibroseis truck method seismic campaign	100 personnel	5 exploration areas Duration: Approximately 1 year	500 personnel[32]	Expat specialists: 50%[33] National professionals: 20% National skilled: 10% Local unskilled: 20%
Employment provided: Shot-point method seismic campaign	150 personnel	5 exploration areas Duration: Approximately 1 year	750[30]	Expat specialists: 50% National professionals: 20% National skilled: 10% Local unskilled: 20%
Establishment of seismic lines	Up to 2 000 km		Up to 2 000 km	90% vibroseis truck method; 10% shot-point method
Density of seismic lines: Regional survey (Vibroseis trucks)	0.25 - 10 km spacing (Note: relatively wide spacing for regional 2-D survey; closer spacing for 3-D survey of specific targeted areas)			90% vibroseis truck method assumed (10% shot-point method; see below)
Vibroseis trucks and shot-point methods: distribution of vibration impact or shot points	20 per km	1 800 km vibroseis method [34] 200 km shot point method	36 000 vibration impact points 4 000 shot points	
Shot-point method: explosive detonated per shot hole	Up to 1 kg per shot 20 shots per km	Up to 20 kg per km 200 km	Up to 4 000 kg	
Vibroseis trucks: Vibration impact footprint	5 m^2	20 per km 100 m^2 per km 1 800 km	180 000 m^2 18 ha	

[32] This assumes that each campaign will be separately resourced in terms of personnel. However, there could be collaboration involving sharing of resources, with one campaign scheduled to follow another.

[33] There is currently limited local capacity to undertake seismic, drilling and fracking operations; this implies that these services will need to be contracted in from international sources, initially. The percentage of employed expatriates will decrease over time as local capacity develops.

[34] The assumption made is that the vibroseis method will be employed more extensively than the shot point method (1 800 km compared to 200 km of shot-point method); the quantifications listed here would be adjusted if a different ratio between the two methods materialises.

Impact driver	Unit	Factor	Total	Comments
Vibroseis tyre track width	Up to 2 m tyre width; dual tracks	2 m x 2 tracks 1 800 km	720 ha	Linear effect
Vibroseis trucks in operation: Noise emission	74 dB at 15 m			12 – 24 hr operation
Shot-point method: Auger drilling operations noise emissions	90 dB at 1 m			12 – 24 hr operation
Vehicle fleet size: Vibroseis truck method	4x Vibroseiss trucks @ 10 t each; 3 x 5 t trucks; 6 x 1t utility vehicles		13 vehicles per fleet	
Vehicle fleet size: Shot-point method	1 x 10 t auger drilling truck; 3 x 5 t trucks; 3 x 1t utility vehicles		7 vehicles per fleet	
Shot-point method: Number of passages per vehicle per seismic line	5 passages by half the fleet	7 vehicles	15 passages per km	
Vibroseis method: Number of passages per vehicle per seismic line	2 passages along each line section by half the fleet	13 vehicles	7 vehicle passages per km of seismic line	
Domestic solid waste produced	0.46 kg per worker per day			See crew sizes per operation
Domestic water use (drinking, sanitation)	0.15 m^3 per person per day			See crew sizes per operation
Sanitary waste produced	0.1425 m^3 per worker per day			See crew sizes per operation
Hazardous waste	1-5 tonnes per campaign	5 campaigns	5 – 25 tonnes	
Exploration and appraisal drilling				
Drilling rigs commissioned	1 rig per campaign	5 campaigns	1 - 5 rigs[35]	
Employment: Drilling campaign	100 personnel per drilling rig	5 campaigns	Up to 500 personnel [34]	Expat specialists 20%; National professionals 10%; National skilled 10%; Local unskilled 60%
Drill rig height	40 m			

[35] This range allows for the possibility that drilling rigs and crews might be shared between the different campaigns.

Impact driver	Unit	Factor	Total	Comments
Number of wellpads established	6 wellpads per campaign	5 campaigns	30 wellpads	
Access roads constructed to wellpads	1 km per wellpad	6 wellpads per campaign; 5 campaigns	6 km per campaign; 30 km for 5 campaigns	
Wellpad footprint	2 ha per wellpad	6 wellpads per campaign; 5 campaigns	Up to 12 ha per campaign. Up to 60 ha for 5 campaigns	
Crew accommodation camp footprint	1 ha per camp; 1 camp per campaign	5 campaigns	5 ha for 5 campaigns	The size of the camp footprints could be slightly smaller than stated here
Transport of drilling rig, casing and ancillary equipment to and from wellpads	500 truck visits per well drilled (split between 10 t and 20 t trucks)	5 campaigns 12 wells per campaign	30 000 truck visits for 5 campaigns	Extrapolated from and adjusted based on Shell EMPr: (http://southafrica.shell.com/aboutshell/shell-businesses/e-and-p/karoo.html). Golder Associates (2011)
General utility vehicles in operation throughout	Numerous	5 campaigns	Numerous	To be confirmed (tbc) through transport planning study
Hydraulic fracturing: truck visits per well	500 truck visits per well	Hydraulic fracturing x 6 wells per campaign 5 campaigns	15 000 truck visits for 5 campaigns	Extrapolated from and adjusted based on Shell EMPr: (http://southafrica.shell.com/aboutshell/shell-businesses/e-and-p/karoo.html). Golder Associates (2011)
Drilling fluid water: stratigraphic wells. Assumed 3000 m depth (no re-use of water)	825 m^3	4 wells per campaign 5 campaigns	3 300 m^3 per campaign 16 500 m^3 for 5 campaigns	
Drilling fluid water: Vertical wells from which horizontal drilling will be conducted. Assumed 3000 m depth (no re-use of water)	825 m^3	2 wells per campaign 5 campaigns	1 650 m^3 per campaign 8 250 m^3 for 5 campaigns	

Impact driver	Unit	Factor	Total	Comments
Drilling fluid water: horizontal wells. Assumed 1500 m horizontal (no re-use of water)	450 m^3	6 wells per campaign 5 campaigns	2 700 m^3 per campaign 13 500 m^3 for 5 campaigns	
Drilling fluid water: stratigraphic wells (50% re-use of water)	412 m^3	4 wells per campaign 5 campaigns	1 648 m^3 per campaign 8 240 m^3 for 5 campaigns	
Drilling fluid water: Vertical wells from which horizontal drilling will be conducted (50% re-use of water)	412 m^3	2 wells per campaign 5 campaigns	824 m^3 per campaign 4 120 m^3 for 5 campaigns	
Drilling fluid water: horizontal wells. Assumed 1 500 m horizontal (50% re-use of water)	225 m^3	6 wells per campaign 5 campaigns	1 350 m^3 per campaign 6 750 m^3 for 5 campaigns	
Drilling fluid compounds: stratigraphic wells (no re-use)	300 t per well	4 wells per campaign 5 campaigns	1 200 t per campaign 6 000 t for 5 campaigns	
Drilling fluid compounds: Vertical wells from which horizontal drilling will be conducted (no re-use)	300 t per well	2 wells per campaign 5 campaigns	600 t per campaign 3 000 t for 5 campaigns	
Drilling fluid compounds: horizontal wells (no re-use)	150 t per well	6 wells per campaign 5 campaigns	900 t per campaign 4 500 t for 5 campaigns	
Drilling fluid compounds: stratigraphic wells (50% re-use)	150 t per well	4 wells per campaign 5 campaigns	600 t per campaign 3 000 t for 5 campaigns	
Drilling fluid compounds: Vertical wells from which horizontal drilling will be conducted (50% re-use)	150 t per well	2 wells per campaign 5 campaigns	300 t per campaign 1 500 t for 5 campaigns	

Impact driver	Unit	Factor	Total	Comments
Drilling fluid compounds: horizontal wells (50% re-use)	75 t per well	6 wells per campaign 5 campaigns	450 t per campaign 2 250 t for 5 campaigns	
Drill cuttings per stratigraphic well	550 m^3 per well	4 wells per campaign 5 campaigns	2 200 m^3 per campaign 11 000 m^3 for 5 campaigns	
Drill cuttings per vertical well from which horizontal drilling will be conducted	550 m^3 per well	2 wells per campaign 5 campaigns	1 100 m^3 per campaign 5 500 m^3 for 5 campaigns	
Drill cuttings per horizontal well	300 m^3 per well	6 wells per campaign 5 campaigns	1 800 m^3 per campaign 9 000 m^3 for 5 campaigns	
Drilling rig fuel use	1. Diesel: 1 850 gal/day; 7 t /day[36] 2. Natural gas: 257 MMBtu/day; 6.5 t/day oil equivalent[37]	5 rigs 30 days per well 12 wells per campaign 5 campaigns	Total fuel use, 5 campaigns 1. Diesel: 12 600 t 2 Gas: 11 700 t	Approximately 30 days drilling per well
Hydraulic fracturing water: (no-reuse)	15 000 m^3 per well	6 wells per campaign 5 campaigns	90 000 m^3 per campaign 450 000 m^3 for 5 campaigns	
Hydraulic fracturing water: (30% re-use)	10 000 m^3 per well	6 wells per campaign 5 campaigns	60 000 m^3 per campaign 300 000 m^3 for 5 campaigns	
Flowback sludge	Injected volume of fluid per well: approx. 15 000 m^3; Flowback: 30% of injected volume (5 000 m^3); Sludge: 3% of flowback (i.e. 150 m^3 per well)	6 wells per campaign 5 campaigns	900 m^3 sludge per campaign 4 500 m^3 sludge for 5 campaigns	

[36] Diesel consumption of a drilling rig powered by a Caterpillar C32 or C3512 engine
[37] Natural gas consumption of a drilling rig powered by a General Electric JC 320 Jenbacher engine

Impact driver	Unit	Factor	Total	Comments
Flowback brine	Injected volume of fluid per well: approx. 15 000 m^3; Flowback: 30% of injected volume (5 000 m^3); Brine: 50% of flowback (i.e. 2 500 m^3 per well);	6 wells per campaign 5 campaigns	15 000 m^3 brine per campaign 75 000 m^3 brine for 5 campaigns	
Produced water	2 m^3 per well per day; 1 year well lifetime	6 wells per campaign 5 campaigns	4 380 m^3 produced water per campaign; 21 900 m^3 produced water for 5 campaigns	Some fraction of this volume may be classed as hazardous
Light emissions				24 hr operational and security lighting; wellpads with development operations underway; crew accommodation areas.
Drilling rig emissions	Diesel-fuelled rig CO: 10.38 kg/day NOx: 160.13 kg/day Particulates: 1.675 kg/day Hydrocarbons: 2.345 kg/day	12 wells per campaign 30 days drilling per well 5 campaigns	Diesel-fuelled rig CO: 3 736 kg NOx: 57 646 kg PM: 603 kg HC: 844 kg	Approximately 30 days drilling per well; 12 wells per campaign.
Hazardous waste (e.g. grease, used engine oil)	1 t per well	12 wells per campaign 5 campaigns	12 t per campaign 60 t for 5 campaigns	
Drilling rig noise emissions	90 dB			24 hrs operations
Flaring during flow-testing: gaseous emissions		6 wells would be flared per campaign	5 campaigns; 30 wells flared	Approximately 30 days flaring per well
Domestic waste	0.46 kg per worker per day			See crew sizes per operation
Sanitary waste	0.1425 m^3 per worker per day			See crew sizes per operation

In the event that none of the exploration drilling campaigns reveals shale gas reserves that are economically viable, the SGD programme within the study area would terminate. Failure criteria would include a discovery with extrapolated results that indicate a reserve magnitude considerably smaller than 5 tcf and/or where appraised gas flow rates from a discovery that is made do not allow for economically viable production. Considerations that could impact this decision include unfavourable gas pricing, high operational costs, technology challenges and complex geological conditions that might be encountered.

Any surface and other disturbances resulting from operations would be rehabilitated in line with EMPr commitments. If an economically viable discovery is made, the SGD process would advance to further evaluation and potential development of the resource. This would include production through scaled-up drilling, fracking, installation of gas pipelines and processing facilities and other infrastructure. Although an element of exploration would continue to define the extent of potential development (e.g. ongoing 3-D seismic surveys to accurately inform the location of production wells), there would be a general transition away from exploration and appraisal activities towards those more typical of production. This situation is described in Sections 4.4 and 4.5 for Small and Big Gas production scenarios respectively.

1.4.4 Small Gas

1.4.4.1 <u>Scenario statement</u>

The scenario that could result from SGD proceeding to a small-scale development and production within the study area is expressed as follows:

Box 1.9. Small Gas Scenario

In 2050 there is a 1 000 MW CCGT power station established in the central Karoo. The modular design of the facility allowed for its easy construction and early commissioning. The power station, which has recently undergone refurbishment, is the only downstream project that has materialised within the SGD sector within the study area. The power station makes a relatively small contribution to the country's energy supply mix which, for the Western Cape, is mostly defined by contributions from an LNG-fuelled power station established north of Cape Town and from the region's renewable energy sector.

Shale gas exploration was initiated in 2018. By 2025, exploration and appraisal operations revealed modest, but economically viable shale gas reserves in the central Karoo totalling approximately 5 tcf. This triggered a development programme of early monetisation of the reserve in a directed response to the shortfall in the country's electricity generation capacity at the time.

An environmental audit of all SGD activities in the study area, undertaken in 2048, showed that rehabilitation of areas at abandoned exploration, appraisal and decommissioned production wellpads and the network of decommissioned access roads to these sites have fully achieved the targets specified in the project Environmental Impact Assessments and accompanying Environmental Management Programmes. Environmental monitoring will, nevertheless, continue for at least another decade.

The suite of SGD activities comprising this scenario corresponds largely with those described previously for exploration and appraisal (Section 1.4.3), but scaled up and supplemented with production-related infrastructure development[38]. The up-scaling process and infrastructure development are discussed below, including a quantification of key SGD activities/impact drivers that would define this production scenario.

1.4.4.2 Key impact drivers of small-scale gas development

For the SGD scenario considered here, development would proceed based on the results of the most successful of the exploration and appraisal campaigns that are undertaken; i.e. it is assumed that development would proceed for a single location situated in the central part of the study area. It is further assumed that all of the activities associated with the development and production scenario would be contained within a single block measuring approximately 30 x 30 km (Figure 1.40).

It is likely that a significant proportion of activities undertaken to support production would be initiated immediately following exploration and appraisal, *inter alia* to accelerate monetisation of the gas to offset exploration and production development costs. The construction of production infrastructure (e.g. the initial suite of production wells, the associated gathering pipeline network, gas processing stations) would be concluded in a period of 5- 10 years (Figure 1.19). Ongoing drilling, completion and testing of production wells and related infrastructure would continue for much of the duration of production, extending over several decades. New wellpads would be developed on a regular basis, whilst existing wellpads would remain operational for several years as additional horizontal wells and/or horizontal laterals are drilled and fracking is undertaken to maintain a supply of gas at the required level.

[38] Development and production operations would proceed on the basis of the award of production rights (i.e. conversion of exploration rights to production rights). As for exploration, Environmental Authorisation for operations would be required, based on EIA that is carried out and an approved EMPr. Several other authorisations and permits would apply.

Figure 1.37: Cluster of producing wellheads
(*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA)

For technical and economic reasons the initial development would target areas which, in the course of exploration and appraisal, promised the highest production rates and ultimate recovery volumes. This would be followed by ongoing expansion into peripheral areas. Production from shale gas wells typically declines rapidly after start-up. Calculations are, therefore, made of the EUR per well, which then determine the number and average spacing of the wells (i.e. number of wells per unit area) and the rate at which they are established. New wells are drilled constantly in order to maintain a particular level of gas production[39].

Development would commence with the commissioning of supplementary seismic surveys across the production block. In parallel with or immediately following this, access roads and new wellpads would be established to enable drilling of a series of wells aimed at both resource delineation and production. Importantly, a supply of process water would be sourced and, most likely, a central treatment facility designed and constructed to treat the water evacuated from the wells (flowback water, including produced water)[40]. Water would be recovered for re-use and the waste separated

[39] The regulatory regime may prescribe production rates and, therefore, the rate of establishment of wells, their number and spacing (as is the case in some states in the USA).
[40] Modular water treatment facilities may be provided as an alternative to a central facility.

from the flowback for disposal. A considerably greater volume of fracking fluid would be used in this scenario than during the exploration and appraisal phase (Exploration Only scenario).

The drilling and production of wells would proceed at a pace aimed at achieving a targeted rate of gas-flow that can be maintained over time[41]. For the scenario considered here a sustained flow of gas of approximately 172 million standard cubic feet (MMscf) per day would be the target. To achieve this, approximately 550 production wells would be drilled from 55 wellpads (i.e. 10 wells per wellpad)[42]. In addition to this total, a relatively small number of resource delineation wells would be drilled. A schematic indication of how the suite of wellpads and associated access roads and other infrastructure might be distributed across a production block is presented in Figure 1.40.

Box 1.10. Gas flow required from production wells

The fuel consumption of an SGT5 8000H gas turbine with an electricity generation capacity of 1 150 MW is 40 kg/s. Expressed in scf, total fuel consumption over a 35-year operational lifetime would be approximately 2 207 billion standard cubic feet (bscf). Assuming an EUR/well of 4.0 bscf[42], the minimum number of wells required to provide for this consumption would total approximately 550. This is the number of production wells assumed for the Big Gas scenario. Note that this is less than the number of wells that could theoretically exhaust a shale gas reserve of 5 tcf, which is approximately 1 250 wells. For this report, the conservative total of 550 wells is assumed.

At the production sites condensate and produced water would be stripped from any ‘wet gas’ that is produced and directed into storage tanks. This would be of either a decentralised modular or centralised (Figure 1.31) design. A flare would be installed to provide for safe shut down, de-pressuring of the facility in an emergency and for the safe discharge of small volumes of gas associated with routine maintenance and operations. Equipment such as well chokes and manifolds would be installed to control gas flow pressures and a network of gathering pipelines would be installed to convey the product to a gas compressor station (Figure 1.38 and 1.39). A proportion of the pipeline network would probably be located within the corridors established for the wellpad access roads.

[41] The assumption here is that there is synchronisation and cooperation between the E&P Applicant/s and state interests. An E&P Applicant’s likely desire to exploit resources as quickly and financially favourably as possible would need to be balanced against state economic interests for production to sustain the downstream development presented for this scenario (also for the next scenario that is described).

[42] An average EUR/well of 2.2 bscf is reported for the USA Barnett Shales (Oil and Gas Journal, 2014; http://www.ogj.com/articles/print/volume-112/issue-11/drilling-production/new-well-productivity-data-provide-us-shale-potential-insights.html). Production from the Marcellus Shales, in Pennsylvania USA, is averaging approximately 6.5 bscf per well (Tom Murphy (n.d.), Pennsylvania State University, USA). For this assessment, a conservative EUR/well value of 4.0 bscf is assumed; i.e. mid-way between the reported Barnett and Marcellus shale production values.

Treated gas would be exported from the production block at the requisite pressure and flow rate via a pipeline. This would supply gas to the 1 000 MW CCGT power station, which would be established probably less than 100 km from the production block.

Figure 1.38: Example of a shale gas compressor station situated at a wellhead complex. Tanks used to store produced water and condensate, separated from 'wet gas', are shown located towards the top left of the photograph (*Source*: Tom Murphy (n.d.), Pennsylvania State University, USA).

Figure 1.39: Example of a centralised gas compressor station. Compressed gas would be exported from this facility, via pipeline, to a downstream facility such as a CCGT power station (Source: Tom Murphy (n.d.), Pennsylvania State University, USA).

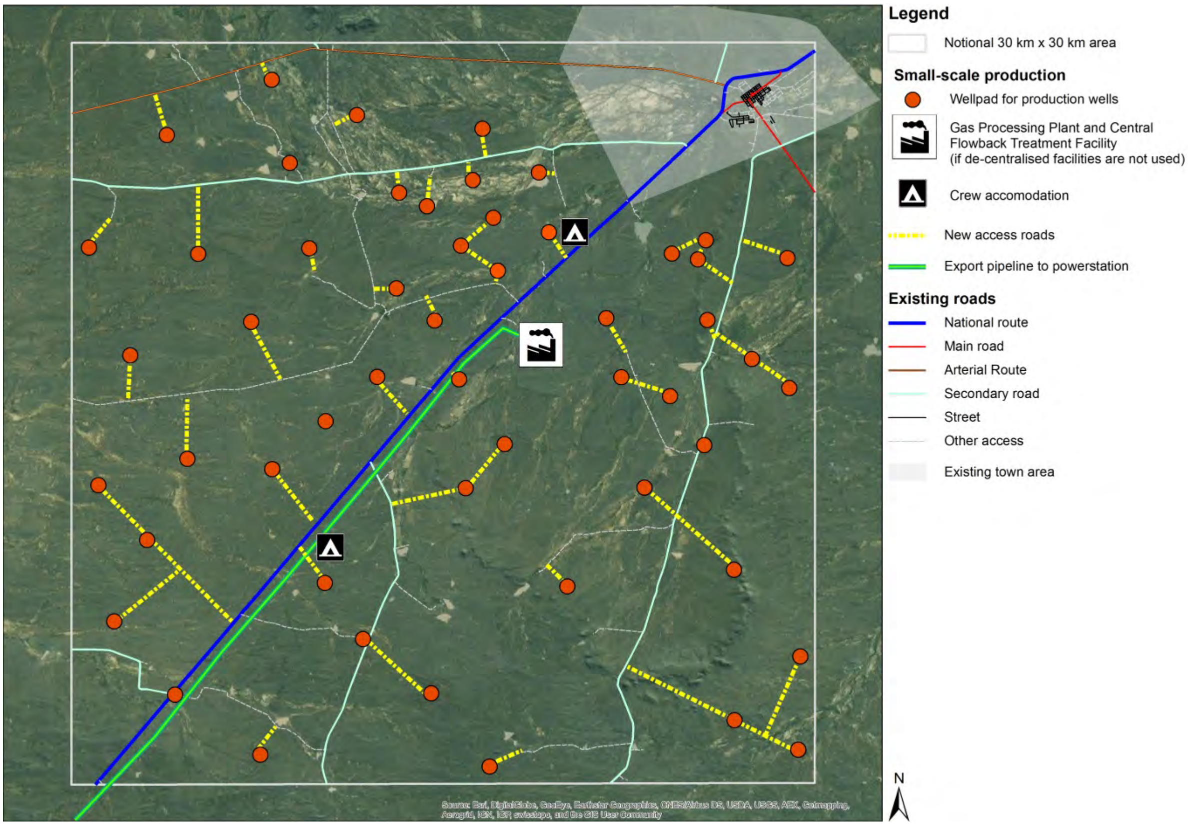


Figure 1.40: Notional schematic illustration of wellpads, access roads pipeline grids and other infrastructure established in an area (30 x 30 km) notionally targeted for small-scale development and production. In practice, there would likely be greater orderliness, than indicated here, to the distribution pattern of wellpads and wells, for example, to accommodate regional tectonic stresses. For the scheme presented here, the gathering pipeline system conveying gas to the processing plant would be located within the road corridors that are indicated.

Planning, site preparation, drilling, fracking and production would proceed as described in Section 1.4.3.2.2.1. Although many activities would be associated with each of these project elements, those to which the status can be assigned of being key impact drivers include the following:

- Clearing of wellpad areas and the crew accommodation sites.
- Construction of new access roads to wellpads.
- Rail plus road transport to site of drilling fluid compounds (mostly containerised).
- Rail plus road transport to site of well casing.
- Road transport to site of the components for several drilling rigs (power units, derricks and other equipment).
- Road transport to site of the components for several drilling rigs (power units, derricks and other equipment).

- Road transport to site of ancillary equipment supporting drilling operations at the wellpads (e.g. pumps, generators).
- Road transport to site of temporary infrastructure and equipment used to refurbish the crew accommodation (e.g. to upgrade the camp previously used for exploration operations).
- Transport to site of a truck-mounted drilling unit for creating shallow aquifer water monitoring wells (probably mobilised to site during the phase of establishing environmental baseline conditions).
- Road transport during operations.
- Sourcing and supply of potable water for domestic use.
- Sourcing and supply of process water to prepare drilling mud and for fracking fluid.
- Process water treatment and disposal of waste (including brine and sludge recovered from flowback).
- Drill cuttings disposal.
- Noise and light emissions.
- Construction of gathering gas pipeline networks.
- Construction of gas processing facilities, including a compressor station.
- Servitude arrangement and construction of a gas export pipeline and its connection to the CCGT power station.
- Domestic and solid waste management.
- Hazardous waste management.
- Flaring of gas during drilling and well-flow testing.
- Employment, personnel logistics, and labour negotiations.
- Management of safety, security and medical/health.

Quantification of the main activities/impact drivers is presented in Table 1.5.

Table 1.5: Small Gas development and production scenario: Quantification of key activities/impact drivers associated with drilling, gas-processing and -pipeline infrastructure within the study area.

Impact driver	Unit	Factor	Total	Comments
Drilling rigs commissioned	3 rigs		3 rigs	
Employment: Drilling campaign	100 personnel per rig[43]	3 rigs; 5-10 years duration of operations	300 personnel	Expat specialists 20%[44]; National professionals 10%; National skilled 10%; Local unskilled 60%
Drill rig height	40 m			
Number of wellpads established (10 wells per wellpad)	55 wellpads		55 wellpads	
Access roads constructed to wellpads	0.5 km per wellpad	55 wellpads	27.5 km	
Wellpad footprint	2 ha per wellpad	55 wellpads	Up to 110 ha	Larger multi-well wellpads, compared to exploration
Crew accommodation camp footprint	1 ha	1 camp	1 ha	Same camp used for exploration, but refurbished
Transport of drilling rig, casing and ancillary equipment to and from wellpads	Truck visits per well First 100 wells: 500 Next 100 wells: 400 Next 100 wells: 300 >300 wells: 200 (split between 10 t and 20 t trucks)	550 wells	160 000 truck visits	Extrapolated from and adjusted based on Shell EMPr: (http://southafrica.shell.com/aboutshell/shell-businesses/e-and-p/karoo.html). Golder Associates (2011)
Hydraulic fracturing: truck visits per well	Truck visits per well First 100 wells: 500 Next 100 wells: 400 Next 100 wells: 300 >300 wells: 200	550 wells	160 000 truck visits	Extrapolated from and adjusted based on Shell EMPr: (http://southafrica.shell.com/aboutshell/shell-businesses/e-and-p/karoo.html). Golder Associates (2011)
General utility vehicles in operation throughout	Numerous		Numerous	Tbc through transport planning study.
Drilling fluid water: vertical wells sections. Assumed 3000 m depth (no re-use of water)[45]	825 m^3	275 wells [46]	226 875 m^3	

[43] As experienced drilling crews are established, this total number of personnel could reduce; i.e. this is an estimate of the maximum crew size (also, the crew size that would likely be employed in the first number of years).

[44] Over time, the proportion of expatriate personnel would diminish relative to the involvement of national professionals. Local competency and capacity would develop through training, experience gained and entrepreneurial drive – probably also in response to licensing conditions.

[45] “no.” and “% re-use” statistics are given here (and elsewhere in the table) to indicate the range of possibilities regarding the demand for process water and the use of drilling and fracking compounds. Total demand/use will be lower in the event that there is recovery and re-use at the levels (%) indicated.

[46] It is assumed that a pair of horizontal wells would be directionally drilled for fracking from each vertical well.

Impact driver	Unit	Factor	Total	Comments
Drilling fluid water: horizontal wells. Assumed 1500 m horizontal (no re-use of water)	450 m^3	550 wells	247 500 m^3	
Drilling fluid water: vertical well sections (50% re-use of water)	412 m^3	275 wells	113 300 m^3	
Drilling fluid water: horizontal wells (50% re-use of water)	225 m^3	550 wells	123 750 m^3	
Drilling fluid compounds: vertical well sections (no re-use)	300 t per well	275 wells	82 500 t	
Drilling fluid compounds: horizontal wells (no re-use)	150 t per well	550 wells	82 500 t	
Drilling fluid compounds: vertical well sections (50% re-use)	150 t per well	275 wells	42 250 t	
Drilling fluid compounds: horizontal wells (50% re-use)	75 t per well	550 wells	41 250 t	
Drill cuttings: vertical well sections	550 m^3 per well	275 wells	151 250 m^3	
Drill cuttings: horizontal wells	300 m^3 per well	550 wells	165 000 m^3	
Drilling rig fuel use	1. Diesel: 1 850 gal/day; 7 t /day[47] 2. Natural gas: 257 MMBtu/day; 6.5 t/day oil equivalent[48]	30 days drilling per well 550 wells	1. Diesel: 115 000 t 2 Gas: 107 000 t	Over time, with experience gained by drilling crews, the assumed drilling duration of approximately 30 days per well could reduce to around 20 days.
Hydraulic fracturing water: (no-reuse)	15 000 m^3 per well	550 wells	8 250 000 m^3	

[47] Diesel consumption of a drilling rig powered by a Caterpillar C32 or C3512 engine
[48] Natural gas consumption of a drilling rig powered by a General Electric JC 320 Jenbacher engine

Impact driver	Unit	Factor	Total	Comments
Hydraulic fracturing water: (30% re-use)	10 000 m^3 per well	550 wells	5 500 000 m^3	
Flowback sludge	Injected volume of fluid per well: approx. 15 000 m^3; Flowback: 30% of injected volume (5 000 m^3); Sludge: 3% of flowback (i.e. 150 m^3 per well)	550 wells	82 500 m^3	
Flowback brine	Injected volume of fluid per well: approx. 15 000 m^3; Flowback: 30% of injected volume (5000 m^3); Brine: 50% of flowback (i.e. 2 500 m^3 per well);	550 wells	1 375 000 m^3	
Produced water	2 m^3 per well per day; 10 year well lifetime	550 wells	4 015 000 m^3 produced water	Some fraction of this volume may be classed hazardous
Light emissions				24 hr operational and security lighting of wellpads with development operations underway; crew accommodation areas.
Drilling rig emissions	Diesel-fuelled rig CO: 10.38 kg/day NOx: 160.13 kg/day PM: 1.675 kg/day HC: 2.345 kg/day Gas-fuelled rig CO: 9.94 kg/day NOx: 34.27 kg/day Particulates: 0.08 kg/day Hydrocarbons: 0.5 kg/day	550 wells 30 days drilling per well	Diesel-fuelled rig CO:171 270 kg NOx: 2 642 145 kg PM: 27 637 kg HC: 38 692 kg Gas-fuelled rig CO: 164 010 kg NOx: 565 455 kg PM: 1 320 kg HC: 8 250 kg	Approximately 30 days drilling per well; drilling duration could decrease to around 20 days as drilling crews gain experience. Emissions calculations based on 30 days drilling duration per well (compare diesel vs gas)
Hazardous waste (e.g. grease, used engine oil)	1 t per well	550 wells	550 t	
Domestic water use (drinking, sanitation)	0.15 m^3 per person per day			See crew sizes per operation
Drilling rig noise emissions	90 dB			24 hrs
Domestic waste	0.46 kg per worker per day			See crew sizes per operation
Sanitary waste	0.1425 m^3 per worker per day			See crew sizes per operation

In the event that an economically viable shale gas discovery within the study area does not exceed 5 tcf, the Small Gas scenario would be limited to what has just been described. However, if the gas discovery is considerably larger, development and production could proceed via an initial small-scale development (e.g. as above) to the scenario that is described next.

1.4.5 Big Gas

1.4.5.1 Scenario statement

The scenario that could result from SGD proceeding to a large-scale production development is expressed as follows:

Box 1.11. Big Gas scenario

In 2050, directed by the country's Gas Utilisation Master Plan, there are two CCGT power stations established in the central Karoo. Each of the power stations is of 2 000 MW generating capacity. One of the power stations is an upgrade to and expansion of the 1 000 MW CCGT facility built almost 20 years ago as the first downstream SGD project was initiated in partial response to constraints on electricity generation capacity experienced in South Africa at the time. The second power station is recently constructed. The modular design of both facilities allowed for their construction much more efficiently than, for example, coal-fired equivalents. The power stations contribute significantly to the country's energy supply mix, which is also defined by major contributions from an LNG-fuelled power station established north of Cape Town and from the Karoo's renewable energy sector. Directed by the country's Integrated Energy Plan, there is also a new GTL plant established at the coast. It is supplied with shale gas via a pipeline from the central Karoo[49]. Designed and built using best available technology, its operations are in compliance with strict global environmental standards[50].

Shale gas exploration was initiated in 2018. By 2025, exploration operations revealed an economically viable shale gas reserves in the central Karoo totalling approximately 20 tcf, sufficient to sustain production demand for several decades. An environmental audit of all SGD activities in the study area, undertaken in 2048, showed that rehabilitation of areas at abandoned exploration, appraisal and decommissioned production wellpads and the network of decommissioned access roads to these sites have fully achieved the targets specified in the project Environmental Impact Assessments and accompanying Environmental Management Programmes. Environmental monitoring will continue for a number of decades.

The suite of SGD activities comprising this scenario correspond largely with those just described for the Small Gas scenario (Section 4.4) but scaled up considerably. The up-scaling process and infrastructure development are discussed below, including a quantification of key SGD activities/impact drivers that would define this production scenario.

[49] The facility could be located elsewhere (e.g. at Sasolburg).

[50] Although production via a GTL plant is more expensive than, for example, refining of crude oil, economic justification for the plant could be based on balance of payment savings (i.e. through reduced importation of purchased crude oil or LNG). The country's Integrated Energy Plan provides for the establishment of one new GTL plant in South Africa of relatively small refining capacity (similar to what is proposed in this scenario).

1.4.5.2 Key impact drivers of large-scale gas development

The scenario considered here, of large-scale production, would materialise in stages, with the development described in Section 1.4.4 being an early stage initiative. Commencement of development and production of subsequent stages would likely occur approximately 10 years after initiation of SGD activities within the study area and would continue over a period of decades (Figure 1.19).

It is assumed that the main activities through which the Big Gas scenario would materialise would occur within four production blocks, each measuring 30 x 30 km; i.e. three blocks additional to the single block developed for the already-described Small Gas scenario. A schematic indication of how the suite of wellpads and associated access roads and other infrastructure might be distributed per production block, in their fully developed state, is presented in Figure 1.41.

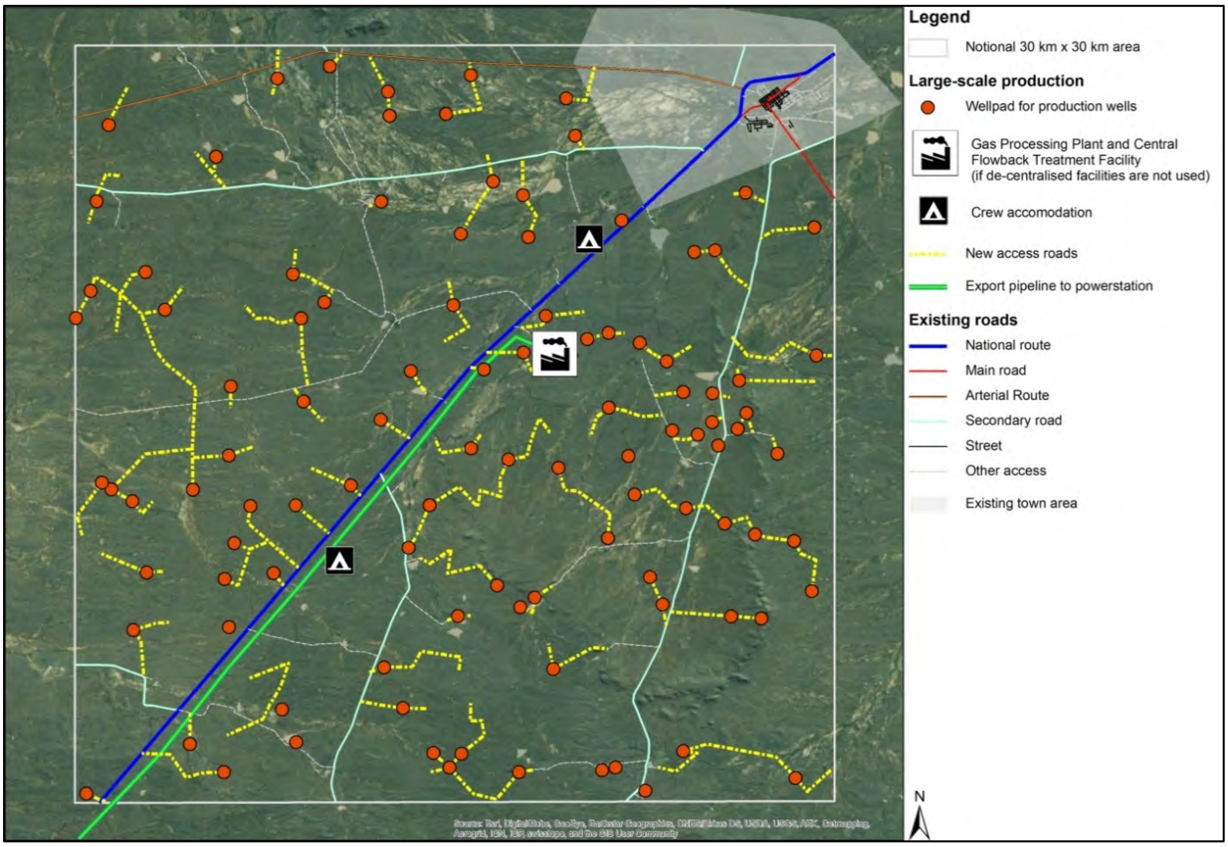


Figure 1.41: Notional schematic representation of gas production infrastructure within one fully developed block (30 x 30 km). See caption of Figure 1.40 regarding the greater degree orderliness expected for the wellpad locations in practice. Note that an additional three similar production blocks would be developed to deliver the volumes of gas required for the Big Gas scenario (i.e. a total of four production blocks with similar development layouts). For the Big Gas scenario the size of the production blocks may increase in extent to account for technical and environmental buffer areas between wellpad locations. These buffer areas are not indicated in the notional schematic.

Development would follow a similar pattern as for the Small Gas scenario. On a block-by-block basis, an initial suite of wells and infrastructure would be developed to supply the downstream gas demand, with ongoing development compensating for diminishing gas flow from older wells[51]. Development and production would have a dual focus: First, gas production would ramp up to approximately 688 MMscf per day to supply two 2 000 MW CCGT power stations. This would include the 172 MMscf flow of gas per day sourced from 550 wells already in production supplying the established 1 000 MW power station, which would be upgraded (Section 1.4.4). Second, production would provide a sustained flow of gas of approximately 600 MMscf per day to supply a GTL plant with a refining capacity of 65 000 bbl per day[52]. Feedstock supplying both the power stations and the GTL plant (approximately 1 100 MMscf per day) would be sourced from approximately 4 100 production wells (410 wellpads; 10 wells per wellpad)[53].

Planning, site preparation, drilling, fracking and production would proceed as described in Sections 1.4.3.2.2.1 and 1.4.4.2. Although many activities would be associated with each of these project elements, those to which the status of key impact drivers can be assigned include the following:

Box 1.12. Gas demand for downstream utilisation

CCGT power station gas consumption

As stated for the Small Gas scenario, the fuel consumption of an SGT5 8000H gas turbine with an electricity generation capacity of 1 150 MW is 40 kg/s. For a 35-year operating lifetime, total fuel consumption (expressed in scf) for a set of turbines with four times this generating capacity (i.e. in the order of 4 000 MW) would be approx. 8 829 bscf. Assuming an EUR/well of 4.0 bscf (see earlier footnote), the minimum number of wells required to provide for this consumption would be 2 200. This is the number of production wells assumed for the Big Gas scenario relating to the CCGT facilities.

GTL gas supply

For a flow-rate of 600 MMscf per day (0.6 bscf per day) supplying a GTL facility over a 35-year operating lifetime, total consumption of gas would be approx. 7 665 bscf. Assuming an EUR/well of 4.0 bscf, the minimum number of wells required to provide for this consumption would be approximately 1 900.

Gas demand of CCGT and GTL facilities

For the Big Gas scenario the assumed total number of production wells that would be developed is approx. 4 100. Note this is less than the number of wells that could theoretically exhaust a shale gas reserve of 20 tcf, which is approx. 5 000. For this assessment, the total of 4 100 production wells is assumed.

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[51] Each production block (30 x 30 km) would be divided into a series of smaller sub-blocks (e.g. 9 x 6 km), which would be individually developed as discrete units.

[52] The rate of 600 MMscf per day is derived from supply statistics for PetroSA's Mossel Bay GTL facility.

[53] An average EUR/well of 2.2 bscf is reported for the USA Barnett Shales (Oil and Gas Journal, 2014; http://www.ogj.com/articles/print/volume-112/issue-11/drilling-production/new-well-productivity-data-provide-us-shale-potential-insights.html). Production from the Marcellus Shales, in Pennsylvania USA, is averaging approximately 6.5 bscf per well (Tom Murphy (n.d.), Pennsylvania State University, USA). For this assessment, an EUR/well value of 4.0 bscf is assumed; i.e. mid-way between the reported Barnett and Marcellus shale production values.

- Clearing of wellpad areas and crew accommodation sites.
- Construction of new access roads to wellpads.
- Rail plus road transport to site of drilling fluid compounds (mostly containerised).
- Rail plus road transport to site of well casing.
- Road transport to site of the components for a number of drilling rigs (power units, derricks and other equipment).
- Road transport to site of ancillary equipment supporting drilling operations at the wellpads (e.g. pumps, generators).
- Road transport to site of temporary infrastructure and equipment used to refurbish and establish new crew accommodation facilities.
- Transport to site of a truck-mounted drilling unit for creating shallow aquifer water monitoring wells (probably mobilised to site during the phase of establishing environmental baseline conditions).
- Road transport for operations.
- Sourcing and supply of water for domestic use.
- Sourcing and supply of process water to prepare drilling mud and for fracking fluid.
- Process water treatment and disposal of waste (e.g. brine and sludge recovered from flowback).
- Drill cuttings disposal.
- Noise and light emissions.
- Construction of gathering gas pipeline networks.
- Construction of gas processing facilities, including an upgraded compressor station.
- Servitude arrangements; construction of gas export pipelines to the power stations and the GTL plant.
- Domestic and solid waste management.
- Hazardous waste management.
- Flaring of gas during drilling and well-flow testing.
- Employment, personnel logistics, and labour negotiations.
- Management of safety, security and medical/health.

Quantification of the main activities/impact drivers comprising the production drilling and gas processing and pipeline infrastructure is presented in Table 1.6.

Table 1.6: Big Gas scenario: Quantification of key activities/impact drivers associated with drilling and gas-processing and -pipeline infrastructure within the study area.

Impact driver	Unit	Factor	Total	Comments
Drilling rigs commissioned	Up to 20 rigs		Up to 20 rigs	
Employment: Drilling campaign	100 personnel per well rig[54]	20 rigs (assumed)	2 000 personnel employed	Expat specialists 20%[55]; National professionals 10%; National skilled 10%; Local unskilled 60%.
Drill rig height	40 m			
Number of wellpads established (10 wells per wellpad)	410 wellpads		410 wellpads	
Access roads constructed to wellpads	0.5 km per wellpad	410 wellpads	205 km access roads	
Wellpad footprint	2 ha per wellpad	410 wellpads	Up to 820 ha	
Crew accommodation camp footprint	1 ha per camp	2 camps per production block; 4 blocks; 8 camps	Up to 8 ha	
Transport of drilling rig, casing and ancillary equipment to and from wellpads	Truck visits per well First 100 wells: 500 Next 100 wells: 400 Next 100 wells: 300 >300 wells : 200 (split between 10 t and 20 t trucks)	4 100 wells	1 066 000 truck visits	Extrapolated from and adjusted based on Shell EMPr: (http://southafrica.shell.com/aboutshell/shell-businesses/e-and-p/karoo.html). Golder Associates (2011)
Hydraulic fracturing: truck visits per well	Truck visits per well First 100 wells: 500 Next 100 wells: 400 Next 100 wells: 300 >300 wells : 200	4 100 wells	1 066 000 truck visits	Extrapolated from and adjusted based on Shell EMPr: (http://southafrica.shell.com/aboutshell/shell-businesses/e-and-p/karoo.html).
General utility vehicles in operation throughout	Numerous		Numerous	Tbc through transport planning study.
Drilling fluid water: vertical well sections 3000 m depth (no re-use of water)	825 m^3 per well	2 050 wells[56]	1 691 250 m^3	

[54] As drilling crews gain experience, this total number of personnel could reduce; i.e. this is an estimate of the maximum crew size. It is assumed that this is the crew size that would be employed in the first number of years of production.
[55] Over time, the proportion of expatriate personnel would diminish relative to national professionals; i.e. local competency and capacity would develop.
[56] It is assumed that a pair of horizontal wells would be directionally drilled for fracking from each vertical well.

Impact driver	Unit	Factor	Total	Comments
Drilling fluid water: horizontal wells 1500 m horizontal (no re-use of water)	450 m^3 per well	4 100 wells	1 845 000 m^3	
Drilling fluid water: vertical well sections (50% re-use of water)	412.5 m^3 per well	2 050 wells	845 625 m^3	
Drilling fluid water: horizontal wells (50% re-use of water)	225 m^3 per well	4 100 wells	922 500 m^3	
Drilling fluid compounds: vertical well sections (no re-use)	300 t per well	2 050 wells	615 000 t	
Drilling fluid compounds: horizontal wells (no re-use)	150 t per well	4 100 wells	615 000 t	
Drilling fluid compounds: vertical well sections (50% re-use)	150 t per well	2 050 wells	307 500 t	
Drilling fluid compounds: horizontal wells (50% re-use)	75 t per well	4 100 wells	307 500 t	
Drill cuttings: vertical well sections	550 m^3 per well	2 050 wells	1 127 500 m^3	
Drill cuttings: horizontal wells	300 m^3 per well	4 100 wells	1 230 000 m^3	
Drilling rig fuel use	1. Diesel: 1 850 gal/day; 7 t /day[57] 2. Natural gas: 257 MMBtu/day; 6.5 t/day oil equivalent[58]	Approximatel y 30 days drilling per well; 4 100 wells	1. Diesel: 861 000 t 3. Gas 799 500 t	Over time, the drilling duration of approximately 30 days per well could reduce to around 20 days.
Hydraulic fracturing water: (no-reuse)	15 000 m^3 per well	4 100 wells	61 500 000 m^3	
Hydraulic fracturing water: (30% re-use)	10 000 m^3 per well	4 100 wells	41 000 000 m^3	

[57] Diesel consumption assumed for a drilling rig powered by a Caterpillar C32 or C3512 engine
[58] Natural gas consumption assumed for a drilling rig powered by a General Electric JC 320 Jenbacher engine

Impact driver	Unit	Factor	Total	Comments
Flowback sludge	Injected volume of fluid per well: approx. 15 000 m^3; Flowback: 30% of injected volume (5 000 m^3); Sludge: 3% of flowback (i.e. 150 m^3 per well)	4 100 wells	615 000 m^3	
Flowback brine	Injected volume of fluid per well: approx. 15 000 m^3; Flowback: 30% of injected volume (5 000 m^3); Brine: 50% of flowback (i.e. 2 500 m^3 per well);	4 100 wells	10 250 000 m^3	
Produced water	2 m^3 per well per day; 10 year well lifetime	4 100 wells	29 930 000 m^3	Some fraction of this volume may be classed as hazardous.
Light emissions				24 hr operational and security lighting for wellpads with development operations underway; crew accommodation areas.
Drilling rig emissions	Diesel-fuelled rig CO: 10.38 kg/day NOx: 160.13 kg/day Particulates: 1.675 kg/day Hydrocarbons: 2.345 kg/day Gas-fuelled rig CO: 9.94 kg/day NOx: 34.27 kg/day Particulates: 0.08 kg/day Hydrocarbons: 0.5 kg/day	4 100 wells 30 days drilling per well	Diesel-fuelled rig CO: 1 276 740 kg NOx: 19 695 990 kg PM: 2 016 025 kg HC: 288 435 kg Gas-fuelled rig CO: 1 222 620 kg NOx: 4 215 210 kg PM: 9 840 kg HC: 61 500 kg	Approximately 30 days drilling per well; drilling duration could decrease to around 20 days as drilling crews gain experience. Emissions calculations based on 30 days drilling duration per well (compare diesel vs gas)
Hazardous waste (e.g. grease, used engine oil)	1 t per well	4 100 wells	4 100 t	
Domestic water use (drinking, sanitation)	0.15 m^3 per person per day			See crew sizes per operation
Drilling rig noise emissions	90 dB within 10 m			24 hrs operations
Domestic waste	0.46 kg per worker per day			See crew sizes per operation
Sanitary waste	0.1425 m^3 per worker per day			See crew sizes per operation

Box 1.13. Key features of a Combined Cycle Gas Turbine (CCGT) power station

Produced shale gas would provide the feedstock for the two CCGT power stations assumed for this report. After compression, the gas would be transported to the power stations by pipeline. The duration of construction of the facilities would be approximately 24 and 30 months for a 1 000 and 2 000 MW facility, respectively. About 150 permanent operation jobs would be created for skilled staff and support labour per facility. The combined spatial footprint of the two power stations would be in the order of 30 ha (an additional 10 ha during construction). Gas turbine air emissions would be in the order of:

NO_x: < 25 parts per million by volume dry mass (ppmvd) during base load

CO: < 10 ppmvd during base load

CO_2: 650 kg/MW (IPCC, 2014)

Exhaust flow: 850 kg/s

In the water scarce environment of the study area, air cooling technology would be employed. The total water consumption (not for cooling) would be about 10 m^3 per day. Generated power would feed into the national electricity grid via either an existing or a new dedicated sub-station. The appropriate kv transmission line capacities would be provided for the power stations.

Box 1.14. Key features of a Gas to Liquid (GTL) plant

For the scenario considered here, produced shale gas would be compressed and piped to a GTL plant located either at the coast (e.g. Coega Industrial Development Zone, the existing PetroSA GTL refinery at Mossel Bay) or in Gauteng (e.g. Sasolburg). A new GTL plant would take about 5 years to construct. The basic GTL process converts natural gas into longer-chain hydrocarbons such as gasoline, diesel and other valuable petrochemical products using modern Low-Temperature Fischer–Tropsch technologies. Piped shale gas would feed the GTL plant at a rate of 600 MMscf per day. About 65 000 bbls per day of refined product would be produced. The facility would have a physical footprint of approximately 160 ha. A GTL plant at the coast would use sea water as a cooling medium. In the case of an inland facility, fresh water would be used, with the quantity determined on the basis of the quality of available fresh water and average water and ambient air temperatures. Approximately 750 – 900 permanent jobs would be created during operations. GTL air emissions would be in the region of:

Flue gas: 1800 t/hr; CO_2 = 24% - 27%.

Nitrogen: 2000 t/hr

Cooling water evaporation losses: 1200 t/h

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1.6 Digital Addenda 1A

SEPARATE DIGITAL DOCUMENT

Table A.1: Substances commonly used in drilling and fracking fluids, and an indication of their toxicity levels.

Table A.2: Chemicals that may not be added to fracking fluids in South Africa (DMR 2015).

DIGITAL ADDENDA 1A

Table A.1: Substances commonly used in drilling and fracking fluids, and an indication of their toxicity levels.

Compiled from US EPA 2015a and US EPA 2015b.

Additive type	Function	Types of chemical used	Toxicity
Thickeners	increase viscosity of the fracking fluid, making high-pressure pumping more efficient; suspension of proppants	carboxymethylcellulose, xanthan gum, guar gum, glycol	ethylene glycol (radiator fluid) extremely toxic
Deflocculants	thinning agents used to reduce viscosity or prevent flocculation (sometimes incorrectly called "dispersants")	acrylates, polyphosphates, lignosulphonates	acrylates may be toxic; acrylamide is a known neurotoxin
Friction reducers, lubricants	additives used to produce "slick water", which reduces friction in the wellbore, increasing fluid-flow velocity	petroleum distillate, used as a carrier fluid for poly-acrylamides or polyacrylics	petroleum distillates contain hazardous chemicals; polyacrylamide not toxic but breaks down to toxic acrylamides
Weighting agents	increase weight of muds, prevent ingress of water into the well being drilled; prevents blow-outs	barium sulphate (barite)	extremely insoluble so not classified by USEPA as hazardous
Fluid-loss additives	reduce loss of drilling fluids into permeable rock formations	diesel, particulates, sand	diesel contains hazardous chemicals
Clay control	Prevent swelling and migration of formation clays, which can cause reduced permeability and productivity by clogging pore spaces in the formation	KCl; quaternary amines (= quaternary ammonium compounds: QACs)	QACs toxic to aquatic organisms at environmentally relevant concentrations (Tezel, 2009)
Gelling agents	Increase fluid viscosity; increase the ability of the fluid to carry proppant and help to minimise fluid loss.	Hydroxy-ethyl cellulose (HEC) HEC and carboxy-methyl-hydroxy-ethyl cellulose (CMHEC); guar gum; foams/ poly-emulsions using N_2, CO_2 or a hydrocarbon (e.g. propane), diesel or condensate; ethylene glycol	Diesel and condensate (ultra-light fuel oil) contain hazardous chemicals; ethylene glycol (radiator fluid) extremely toxic
Cross-linkers	Increase molecular weight of polymers by cross-linking, thereby increasing viscosity, elasticity and ability of the fluid to transport proppant	guar and CMHEC based gels; Boric acid and B salts of Ca and Mg; metals including Titanium, Zirconium, Iron, Chromium & Aluminium; organic borate complexes; ethylene glycol; methanol	Some metals toxic at low concentrations; borates used in insecticides and antibiotics, and "toxic for reproduction" (EU regulations); ethylene glycol (radiator fluid) extremely toxic; methanol highly toxic
Buffers	Adjust pH to allow for dispersion, hydration and crosslinking of the fracking-fluid polymers	Combinations of sodium bicarbonate; formic acid; sodium carbonate; fumaric acid; sodium hydroxide; hydrochloric acid; monosodium phosphate; magnesium oxide	formic and fumaric acids mildly toxic; hydrochloric acid corrosive, causes severe burns when concentrated
Surfactants	Reduce the surface tension of the fracturing fluid to improve fluid recovery; prevent formation of emulsions; can be used as emulsifiers, foaming agents, defoaming agents, and dispersants.	EGMBE (ethylene glycol monobutyl ether) and BGMBE (butylene glycol monobutyl ether)	toxicity of both EGMBE and BGMBE low but "potentially toxic inert, with high priority for testing" (USEPA)

Additive type	Function	Types of chemical used	Toxicity
Viscosity stabilisers	Stabilise the fluid at high temperatures	methanol (used at 5 to 10% of the fluid volume) and sodium thiosulfate	methanol highly toxic
Scale inhibitors	Prevent scale deposits in pipes	sodium polycarboxylates including co-polymers of acrylamide and sodium acrylate; phosphonic acid salts	acrylates may be toxic; acrylamide is a known neurotoxin
Acids	Restore permeability lost as a result of the drilling process or initiate fracturing, achieve greater fracture penetration, and reduce clogging of the pore spaces and fractures by dissolving minerals and clays.	hydrochloric acid (concentrations up to 15%) and hydrofluoric acid	both acids corrosive, cause severe burns when concentrated
Biocides	Minimise decomposition of gelling polymers by aerobic bacteria; prevent anaerobic sulphate- reducing bacteria, which can "sour" a well and produce corrosive hydrogen sulphide gas	quaternary amines, amides and aldehydes (= quaternary ammonium compounds: QACs); glutaraldehyde; chloro-phenates [= chlorophenols?]; isothiazolinone; ozone; chlorine as hypochlorous acid, chlorine dioxide; UV light	Biocides are by their nature toxic: QACs (Tezel, 2009) and isothiazolinone toxic to aquatic organisms at environmentally relevant concentrations; glutaraldehyde (similar to formaldehyde) and chlorophenols highly toxic
(Gel) breakers	Reduce viscosity and facilitate blowback of fluid after fracking	oxidisers: ammonium persulfate, sodium persulfate; calcium and magnesium peroxides; acids: acetic or hydrochloric acid; enzymes: hemicellulase, cellulase, amylase and pectinase	Persulphates irritants and toxic; peroxides unstable and sometimes explosive; hydrochloric acid corrosive, cause severe burns when concentrated
Corrosion inhibitors	Protect iron and steel equipment and well-bore components from corrosive acids	e.g. N,n-dimethyl formamide	N,n-dimethyl formamide a hazardous chemical; thought to cause birth defects
Radioactive tracers	Show the injection profile and locations of fractures	Antimony-124, argon-41, cobalt-60, iodine-131, iridium-192, lanthanum-140, manganese-56, scandium-46, sodium-24, silver-110m, technetium-99m, xenon-133	Radioactive tracers pose negligible risk to the public when handled, transported, stored and used according to appropriate guidelines.
Scale inhibitors, iron control	Increase the solubility of metals, particularly iron, so controlling rust, sludges, and mineral scales	citric and acetic acids; ethylene glycol	ethylene glycol (radiator fluid) extremely toxic
Oxygen scavengers	Control rust by removing oxygen from the fluid	ammonium bisulphite	ammonium bisulphite "hazardous to health"
		volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene and xylene - (BTEX compounds)	effects on CNS; human carcinogens

Table A.2: Chemicals that may not be added to fracking fluids in South Africa (DMR 2015).

NOTE that the heading of the list refers to "chemicals regulated under Safe Drinking Water Act ...", but this seems to be an Australian Act (there is no such Act in South Africa, where drinking water is regulated under SANAS 421).

1- Methylnaphthalene
2- Butanone
2- Hexanone
2- Methylnaphthalene
2- Methylphenol
2- Pyrrolidone
3- Methylphenol
4- Methylphenol
4- Methylphenol
Acetaldehyde
Acetone
Acetonitrile
Acetophenone
Acrylamide
Aniline
Benzene
Benzidine
Benzyl chloride
Bromomethane
Chloroethane
Copper
Cumene (isopropylbenzene)
Di (2- [Incomplete name - might be able to identify the substance by searching for CAS no. 117-82-7 at https://www.cas.org/content/chemical-substances]*
Diesel
Diethanolamine (2,2-iminodiethanol)
Dimethyl formamide
Ethylbenzene
Ethylene glycol
Ethylene oxide
Formaldehyde
Hydrogen chloride [hydrochloric acid]
Hydrogen fluoride (hydrofluoric acid)
Isophorone

Lead
Methanol
Naphthalene
Nitrilotriacetic acid
p- Xylene
Phenol
Phenol
Phthalic anhydride
Propylene oxide
Pyrrole
Sulphuric acid
Thiophene
Thoreau [Thoreau is a chemical company - might be able to identify the substance by searching for CAS no. 62-56-6 at https://www.cas.org/content/chemical-substances]*
Toluene
Vinyl chloride

CHAPTER 2

Effects on National Energy Planning and Energy Security

CHAPTER 2:
EFFECTS ON NATIONAL ENERGY PLANNING AND ENERGY SECURITY

Integrating Author:	Jarrad Wright[1]
Contributing Authors:	Tobias Bischof-Niemz[1], Clinton Carter-Brown[2], Owen Zinaman[3]

1 Energy Centre, Council for Scientific and Industrial Research (CSIR), Pretoria, 0184

2 Energy Services, Aurecon, Pretoria, 0081

3 21st Century Power Partnerships (21CPP), Colorado, 80401

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Executive Summary

South Africa's energy system is based on coal and oil; natural gas could be a missing link

The South African energy system is currently based on domestic coal and imported oil, with limited wind and solar photovoltaic (PV) renewable energy supply. Natural gas is currently only available in small quantities. The electrical power sector is the largest energy supply sector, predominantly based on the burning of domestic coal (~90%). The heating sector is generally small, and the transport sector is supplied by liquid fuels (crude or refined) which are either imported or domestically produced through coal-to-liquid (CTL) and gas-to-liquid (GTL) processes.

Domestic gas resources (from a number of offshore gas fields close to Mossel Bay) are nearing depletion, and imported piped gas from Mozambique is currently predominantly utilised by Sasol as feedstock into their CTL process. In this process, the natural gas is used for hydrogen production as a necessary feedstock for the production of carbon monoxide which together forms syngas (CO, H_2).

Natural gas could be a missing link in South Africa's energy system, as it exhibits certain qualities that existing energy carriers do not possess. Natural gas:

1. Cuts across a number of sectors in its possible end use (power generation, heat and transport);
2. Is easily transported via pipelines;
3. Is supported via a growing international market capacitated via increasing liquefied natural gas (LNG) trade volumes;
4. The complexities surrounding gas storage (gaseous/liquefied) are appreciable, but relative to coal, is typically considered to be a more homogeneous fuel and thus more flexible and easier to handle;
5. Is less CO_2 intensive when burnt per heat value than coal and in addition its heat value can be more efficiently utilised (combined-cycle gas turbines with up to 60% efficiency);
6. Is less of a general air pollutant than coal (Sulphur Oxide (SOx), Nitrogen Oxide (NOx), Mercury, particulates etc.);
7. Fires power stations (gas turbines and gas engines) that are technically highly flexible in their ramping and cold-start capabilities and can be operated at very low power output compared to their nameplate capacity without much deterioration in efficiency; and
8. Has an inherent end-use cost structure that is capital light and more fuel intensive, which makes it economically flexible.

Possible drawbacks of natural gas could include:

1. Price volatility if procuring gas on spot markets or linked to oil prices (albeit limited in comparison to overall system size);
2. If imported (not domestically sourced via conventional/unconventional sources), there is exchange rate risk (albeit limited in comparison to overall system size);
3. Natural gas leakage during production and transport when considering large scale usage is problematic, especially when considering the greenhouse gas (GHG) potential of natural gas. However, the electricity mix when including natural gas will likely include significant renewables and as a result system level emissions will be significantly lower. More detail on this can be found in Chapter 3 of this report (Winkler et al., 2016).
4. Hydraulic fracturing can cause environmental problems (water and air contamination as well as general biodiversity impacts). This is dealt with in various other Chapters of this report (Hobbs et al., 2016; Winkler et al., 2016; Holness et al., 2016).

Energy planning in South Africa done in different layers

Ideally, the Integrated Energy Plan (IEP) is the plan that links the different energy sectors and plans for the entire South African energy system in an integrated strategic planning framework. The Integrated Resource Plan (IRP) is the electricity plan for the country. The Gas Utilisation Master Plan (GUMP) is a strategic plan which provides a long term roadmap for the strategic development of natural gas demand and supply into South Africa's diversified future energy mix. These plans are led by the South African Department of Energy (DoE) usually in consultation with other government entities and external stakeholders.

In terms of gas supply, South Africa has in principle three options:

1. To increase the volumes of piped gas imported from neighbouring countries;
2. To import LNG that is supplied from a global market; and/ or
3. To develop domestic sources (either conventional or unconventional).

Initial gas demand and the development of a gas market will likely be stimulated by LNG-based gas supply creating large anchor demand that would trigger investments into additional gas infrastructure. Following this, related investments into indigenous conventional (offshore) and unconventional (shale/Coal-Bed Methane (CBM)) gas exploration will occur supplemented with increasing volumes of imported piped gas. All these scenarios are similar in that the cost of natural gas would be above the pure heat-value-based fuel cost of coal or diesel/petrol (while remaining cognisant of the fact that it is still a fossil fuel but one that is less carbon intensive than coal).

If shale gas became a new supply option with potentially low cost, it would affect the fundamentals of the different energy plans' scenarios. It mostly affects the IRP, as the electricity sector consumes most of the primary energy sources (other than oil). The availability of an electrical power generation technology and fuel that is cost competitive to new coal fundamentally changes the planning assumptions and hence the planning outcomes.

Effect of significant shale gas on energy planning: Renewable energy enabler and less coal

Scenarios identified for shale gas development (SGD) in South Africa are summarised below.

Table i: Overview of scenarios as defined for the scientific assessment.

Scenario	Available shale gas	Annual shale gas production (40 years)[1]	Estimated cost range of shale gas[1]
Scenario 0 (Reference Case)	-	-	-
Scenario 1 (Exploration Only)	0 tcf	0 PJ/a	N/A
Scenario 2 (Small Gas)	5 tcf ≈ 5 300 PJ ≈ 1 500 TWh	130 PJ/a ≈ 40 TWh/a *(≈50% of current natural gas supply in South Africa)*	6-10 US$/MMBtu = 20-35 US$/MWh
Scenario 3 (Big Gas[2])	20 tcf ≈ 21 000 PJ ≈ 5 900 TWh	530 PJ/a = 150 TWh/a *(2.5-3 times current natural gas supply in South Africa)*	4 US$/MMBtu = 15 US$/MWh

[1] *Estimated based on generally accepted industry practice and national energy planning resources.*
[2] *The "Big Gas" scenario of this scientific assessment and the "Big Gas" scenarios of the IRP and GUMP are not the same scenarios and should be treated accordingly.*

Significant domestic shale gas resources would affect the planning for the South African energy sector. If the volumes are significant enough to justify energy plans for a couple of decades to be developed around them, a second question would then be at what price the domestic shale gas can be exploited.

<u>Nominally priced shale gas (≈6-10 US$/MMBTu)</u>

LNG-priced natural gas in a mix with cost effective variable renewables (VRE: solar PV and wind) is today already cheaper than alternative base-load-capable new-build options in the electricity sector, and would hence replace baseload and mid-merit coal in the electricity sector. This is regardless of whether the natural gas is imported (LNG or piped) or whether it is domestic. As such, shale gas finds do not affect the optimal planning scenario for the electricity sector. But if large volumes of shale gas at prices below imported LNG and below imported piped gas could be made available, the domestic shale gas would then essentially be a replacement for imported natural gas, hence improving the trade balance and shielding the country from volatility in the pricing of a globally traded commodity like LNG.

Cheaply priced shale gas (<= 4 US$/MMBTu)

Displacement of coal fired power generation: Cheaply priced shale gas would enable the creation of a large, flexible gas-fired fleet of power generators that would be complementary to planned significant VRE capacities for South Africa (while coal is retiring). In the electricity sector, gas-fired power generation would now become cost competitive to new coal in its own right, even without blending with low cost VRE. In such a scenario of cheap gas, domestically accessed without risk of exchange rate fluctuations or global market volatility (local market volatility will still be present though), it would be a no-regret move to deploy large amounts of gas-fired power stations and subsequently complement them with a VRE fleet.

Fertiliser production: Potentially, South Africa could start producing its own fertiliser from very cheap domestic shale gas. Fertiliser production is not an energy-related topic, but would create a link between the energy and chemical sectors, which helps to balance fluctuations in energy demand (chemical sector being the anchor gas off-taker).

Gas-fired transportation: If cheaply priced, shale gas could be utilised for transportation (internal combustion engines run on compressed natural gas, electric vehicles running on gas fired power generation and/or natural gas derived hydrogen fuelled vehicles). It furthermore can be used as input feedstock into the GTL process to produce liquid transportation fuels. This would leverage the existing expertise in this sector, but it comes at the risk of increasing CO_2 emissions unnecessarily, as the natural gas could be burned with fewer emissions in internal combustion engines directly (especially in urban areas).

Heating: With sufficient network infrastructure, residential space heating and cooking demand could be supplied from natural gas. Similarly, industrial heat demand could switch from being supplied by biomass, coal and electricity to natural gas. However, this would necessitate large investments in domestic gas network infrastructure.

In general, the introduction of large quantities of cheap natural gas would increase the complexity while assisting in the integration of energy planning, because it introduces links between previously de-coupled energy sectors. It would however, for the very same reason, also make energy planning more resilient, because natural gas can also be seen as a “pressure valve” that is introduced between different energy sectors and that allows for adjustment to changing planning assumptions between sectors.

Risk of not finding sufficient or cheaply priced shale-gas resources

Not finding sufficient shale-gas resources

The role that shale gas would play in the energy mix, priced comparatively to imported piped gas (i.e. cheaper than LNG) would be an improved trade balance and the lowered risk exposure to globally determined commodity costs (in the case of LNG). These benefits of shale gas, even if not very cheaply priced, are certainly beneficial for the economy from a financial and energy security perspective.

From a purely technical energy planning perspective, the risk of not finding significant shale gas resources is therefore relatively small as gas demand could be supplied via imported gas (pipeline and/or LNG). Of course, energy security in some respect would be slightly reduced if gas supply remains dependent on imports, and exchange rate risk would be present. The IRP considers gas on the basis of its pricing and not primarily on the basis of where it originates from. Shale gas finds, even if not very cheaply priced, will therefore come as a macroeconomic added benefit under gas-dominated planning scenarios.

Not finding cheaply priced shale gas resources

Since the capital expenditure that leads to a gas-dominated energy sector (gas-fired power stations, gas-fired boilers, gas cooking/heating, etc.) are relatively small compared to the alternative new-build options (mainly coal), there are substantial "no-regret moves" associated with planning for a gas-dominated energy system. If the energy planning for the country anticipates very cheap shale gas and this is then not discovered, it would mean that the gas infrastructure built would have to be supplied with gas from more expensive sources. This would have a cost escalation effect. At the same time, even more VRE would be deployed to burn less of the more expensive gas. Because of the relatively light capital intensiveness of the gas infrastructure, the lower utilisation would not have a major effect on the overall costs of the energy system.

The main risk in energy planning related to the role of natural gas lies in the decisions that are taken in anticipation of no shale gas finds in South Africa, i.e. an energy future with relatively speaking smaller gas supply (although LNG, piped gas and domestic conventional sources can still make a significant energy contribution, even if shale gas does not materialise). This might lock the country into energy infrastructure that is not compatible with energy infrastructure flooded with inexpensive gas.

CHAPTER 2: EFFECTS ON NATIONAL ENERGY PLANNING AND ENERGY SECURITY

2.1 Introduction and scope

Natural gas has substantial benefits to offer the South African energy system, which at present is largely based on domestic coal resources. With natural gas, a diversification of energy supply is possible, sector coupling between different energy end-use sectors can be easily established, and gas-fired power stations bring economic and technical flexibility into the power system.

Three different natural gas supply sources can in principle be available to South Africa:

1. Piped natural gas from neighbouring countries;
2. Imported liquefied natural gas (LNG);
3. Domestic natural gas, either from conventional (onshore/offshore) or unconventional sources (shale gas/coal-bed methane (CBM)).

One of the unconventional domestic natural gas resources; shale gas, is the focus of this Chapter.

2.1.1 Scope

This Chapter elaborates on the effect that different South African SGD scenarios will have on investment decisions made, as based on energy planning and scenario development for the country. The Chapter considers the changes in planning outcomes for the long-term energy planning of the country in terms of supply sources and demand patterns for the different shale-gas scenarios. Although a specific study area is defined (geographically), historically energy planning in South Africa has tended to be performed at a national level.

The main links between this Chapter and the other Chapters of the scientific assessment are:

- Chapter 1: Scenarios and Activities (Burns et al., 2016)
- Chapter 3: Air Quality and Greenhouse Gases (Winkler et al., 2016)
- Chapter 4: Economics (Van Zyl et al., 2016)

The main assumptions (other than those outlined in the shale gas scenarios themselves) are based on principal plans developed for South Africa including the National Development Plan (NDP), Integrated Energy Plan (IEP), Integrated Resource Plan (IRP), and Gas Utilisation Master Plan (GUMP).

2.1.2 Special features of South Africa in relation to energy

Energy Balance

The present South African energy system is relatively self-sufficient; with less than 20% energy imports (Figure 2.1). Oil as a feedstock to refine liquid fuels and a small amount of gas is imported, but all other energy is supplied from domestic sources (mainly coal). Unique to South Africa is that large parts of the liquid fuel demand (approximately 33%) is supplied from coal-to-liquid (CTL) processes, based on domestic coal as feedstock (South African Department of Energy (DoE), n.d.). Additionally, gas-to-liquid (GTL) processes supply approximately 4-6% of the country's liquid fuel demand (South African Department of Energy, n.d.). The Mossgas plant close to Mossel Bay recently had to reduce its output due to depletion of the domestic natural gas fields that supply its feedstock. Hence, the South African energy system is not well diversified, and natural gas can be considered to be a possible missing link in the energy mix.

The total primary energy production and import in 2013 was 8 400 PJ (approximately 2 300 TWh_{th}) (International Energy Agency (IEA), 2013). The vast majority of this primary energy was supplied from coal at 6 100 PJ in 2013 (approximately 1 700 TWh_{th}). Natural gas only accounted for a small component of primary energy (~2%) with 170 PJ in 2013 (approximately 45-50 TWh_{th}). The total breakdown of primary energy production and imports in 2013 for South Africa is shown in Figure 2.1 and Figure 2.2.

The recent significant procurement of renewable electricity through Independent Power Producers (IPPs) in the electricity sector is not yet in this figure (as IPPs only started connecting to the electrical grid from 2014 onwards). By the end of 2015, all operational solar PV and wind power generation together stood for approximately 17 PJ of produced energy (4.65 TWh) (DoE, 2016b).

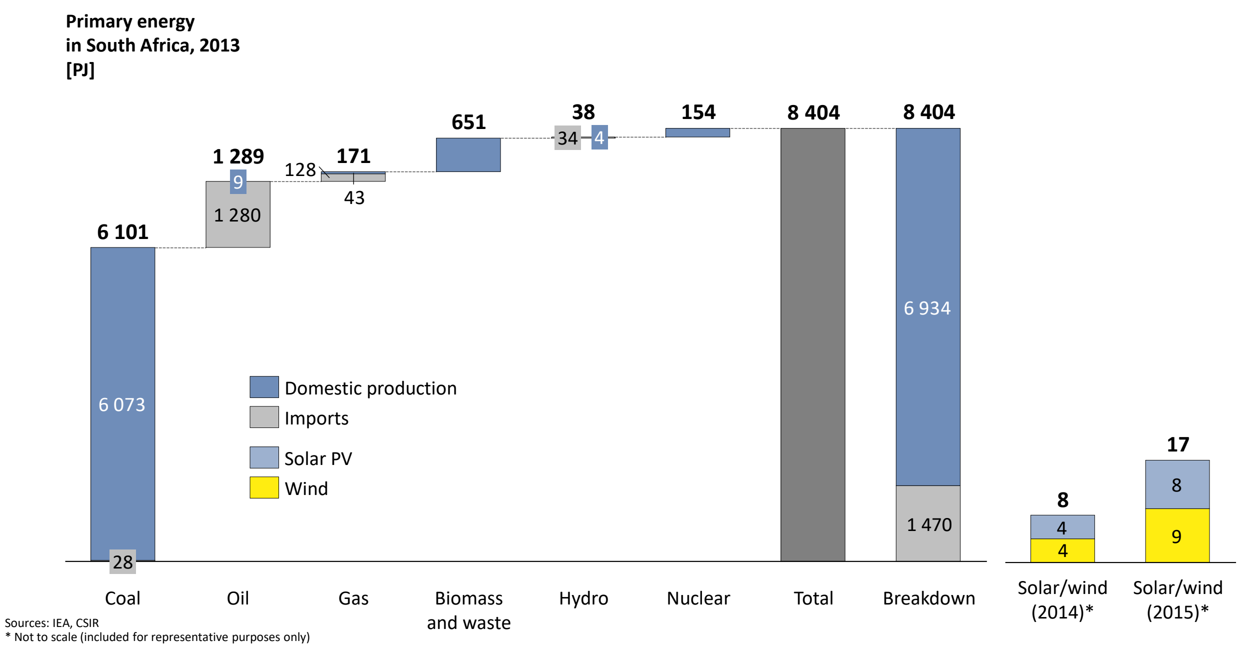

Figure 2.1: Primary energy production and imports for South Africa in 2013 showing the clear reliance on coal as a primary energy source and minimal local oil production (\IEA, 2013). Only in recent years (2014 onwards) has renewable energy made a significant contribution (mainly wind and solar PV, as shown) complemented by Concentrated Solar Power (CSP), mini-hydro, biomass, biogas and landfill gas produced domestically.

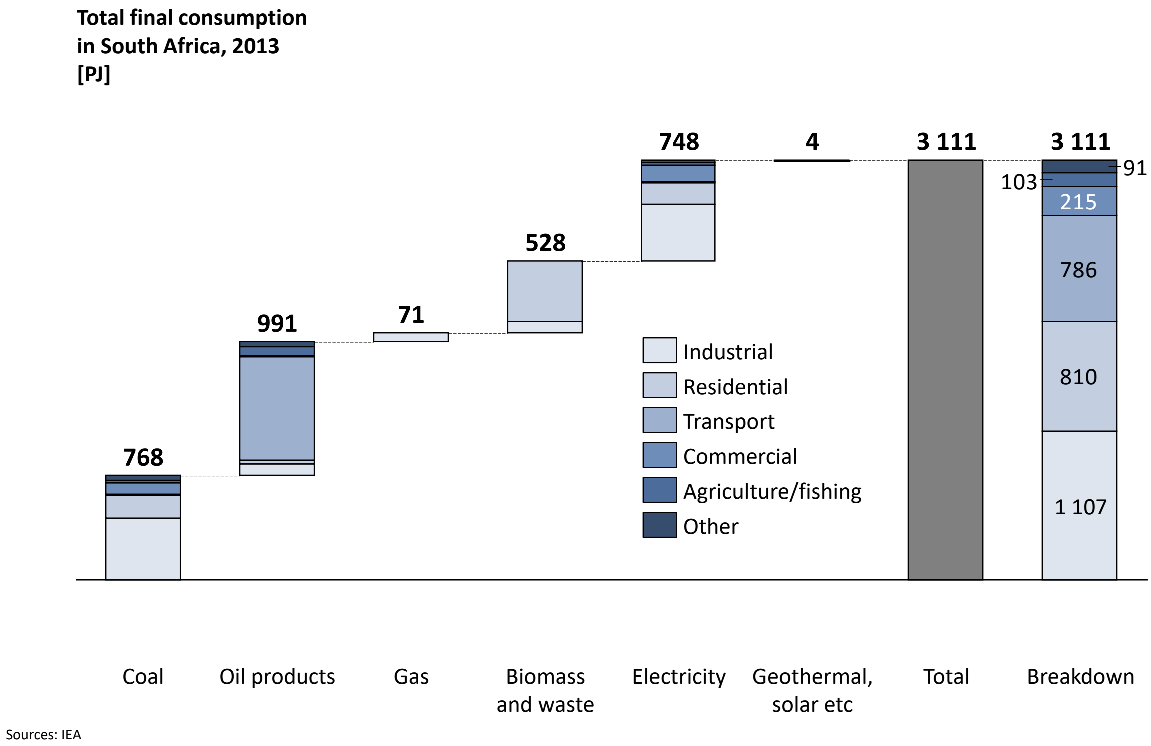

Figure 2.2: Total final energy consumption in South Africa in 2013 illustrating that most of South Africa's energy is industrial end-use with transportation and residential end-use being similar (IEA, 2013).

Coal

The South African energy system is highly dependent on its domestic coal resources. Coal was historically utilised when carbon dioxide (CO_2) emissions were not of concern and alternatives were prohibitively expensive. South African coal has been easy to mine and therefore has been a low cost position – even in a global market with current relatively low coal prices. However, in support of the clear direction given in the Energy Policy White Paper of 1998 (Department of Minerals and Energy, (DME), 1998) where security of supply through energy diversity is stated explicitly, there are a number of reasons why South Africa needs to diversify its energy mix away from a coal dominated energy system:

1. Heavy coal-reliance makes the country one of the largest emitters of CO_2 globally (ranked in the top twenty absolute CO_2 emitters in the world and top ten in terms of CO_2 emissions per GDP) (The World Bank, n.d.a; The World Bank n.d.b);
2. The single-failure risk of a one-fuel-reliant power system e.g. controlled load shedding after heavy rains due to wet coal in 2008;
3. Financial risk: South African coal prices are not reflective of globally traded prices for coal (high risk exposure to coal-price changes in the electricity sector);
4. The depletion of coal reserves in the Mpumalanga region and challenges associated with developing the relatively underutilised Waterberg coalfields (Hartnady, 2010) e.g. low grades, high ash content, complex geology, water scarcity and the requirement for new transport linkages including major electrical grid strengthening.

The South African government has recognised the problematic nature of a high dependency on one fuel source, and has expressed its desire to diversify the energy mix in a number of government plans. The Department of Energy's Integrated Resources Plan (DoE's IRP 2010 (DoE, 2011b)) describes a doubling of power capacity by 2030 (compared to 2010) and a significant diversification of the power mix, away from "coal only". This diversification of the energy mix includes a range of sources (solar PV, hydro wind, gas and nuclear).

Natural Gas

Natural gas could be a missing link in South Africa's energy system, as it exhibits certain qualities that existing energy carriers do not possess. Natural gas:

1. Cuts across a number of sectors in its possible end use (power generation, heat and transport);
2. Is easily transported via pipelines;
3. Is supported via a growing international market capacitated via increasing LNG trade volumes;

4. The complexities surrounding gas storage (gaseous/liquefied) are appreciable, but relative to coal, is typically considered to be a more homogeneous fuel and thus more flexible and easier to handle;
5. Is less CO_2 intensive when burnt per heat value than coal and, in addition its heat value, can be more efficiently utilised (combined-cycle gas turbines with up to 60% efficiency);
6. Is less of a general air pollutant than coal (Sulphur Oxide (SOx), Nitrogen Oxide (NOx), Mercury, particulates etc.);
7. Fires power stations (gas turbines and gas engines) that are technically highly flexible in their ramping and cold-start capabilities and can be operated at very low power output compared to their nameplate capacity without much deterioration in efficiency;
8. Has an inherent end-use cost structure that is capital light and more fuel intensive, which makes it economically flexible.

Possible drawbacks of natural gas could include:

1. Price volatility if procuring gas on spot markets or linked to oil prices (albeit limited in comparison to overall system size);
2. If imported (not domestically sourced via conventional/unconventional sources), there is exchange rate risk (albeit limited in comparison to overall system size);
3. Natural gas leakage during production and transport when considering large scale usage is problematic, especially when considering the greenhouse gas (GHG) potential of natural gas (the electricity mix when including natural gas will likely include significant renewables and as a result system level emissions will be significantly lower);
4. Hydraulic fracturing can cause environmental problems such as water and air contamination (Hobbs et al., 2016; Winkler et al., 2016) as well as general ecosystem and biodiversity impacts (Holness et al., 2016).

At present, there is very little gas infrastructure in South Africa. Domestic resources are limited to offshore gas fields close to Mossel Bay (F-A field), where the gas is piped onshore and converted into petrochemical products (predominantly liquid fuels). According to the draft GUMP, the volume of gas supply from the Mossel Bay gas fields steadily declined from ~60 PJ/yr (17 TWh_{th}) in 2010 to approximately 35 PJ/yr in 2013 (10 TWh_{th}/yr) i.e. averaging ~40-50 PJ per year (8-14 TWh_{th}/yr). Based on the draft GUMP, these gas fields are in an advanced stage of decline and are only expected to last for a further 6-7 years. The F-0 offshore field (Project Ikhwezi) is envisioned to complement this supply in the short to medium term. Other offshore potential in the Ibhubesi field off the West Coast of South Africa has proven reserves of ~540 bcf (Sunbird Energy, 2016).

Neighbouring countries have substantial gas reserves (i.e. Mozambique and Namibia) as do regional African nations (i.e. Angola and Tanzania). Some gas quantities are already imported through the Republic of Mozambique Pipeline Company (ROMPCO) pipeline from Mozambique, which stands for the entire imported primary energy from natural gas (120-140 PJ per year, which is 33-39 TWh_{th}/yr). This gas is mostly used for chemical processes (hydrogen production as feedstock for syngas) in Sasol's CTL process. The Transnet-operated Lilly pipeline from Secunda to Richards Bay/Durban transports synthetic gas produced in Sasol's CTL plant in Secunda to Durban via Empangeni. The volume delivered through this pipeline is approximately 16 PJ per year (4.5 TWh_{th}/yr) (Transnet SOC Ltd, 2015).

In 2013, the total natural gas supply in South Africa (domestic production and import) was approximately 170 PJ (45-50 TWh_{th}), plus the synthetic gas from Sasol's Secunda plant of 16 PJ (4.5 TWh_{th}); a total of gas supply of approximately 190 PJ (53 TWh_{th}), which is ~2.5% of total primary energy supply. To put this into perspective, it is the equivalent throughput of one medium size LNG landing terminal. Spain, a country with a similar primary energy and electricity demand as South Africa, has an annual natural gas supply of 1 260 PJ (350 TWh_{th});~7-8 times the current South African volume.

Crude Oil and Synthetic Crude Oil

South Africa has almost no domestic crude oil resources, but very significant scale and expertise in CTL and GTL processes. It should be noted that the high carbon-intensity of fuels from these processes has significant impacts on South African climate change obligations. The country consumes approximately 24 billion litres of petrol and diesel per year (approximately 820 PJ/yr or 230 TWh_{th}/yr) (DoE, 2015). *"… about 36% of the demand is met by coal-to-liquids synthetic fuels as well as gas-to-liquid synthetic fuels plus a very small amount of domestic crude oil. South Africa has the second largest oil refining capacity in Africa. The current total refining capacity amounts to 703 000 barrels per day, of which 72% is allocated to crude oil refining, with the balance allocated to synthetic fuel refining*" (DoE, 2015).

In fact, South Africa is the only country globally that produces liquid fuels from coal to the scale that makes these fuels a very dominant contributor to the domestic liquid-fuels market. Only China produces liquids from coal in similar absolute scale, but in relative numbers it is significantly less than in South Africa.

Nuclear

South Africa hosts the only nuclear power plant on the African continent. Koeberg nuclear power station consists of two French-designed and -built reactors of a total of 1 800 MW net capacity with Unit 1 being completed in 1984 and Unit 2 in 1985. This power station produces approximately 5% of the South African domestic electricity supply.

Renewables

South Africa exhibits world-class solar resources with achievable annual energy yields from solar technologies that are amongst the best globally (SolarGIS, n.d.).

Less known, the country also has excellent wind resources with achievable load factors well above that of leading wind markets (Council for Scientific and Industrial Research (CSIR), 2016). More than 80% of the entire South African land mass has enough wind resource to achieve 30% annual load factor or more, whereas the actual average annual load factor of the entire wind fleets in Germany (46 GW installed capacity) and Spain (23 GW installed capacity) are 17-23% and 25-27% respectively (CSIR, 2016).

The highly successful Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has grown utility scale wind and solar PV in South Africa from a zero base in 2013 to 2 040 MW by the end of 2015 (contributing 4.75 TWh to the electricity mix) (CSIR, 2015). The Small Projects IPP Procurement Programme also run by the DoE aims to procure renewable energy from smaller renewable power plants (<5 MW), while small-scale embedded generation is being considered by various industry stakeholders (likely via rooftop solar PV installations).

The hydro potential in South Africa is relatively limited, but countries in the South African Development Community (SADC) region (including Zimbabwe, Zambia, Democratic Republic of Congo and Mozambique) have vast potential for hydro power. In fact, ~5% of South Africa's electricity demand is currently supplied through hydro power imported from Cahora Bassa power station in Mozambique.

Transmission Grid

The South African transmission grid is characterised by the large geographical area that power is transmitted over (see Figure 2.3). Currently, the majority of the power generation (coal-fired) is located in the North East of the country, with a significant component of this power needing to be transmitted over significant distances e.g. ~1500 km. The 400 kV and 765 kV transmission systems transmits power from North to South. In future, it is anticipated that this power flow direction will reverse, predominantly as a result of a changing power generation mix. Strategic documents like the periodically published Eskom Transmission Development Plan (TDP) (Eskom Holdings SOC Limited, 2015b) and Generation Connection Capacity Assessment (Eskom Holdings SOC Limited, 2015a) as well as Strategic Grid Plan (SGP) (Eskom Holdings SOC Ltd, 2014) consider various scenarios to ensure that sufficient power transmission corridors and substations are planned for in advance to adequately integrate power generation expected in the future. The key planning document that feeds into these transmission plans is presently the IRP 2010.

Pipeline Infrastructure

The existing and potential South African national pipeline infrastructure is shown graphically in Figure 2.4 (Transnet SOC Ltd, 2015). There are currently only two major pipeline operators in South Africa; Sasol and Transnet. There is a minimal amount of existing gas pipeline infrastructure in South Africa. The main existing pipeline infrastructure is:

- The 865 km ROMPCO import pipeline (Pande/Temane-Secunda);
- The 85 km offshore PetroSA pipeline (FA platform-Mossel Bay);
- The 600 km Lilly pipeline (Secunda-Durban); and
- The 145 km Secunda-Sasolburg pipeline

As shown in Figure 2.4, there are long-term options for pipeline infrastructure in the study area (depending on SGD outcomes). These could link with existing ports in Cape Town, Saldannha Bay, Mossel Bay and Ngqura (Port Elizabeth). This gas network could then, in the future, link up to the existing gas networks at Sasolburg and Durban.

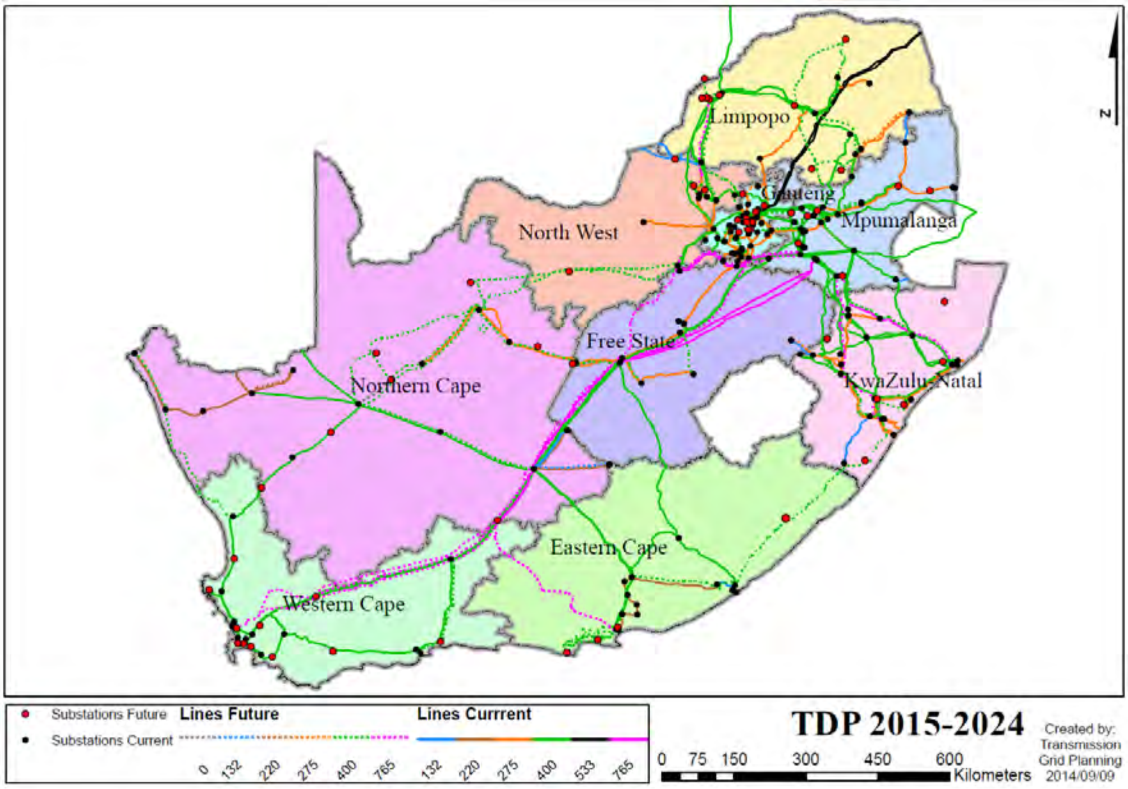

Figure 2.3: Existing and planned Eskom transmission grid infrastructure as per the Transmission Development Plan 2015-2024 (Eskom Transmission Group, 2014). There is existing transmission network infrastructure through the study area, with additional planned transmission infrastructure into the future.

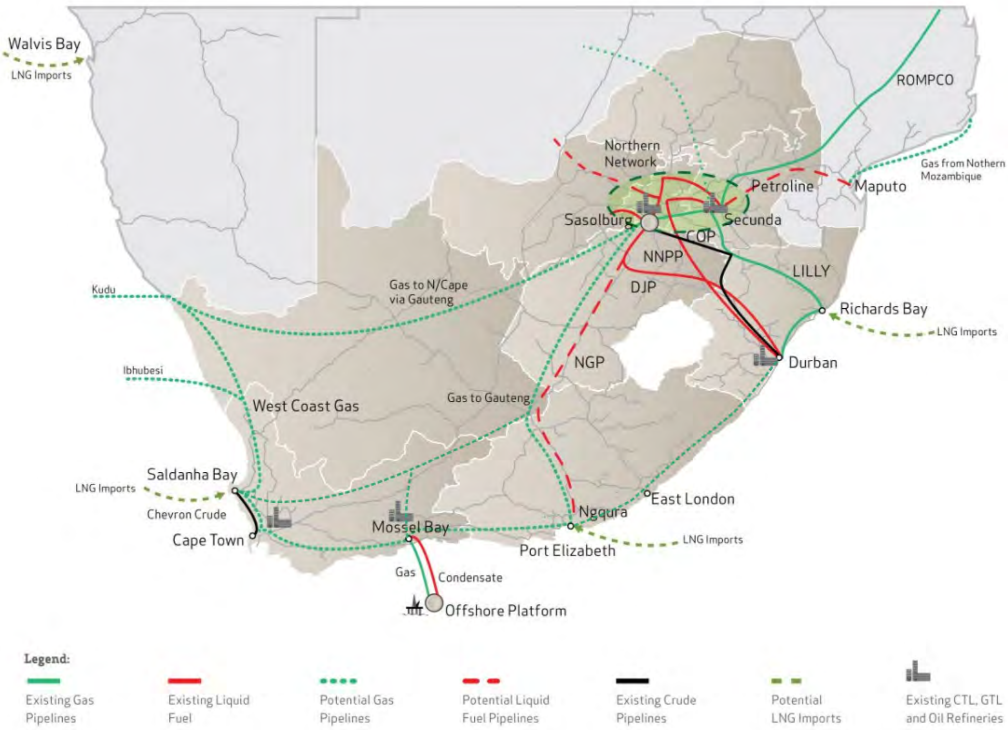

Figure 2.4: Existing and potential South African pipeline networks showing minimal existing gas pipeline infrastructure (adjusted from Transnet SOC Ltd (2015)). The long term potential for gas pipeline infrastructure through the study area is shown here.

2.1.3 Relevant legislation, regulation and practice

Energy Policy White Paper

The White Paper on the Energy Policy of the Republic of South Africa of 1998 laid the foundation for the approach to energy planning in the country (DME, 1998). Integrated energy planning, yet not optimal and dependent on availability of reliable data, was identified as the tool to be used by South African policy makers in the planning of the energy system (DME, 1998). Security of energy supply for South Africa through energy supply diversity was identified as one of the main goals. In addition, natural gas was already identified as a viable source of complementary primary energy supply to the existing mix.

National Energy Act and Electricity Regulation Act

The National Energy Act of 2008 prescribes that energy planning in South Africa must be conducted in an integrated manner and that the Energy Minister has the mandate and the obligation to conduct such planning (Parliament of the Republic of South Africa, 2008). Already, the Electricity Regulation Act of 2006 mentioned the term "Integrated Resources Plan", but was not explicit about the details of such a planning instrument (Parliament of the Republic of South Africa, 2006). The draft version of the Electricity Regulation Second Amendment Bill of 2011 is very explicit in that it prescribes an IRP to precede any implementation of new power generation capacity (DoE, 2011b).

National Development Plan (NDP) 2030

The NDP 2030 (National Planning Commission (NPC), 2012) is the overarching planning document for the development of South Africa and aims to eliminate poverty and reduce inequality in South Africa by:

- Enhancing the quality of life;
- Realising an expanded, more efficient, inclusive and fairer economy; and
- Enshrining leadership and promoting active citisenry.

The NDP 2030, as published in 2012, is composed of 15 Chapters. Two (2) introductory Chapters focus on policy-making and local demographic trends and the remaining 13 Chapters focus on specific sectors of South Africa each having their own defined specific objectives and actions. The NDP 2030 has 119 actions to implement. The NDP considers energy planning in a number of clear actions in Chapters 3, 4, 5 and 7. Specifically, related to natural gas in the energy system it states:

- *Chapter 4: Economic Infrastructure*

16. *Enable exploratory drilling to identify economically recoverable coal seam and shale gas reserves, while environmental investigations will continue to ascertain whether sustainable* *exploitation of these resources is possible. If gas reserves are proven and environmental concerns alleviated, then development of these resources and gas-to-power (GTP) projects should be fast-tracked.*

17. *Incorporate a greater share of gas in the energy mix, both through importing LNG and if reserves prove commercial, using shale gas. Develop infrastructure for the import of LNG, mainly for power production, over the short to medium term.*

18. *Move to less carbon-intensive electricity production through procuring at least 20 000 MW of renewable energy, increased hydro-imports from the region and increased demand-side measures, including solar water heating.*

From a national planning perspective, it is therefore clearly supported to not only investigate shale gas opportunities, but to also exploit them, should they be economically viable.

Integrated Energy Plan (IEP) and Integrated Resources Plan (IRP)

From these high-level government policies flow the IEP for the entire energy sector, and the IRP for electricity. An overview of the integration between these plans (as well as others) is shown in Figure 2.5.

A draft of the IEP was circulated in 2013 for public comment (DoE, 2013a), but was not finalised. The most recent version of the IEP was being finalised, but was not publicly available for inclusion as a formal guiding policy document at the time of publication. However, it has been considered as a guide for the strategic direction of gas policy in South Africa. The DoE reported to Parliament in May 2016 on the IEP and IRP and indicated that they will be presented to the Parliamentary Portfolio Committee on Energy in the 3rd quarter of 2016/17 financial year, following which they would be submitted to Cabinet for approval. While these key planning documents are currently under revision and have not been updated for an extended period of time, it is very likely that natural gas as a primary energy fuel source will have a significant role to play in South Africa's energy future.

The DoE has adopted a central planning approach for the electricity sector. The latest promulgated version of the IRP is the IRP 2010 (DoE, 2011b). An update of the IRP 2010 was conducted in 2013, which was published for public comment but never promulgated (DoE, 2013b).

The approach (in-principle) to planning in the South African electricity sector is illustrated in Figure 2.6. At the core of the process is a mathematical least-cost optimisation model that, subject to certain boundary conditions and policy-adjustments, determines the least-cost expansion path for the South

African electricity system. The IRP 2010 has so far been implemented via the procurement of Independent Power Producers (IPPs).

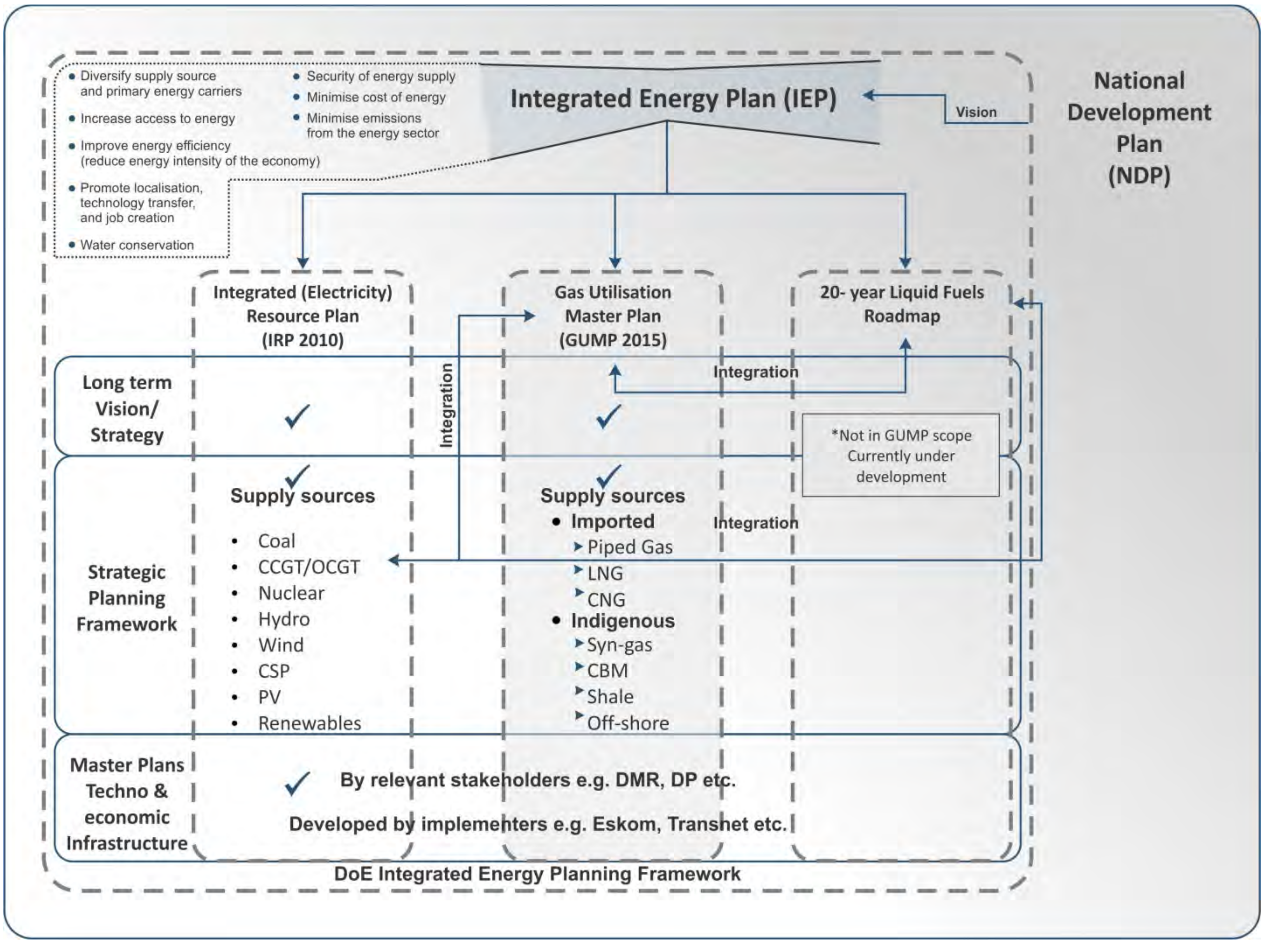

Figure 2.5: An extract from the draft IEP indicating the DoE Integrated Energy Planning Framework. The framework shows the envisioned integration between the principal energy plans of South Africa and the NDP 2030.

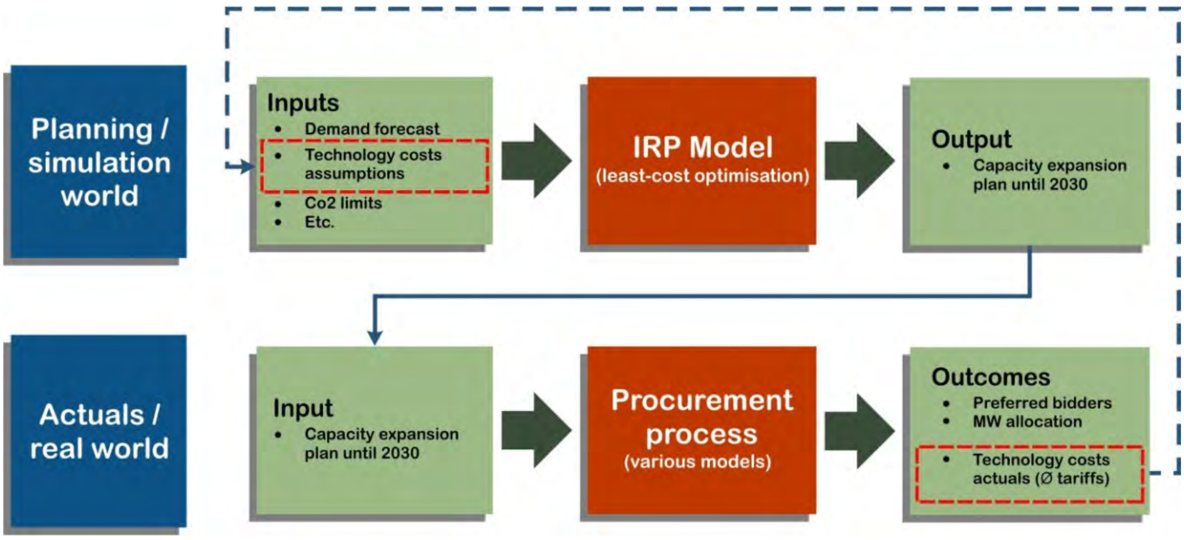

Figure 2.6: The principle approach to planning in the South African electricity sector, showing the expected feedback between the planning/simulation and the actual/real world domains.

Gas Act

As for natural gas specifically, the Gas Act of 2001 was promulgated with the objectives (amongst others) to promote the orderly development of the piped gas industry and to establish a national regulatory framework (Parliament of the Republic of South Africa, 2001). The Gas Amendment Bill (published draft for public comments in 2013), more broadly, has the objective to stimulate the natural gas industry and explicitly introduces a number of new gas technologies (e.g. gas liquefaction and regasification) (DoE, 2013c).

Gas Utilisation Master Plan (GUMP)

The DoE is at present finalising a Gas Utilisation Master Plan (GUMP) for South Africa, which will *"analyse potential and opportunity for the development of South Africa's gas economy and sets out a plan of how this could be achieved"* (DoE, 2016a). The GUMP will fit into South Africa's energy planning landscape with other principal energy planning processes as shown in Figure 2.6.

Natural gas plays a very small part of South Africa's current energy mix and the GUMP will form a critical part of diversifying the energy mix by outlining the possible future paths for natural gas market development. The DoE reported to Parliament in May 2016 on the GUMP and indicated that it will be presented to the Parliamentary Portfolio Committee on Energy in the 3rd quarter of 2016/17 financial year, following which they would be submitted to Cabinet for approval. At a high level, possible future gas market evolution paths taken from the draft of the GUMP are illustrated in Figure 2.7, where the three paths of "Niche", "Hub" and "Big Gas" are shown. The relationship between the scenarios developed in the GUMP and this scientific assessment are outlined in more detail in

Section 2.2. It should be noted that the "Big Gas" scenario of the GUMP and the "Big Gas" scenario of this scientific assessment are not the same and should be treated accordingly.

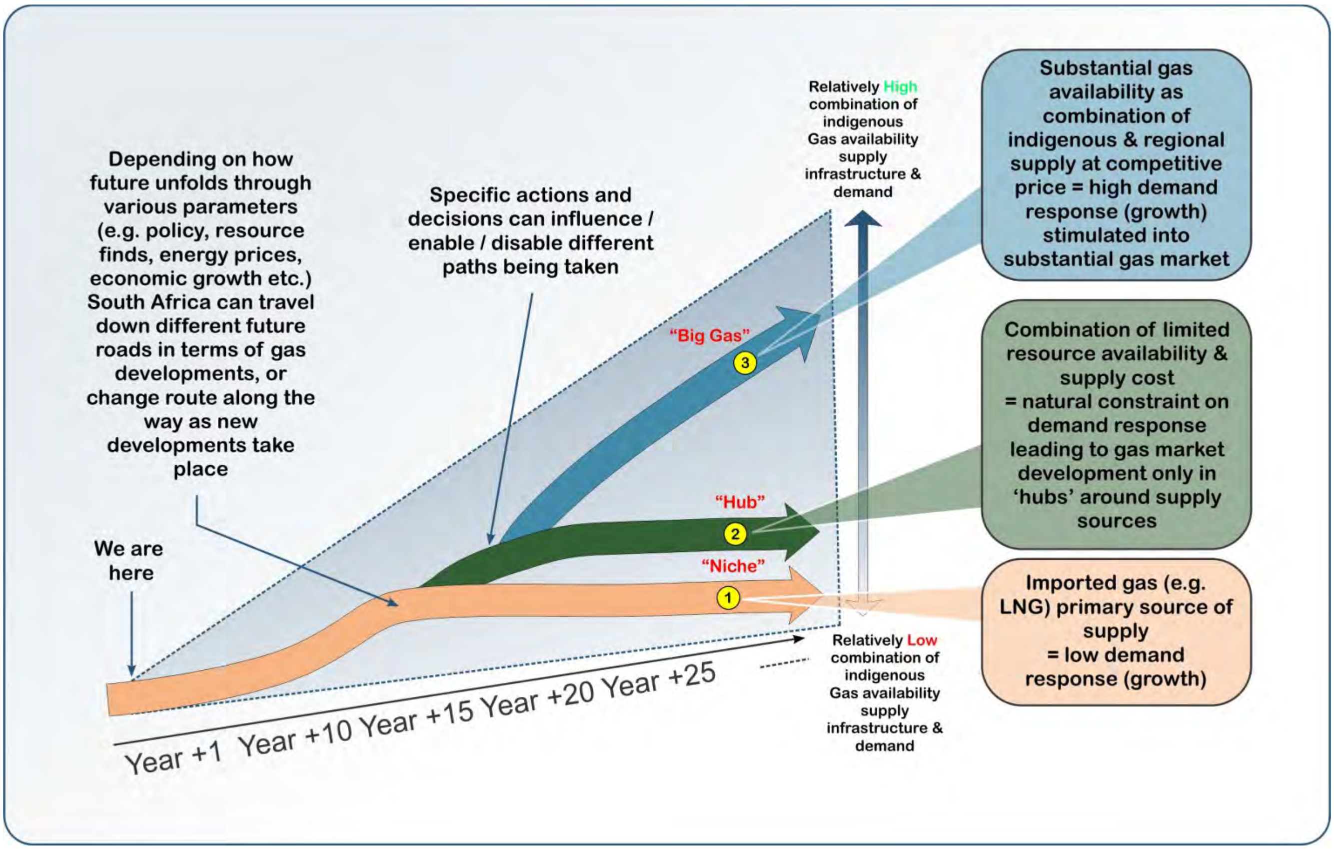

Figure 2.7: Gas Utilisation Master Plan (GUMP) illustration of possible future gas market evolution paths (Source: DoE, GUMP (Draft)).

Eskom Transmission Development Plan (TDP)

The TDP is an Eskom plan that outlines how the electric transmission system needs to be developed over the next 10 years. *"The Transmission Development Plan (TDP) represents the transmission network infrastructure investment requirements. The TDP covers a 10 year window and is updated annually. It indicates the financial commitments required by Eskom in the short to medium term."* (Eskom Holdings SOC Limited, 2015b). Specifically, this is inclusive of grid infrastructure required to integrate new gas-fired power plants.

Eskom Strategic Grid Plan (SGP)

The SGP is also an Eskom plan, which outlines strategically where new transmission grid developments need to be triggered (Eskom Holdings SOC Ltd, 2014). *"The Strategic Grid Plan formulates long term strategic transmission corridor requirements. The Plan is based on a range of generation scenarios and associated strategic network analysis. The time horizon is 20 years. The SGP is updated every 2-3 years"* (Eskom Holdings SOC Limited, 2015b).

Eskom Generation Capacity Connection Assessment (GCCA)

The GCCA (Eskom Holdings SOC Limited, 2015a) is periodically published by Eskom in response to a government call to connect IPPs planned for under the IRP 2010. It establishes existing connection capacity available at each Main Transmission Substation (MTS) as well as planned strategic transmission corridors and MTSs based on the latest version of the TDP (Eskom Holdings SOC Limited, 2015b). The GCCA has historically been updated every 2-4 years.

Transnet Long-term Strategic Framework (LTSF)

The LTSF, as developed by Transnet in 2015, provides a long term and broader view of transportation networks required, including expansions of existing transportation infrastructure (Transnet SOC Ltd, 2015). Specifically, natural gas infrastructure planning and pipeline developments include the possibility of SGD.

2.1.4 Overview of international experience

The United States of America (USA) has by far the largest experience in shale gas exploration and production. In 2014, shale gas to the amount of almost 14 000 PJ was produced in the United States (US), which contributed almost 20% to the entire domestic primary energy production of 82 500 PJ in the US (EIA, 2014; EIA, 2015a). This is a tenfold increase of shale gas contribution compared to 2007, when less than 1 400 PJ of shale gas where produced. Shale gas has therefore been a significant contributor to domestic energy sources and hence to security of supply and trade balance improvements for the US in recent years. The latest projections to 2040 by the EIA indicate that the majority of natural gas production in the US will come from shale gas (Figure 2.8) while Figure 2.9 shows that there will likely be a growing role for shale gas to play internationally (EIA, 2016a).

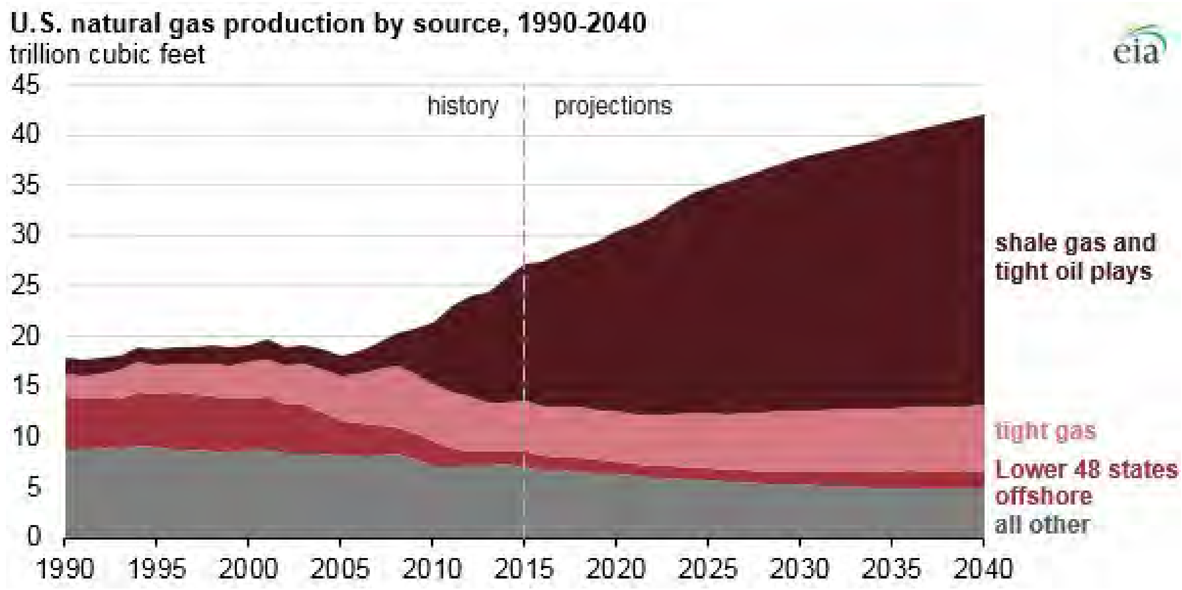

Figure 2.8: Historical and projected shale gas production in the US (EIA, 2016a), showing the significant and growing role that shale gas is likely to play in future for the US.

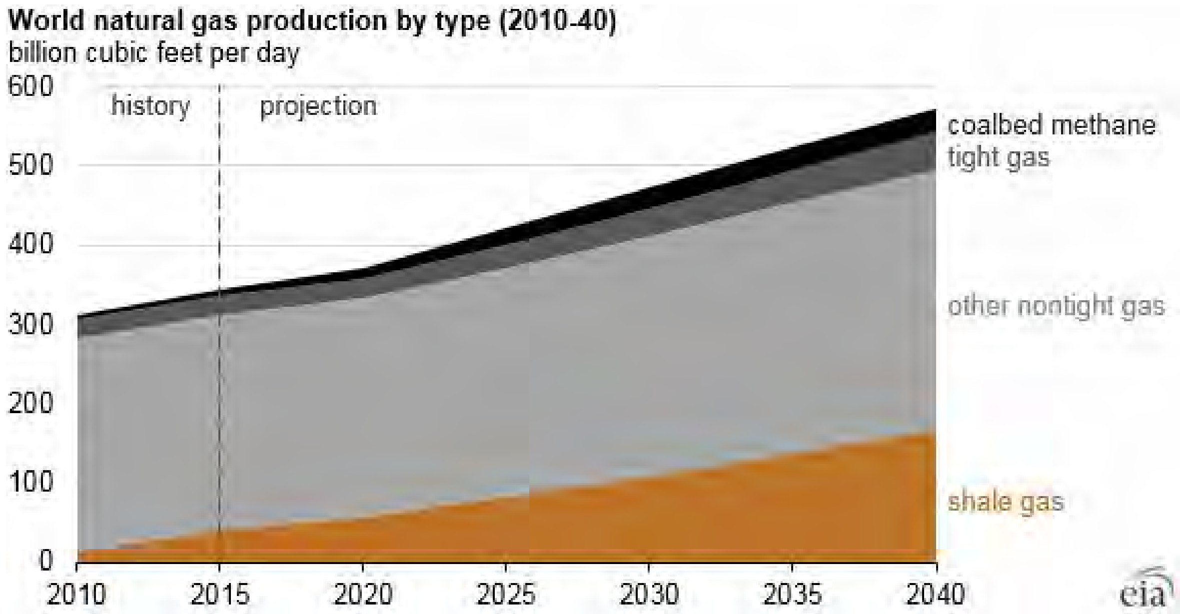

Figure 2.9: Historical and projected shale gas production internationally (EIA, 2016a), showing the growing role that shale gas is likely to play in future.

In the US, if a shale gas resource is discovered, the land owner is the owner of the resource. As a result, shale gas is predominantly privately owned but with regulatory oversight. This is notable considering the South African context of resource ownership in the context of the Mineral and Petroleum Resources Development Act (MPRDA) Amendment Bill released in 2012 (but referred back to Parliament by the President in January 2015). More recently, in the Minister of Energy Budget Speech Vote 2016/17, the relevant framework for the oil and gas supply chain is proposed to be separated from the MPRDA Amendment Bill into an “Upstream Gas Bill” and a separate “Gas Amendment Bill” for the midstream gas value chain (DoE, 2016c).

The developments in the US happened in a short timeframe of just the last decade. The high-level effects of the shale gas boom in the US are that:

- First, a portion of power production from coal was replaced by electricity from gas-fired power stations (Logan et al., 2015);
- Second, domestic shale gas replaced imported gas and put on hold or cancelled the envisaged importation of natural gas;
- Third, shale gas added sufficient supply to the US natural gas sector to cut natural gas spot prices by more than half in recent years (from 4-5 US$/MMBtu in 2009-2011 to below ~2.50 US$/MMBtu in 2015) (EIA, 2016b).

The first effect is the significantly reduced carbon emissions in the US power sector in the last 10 years (EIA, 2015b). As a first-order effect, cheap shale gas-fired power generation replaced coal-fired power generation. The deployment of new natural gas fired power generation has not been significantly high in the past decade but rather most of the shift away from coal-fired generation has been a result of a "re-dispatch" of existing plants. Utilities are operating existing fleets of coal plants less and increasing operations at existing gas-fired plants. This has all happened as a result of significant amounts of new renewable capacity being deployed (specifically solar PV). Because of the roughly 50% lower carbon emission factor of natural gas compared to coal, combined with the higher efficiency of gas-fired compared to coal-fired power stations, this led to a lower carbon-intensity of the electricity supply. From an energy planning perspective, this development reduced the immediate need for a very fast deployment of renewable energy sources in the energy and power sector in order to contain the US’s CO_2 emissions.

In the African context (see Figure 2.10), based on EIA (2013), Algeria has by far the highest level of technically recoverable resources (707 tcf, ~750 000PJ) while South Africa (390 tcf, 410 000 PJ), Libya (122 tcf, 130 000 PJ) and Egypt (100 tcf, 110 000 PJ) have significant technically recoverable shale gas resources. Other African countries with smaller shale gas resources thus far include Chad (44 tcf, 47 000 PJ), Tunisia (23 tcf, 24 000 PJ), Morocco (12 tcf, 12 500 PJ) and Western Sahara (8.6 tcf, 9 100 PJ). The technically recoverable reserves in South Africa do have a high level of uncertainty associated with them but an independent study performed for the DoE as part of the GUMP has revealed up to 120 tcf of shale gas potential; of which 9 tcf is economically recoverable.

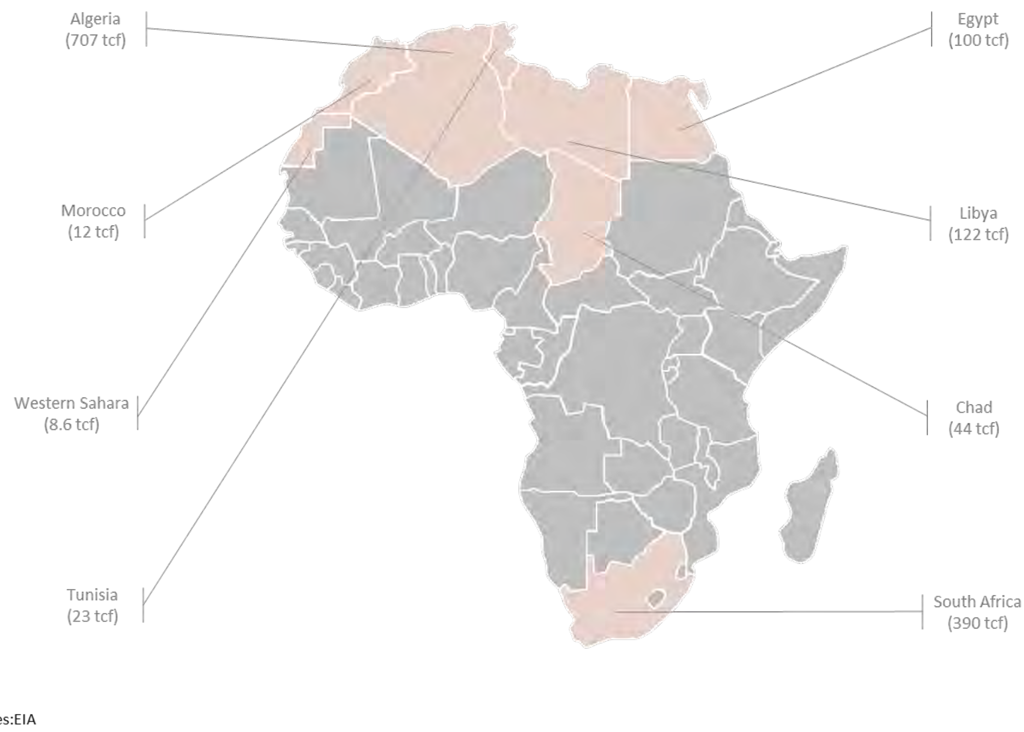

Figure 2.10: Technically recoverable shale gas resources in Africa (EIA, 2013). Most shale gas countries are in North Africa. Algeria has the largest shale gas resource with South Africa having the second largest.

2.2 Key potential impacts on energy planning and options

2.2.1 Natural gas in the South African energy planning landscape

In this Chapter the impacts of the different shale gas scenarios on energy planning and energy security are elaborated. This will lead to a risk assessment of the shale gas scenarios from an energy planning and energy security perspective.

The draft of the IEP includes four main scenarios (Base Case, Environmental Awareness, Resource Constrained and Green Shoots). A sensitivity of these scenarios was a scenario that explicitly assumed no shale gas in South Africa. The impact of this no shale gas scenario is that energy security will be slightly reduced following an increased requirement for imports of comparatively more expensive refined petroleum products (and resultant increased overall energy costs, specifically LNG). This scenario also aligns quite well with the “Niche” scenario in the draft of the GUMP being developed where gas is predominantly imported (via LNG terminals) with very small scale indigenous production and regional pipeline imports.

The IRP 2010 plans the capacity-expansion programme for the power sector in South Africa until 2030 (DoE, 2011b). The promulgated version of IRP 2010 calls for 3.9 GW of new peaking plants (gas-fired Open Cycle Gas Turbines (OCGTs), or similar) and 2.4 GW of new mid-merit gas-fired power plants (Combined Cycle Gas Turbine (CCGTs)) (DoE, 2011a). Examples of OCGTs and CCGTs are shown in Figure 2.11 and Figure 2.12 respectively. OCGTs are cheaper to build than CCGTs, they are more flexible, but also have a lower efficiency when compared to CCGTs. Figure 2.13 shows the planned capacities and electricity production as per the IRP 2010.

In the IRP 2010, the planned CCGT and OCGT capacities by 2030 have the operating regime outlined in Table 2.1. These numbers indicate that CCGTs in the IRP 2010 are planned as mid-merit plants which do load-following during the day and which usually do not operate during night. The reason for this is that gas-fired CCGTs have a lower levelised cost of energy than new-build coal-fired power stations at low load factors. Hence they supply the mid-merit-type of demand of load-following during the day. The OCGTs are planned as a pure “safety net” for the system with insignificant load factors and hence with insignificant gas demand/throughput for these plants. OCGTs are relatively cheap to build but expensive to operate, and are therefore pre-destined for this type of use case with very low annual load factor.

Although never promulgated, in the Base Case of the IRP Update 2013, the installed capacities for gas-fired power stations were adjusted upwards to 3.6 GW of CCGT and 4.7 GW of OCGT by 2030. The electricity production and associated load factors of these plants in the IRP Update 2013 are shown in Table 2.1 (the IRP update was not promulgated and hence the values are shown for indicative purposes). The load factor of the CCGTs in 2030 is considerably higher than in the original IRP 2010 (38%) but by 2050 drops back to 22%. The main reason for the increased capacities of gas-fired power generators moving from the IRP 2010 to the IRP Update 2013 is the more graduated phasing of planned nuclear capacity by 2030. The resulting energy gap in the IRP Update 2013 is filled with a mix of VRE and natural gas-fired power stations. The load factor for the OCGT fleet stands at 2-3% in 2030/2050 – again acting as the safety net for the power system.

Figure 2.11: Existing OCGTs at Atlantis, South Africa (9 x 148 MW, 1 327 MW Ankerlig power station) currently running on diesel (Eskom Holdings SOC Ltd, n.d.). Similar plants will be part of new OCGT capacity planned for in the IRP 2010 but will run on natural gas.

Figure 2.12: Existing CCGTs at Wilaya of Tipaza, Algeria (3x400 MW configuration, 1 227 MW Shariket Kahraba Hadjret En Nous power station) (Mubadala Development Company PJSC, 2016). Similar plants will be part of new CCGT capacity planned for in the IRP 2010.

The IRP 2010 assumed natural gas to be priced at LNG prices (planning assumption in the IRP 2010: 42 ZAR/GJ i.e. ~11 US$/MMBtu). The plan did not explicitly consider shale gas yet as a planning option. It assumed a certain gas supply at a certain cost without making reference to shale gas. From an energy planning perspective in the power sector, it should be noted that the only relevance that shale gas has is the availability of fuel (quantities) and the price of the fuel (US$/MMBtu). Whether a certain quantity and a certain fuel price can be achieved through imported piped gas, imported LNG or through domestic conventional or shale gas resources is irrelevant for the IRP-type power sector planning. These different supply streams will obviously lead to a very different gas industry structure depending on what combination is pursued. This is however something not considered in the IRP. This is considered in more detail in the GUMP, which will integrate with the IRP in future revisions. Similarly, these plans (IRP and GUMP) are guided by the overarching IEP (as is the Liquid Fuels Master Plan (LFMP) currently under development). The integration between the key energy planning processes in the South African energy sector is shown in Figure 2.13.

Table 2.1: Installed capacities and load factors of new CCGT/OCGT for South Africa as per IRP 2010 (DoE, 2011b) and Base Case of the IRP 2010 Update (2013) (DoE, 2013b).

IRP 2010 Policy adjusted	**CCGT**	**OCGT (new)**
Total electricity demand in 2030	435 TWh, 68 GW (peak load)	
Installed capacity in 2030	2.4 GW	3.9 GW
Electricity production in 2030	4.2 TWh *(shale gas equivalent: 25-35 PJ/a)* *(LNG equivalent: 0.8 mmtpa)*	0.1 TWh
Average load factor in 2030	20%	< 1%
IRP Update 2013 Updated Base Case	**CCGT**	**OCGT (new)**
Total electricity demand in 2030	410 TWh, 61 GW (peak load)	
Installed capacity in 2030	3.6 GW	4.7 GW
Electricity production in 2030	12 TWh *(shale gas equivalent: 70-80 PJ/a)* *(LNG equivalent: 2.5 mmtpa)*	0.9 TWh *(shale gas equivalent: 10-15 PJ/a)* *(LNG equivalent: 0.5 mmtpa)*
Average load factor in 2030	38%	2%
Total demand in 2050	525 TWh, 80 GW peak load	
Installed capacity in 2050	6.4 GW	12.2 GW
Electricity production in 2050	12 TWh *(shale gas equivalent: 70-80 PJ/a)* *(LNG equivalent: 2.5 mmtpa)*	3.3 TWh *(shale gas equivalent: 35-45 PJ/a)* *(LNG equivalent: 1 mmtpa)*
Average load factor in 2050	22%	3%

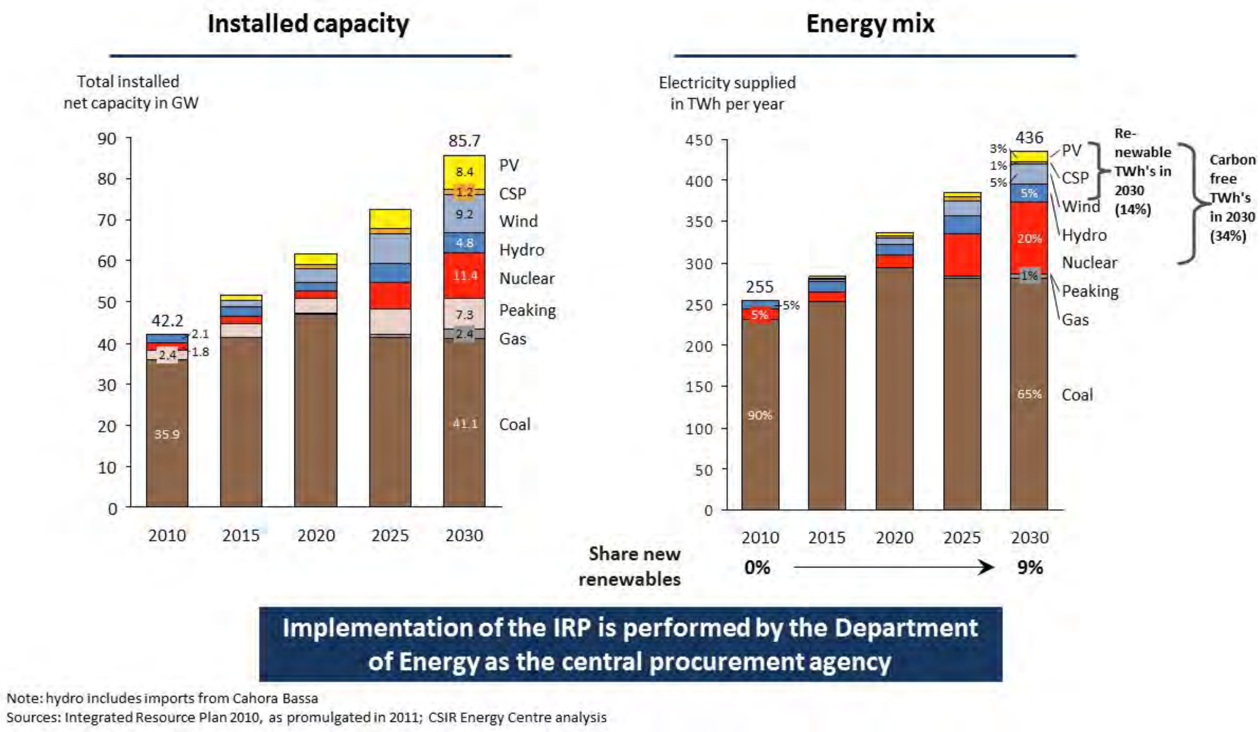

Figure 2.13: IRP 2010-2030 as promulgated in 2011

2.2.2 Impacts and mitigations

For reference, scenarios considered in this scientific assessment report are summarised in Table 2.2.

Table 2.2: Overview of scenarios as defined for the scientific assessment

Scenario	Available shale gas	Annual shale gas production (40 years)[1]	Estimated cost of shale gas[1]
Scenario 0 (Reference Case)	-	-	-
Scenario 1 (Exploration Only)	0 tcf	0 PJ/a	N/A
Scenario 2 (Small Gas)	5 tcf ≈ 5 300 PJ ≈ 1 500 TWh	130 PJ/a ≈ 40 TWh/a *(≈50% of current natural gas supply in South Africa)*	6-10 US$/MMBtu = 20-35 US$/MWh
Scenario 3 (Big Gas[2])	20 tcf ≈ 21 000 PJ ≈ 5 900 TWh	530 PJ/a = 150 TWh/a *(2.5-3.0 times current natural gas supply in South Africa)*	4 US$/MMBtu = 15 US$/MWh

[1] *Estimated based on generally accepted industry practice and national energy planning resources.*
[2] *The "Big Gas" scenario of this report and the "Big Gas" scenarios of the IRP and GUMP are not the same scenarios and should be treated accordingly.*

In principle, "expensive", "nominal" and "cheap" gas prices can be envisaged from an energy planning perspective for the scenarios presented. At this stage, whether natural gas is sourced from regional pipeline imports, LNG imports or shale gas is not considered yet nor is the source of gas critically significant from an energy planning perspective. The impacts on energy planning and energy security for each of the scenarios are outlined.

For all cases we assume that the available gas quantities are not a constraint and that only economic considerations determine gas utilisation[1].

1) Expensive gas (gas priced between 10-20 US$/MMBtu - ≈35-70 US$/MWh)
    a. It is economical to utilise gas-fired power stations as an enabler for renewables (solar PV and wind), where the relatively expensive gas provides the flexibility to allow large quantities of relatively cheap renewables based electricity to be deployed in the electricity sector. This is one of the many complementarities between natural gas and renewables like solar PV and wind (Lee et al., 2012). As mentioned in the draft of the GUMP, gas usage at these prices would also act as a "primer" for possible future expanded natural gas usage in the wider economy. Solar PV and wind act as fuel-savers for the existing thermal fleet (coal and gas). Depending on the cost of new build coal and nuclear capacity, the mix of solar PV, wind and natural gas can already be cheaper than these new-build options, even at these high gas prices (gas-based electricity will only make up a small portion of the total solar PV, wind and gas mix) (Bischof-Niemz, 2016).
    b. The electrical grid implications in this case will be minimal as significant transmission grid infrastructure already exists in the study area and it is likely that there will be a de-loading effect on the large North-South transmission corridor for the proposed power plant. Of course, sufficient proactive detailed grid planning will be required of which a significant portion of this is already being performed as part of various strategic planning documents (TDP, GCCA and SGP previously outlined).
    c. It is also economical to use gas as a substitute to electricity in the heating sector (especially residential space heating and cooking). Of course, localised heating demand in the study area will likely be very small. As a result, associated pipeline infrastructure will need to be developed if deemed economically feasible to transport gas to major urban settlements where end-use markets will be much larger.
    d. For a large compressed natural gas (CNG) uptake in the transport sector these gas prices are too high. However, even at high natural gas prices, the use of gas in transportation can prove beneficial in terms of emissions (especially in urban environments).

[1] Projections of actual shale gas prices would require an individual investigation in itself (or set of investigations); hence, the reason for assuming three cases of shale gas prices ("cheap", "nominal" and "expensive"). The draft of the GUMP does attempt to estimate shale gas prices but these are for illustrative purposes only.

e. For GTL production these prices are also too high (Sajjad et al., 2014; Al-Shalchi, 2006). Break-even crude oil prices at which GTL would be feasible at these natural gas prices would be in the range of ~100-180 US$/bbl i.e. only in very expensive crude oil scenarios.

f. The price of gas at these levels is aligned with the IRP Update 2013 (~11 US$/MMBtu). Thus, the gas volume by 2030 at these gas prices is anticipated to be as per the IRP Update 2013, approximately 80-90 PJ/yr (3 mmtpa of LNG equivalent), which is an additional ~50% of current gas demand in South Africa.

2) Nominal gas (gas priced between 6-10 US$/MMBtu – ≈20-35 US$/MWh)

a. Solar PV and wind are still fuel savers for a gas-fired power fleet, because the full lifetime cost of solar PV and wind per energy unit (today: 50-70 US$/MWh; by 2030: 40-60 US$/MWh) are still lower than the pure fuel-cost of gas-fired power generation. The mix of natural gas, solar PV and wind is now certainly cheaper than new-build coal and nuclear capacity.

b. More detailed grid planning (not only relating to the study area) may be necessary in this case as a result of significantly higher levels of gas-fired generation in a number of geographical locations. This will be in addition to the periodic strategic plans currently developed by Eskom (TDP, GCCA and SGP amongst others). Likely geographical locations could include locations within the study area, ports (Saldanha Bay, Mossel Bay, Richards Bay, Coega) and possibly areas surrounding Secunda and Sasolburg where pipeline gas is currently imported from Mozambique (Transnet SOC Ltd, 2015).

c. The utilisation of gas in the heating sector starts making sense not only in residential applications with relatively high cost of alternatives (high residential electricity tariffs), but also in industrial applications for process heat production (competitors: coal, biomass, cheaper-priced electricity). As previously mentioned, associated pipeline infrastructure will need to be developed if deemed economically feasible to transport gas to major urban settlements where end-use markets will be much larger.

d. Petrol and diesel cost approximately 40 US$/MWh to produce (at 50 US$/bbl crude oil price). At the assumed gas prices it therefore starts to become economical to convert the petrol-driven car fleet to CNG fuel. To put this into perspective, the petrol energy demand in Gauteng represents approximately 36 TWh/yr (South African Petroleum Industry Association (SAPIA), 2014). This is equivalent to ≈120 bcf/yr of natural gas or 20% of South Africa's 2013 natural gas production and imports.

e. For GTL or other chemical processes, the envisaged gas prices are still too high (Sajjad et al., 2014; Al-Shalchi, 2006). Break-even crude oil prices at which GTL would be feasible at these natural gas prices would be in the range of ~70-100 US$/bbl.

f. The additional gas volume triggered at these gas prices is likely higher than in the IRP Update 2013 as a result of additional end-use opportunities for gas at these prices. A re-run of the IRP at these gas prices would likely also lead to solar PV/wind/gas contributing significantly more to the electricity mix than currently envisaged. Indicative additional gas demand is 200-300 PJ/yr (56-83 TWh/yr or 190-280 bcf/yr). This is made up of 200 PJ/yr in the electricity sector to balance VRE and 100 PJ/yr from additional gas demand outside the electricity sector.

3) Cheap gas (gas priced at 4 US$/MMBtu – ≈15 US$/MWh)

a. Baseload gas-fired power generation in the form of CCGTs are now the cheapest new-build options of all alternatives (selected existing coal plants could also be repowered to run on natural gas if deemed feasible). It is cheaper than new-build coal, but in addition the pure fuel cost of natural-gas-fired power stations are now cheaper than the envisaged full lifetime costs of solar PV and wind. Solar PV and wind do not play a cost-efficient fuel-saver role anymore. From a pure economic perspective, it would make most sense to supply the entire electricity demand from natural gas only (refer to Big Gas scenario in IRP Update 2013 and draft of the GUMP). But from an environmental perspective, significant amounts of renewables would have to be introduced into the electricity system to achieve the country's CO_2 reduction targets. A pure gas-based power system and a VRE/gas power system are cost-wise at a tipping point at such low gas prices. Therefore, it a minimal regret decision to deploy renewables anyways, even if the fuel-saver logic of scenarios with higher gas costs does not fully apply anymore.

b. Significant changes in detailed grid planning assumptions will be necessary as a result of notable changes in generation mix (as mentioned above). As previously mentioned, in addition to the strategic grid planning performed in periodic plans like the TDP and SGP it will be necessary to perform a significant amount of detailed grid planning in order to integrate the significant gas-fired fleet when gas prices are at these low levels.

c. Gas is fully cost competitive in all heating applications. Associated pipeline infrastructure will need to be developed to transport gas to major urban settlements for residential end-use. Local industrial demand may be significant in this scenario.

d. Gas is fully cost competitive in the transport sector as replacement fuel for petrol/diesel-driven vehicles.
e. GTL now also starts to become economical (Sajjad et al., 2014; Al-Shalchi, 2006) as break-even crude oil prices would be > 50 US$/bbl – however for the domestic market it is likely more reasonable to convert the transport fleet into CNG-driven vehicles. In addition, the high carbon-intensity of GTL fuels will have clear impacts on South African climate change obligations. For an export market, GTL-based fuel can make economic sense but it is likely in this scenario that global oil prices will also be low as a result of successful shale programs globally. However, because of the high carbon-intensity of such a fuel it is unlikely that the addressable market size globally will be large.
f. At such low gas prices the domestic production of fertilisers may start to make economic sense.
g. Exporting of natural gas through LNG export terminals may become an option.
h. The additional gas demand under this very-low gas price scenario would be as per the Big Gas scenario of the IRP Update 2013, i.e. between 2 600 – 3 300 PJ/yr (720 – 920 TWh/yr, 2 450-3 100 bcf/yr) with additional offtake from many sectors outside the electricity sector.

Reference Case and Exploration Only Scenario

The Reference Case and Exploration Only scenarios align quite well with the draft IEP scenario where no shale gas is assumed. The impact of this is that energy security will be slightly reduced following an increased requirement for imports of comparatively more expensive refined petroleum products and LNG and/or pipeline imports. This scenario also aligns quite well with the “Niche” scenario in the draft GUMP, where gas is predominantly imported (via LNG terminals) with very small scale indigenous production and regional pipeline imports (an estimate of 1 tcf of overall gas supply assumed for South Africa in this scenario).

In the electricity sector, the status quo in energy planning would be to consider shale gas as an “add on” to the already planned GTP generation based on the abovementioned LNG and/ or regional pipeline imports. No shale gas will mean that the IRP base case planning assumptions are implemented, and any cheaper gas than planned will improve the cost and flexibility position.

Small Gas

The draft version of the GUMP estimates shale gas prices in the range of 7-11 US$/MMBTu, and up to 10-14 US$/MMBTu if the state’s free carry is implemented as part of the MPRDA Amendment

Bill and associated legislation being considered (depending on size of reserves and cost assumptions). In this scenario, it is likely to be on the higher end of the estimation at 11-14 US$/MMBTu.

This scenario aligns quite well with the “Hub” scenario of the GUMP where a combination of limited domestic shale gas (and CBM) is available, and localised hubs develop around gas sources i.e. surrounding the study area for shale gas. In the GUMP, there is an estimate of 1-10 tcf of gas supply assumed in this scenario (fitting quite well with the volumes assumed for this scenario, 5 tcf).

The quantity of shale gas available in this scenario is approximately 65% of the natural gas in the South African energy system. The gas volume in this scenario is therefore not suitable for a very large uptake of natural gas and subsequent large gas infrastructure investments. In this scenario the shale gas will likely be utilised for power production and possibly some domestic offtake with small volumes (some residential and industrial heating applications and possible conversion of a portion of the petrol/diesel-driven car fleet to CNG) in urban environments outside of the study area.

In this scenario, some additional detailed electrical grid planning (not only relating to the study area) may be necessary as a result of likely higher levels of gas-fired generation in a number of geographical locations.

It is unlikely that GTL will be deployed in this scenario, as the quantities of available natural gas are expected to be too small to justify such investment. In this scenario there could be a transition of anchor gas demand away from imported gas (pipeline and/or LNG) to domestic shale gas. As long as the shale gas is cheaper than these two alternative gas sources, a substitution effect will happen. No additional switching to gas due to low enough prices would materialise.

The main effect of this scenario on energy planning is a trade balance effect, where imported gas sources would be substituted with domestic shale gas. No significant implications are envisioned regarding gas transmission infrastructure planning requirements unless CNG for transportation in urban environments is opted for following which a pipeline network to these urban environments will be required.

Big Gas

As previously mentioned, the draft version of the GUMP estimates shale gas prices in the range of 7-11 US$/MMBTu and up to 10-14 US$/MMBTu if the state's free carry is implemented as part of the MPRDA Amendment Bill and associated legislation being considered (depending on size of reserves and cost assumptions). In this scenario, the price of shale gas is likely to be on the lower end of the estimation at 7-10 US$/MMBTu or less. However, there is a risk of escalating costs even with high shale gas quantities due to up-scaling challenges.

The quantities of shale gas in the Big Gas scenario align relatively well with the IRP 2013 Update Big Gas scenario and high levels of shale gas in the "Big Gas" scenario of the draft GUMP, in which the assumption of a significant shale gas-based boom occurs in South Africa (with gas at relatively low prices). There is assumed gas supply of 10-30 tcf of gas supply in South Africa in this scenario. The assumed gas price in this Big Gas scenario of the IRP Update 2013 is 4 US$/MMBtu. This Big Gas scenario of the IRP 2013 Update and draft of the GUMP is slightly higher when compared to the Big Gas scenario for this report in terms of assumed gas costs but is used as a proxy at this stage to represent a large shale gas scenario. To give an idea of the relative scale of this, in the Big Gas scenario of the IRP Update 2013 the total gas consumed in 2030 and 2050 absorbs the shale gas quantities of the Small Gas and Big Gas scenarios respectively in 6-8 years.

The results for a "Big Gas" scenario from the IRP Update are shown in Table 2.3. In this case of very cheap gas, the bulk of the South African electricity is supplied from gas-fired power stations. The entire fleet of CCGTs now runs at 70-80% average annual load factor, supplying mid-merit and baseload demand. In 2030, there is a ≈25% share of gas fired power generation in the energy mix while in 2050 this becomes ≈85% (this is a very imbalanced energy mix but is expected as a result of this being a "Big Gas" scenario).

The rollout of these levels of gas-fired power generation will likely necessitate significant changes in detailed transmission grid planning assumptions as a result of notable changes in generation mix (not only for gas fired generation). As previously mentioned, detailed grid planning performed in the periodic plans like the TDP and GCCA will need to be updated accordingly.

In this scenario, gas is fully cost competitive in heating (residential/commercial/industrial), transport, GTL (with the development of a new GTL facility), domestic fertiliser production and possibly LNG export applications.

Table 2.3: Installed capacities and load factors of new CCGT/OCGT in South Africa as per the Big Gas scenario of the IRP Update 2013 (DoE, 2013b)

IRP Update 2013 Updated Base Case	**CCGT**	**OCGT (new)**
Total electricity demand in 2030	410 TWh, 61 GW (peak load)	
Installed capacity in 2030	16.3 GW	1.4 GW
Electricity production in 2030	106 TWh *(shale gas equivalent: 600-800 PJ/a)*	0.3 TWh
Average load factor in 2030	74%	2%
Total demand in 2050	525 TWh, 80 GW peak load	
Installed capacity in 2050	62.5 GW	6.7 GW
Electricity production in 2050	440 TWh *(shale gas equivalent: 2 600-3 300 PJ/a)*	0.3 TWh
Average load factor in 2050	80%	< 1%

2.3 Risk assessment

2.3.1 Measuring risks and opportunities

The risk assessment approach considers risk to be the product of the probability of a specific event/trend occurring and the consequences of that specific event/trend with/without mitigation[2].

Table 2.4 summarises the impacts considered in the following risk assessment. Details of the impacts are:

1) Energy security: How does the development of shale gas affect the position with respect to energy security?
   a. Consequences of reduced energy security has the following range:
      i. *"Slight"* considered to be a minimal increase in energy imports of an additional ~5% from existing ~20% of total primary energy;
      ii. *"Extreme"* is considered to be a doubling of energy imports to more than 50% of total primary energy.
   b. The risk of reduced energy security with low levels of SGD is relatively low but measurable as increased imports of LNG will be necessary (as well as refined petroleum products). Even without shale gas though, the planning assumptions are such that energy security and energy independence are not jeopardised significantly (LNG infrastructure is already being considered as the "primer" for gas to play a bigger role in South Africa's energy future). Any domestic energy

[2] Please refer to the Preface of this scientific assessment for details on this approach (Scholes et al., 2016).

source in addition to the already highly endowed energy landscape (abundant coal, solar and wind resources) can only improve the already high security of supply level.

c. The high dependence of the country on imported crude oil for transport is an energy security consideration that if abundant and cheap shale gas results; GTL, CNG and electricity-driven transport systems could bolster energy security.

d. The primary actors likely best positioned to mitigate against energy security risk related to shale gas would be at a national level i.e. the DoE and Department of Mineral Resources (DMR). Other actors would include Nersa, state-owned enterprises (Eskom, PetroSA) and upstream/midstream operators and developers.

2) Energy cost: How does the development of shale gas affect the cost of energy in South Africa?

   a. Consequences of increased energy costs has the following range:

      i. *"Slight"* is considered to be annual energy cost increases aligned with consumer price index (CPI);

      ii. *"Extreme"* is considered to be annual energy cost increases at more than double CPI.

   b. The risk of high energy costs due to SGD is low if energy planning is initially based off LNG and imported piped gas as baseline planning assumptions.

   c. The risk is mainly linked to sub-optimal planning outcomes if energy planning is based on the assumption of the availability of low-cost shale gas which then does not materialise. Shale gas is low risk when planning off a zero shale gas baseline. The main risk arises if shale gas pricing/volumes are assumed, influencing investment decisions, but then don't materialise. At this stage, the key mitigation is that energy planning principal documents (IEP, IRP and GUMP) do not primarily assume cheap shale gas but rather assume the availability of shale gas as an option in specific scenarios.

   d. The primary actors who would likely be in the best position to mitigate against high energy costs would be at a national level and include Nersa, DoE and DMR. Other actors would include state-owned enterprises as well as private operators and developers active in the upstream/midstream South African gas market.

3) Energy accessibility to disadvantaged populations: How does the development of shale gas affect the delivery of modern energy to disadvantaged communities?

   a. Consequences of energy accessibility has the following range:

      i. *"Slight"* is considered to be 100% envisioned access to modern energy systems;

ii. *"Extreme"* is considered to be any decline in access to modern energy systems as a result of SGD.

b. Communities in the immediate study area of the SGD could benefit directly from the available gas either via cheap shale gas supply from electric power generation blended into the power generation mix (which when provided with electricity access will realise the benefits of cheap modern energy) or gas for direct use in residential heating/cooking, localised commercial/industrial end-use applications (creating job opportunities) and possibly transport end-use.

c. If shale gas does not materialise, electrification in the study area is already planned for where access is not yet available as defined in the NDP 2030 where universal access is envisioned.

d. There is an opportunity for energy price trajectories to be lower into the future relative to other options if significant cheap shale gas is found. In turn, this will result in cheaper energy access to disadvantaged populations.

e. Communities in the rest of South Africa do not feel the direct benefit of shale gas availability but could realise these benefits via reduced energy system costs and environmental impact as significant gas-fired power generation will likely displace coal-fired power generation. If shale gas does not materialise, the rollout of solar PV and wind power generation in South Africa will still allow for significantly reduced energy system costs and environmental impact.

f. The primary actors who would likely be in the best position to mitigate against reduced energy accessibility would be at a national level (the DoE). State owned enterprises like Eskom as well as municipalities implement electricity access specifically in areas that do not currently have access via the DoE subsidised Integrated National Electrification Programme (INEP). Direct access to gas for heating/cooking for residential use would be led by DoE, Nersa and downstream gas infrastructure developers as minimal existing infrastructure is currently in place.

4) Potentially obsolete energy infrastructure lock-in: Does the development of shale gas pose the risk of locking the country into potentially obsolete energy infrastructure?

a. Consequences of potentially obsolete energy infrastructure has the following range:

i. *"Slight"* is considered to be investment in two (2) or less major upstream/midstream infrastructure investments that become obsolete i.e. a gas-fired power station, pipeline, storage, LNG facility etc.;

ii. *"Extreme"* is considered to be investment in an integrated network of gas infrastructure that becomes obsolete from upstream to midstream to downstream investments e.g. LNG import facilities, storage facilities, gas-fired power stations, GTL facilities, gas transmission pipelines, distribution and reticulation infrastructure.

b. Planning for large shale gas uptake could lead to the development of large GTL infrastructure for transport end-use. This may become obsolete if envisaged shale gas quantities and costs do not materialise. In order to mitigate this, it would likely be better to continue importing liquid fuels into the medium term, and also as a result of the high overall CO_2 emissions associated with GTL technology anyway.

c. Planning for large shale gas uptake at very low prices and with significant volumes could lead to less development of renewable energy sources (at very low gas prices a high energy-share of gas-fired power stations can potentially be cheaper than a mix of solar PV, wind and relatively more costly natural gas fired generation). However, if the envisaged low shale-gas costs do not materialise, then the large solar PV and wind fleet that is needed as a gas fuel-saver is only built with a significant delay, and there is little risk in stranded gas-fired power generation.

d. Obsolete pipeline infrastructure to connect potential shale gas to demand areas could be a risk. In order to mitigate this, only when reasonable expectation and evidence of commercial scale shale gas resources are found should there be investment decisions made on pipeline infrastructure. Localised and limited power generation in the study area should be pursued initially with imported LNG and/or regional piped gas being sought while initial SGD is being undertaken. Only once significant shale gas volumes at proven low prices is feasible, should pipeline infrastructure be considered for transport of gas to demand areas.

e. Obsolete LNG import infrastructure, which is a natural outcome of a Big Gas scenario (a consequence of success), could materialise, but the associated storage facilities could potentially be converted to support liquefaction for LNG export and thus would not be stranded.

f. Gas reticulation infrastructure for residential/industrial/commercial end-use may become stranded if developed too quickly. Similar to large pipeline infrastructure from the study area to demand areas around the country, developments in this regard should be moderated initially until significant shale gas volumes at feasible prices are established.

g. There is a risk of gas end-users converting processes to gas and then having sub-optimal outcomes as a result of higher gas prices and needing to convert to other energy sources if gas prices increase. Again, the switch to gas as a primary energy source should only be sought once domestic gas volumes and prices are better defined (early adoption will prove risky).

h. As for power generation, the risk of stranded assets is relatively low, as a gas fleet built on the assumption of large and cheap shale gas supply can be utilised in a Big Gas scenario and in a solar PV/wind/LNG or solar PV/wind/piped gas scenario alike (with lower load factors – which does not affect the unit cost much for relatively cheap-to-build gas-fired power stations). The clear requirement for pipeline infrastructure to get shale gas to demand centres not located in the study area is a risk. However, planning for and implementation of significant pipeline infrastructure from the study area to demand centres will only take place once considerable verification of the shale gas resource has taken place and risk of stranded infrastructure is minimised.

i. Key actors to mitigate against obsolete infrastructure investment would include DoE at a national level as well as key state-owned enterprises (Transnet, PetroSA) as well as upstream/midstream developers. Key actors in mitigating against over-investment in gas distribution and reticulation infrastructure would likely include DoE, Nersa and downstream industry stakeholders.

5) Emissions:

a. For details on the consequences of a risk of a change in emissions please refer to Winkler et al. (2016).

b. Generally, an increase in carbon emissions relative to an alternative scenario that is based on VRE and (more costly, but less) natural gas. If shale gas is found at very cheap prices, it will play a larger role in the electricity mix, displacing coal but also replacing some VRE. The more gas-heavy VRE/gas mix will lead to higher overall carbon emissions from the electricity sector (but less carbon intensive than present day). A balanced policy approach will be necessary in this regard to ensure planned carbon emission trajectories are adhered to i.e. gas fleet expansion along with carbon free power generation (solar PV and wind).

c. More importantly, very cheap shale gas has the potential to increase the volume of GTL production in South Africa (which is a cost-efficient process if input gas cost is low) but a very carbon-intensive one. In order to mitigate this, crude and/or refined fuel imports may need to continue even with cheap natural gas that could enable economic GTL conversion. Winkler et al. (2016) considers this in more detail.

   d. The prevention of gas leakage during production and transport is important to any potential carbon mitigation scheme if large scale natural gas use is considered for South Africa.

6) Network infrastructure:
   a. Consequences of insufficient network infrastructure has the following range:
      i. *"Slight"* is considered to be when there is largely sufficient network infrastructure available but constrained electrical networks result in a re-dispatch of the shale gas based power generation less than 5% of unconstrained levels and gas transmission pipelines are never utilised at more than 100% monthly average utilisation;
      ii. *"Extreme"* is considered to be when there is constant curtailment of shale gas-fired power generation as a result of insufficient electrical transmission networks (>20% curtailment) and gas transmission pipelines are utilised at above 100% daily utilisation for one day in each month of the year.
   b. The development of sufficient network infrastructure to evacuate gas-fired power generation as well as transport natural gas to demand centres from relevant geographical locations (not only in the study area) becomes more essential at high shale gas volumes. It will become increasingly critical to ensure that sufficient electrical and natural gas network planning is periodically performed and updated in order to ensure sufficient network capacity at appropriate timescales in various locations (including the study area).
   c. Key actors to mitigate against insufficient transmission network infrastructure would include current state-owned enterprises like Eskom and Transnet while private industry midstream operators and developers would also play a key role. Key actors in ensuring sufficient gas distribution and reticulation infrastructure would likely include DoE, Nersa and downstream industry stakeholders.

2.3.2 Limits of acceptable change

The limits of acceptable change to SGD in South Africa as it relates to energy planning and energy security are assumed to be outlined in the following policy guiding principal planning documents:

- Integrated Energy Plan 2015 (IEP 2015) [DRAFT]
- Integrated Resource Plan (IRP) 2010-2030

- Integrated Resource Plan (IRP) Update 2013
- Gas Utilisation Master Plan 2015 (GUMP 2015) [DRAFT]

At a more strategic level, the NDP 2030 outlines the high level plan for the development of South Africa to 2030. The above guiding policy documents flow from the NDP 2030 and align with the envisioned future for South Africa as it relates to energy.

Of course, the relevant regulatory frameworks required and necessary legislation to enable the development of shale gas in South Africa will act as limits of acceptable change into the future. Details of the relevant legislation are included in Section 2.1.3 of this Chapter. The speed at which SGD could occur and resulting limits to change from the status quo will depend on the speed and flexibility of development of additional legislation and adjustments to existing legislation. More specifically, envisaged MPRDA amendments (as well as other associated legislation) in order to ensure a balance between investors and the state share in the value of projects.

Relatively small gas-fired power station capacities with low annual gas throughput are currently envisaged in the IRP 2010 but scenarios are included for “Big Gas” in the IRP Update 2013 and in the draft of the GUMP where significant natural gas finds are assumed (10-30 tcf). The other principal scenarios in the draft of the GUMP are “Niche” which assumes 1 tcf of gas supply in South Africa and “Hub” which assumes 1-10 tcf of gas supply.

Table 2.4: Risk Assessment Matrix for Energy Planning and Energy Security (See Section 2.3.1 for details)

			Without mitigation			*With mitigation*		
Impact	**Scenario**	**Location**	**Consequence**	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Energy security Negatively affected security-of-supply position	Reference Case	National	Substantial	Not likely	Low	None	Not likely	Very low
	Exploration Only		Substantial	Not likely	Low	None	Not likely	Very low
	Small Gas		Substantial	Very unlikely	Low	Moderate	Very unlikely	Low
	Big Gas		Substantial	Extremely unlikely	Low	Moderate	Extremely unlikely	Low
Energy cost Increasing electricity, heating and/or transport fuel cost	Reference Case	National	Moderate	Likely	Low	Slight	Likely	Very low
	Exploration Only		Moderate	Likely	Low	Slight	Likely	Very low
	Small Gas		Moderate	Not likely	Low	Moderate	Very unlikely	Low
	Big Gas		Slight	Not likely	Very low	Slight	Extremely unlikely	Very low
Energy accessibility to disadvantaged populations Inadequate supply of modern energy to communities in shale gas areas	Reference Case	Regional	Substantial	Likely	Moderate	Moderate	Not likely	Low
	Exploration Only		Substantial	Likely	Moderate	Moderate	Not likely	Low
	Small Gas		Moderate	Not likely	Low	Moderate	Very unlikely	Low
	Big Gas		Moderate	Very unlikely	Low	Moderate	Extremely unlikely	Very low
Lock-in to potentially obsolete energy infrastructure	Reference Case	National	Severe	Very unlikely	Low	Severe	Extremely unlikely	Very low
	Exploration Only		Severe	Very unlikely	Low	Severe	Extremely unlikely	Very low

			Without mitigation			*With mitigation*		
Impact	**Scenario**	**Location**	**Consequence**	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Investment into large energy infrastructure that does not match domestic shale gas supply	Small Gas		Severe	Not likely	Moderate	Severe	Very unlikely	Low
	Big Gas		Extreme	Likely	High	Severe	Not likely	Moderate
Emissions Increased emissions as a result of cheap shale gas that results in a relative change in future portfolio mix (less VRE, more gas)	Reference Case	National	Substantial	Extremely unlikely	Very low	Moderate	Extremely unlikely	Very low
	Exploration Only		Substantial	Extremely unlikely	Very low	Moderate	Extremely unlikely	Very low
	Small Gas		Substantial	Very unlikely	Low	Moderate	Very unlikely	Low
	Big Gas		Substantial	Likely	Moderate	Moderate	Very unlikely	Low
Availability of sufficient network capacity to evacuate gas and gas-fired power generation	Reference Case	National	Severe	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Severe	Extremely unlikely	Low	Slight	Extremely unlikely	Very low
	Small Gas		Severe	Very unlikely	Low	Slight	Very unlikely	Very low
	Big Gas		Severe	Likely	High	Slight	Very unlikely	Very low

2.4 Best practice guidelines and monitoring requirements

Best practice with respect to shale gas production and energy planning is best referenced to the US experience in recent years.

The story of North American shale gas, particularly within the United States, offers a deep set of experiences as to how the onset of large scale shale gas production impacts long-term energy planning decisions. However, it is an important element in the US story to understand that until shale gas took off, few could have truly anticipated such a pronounced and prominent future for shale gas. Figure 2.14 illustrates the sources of US natural gas production through its rapid transition to dominance of US natural gas production.

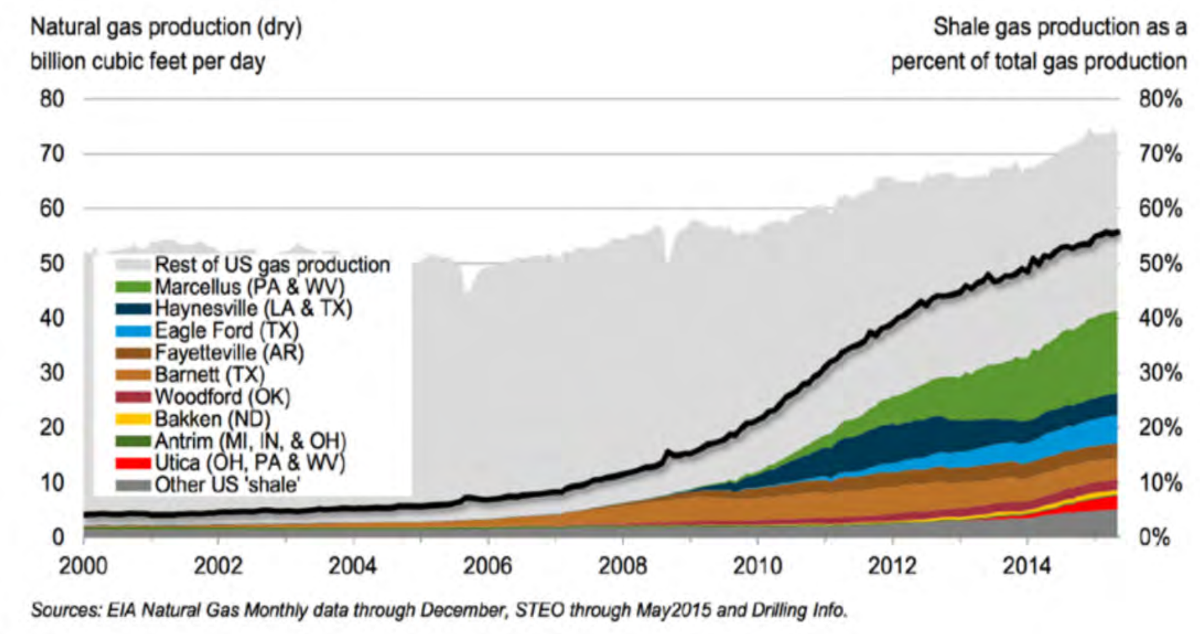

Figure 2.14: Sources of US Natural Gas Production (solid black line represents shale gas production as a percent of total gas production) (Staub, 2015).

It is also important to note that between 1999 and 2005, over 200 GW of new natural gas generation capacity was installed, reflecting an expectation of massive private sector investment in LNG import terminals, strong economic growth, lower capital intensity of new gas CCGT capacity relative to coal, and a variety of technological advancements which shifted the competitive landscape of natural gas CCGT generation over coal. While LNG import terminals never materialised, this massive (and largely underutilised) fleet was well positioned when abundant, low-cost shale gas began flooding the US market. Figure 2.15 illustrates natural gas generation quickly increasing and displacing coal-fired generation, reflecting many natural gas generators reaching a "tipping point" with respect to generation costs (driven by low fuel costs) where they could produce electricity at or below the cost of coal-fired generation, and in some cases, nuclear generation as well. Given that most CCGTs in the US currently sit beyond the aforementioned baseload "tipping point" of cost-competitiveness with nuclear and coal-fired generation, these facilities are often evaluated as the most economic candidates for providing baseload power (on top of being used for mid-merit and peaking services) during IRP processes. Given the cost of coal-fired generation in South Africa, and that in the immediate-term South Africa intends to import LNG, this baseload tipping point for CCGTs in South Africa is likely quite far away.

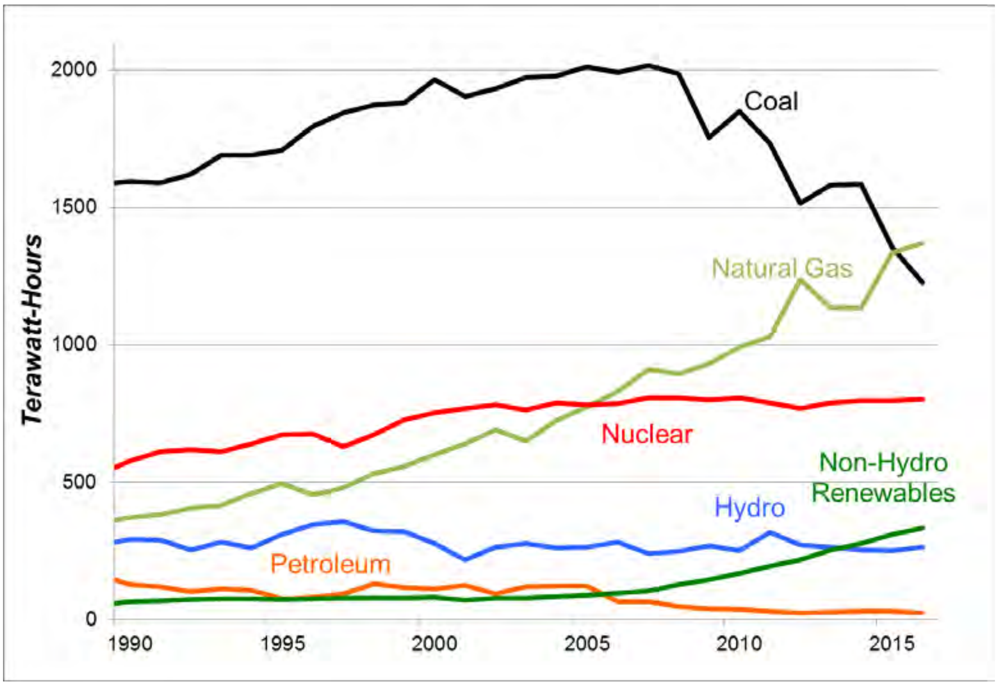

Figure 2.15: Annual US Generation by technology category 1990-2016 (EIA, 2016)

In order to understand how planning decisions were affected by the relative surge of US shale gas, it is first necessary to establish how US energy planning decisions are made in practice. Relative to the South African approach of more centralised and integrated energy plan with controlled private participation and competition, energy planning related activities are decentralised in the US, and nearly exclusively conducted by private sector entities with regulatory oversight. There is significant heterogeneity in the US market in terms of actors, interests, and activities.

Private sector planning activities, as they relate to shale gas, touch upon investment decisions for *inter alia*:

- Production, processing, storage and delivery infrastructure for shale gas.
- LNG export facilities.

- End-use investments across multiple industries (e.g., electric generation capacity, chemical production facilities, transportation fleet and refuelling infrastructure, heating and cooling infrastructure).

The private sector actors that develop shale-related infrastructure investment are a diverse and nimble group, having experienced massive and foundational market transformation in a very short period of time. They exhibit highly diverse characteristics with respect to:

- Expectations and risk tolerances for long-term price fluctuations due to evolving market dynamics and physical/market disruptions;
- Expectations of trends for various end-use sectors and regions across multiple timeframes;
- Expectations of the direction of the US LNG export market;
- Access to capital, financing, and hedging mechanisms;
- Existing investment portfolios and risk diversification strategies; and
- Regulatory paradigms (if any) to navigate.

Electricity planning processes for electric utilities, such as IRP, frequently employ natural gas price projections (informed by, *inter alia*, expectations of shale gas production) to inform and balance new investment decisions for generation capacity. Throughout procurement processes for new generation capacity, various mechanisms can be employed to manage risk and secure favourable natural gas prices. In some regions of the US utility planners are risk averse when it comes to natural gas price volatility and are currently reluctant to plan for gas-dominant generation mixes as a result. However, in other regions of the US, natural gas now accounts for over 50% of the electricity mix with many planners in these regions being urged by some stakeholders to not become over-exposed to gas as a generation source.

Perhaps salient for South Africa’s natural gas related power sector planning is that new natural gas power plants in the US are typically proposed by utilities and approved by regulators upon demonstrating that:

1) From a power system perspective, the economics of a proposed natural gas power plant must be proven as the most cost-effective option, relative to other generation options to meet grid requirements.
2) From a power system perspective, a given proposed project meets an expected and concrete need of the system (i.e. peaking, mid-merit, baseload) as demonstrated by a techno-economic modelling exercise that assumes a given price of natural gas fuel, among a variety of other input assumptions. This model will simulate dispatch of the generation portfolio based on lowest short-run marginal cost (*not* a Power Purchase Agreement (PPA) price) to meet

projected demand, as this is what the grid operator is obligated to do in real life, and quantify the need for new natural gas generators and their expected generation behaviour on this basis.

3) From the utility/regulator perspective, that the compensation level for the proposed plant (either via PPA price, or rate-based CapEx and OpEx) is efficiently discovered (often via public tender) and is near, at, or below the assumed short-run marginal cost modelled from the system perspective (a convergence between modelled cost and procured price).
4) From a project developer perspective, the proposed project will be a bankable investment based on the aforementioned compensation level and the expected generation profile over the economic lifetime of the facility.
5) From a gas market perspective, that natural gas fuel will be available when it is needed (and at a reasonable price) to meet demand and reliability requirements.

In the US context, the gas market is assumed to be deep and liquid during planning and procurement exercises, with minimal constraints with respect to fuel availability, storage, or contractual constraints (such as take-or-pay stipulations).There is generally strong convergence between the assumed/modelled short-run marginal cost of the facility in planning exercises and the overall compensation level for the proposed plant over its economic lifetime, such that projects are bankable and utilities/consumers are paying a fair price for electricity.

The South African context offers a unique set of circumstances with strong implications for planning. First, given the relative economics of all new-build generation options in South Africa, the power system will almost certainly require natural gas power plants for mid-merit and peaking services, and not for baseload. Second, without prior experience, it is unclear to what extent there will be convergence between assumed short-run marginal prices in planning exercises and compensation levels for project developers, and whether or not those compensation levels will make for bankable investments given the expected generation profiles of the projects. There is, however, a great degree of certainty that GTP PPAs will be higher than those of coal-fired power plants, but lower than diesel. Finally, South Africa does not have a deep and LNG market and must procure LNG from the global market, likely through a long-term take-or-pay contract.

Table 2.5 compares the relevant USA and South African solutions to a range of questions that might be raised while evaluating a prospective natural gas power plant investment, organised by stakeholder perspective.

Table 2.5: Questions for evaluating a prospective natural gas power plant investment by stakeholder perspective for the US and South Africa

Perspective	*United States of America (USA)*	*South Africa*
Power System – Energy Planner		
1. *Is this investment the most cost-effective option to meet the needs of the power system?*	**1.** Commonly addressed using a combination of techno-economic power sector modelling and engineering judgment.	**1.** South Africa's IRP process has addressed this question directly and allocated a defined, cost-effective capacity of natural gas power plants to be built using transparent assumptions about natural gas prices.
Power System Operator		
2. *Does the proposed project meet an expected and concrete need of the power system? What is the power plant's expected generation profile?*	**2.** Techno-economic modelling helps to ensure a concrete need is being met. Given the competitive landscape of generation technologies in the US, natural gas power plants are likely candidates for **baseload**, **mid-merit**, and **peaking** services.	**2.** Techno-economic modelling (via the IRP) helps to ensure a need is being met. Given the immediate-term expectations of imported LNG costs and competitive landscape of generation technologies, natural gas power plants are likely candidates for **mid-merit** and **peaking** services.
Utility/Regulator		
3. *Is the compensation level for the proposed plant fair? Was it efficiently discovered?*	**3.** There are a range of procurement mechanisms utilised by US utilities to ensure efficient price discovery.	**3.** The DoE Independent Power Producer Office (IPPO) has shown immense global leadership in ensuring efficient price discovery for renewable energy, and will likely be able to do the same for natural gas power plants.
4. *To what extent is there convergence between assumed/modelled costs and developer compensation levels?*	**4.** There tends to be strong convergence in the US context.	**4.** There is no experience as of yet to indicate the extent of convergence.
5. *To what extent are developer compensation levels near expected costs of other technologies?*	**5.** In the event that developer compensation levels are quite close to other expectations of other generation technologies, modelling and/or procurement processes may be revisited.	**5.** No experience as of yet. However, in South Africa, natural gas generation short-run marginal cost will almost certainly be more expensive than coal, but less expensive than diesel. Thus, there will not be a need to re-visit modelling or procurement processes.
Project Developer		
6. *Given the compensation level and expected generation profile, is this project bankable?*	**6.** Generally speaking, natural gas power plants that are centrally procured in the US are considered bankable investments.	**6.** There is no experience as of yet. After Round 1 of IPPO's GTP Programme, more information will be available.

Perspective	*United States of America (USA)*	*South Africa*
Natural Gas Market		
7. *Will natural gas fuel be available when it is needed and at a reasonable price to meet the power plant's needs?*	**7.** The natural gas market in the US is deep and liquid. In the current regime of abundant, low-cost shale gas, this answer to this question, generally speaking, is yes.	7. Natural gas will need to be purchased from the global market, likely via a long-term take-or-pay contract. An on-site offtake storage facility will need to be refuelled on a contractually agreed upon. Global LNG market, likely on a take-or-pay contract.
8. *Is the demand from the plant significant enough to obtain an economical fuel price?*	**8.** Yes (see #7)	**8.** There is no experience as of yet. Natural gas purchases will be to procure gas at volumes that stimulate market interest.
9. *What happens if the plant does not use all of the fuel it procures?*	**9.** Because of the deep and liquid market, there are a variety of contractual protections, hedges, storage schemes and alternative uses that can generally be used.	**9.** Natural gas power plants are expected to serve as the anchor customer in the immediate term, while a secondary market for LNG builds up. LNG procurement contracts should be tied to the expected generation profile of power plant, with some storage available to absorb fluctuations in utilisation between LNG top ups.

Shifting away from the US experience with shale gas, regarding procurement of gas-fired power generation in South Africa, the following is noted:

- The techno-economic parameters utilised in procurement should be informed by the power system cost minimisation (with policy adjustment considerations) analysis performed by the IRP or similar studies. Such parameters should include the capacity, year of commercial operation, dispatch profile, provision of reserves and other ancillary services. The IRP should hence provide the use-case specification for procurement. Going forward, the IRP should model anticipated gas price elasticity whereby gas volumes and pricing inter-dependencies are considered.
- The procurement process should be technology agnostic, allowing developers to select and optimise technology choices to minimise total cost for the anticipated dispatch profiles, gas pricing and other parameters (such would include open/close cycle operation, unit sizes and gas-engines/turbines).

- Gas fuel supply agreement will need to be tightly integrated with the power station PPA, ensuring synergy in gas volumes, gas quality, variability and reliability with the PPA dispatch regime and tariff.
- Power generation capacity and dispatch profiles should consider gas price elasticity. Anticipated gas volumes should be at levels that are anticipated to stimulate market interest and competitive gas pricing.
- Certainty in gas volumes should be provided via take-or-pay gas supply contracting for an initial period of time. Such certainty must however support flexibility in power generation dispatch as linked to the gas storage and logistical implications and constraints.
- The contracting must support the provision of flexible power in alignment with the IRP use-case. Current expectations are for high levels of operational flexibility via rapid starting, ramping, reserve provision, and load following.
- Gas fuel supply agreements for the power generation anchor demand should provide access to gas for third parties such as industrial gas users.
- Gas infrastructure and fuel supply agreements should be structured to allow future switching from e.g. imported LNG to future domestic shale gas. Such should include gas specifications that ensure that future indigenous gas sources are not prejudiced. Project bankability must be supported via ensuring adequate compensation for fixed assets that may be stranded in switching to alternative gas supplies e.g. LNG import infrastructure.

2.5 Gaps in knowledge

Available gas volumes and expected prices of domestic shale gas greatly impact the mix in the long-term energy planning (IEP, GUMP, IRP, and SGP). Research in this regard (volumes and expected prices) is the most needed type of research from a pure energy-planning perspective. This will likely be informed by the publication of the final versions of the IEP, IRP and GUMP (as well as associated data and studies that informed them).

The implementation of drilling and exploration by stakeholders with exploration rights in the study area will likely add significant knowledge from a near zero baseline at this stage.

If higher levels of shale gas volumes in the Big Gas scenario are considered (to become a ‘game changer’ scenario), who would be the primary anchor demand sectors (power generation, industrial, residential, commercial, mining, manufacturing) and at what prices would these demand sectors start to use or switch to natural gas provided by shale gas? Would supply of natural gas from other sources be more/less competitive at an aggregate level e.g. imported LNG, regional pipeline import, domestic offshore finds etc.?

Globally, recent publications like Bazilian et al. (2014) outline a research agenda on economic, environmental, and social dimensions of natural gas to ensure benefits of SGD are ensured (with a specific focus on the US but with applicability globally in many respects). At a high level, the following research agenda related to natural gas is as follows (as extracted from Bazilian et al. (2014)):

1) *Increased empirical research into environmental impacts from natural gas, including fugitive emissions of methane and water contamination issues (both surface and subsurface);*
2) *Comprehensive and integrated economic, environmental, and social research in order to understand trade-offs and interactions between different sectors and impacts; and*
3) *Development of decision support tools to convey results of integrated modelling to decision makers in an engaging and informative fashion. Given the scale of possible benefits and impacts from natural gas development, there is no time to waste in clarifying these choices.*

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CHAPTER 3

Air Quality and Greenhouse Gas Emissions

CHAPTER 3: AIR QUALITY AND GREENHOUSE GAS EMISSIONS

Integrating Author:	Harald Winkler[1]
Contributing Authors:	Katye Altieri[1], Simon Clarke[2], Rebecca M. Garland[3,4], Gerrit Kornelius[5], Matthew Meas[1]

[1] Energy Research Centre, University of Cape Town, Rondebosch, 7701

[2] Ibis Consulting, Rivonia, 2128

[3] Natural Resources and the Environment Unit, Council for Scientific and Industrial Research, Pretoria, 0001

[4] Unit for Environmental Sciences and Management, North West University, Potchefstroom, 2520

[5] Department of Chemical Engineering, University of Pretoria, Hatfield, 0028

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Executive Summary

Shale gas development (SGD) presents opportunities and risks with regards to air pollution and greenhouse gas (GHG) emissions. There is a potential opportunity to reduce emissions, if shale gas replaces ‘dirtier’ (more emissions-intensive) fuels, however, there is also a risk of increased emissions if shale gas is added to the existing energy mix, and displaces cleaner fuels for new capacity. Emissions of GHGs have global impacts, while impacts from air pollution are generally assessed at local and regional scales.

The highest risks assessed are due to leakage of methane prior to end-use, a potent GHG; and the exposure of workers to air pollutants on the wellpad. For all three SGD scenarios considered in this assessment, the scale of SGD in South Africa is assumed to be smaller than SGD in the United States of America (USA), which results in lower estimates of air pollution and GHG emissions for South Africa as compared to the USA, even in the Big Gas scenario (Figure i)[1].

An urgent priority is the early establishment of baselines (through air quality and GHG monitoring stations in the study area, and inventories for air pollutants and GHG emissions), to be followed by the design of continuous monitoring systems.

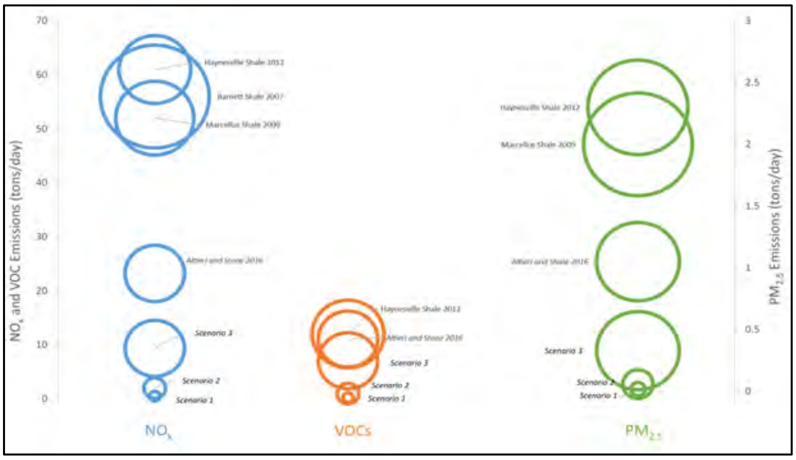


Figure i: Air pollutant emissions from bottom-up inventories for Karoo shale gas compared to main shale plays in USA.

Based on the scientific assessment, it is recommended that further research into the existing regulatory framework and its capacity to deal sufficiently with SGD, along with the potential to enhance institutional and human capacity be explored. Industrial activity in the study area is currently low and the need for this type of regulatory capacity does not currently exist. Good practice guidelines are needed to minimise impacts on air quality and reduce GHG emissions, with guidelines for control technologies, consideration of effective legal regulation, early establishment of baselines and

[1] Further details on figures in the executive summary are in the text surrounding the same figure in the main body of this Chapter.

continuous monitoring, and good governance enabled by coordination across several institutions (see Section 3.4).

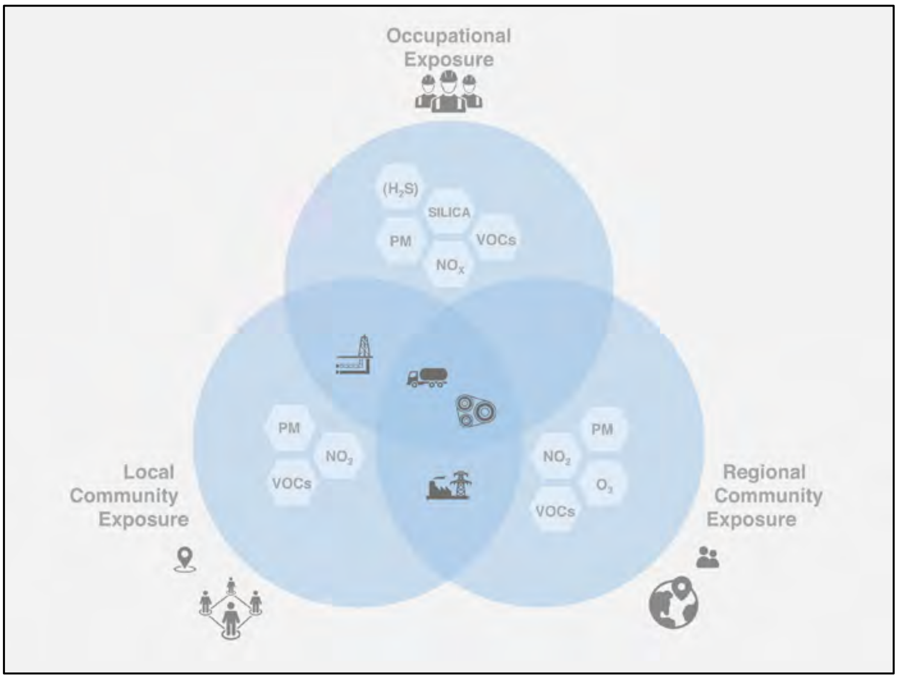


Figure ii: Air pollutants associated with occupational exposure, and local and community exposure.

Local air pollution

Both workers and the local and regional communities may be exposed to local air pollutants during the course of SGD (Figure ii). The air pollutants considered in this assessment are nitrogen oxide (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), diesel exhaust, particulate matter ($PM_{2.5}$, and PM_{10}), hydrogen sulfide (H_2S), ozone (O_3) and respirable crystalline silica. Activities which lead to air pollutant emissions include wellpad and infrastructure preparation (i.e. trucking of equipment), vertical and horizontal drilling, hydraulic fracturing, well completion, transportation (e.g. transport of water and waste materials), production stage distribution of the gas, and associated end-use of the gas. Table 3.6 summarises the main risks to deterioration of air quality.

There is a high risk of workers on the wellpad being exposed to air pollution, if mitigation is absent. This is driven by emissions of respirable crystalline silica, diesel exhaust and VOCs. It is anticipated that the risk of silica exposure can be effectively mitigated, although exposure to VOCs and diesel exhaust will be harder to mitigate. Thus, even with mitigation, occupational exposure is still assessed as a moderate risk.

Risks to human health from local and regional community exposure are assessed as low to moderate, in the Exploration Only (Scenario 1), Small Gas (Scenario 2) and Big Gas (Scenario 3) scenarios for SGD. For local communities, the risk of exposure to air pollution is driven by the increase in ambient PM concentrations, which already occasionally exceed national ambient air quality standards (NAAQS). For communities that are more than 10 km from a production block, the risk is driven by the potential exposure to increased truck traffic, which can be mitigated. The air quality impacts on agriculture and ecosystems are assessed as low or very low. Even at the lowest estimate for exploration alone (Exploration Only scenario), NO_x emissions from unconventional natural gas would dominate regional emissions due to the current low level of industrial activity in the Karoo. SGD on its own is unlikely to cause material exceedances of legal limits of nitrogen dioxide (NO_2) and ozone concentrations, even in the Big Gas scenario. For ozone and PM, no concentration limit has been determined below which there is no impact on human health. It is important to note that the confidence level of findings related to ambient concentrations is limited by the lack of regional air quality information (including measurements and photochemical modeling).

There is some opportunity for shale gas to improve indoor air pollution, which depends on displacing wood, coal and paraffin as domestic fuels. To realise the potential for air quality improvements through replacement of dirtier fuels, the fuel switch should happen in the same geographical area.

Greenhouse gas emissions

SGD presents both risks to increase and opportunities to reduce GHG emissions. The opportunity of emission reductions depends crucially on whether gas displaces coal (the main fuel in South Africa currently, with higher GHG emissions intensity), or gas displaces even lower-emission alternatives (such as renewable energy, nuclear, imported or domestically refined fuel). Even with the worst leakage rates, the ‘worst shale gas’ is roughly as emissions intensive as the ‘best coal’. But if gas displaces even lower-emitting alternative energy supply, GHG emissions would increase. The main risks of increased GHG emissions are summarised in Table 3.9.

Fugitive methane emissions are identified as a high risk in this assessment, and depend significantly on leakage rates and global warming potential (GWP) values (Figure iii). The risk of fugitive methane emissions under the Big Gas scenario might be reduced from high to moderate with mitigation and use of good practice in control technologies and systems.

Shale gas would reduce GHG emissions compared to coal by 0.54 t CO_2-eq per MWh. If Combined Cycle Gas Turbine (CCGT) plants displace nuclear or renewable energy plants, this would increase emissions intensity by +0.45 t CO_2-eq per MWh. By comparison, the emissions intensity of current coal plants is 0.99 t CO_2-eq per MWh.

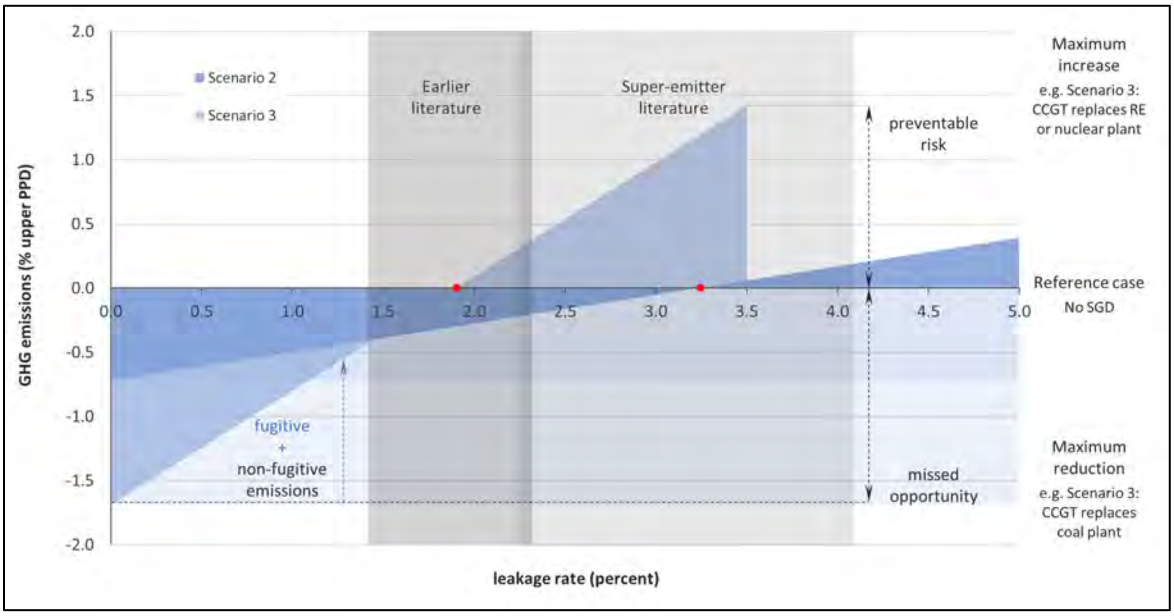


Figure iii: Implications for national GHG emissions for different leakage rates of fugitive methane.

Absolute changes in GHG emissions depend on projections of electricity produced, which is a matter of energy planning (see Wright et al., 2016). Making simple assumptions for this Chapter; the consequences of increased or reduced GHG emissions were calculated as slight to moderate in relation to the national emissions trajectory. An indicative scale of consequences, in absolute units (Mt CO_2-eq per year) was developed for this assessment drawing on the literature (Figure iv and Table 3.8).

Figure iv: Indicative consequences of increases in GHG emission reductions and opportunities for reductions.

Severe consequence can be seen in Figure iv for fugitive methane leading to a net increase in GHG emissions, assuming a Big Gas scenario and higher leakage rate. CCGT displacing new renewable energy or nuclear power has substantial consequences; whereas if gas displaces coal, this is the biggest opportunity to for a net decrease of GHG emissions in Figure iv. Replacing fuel produced from importing crude oil and refining it locally with GTL from shale gas has a low risk of increases, given that is assessed as likely with moderate consequences. The consequence for imported fuel is moderate (4.2 Mt CO_2-eq per year), which is still the case with mitigation but at lower scale (2.8 Mt CO_2-eq per year). The latter consequence comes close to the consequence of GTL displacing imported fuel refined locally (2.4 Mt CO_2-eq per year). Some relative emissions factors need further study, notably for coal- and gas-to-liquids.

International experience regarding leakage rates deserves further study, as the range in the earlier literature is being extended by recent findings on super-emitters – low-frequency but high-consequence events.

CHAPTER 3: AIR QUALITY AND GREENHOUSE GAS EMISSIONS

3.1 Introduction

One dimension of assessing the risks and sustainability of shale gas development (SGD)[2] is the impacts of air pollutant and greenhouse gas (GHG) emissions; these emissions, while they have similar sources, have varying spatial and temporal aspects. Air pollution can have near-source local impacts (e.g. impacts from occupational exposure and impacts to nearby communities), as well as regional impacts. The potential risk of SGD to impact air quality is assessed through its potential to harm human health, with considerations for impacts on ecosystems and agriculture also discussed. GHG emissions, which contribute to climate change “unequivocally” (Intergovernmental Panel on Climate Change (IPCC), 2007; 2013; 2014), add to global concentrations in the atmosphere no matter where in the world they are emitted, and thus the GHG emissions from SGD are global in nature. For both air pollutants and GHGs, there are risks of negative impacts with higher levels of emissions, e.g. negative impacts to human health from exposure to air pollution, or increased levels of GHG emissions in South Africa. There are also opportunities to reduce impacts from other fuel sources.

The overall scope of this Chapter covers emissions of gases to the atmosphere, with impacts at various spatial and temporal scales. Emissions of air pollutants with impacts at local and regional scale are referred to in this Chapter as simply ‘air pollutants’, resulting in changes in ‘air quality’. The impact of GHGs is at a global scale. A more detailed scope is discussed for air quality in section 3.2.1 and for GHGs in section 3.3.1.

For both air quality and GHG, the use of shale gas and possible alternative fuels matters. There is a potential opportunity to reduce emissions, if shale gas replaces ‘dirtier’ (more emissions-intensive) fuels. There is also a risk of increases of emissions, if shale gas is added to the existing energy mix rather than technologies using cleaner fuels. The GHG risk assessment considers cases where shale gas is used in addition to existing electricity generation and liquid fuel supply technologies, as well as cases where shale gas replaces coal, renewable energy or nuclear power; and coal-to-liquids (CTL) or domestically refined products from imported crude oil (see section 3.2.1). Similarly, some of the potential benefits of reducing indoor air pollution depend on shale gas displacing other fuels (e.g. coal), in the form of electricity or piped gas. However, a key difference between air quality and GHG considerations is the spatial component. The source and location where GHGs are emitted is not directly related to where its impacts are felt (which is a function of global emissions), whereas location matters for air quality. Electricity generation from coal for example; also produces air

[2] See definition for shale gas development in Burns et al. (2016).

pollution – but in a different geographical area to the study area. While there is some transport of air pollutants over the distance between Mpumalanga and Karoo, the concentrations of the air pollutants transported would generally be much smaller than the potential impacts from the local SGD (Abiodun et al., 2014; Freiman & Piketh, 2003; Nzotungicimpaye et al., 2014; Piketh et al., 1998).

Emissions of air pollutants and GHGs are closely associated with activities covered in other Chapters of the scientific assessment, notably energy supply and use – as the previous paragraph makes clear (see Wright et al. 2016). Impacts of air pollution are also associated with visibility (Oberholzer et al., 2016), spatial planning (i.e. location of human settlements) (Van Huyssteen et al., 2016), health (Genthe et al., 2016) and agriculture (Oettle et al., 2016).

This rest of this Chapter is organised as follows. Section 3.2 is the major section dealing with air quality, its scope, potential impacts, limits of acceptable change, in order to conduct an analysis of risks and opportunities, with risks summarised in section 3.2.5 and Table 3.6. Section 3.3 is the main section dealing with GHG emissions, with the overview of risks in section 3.3.5 and Table 3.9. Note that in both sections 3.2 and 3.3, consistent with guidance to the scientific assessment, the risk assessment matrices include only risks, while opportunities are dealt with in the text of the section. Section 3.4 considers good practice for minimising impacts, for both air quality and GHG emissions. Section 3.5 identifies gaps in knowledge.

3.2 Air quality

3.2.1 Scope

Air quality concerns related to SGD and usage include the emission of air pollutants during all phases, i.e. exploration, development, use of the gas (in transport and energy sectors), and decommissioning. The pollutants considered here include some of the so-called 'criteria' pollutants, identified in Table 3.1 and described in more detail in Text Box A. Volatile organic compounds (VOCs), including those with carcinogenic potential, are considered, as is diesel exhaust, respirable crystalline silica and hydrogen sulphide (H_2S).

Text Box A: Species of local air pollutants

NO_x are nitrogen oxides ($NO + NO_2 = NO_x$) and CO is carbon monoxide. Volatile organic compounds can also be referred to as non-methane volatile organic compounds, and are hereafter referred to as "VOCs" (Brantley et al., 2015; Gilman et al., 2013). Atmospheric particulate matter is referred to as PM and regulated by particle size ($PM_{2.5}$; ≤ 2.5µm in aerodynamic diameter, PM_{10}; ≤10 µm in aerodynamic diameter and see Table 3.1 below) (Armendariz, 2009; Grant et al., 2009; Roy et al., 2014). Ozone is a secondary pollutant that is formed in the atmosphere from reactions of its precursors (i.e. nitrogen dioxide (NO_2) and VOCs). For emissions related to diesel engine operation, >90% of the NO_x emitted is in the form of nitrogen monoxide (NO), which scavenges available ambient ozone and may lead to near-source ambient ozone reduction, although solar-radiation driven dissociation of the NO_2 that is formed may lead to overall regional increases in ambient ozone concentration (Clapp, 2001; Han et al., 2011; Seinfeld & Pandis, 2006; Song et al., 2011). Diesel exhaust has been classified as a human carcinogen and is most frequently characterised and regulated in terms of its particulate matter content (DPM) (International Agency for Research on Cancer (IARC), 2012).

The air pollutants identified have impacts on communities (locally and regionally) and through exposure in the work place. These are illustrated in Figure 3.1, together with key activities that emit the air pollutant, which are discussed in more detail in the following sections.

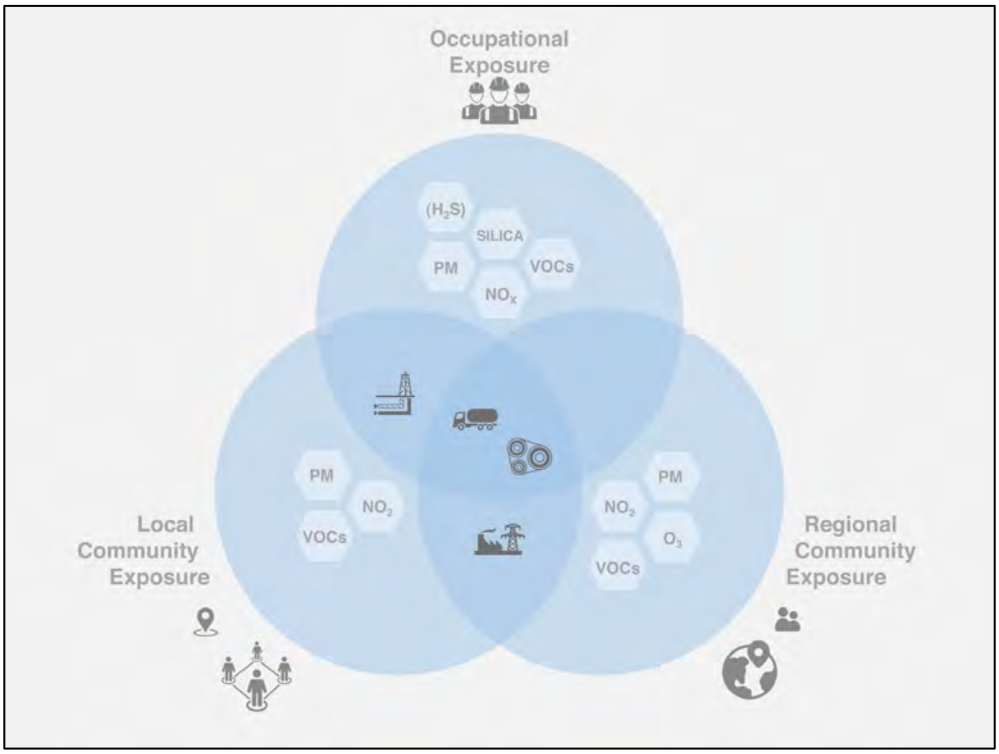


Figure 3.1: Air pollutants associated with occupational exposure and local and community exposure[3]

[3] "Builder" icon by To Uyen, "SAGD" icon by Adam Terpening, "Water Truck" icon by Juan Pablo Bravo, "motor" icon by Aaron K. Kim, "Power Plant" icon by Dimitry Sunseifer, "Map Marker" icon by Alex Almqvist, "community" icon by parkjisun, "people" icon by Berkay Sargin, "Map Marker" icon by Calvin Goodman from thenounproject.com

Note: H_2S is in parentheses to highlight it will be a risk only if H_2S is present in gas deposits.

Ambient (i.e. outdoor) air quality is impacted by emissions from industrial and mining activities, vehicles, power generation, and natural causes such as veld fires, while indoor air pollution can result from burning wood, coal and paraffin in households. The relative contribution of these emission sources likely vary spatially across the Northern, Western, and Eastern Cape Provinces located in the study area. However, it is important to note that there is no ambient monitoring station within the study area, and as such very little is known about the current state of air quality in the region considered in the scientific assessment.

In South Africa, regulatory standards exist for the ambient concentrations of certain air pollutants and the emissions of air pollutants from selected activities. Air quality is governed by the National Environmental Management: Air Quality Act (39/2004), with municipalities responsible for generating and maintaining air quality management plans. Emission limits have been set for certain industrial categories, including the petroleum industry, but no subcategory yet exists for unconventional gas extraction (Republic of South Africa (RSA), 2013). National ambient air quality standards (NAAQS) set limit values over relevant averaging periods for seven air pollutants viz. PM, sulphur dioxide (SO_2), NO_2, O_3, CO, lead (Pb) and benzene (C_6H_6), with PM being divided into two particle sizes (RSA, 2009a; 2012) (Table 3.1). These ambient standards are set to protect communities from air pollution exposure. In South Africa, there is not an ambient standard for H_2S, a gas which is highly toxic and has a pungent odour. The World Health Organization (WHO) recommends that “to avoid substantial complaints about odour annoyance” by communities, the 30-minute average ambient H_2S concentration should not exceed $7 \mu g/m^3$ (WHO, 2000). Occupational exposure to air pollutants is governed by the Occupational Health and Safety Act (85/1993). Table 3.1 includes the occupational limits for H_2S and respirable crystalline silica, which are potential occupational health risks. There is also a risk to occupational health from inhalation of VOCs, however the applicable regulated exposure limits depend upon the composition of the VOCs. As the composition is not yet known, no limits with regards to VOCs are listed in Table 3.1.

Table 3.1: South African ambient air quality standards and allowable frequency of exceedance of the standard as a function of pollutant and averaging time

Species	Averaging time	South African National Standard Concentration	Allowable frequency of exceedance
SO_2	10 minutes	500 µg/m^3 (191 ppb)	526
	1 hour	350 µg/m^3 (134 ppb)	88
	24 hours	125 µg/m^3 (48 ppb)	4
	1 year	50 µg/m^3 (19 ppb)	0
NO_2	1 hour	200 µg/m^3 (106 ppb)	88
	1 year	40 µg/m^3 (21 ppb)	0
PM_{10}	24 hours	75 µg/m^3	4
	1 year	40 µg/m^3	0
$PM_{2.5}$	24 hours	40 µg/m^3 (25 µg/m^3 from 1 Jan 2030)	4
	1 year	20 µg/m^3 (15 µg/m^3 from 1 Jan 2030)	0
O_3	8-hours running	120 µg/m^3 (61 ppb)	11
C_6H_6	1 year	5 µg/m^3 (1.6 ppb)	0
Pb	1 year	0.5 µg/m^3	0
CO	1 hour	30 mg/m^3 (26 ppm)	88
	8 hour	10 mg/m^3 (8.7 ppm)	11

South African Occupational Standards (Department of Labour (DOL), 1995)			
Species	TWA OEL-RL * (mg/m^3)	Short term OEL-RL** (mg/m^3)	TWA OEL-CL *** (mg/m^3)
H_2S	14 (10 ppm)	21 (15 ppm)	NA
Respirable crystalline silica[4]	NA	NA	0.1

Source: (DOL, 1995; RSA, 2009a, 2012)

* TWA OEL-RL Time Weighted Average Occupational Exposure Limit - Recommended Limit

** Short-term exposure is for 15 minutes.

*** TWA OEL-CL Time Weighted Average Occupational Exposure Limit – Control Limit: this is the maximum concentration that employees may be exposed to through inhalation averaged over the reference period under any circumstances. Silica CL was updated in 2008 with an amendment to the Occupational Health and Safety Act (85/1993).

3.2.2 Key potential impacts on air quality

3.2.2.1 Emissions

SGD activities lead to air pollutant emissions at several points across the life cycle (see Burns et al. 2016). Within these life cycle steps, notable activities that lead to air pollutant emissions include wellpad and infrastructure preparation (i.e. trucking of equipment), vertical and horizontal drilling,

[4] The Department of Labour (DOL) defines that "the concentration of respirable dust shall be determined from the fraction passing a size selector with an efficiency that will allow: 100% of particles 1 µm aerodynamic diameter, 50% of particles of 5 µm aerodynamic diameter, 20% particles of 6 µm aerodynamic diameter, 0% of particles 7 µm aerodynamic diameter and larger, to pass through the size selector"

hydraulic fracturing ("fracking"), well completion, transportation (e.g. transport of water and waste materials), production stage distribution of the gas, and associated end-use of the gas.

The life cycle of SGD results in a large number of relatively small point sources of air pollutants spread out over a potentially large geographical area (wellpad activities), as well as mobile sources (truck traffic) and fugitive sources (equipment leaks) (Field et al., 2014). A key feature of shale gas technologies is that several wells can be drilled from one wellpad, which focuses intense industrial activity in one area (Adgate et al., 2014). New wells are drilled regularly as a result of rapid decline in the rate of gas production from a well (Burns et al. 2016), and once drilling commences in a shale play it operates continuously (IEA, 2011). This creates a constant (i.e., 24-hour) output of air pollutants from diesel generators, stationary engines and truck traffic. The activities during well exploration, appraisal and development lead to emissions of NO_x, SO_2, particulate matter ($PM_{2.5}$ and PM_{10}), diesel particulate matter (DPM), VOCs, CO, silica, and H_2S, as indicated in Table 3.2.

Table 3.2: Summary of air pollutant emissions from sub-activities of life cycle stages from Burns et al. (2016)

	CO	NO_x	SO_2	PM	VOCs	Resp. Silica	H_2S
Well Exploration, Appraisal and Development							
Trucking (equipment, water, waste)	x	x	x	x	x		
Drilling (vertical and horizontal)	x	x		x	x	x	xx
Hydraulic Fracturing		x		x	x	x	
Well Completion					x		xx
Production							
Pneumatics					x		xx
Fugitives					x		xx
Wellhead Compressors	x	x		x	x		xx
Blowdown Venting					x		xx
Decommissioning							
Leakage							xx

Notes: PM in this table includes DPM as well as $PM_{2.5}$ and PM_{10}. Those processes where H_2S emissions would occur if H_2S is present in gas deposits are indicated with "xx". SO_2 emissions will depend on the sulphur concentration of the diesel fuel utilised in transport. Methane is not included under "decommissioning" as it is a global GHG discussed below in Section 3.3.

3.2.2.1.1 On-site emissions

On-site emissions could include H_2S, which is a highly toxic gas that is naturally occurring in some natural gas deposits. However, previous studies suggest that the probability of H_2S emissions in the study area is low (Burger, 2011). Silica sand is the most commonly used proppant in the fracking fluid, and can be lofted into the air where workers may be exposed, leading to the risk of respiratory diseases.

The drilling of a well requires five to seven diesel-fired compression-ignition engines, which range from 300 to 1000 kilowatts (kW) (Grant et al., 2009; Roy et al., 2014) while fracking requires the use of stationary pump engines. These engines on-site will emit NO_x, PM, CO, SO_2 and VOCs.

The well completion process requires flowing the well via venting or flaring for a sustained period of time to remove any debris or mud, and to remove any inert gases present from the well stimulation process. This can result in a significant amount of vented gas, and as such can be a large source of VOCs (Pacsi et al., 2013), which in these scenarios is assumed to be controlled by flaring to reduce emissions (Burns et al., 2016). Production emissions on the well-site are primarily VOC emissions, except in the case of the use of wellhead compressors, which also release small amounts of NO_x and DPM. VOCs are released from production fugitives, pneumatic devices, and blowdown venting. Production emissions are assumed to derive from devices and compressors that operate continuously.

3.2.2.1.2 Mobile emissions

Truck traffic will increase substantially with SGD and will lead to emission of NO_x, diesel exhaust (including DPM), $PM_{2.5}$, VOCs and road dust (Adgate et al., 2014; Roy et al., 2014). Trucks will be used initially to transport all of the necessary materials to the well site, including the engines, water, chemicals, and equipment. In addition, trucks will be used to transport materials from one well to another as needed. A potentially large source of truck traffic, and one with a considerable amount of uncertainty in South Africa, is associated with the transport of water to the well for fracking, as well as the transfer of flowback water to wastewater treatment sites or storage ponds. These mobile sources will expose a larger geographical area to the emissions of air pollutants, though it is important to note that if the scale of the resource warranted the necessary infrastructure investments, piping water would help to minimise truck transport emissions.

3.2.2.2 Fate of pollutants

The magnitude and spatial extent of the impact of atmospheric emissions on air quality are influenced by the rate at which pollutants are emitted (as discussed above), and their fate in the atmosphere (i.e. dispersion, transformation (e.g. chemical reaction), and removal). The local dispersion is influenced by the height, velocity, and temperature of release of the emissions, as well as meteorological factors (e.g. wind speed and direction, ground-based inversion layers). In addition, air pollutants can be transported long distances; for example, smoke from biomass burning activities in Zambia may be distributed across southern Africa by prevailing winds in the late winter and spring (RSA, 2009b; Swap et al., 2003). As such, for SGD, pollutants emitted in the study area may be transported outside of its borders. The dominant wind directions as a yearly average reported in Burger (2011) for Beaufort West, which is the only wind analysis that could be found for the study area, were from the east to northeast, and west to southwest, with very few days having calm conditions (i.e. wind speed <1m/s). The Wind Atlas for South Africa[5] has detailed wind climatologies of the study area, which could be used together with measurements for detailed studies on the dispersion of pollutants once the specific locations are selected for SGD. The removal of pollutants from the study area can occur through dry deposition, wet deposition, transport from the area, and transformation to secondary pollutants. The study area is arid and thus wet deposition through precipitation should be a relatively small removal process.

3.2.2.3 Ground-level ozone

Ozone (O_3) is a secondary pollutant, which means it is not released into the atmosphere, but rather is formed in the atmosphere through reactions of its precursors (i.e. NO_2 and VOCs). As SGD activities emit both NO_2 and VOCs, there is potential for significant regional effects on ambient ground-level ozone concentrations (Katzenstein et al., 2003; Kemball-Cook et al., 2010; Monks et al., 2015; Swarthout et al., 2015). Modelling studies in the US have shown that increased SGD and associated emissions of precursors has led to increases in ozone concentrations (Kemball-Cook et al., 2010; Olaguer, 2012; Rodriguez et al., 2009). However, if the use of gas decreases the use and thus emissions from coal-generated electricity, there can also be overall decreases in O_3 and NO_x, although in South Africa these reductions would occur in a different geographic area (Pacsi et al., 2013; 2015). High levels of ozone have been observed in the winter in US northern oil and gas basins, and studies suggest that the elevated ozone levels are correlated with snow cover (Carter & Seinfeld, 2012; Edwards et al., 2014; , 2013; Helmig et al., 2014; Oltmans et al., 2014; Rappengluck et al., 2014; Schnell et al., 2009). An important limitation noted for many air quality modelling studies of shale gas is the lack of an accurate and comprehensive emissions inventory for specific study sites. This is attributed to factors such as variability in well operations (i.e. flaring, number of active well heads), the large number of activities that emit pollutants, the type of gases emitted, and a lack of field observations (Field et al., 2014; Monks et al., 2015; Petron et al., 2012).

3.2.2.4 Reference case (Scenario 0)

There is one air quality monitoring station near the, study area, although it is not within the boundaries of the study area. The Karoo Background monitoring station (31°22'S, 19°6'E) is run by the South African Weather Service (SAWS) and data and monthly reports are available at the South African Air Quality Information System[6]. Hourly monitoring data from 2014 to 2015 were analysed to establish the background level of air quality in the study area. NO_x ranges from 0-12.6 µg/m_3 (0-6.7

[5] Available at: (http://www.wasaproject.info/)
[6] Available at: (www.saaqis.org.za)

ppb), with an average of 0.95 μg/m^3 (0.5 ppb), values which are typical of a remote location with few industrial sources. Hourly NO_2 values never exceed or even approach the South African NAAQS of 200 μg/m^3 (106 ppb) (Table 3.1) and have little seasonal variability. Ambient concentrations of PM do exceed the 24-hour limit value more frequently than the legally allowed NAAQS standard for PM_{10} and $PM_{2.5}$ (75 and 40 μg/m^3, respectively; Table 3.1) at the Karoo station. PM values are highest in spring and autumn. Ozone ranges from 40-60 μg/m^3 (20-30 ppb), significantly lower than the NAAQS value of 120 μg/m^3 (61 ppb), and is typical for a rural background site with low levels of NO_x and VOC emissions (i.e. the precursors required for photochemical ozone formation). The Reference Case includes increased road activity in the study area due to tourism and economic diversification. This will likely lead to increased PM and NO_x emissions, unless offset by more stringent vehicle standards. In addition, there is currently no air quality management plans for the regions within the study area, but considering that PM concentrations currently exceed national ambient standards, the plan(s) under development will have to include a management plan for PM emissions and ambient concentrations. The lack of significant VOC sources increasing over time suggests that there should be little to no increase in regional ozone for the Reference Case. **There are no air quality monitoring stations within the study area and no emissions inventory, critically limiting information on air quality even in the absence of shale gas exploration and development.**

3.2.2.5 SGD Scenarios

3.2.2.5.1 Emissions

The air pollutant emissions for the Exploration Only, Small Gas and Big Gas scenarios (Table 3.3) were calculated from the emission factors, number of days to drill one well, the total number of wells per year, and the total number of truck trips per year as determined by Burns et al. (2016) (see supplementary Digital Addenda for calculations for the present Chapter). Silica is required in all scenarios with SGD, although the amount of silica needed locally is unknown, therefore emissions cannot be calculated. However, a study in the US states that millions of pounds of silica-containing sand may be needed in total for one well (Esswein et al., 2013).

Table 3.3: Calculated air pollutant emissions in tons/day.

tons/day	Exploration Only	Small Gas	Big Gas
CO	0.07	0.24	0.95
NO_x***	0.51	1.9	9.3
Hydrocarbons/VOCs	0.22	0.98	7.1
$PM_{2.5}$**	0.02	0.06	0.33

Notes: Emissions were calculated for seismic surveys, exploration and appraisal drilling, and truck trips based on activities in Burns et al. (2016). Emissions factors were constant across scenarios (Burns et al., 2016) with key drivers including the number of wells and truck trips per year for each scenario (Supplemental Information).

** PM2.5 calculation based on emissions factor from (Altieri & Stone, 2016).

*** The majority of NOx emitted by diesel engines is in the form of NO which is slowly converted to NO2 in the atmosphere, with the rate dependent on atmospheric conditions. Maximum conversion is generally accepted to be approximately 75%.

The scale of air pollutant emissions calculated in Table 3.3 can be compared to the Western Cape Emissions Inventory (Western Cape Department of Environmental Affairs, 2010). The Central Karoo District Municipality is the area closest to where the SGD will take place in which an emissions inventory exists for comparison purposes. There are only four point sources and 11 petrol filling stations within this district municipality, and as such, NO_x emissions are estimated to be only 0.002 tons/day (Western Cape Department of Environmental Affairs, 2010). **Even at the lowest estimate for exploration alone (Exploration Only scenario), NO_x emissions from SGD would dominate regional emissions**. The highest NO_x and VOC emissions, for the Big Gas scenario, are comparable to South Africa's national domestic shipping NO_x emissions (10 tons/day; (Scorgie & Venter, 2006)), and the total industrial VOC emissions from Durban (7 tons/day; (FRiDGE, 2004)). Western Cape VOC emissions total 0.295 tons/day, which is comparable to the estimates presented here for Exploration Only scenario, but lower than estimates for the Small Gas and Big Gas scenarios. In general, such large increases in ozone precursors from shale gas exploration and development (as detailed in Table 3.3) in an area with little current emissions of these precursors, would lead to an increase in ozone production. However, ozone production is dependent upon local atmospheric and meteorological conditions and its formation is not linearly related to precursor concentrations, thus ozone concentrations cannot be quantified for the scenarios (Carter & Seinfeld, 2012; Cooper et al., 2012; Monks et al., 2015; Pacsi et al., 2015; Rutter et al., 2015; Swarthout et al., 2015).

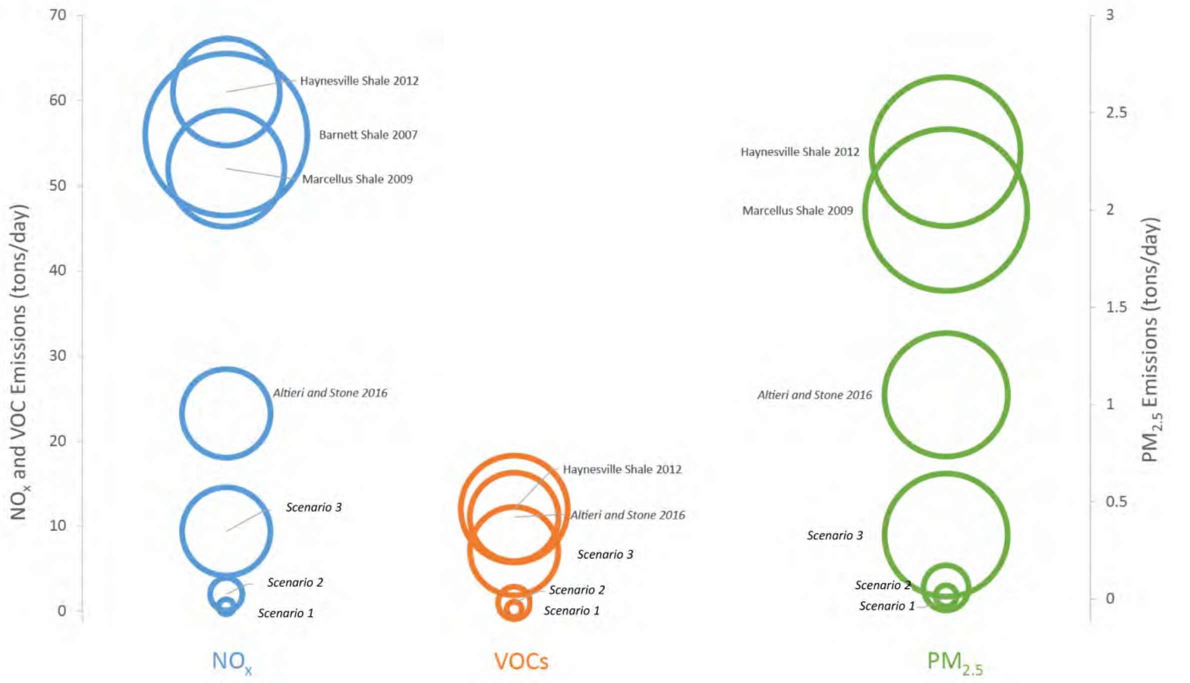


Figure 3.2: Air pollutant emissions for scientific assessment scenarios compared to bottom-up emissions inventories for Karoo shale gas and main shale plays in USA

Note: Air pollutant emissions (tons/day) for SGD in the Karoo, comparing values for the scientific assessment scenarios (as in Table 3.3) to bottom-up emissions inventories for Karoo shale gas (Altieri & Stone, 2016), and the main shale plays in the US (Haynesville from Grant et al. (2009), Barnett from Armendariz (2009), and Marcellus from Roy et al. (2014)). The colour of the circle denotes the pollutant, the size of the circle scales to the number of wells per year, and gray shading and italicised labels denote a South African-specific estimate. The South African estimates are much lower than the US estimates for three reasons: 1) the number of wells in the US is larger than anticipated for South Africa; 2) some states in the US have weak regulatory regimes; and 3) the newer technology which would be applied in South Africa is anticipated to be less polluting.

NO_x and $PM_{2.5}$ emissions from the three main shale plays in the US are considerably higher than any estimates for South Africa (see Figure 3.2), due primarily to the larger number of wells drilled each year in the US than assumed in Small and Big Gas scenarios (Burns et al., 2016), and the use of engines with a wide range of emissions factors (Armendariz, 2009; Grant et al., 2009; Roy et al., 2014). The existing on-shore oil and gas industry in the US is in close proximity to the more recently developed unconventional natural gas extraction areas, allowing for older engines with higher emissions factors to be utilised for shale gas extraction. Figure 3.2 also shows that the emissions calculated for the Exploration Only and Small and Big Gas scenarios are lower than previous estimates for Karoo shale gas exploration and development (Altieri & Stone, 2016). Though the estimates for the size of the resource and the number of wells per year were similar, Altieri & Stone (2016) used emissions factors significantly higher than those reported in Burns et al. (2016).

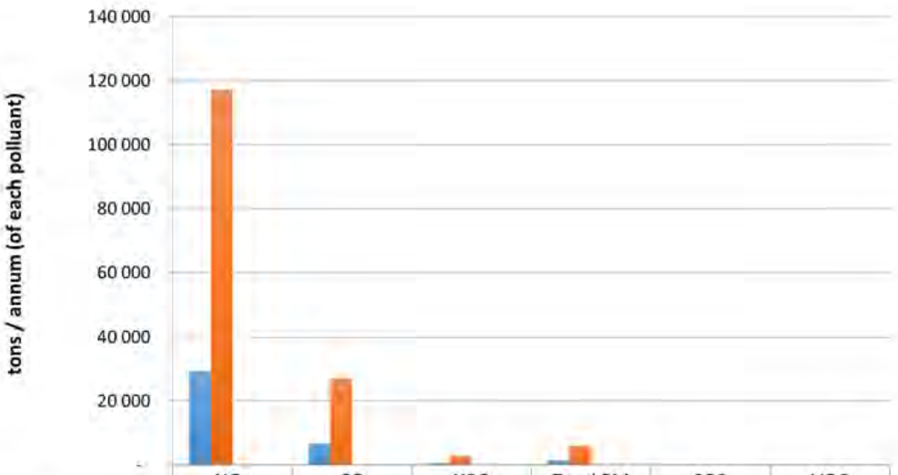
Using a simple Lagrangian dispersion model (limited to the prediction of worst-case impacts, and not taking atmospheric chemistry into account) and the emission inventory of Table 3.3 above, worst-case

NO_x concentrations were calculated for single wells (Exploration Only scenario) and well fields (Small and Big Gas scenarios).

For single wells, the maximum NO_x concentration is approximately 9 µg/m³ at a distance of 200 m from the source; for a well field of 30 by 30 km with 410 production wells being drilled the maximum is of the order of 42 µg/m³ 7 km downwind of the field, assuming release at 5 m height. In both cases, average concentrations should be considerably lower. **This would lead to the preliminary conclusion that the development of wellfields even at the Big Gas scale would not lead to material exceedances of the NAAQS threshold values for NO_2 due to shale gas activities alone. Although ozone concentrations may increase, ozone limit values would likely not be exceeded even in the Big Gas scenario, although no concentration limit has been determined below which there is no impact on humans. However, for PM, as there are already exceedances of the national standard, it is likely that shale gas exploration and development will lead to more exceedances (see Table 3.7).**

3.2.2.5.2 Use of natural gas and impact on net emissions

Natural gas-fired electricity generation leads to lower air pollutant emissions per kWh of generation relative to coal-fired electricity generation (Allen, 2014). The reduced emissions from electricity generation are slightly offset by the increased emissions associated with the exploration, development, and production of unconventional natural gas. In addition to understanding the net emissions reductions (or increases) due to switching from coal to unconventional natural gas for electricity supply, is a need to recognise that the spatial distribution of these emissions will vary. In the case of South Africa, it is a shift from emissions in the Highveld Priority Area and the Mpumalanga coal region to the Karoo basin, and potentially in future in the Waterberg (see Wright et al., 2016). Emissions of air pollutants are estimated for a 1000 MWe (Small Gas scenario) electricity generating plant operating with water/steam injection for NO_x reduction, and 4000 MWe (Big Gas scenario); both are shown in Figure 3.3.



	NOx	CO	N2O	Total PM	SO2	VOC
CCGT 1000 Mwe (Scenario 2)	29 328	6 780	694	1 514		
CCGT 4000 MWe (Scenario 3)	117 314	27 121	2 775	6 055		
GTL production 65,000 bpd (Scenario 3)	23.7		4.7	-	-	
LNG plant 8700 tpd (Scenarios 1, 2 and 3)	212			15.5	27.8	1

Figure 3.3: Emissions of local air pollutants associated with shale gas used for CCGT, GTL and LNG.

Note: Tables for each of electricity generation using CCGT, GTL and LNG are available separately in the supplementary information in the Digital Addenda (start with worksheet ‘Fig 1 AQ for CCGT GTL LNG’).

Comparing the figures in Figure 3.3 to those provided by Eskom as a national grid average for 2014, Eskom estimates that 4.22 tons of NO_x are emitted per GWh of power generated, compared to the approximately 6 ton NO_x/GWh derived from figures shown below Figure 3.3.

While GTL and LNG plants are envisaged at the coast (see Burns et al., 2016), and are therefore outside the study area, the atmospheric emissions or reductions are associated with shale gas and are therefore included in this assessment. Under the Big Gas scenario (Burns et al., 2016), a GTL plant “replacing one of the existing aging refineries” is envisaged. Although the capacity of this is given as 65 000 bpd (barrels per day) of liquid fuels, for purposes of this study we have also considered a 120 000 barrels per day (bpd) plant, as the conventional existing refineries range from 100 000 to 180 000 bpd. The emissions in Figure 3.3 are calculated using emission estimates produced by the US National Energy Technology Laboratory (National Energy Technology Laboratory et al., 2013) and reporting by an existing GTL facility (Oryx GTL Ltd, 2011), both using internally-generated electricity due to energy integration.

On a life cycle basis, some emissions for the two 2000 MWe power plant would be used by the GTL plant. Burns et al. (2016) does not include vehicles directly using compressed natural gas (CNG), which might lead to a lower emissions pathway than converting gas to liquid, and then using it in vehicles.

Alternatively, liquefaction of the shale gas to LNG has been suggested as a product outlet under the Big Gas scenario; a plant equivalent to a 65 000 bpd GTL plant would produce approximately 8 700 ton per day of LNG or 16,000 tpd equivalent to a 120,000 bpd GTL plant's production. The estimated emissions, drawing on the literature (Delphi Group, 2013; SNC Lavalin, 2015), are shown in Figure 3.3 (for calculations, see the Digital Addenda).

3.2.3 Limits of acceptable change

There is an important distinction between exposure limits and emission limits. Exposure limits seek to limit human and ecosystem exposure to harmful pollutants. Emission limits are limits on how much can be emitted by specific processes, such that people are not exposed to harmful levels of pollutants. With regards to exposure limits, it is useful to make a further distinction between occupational exposure limits and community exposure limits, with the former often being an order of magnitude higher than the latter (Table 3.1). Workers consist of a healthy, age-specific group exposed for a limited time per week, whereas communities include vulnerable sub-groups such as the very young, the aged and sick persons. The air quality risk assessment draws on both local/ regional and occupational / community exposure distinctions (see Section 3.2.4).

The South African NAAQS referred to in Section 3.1 are community exposure standards which are implicitly health-based, being largely based on the WHO guidelines for the ambient limit values of the major pollutants, with some local adaptations (South African Bureau of Standards (SABS), 2009). For those pollutants where local exposure limit values have not been specified, a number of widely-referenced sources for health-based exposure limits from foreign agencies are available; these have been summarised in the NAAQS (RSA, 2009a) and include values for carcinogenic pollutants. To determine overall risk, it would thus be necessary to determine the concentration of each of the pollutants to which communities would be exposed and determine the probability of different health endpoints for short- and long-term exposure. For the VOCs, such an estimate would entail considerable uncertainty due to the location-specific composition of these compounds.

Occupational exposure standards will apply on both the well drilling sites and downstream processing facilities under all scenarios. In South Africa, occupational exposure from non-mining activities is regulated under the Hazardous Chemical Substances (HCS) regulations of the Occupational Health and Safety Act (85/1993). The regulations specify the allowed exposure limit over eight hour shifts, and are generally based on the guidelines produced at regular intervals by the American Conference of Governmental Industrial Hygienists (ACGIH). Because the South African regulations have not been updated for some time, it would be prudent to consider a revision of the regulations, taking into account good practice internationally (see Section 3.4).

Minimum emission standards exist in South Africa for the activities in the petroleum refinery industry (RSA, 2013), but at this stage do not include unconventional gas recovery and the processing of the gas. The setting of emission standards in South Africa has previously followed the principle of "Best Practical Environmental Option" and has depended largely on international best practice in this regard. The most complete set of emission standards for unconventional gas exploration and recovery has been developed by the United States Environmental Protection Agency (US EPA) (US Federal Register, 2012). These rules are currently undergoing further review and refinement. In terms of the National Environmental Management: Air Quality Act (NEMAQA), 2004; Sections 21 and 22, read with Government Notice Regulation 248 which lists activities requiring an atmospheric emissions licence (AEL), any legal person undertaking SGD will require an AEL, if they have an incinerator capacity of 10 kg or more of waste processed per hour.

Internationally, there are guidelines for critical levels for air pollution related to impacts on crops and vegetation (Convention on Long-range Transboundary Air Pollution (CLRTAP), 2015); however, South African standards do not exist. Ozone impacts agriculture and ecosystems at concentrations lower than ambient air quality standards for health, partially due to the importance of cumulative exposure of crops and vegetation. The UK critical level using AOT40 for ozone (i.e. cumulative exposure above 40 ppb during daylight hours over a three month growing season) for crops and semi-natural vegetation is 3000 ppb hours (Air Pollution Information System (APIS), n.d.). However, it is not known what the critical level may be for the vegetation in the study area.

3.2.4 Analysis of risks and opportunities for local air pollution

There are risks of increased emissions of air pollutants from SGD, as well as opportunities to reduce exposure where shale gas displaces fuels that emit more air pollutants. The opportunities to reduce indoor air pollution for (mainly poor) households are explored in Section 3.2.4.1 below. The risks of exposure to local air pollutants are assessed in relation to four categories: 1) occupational exposure; 2) local community exposure; 3) regional community exposure; and 4) agriculture and ecosystem exposure. These risks are considered in turn, in Sections 3.2.4.2 to 3.2.4.4 below. The summary risk matrix is presented in Table 3.6.

In this assessment, the likelihood is defined as the likelihood that someone in the study area will be exposed, while the consequence is if a person is exposed, on a scale of consequences ranging from 'slight but noticeable' to 'extreme'. The consequence is considered 'slight' if ambient values will be below regulatory limits (e.g. NAAQS), ‘moderate’ if ambient values are at or close to regulatory limits, ‘substantial’ if ambient values exceed regulatory limits, and ‘severe’ if multiple pollutants exceed regulatory limits, and ‘extreme’ if multiple pollutants greatly exceed regulatory limits. The “likelihood” increases as SGD increases to cover a larger proportion of the study area.

3.2.4.1 Opportunities for air pollution reduction

Shale gas presents opportunities for air pollution reduction as well as risks. Should exploration lead to Small or Big Gas levels of development, the potential exists to use natural gas for domestic energy supply, replacing or partly replacing wood used extensively by poor households all over South Africa, but in this context mainly in the Eastern, Western and Northern Cape. Reductions in indoor air pollution exposure could be achieved under the Big Gas scenario by replacing the use of wood for cooking and space heating, although such interventions would have to be carefully considered with regards to cost and social acceptability. Such benefits might be achieved especially in low-income households, who typically use more fuels other than electricity (Davis, 1998; Tait, 2015). This is demonstrated by the emission factors given in Table 3.4 below (FRiDGE, 2004).

Table 3.4: Emission factors for various pollutants from household energy use.

Fuel	Unit	SO_2	NO_x	VOC	PM_{10}	CO_2	CH_4
Coal	g/kg	19	1.5	5	4.1	3000	3.6
Paraffin	g/l	8.5	1.5	0.09	0.2	n.a.	n.a.
LPG	g/kg	0.01	1.4	0.5	0.07	2080	n a
Wood	g/kg	0.18	5	22	15.7	1540	13.6

Source: data from FRiDGE, 2004

The emission factors for the direct use of shale gas are comparable to those for the use of LPG, while gas as a source of household energy is considerably more efficient than wood, which is often used with open fires or unsophisticated appliances (Msibi, 2016). **A considerable health benefit could ensue if shale gas displaced other fuels for use indoors, as the emissions from wood and coal have been shown to create large health risks and associated societal costs** (Annegarn et al., 2000; FRiDGE, 2004; Friedl et al., 2008; Mehlwana, 1999; Spalding-Fecher, 2005; Terblanche et al., 1992; WHO, 2002).

3.2.4.2 Occupational exposure to air pollutants

In the Reference Case there are no shale gas workers, and as such the likelihood of occupational exposure is very unlikely, and the risk is very low, even without mitigation (Table 3.6). However, in the Exploration Only, and Small and Big Gas scenarios, occupational exposure to air pollutants is very likely and the consequences are severe, leading to a high risk for occupational exposure to air pollutants without mitigation. The main drivers of this risk are respirable crystalline silica, diesel exhaust and VOCs. Inhalation of respirable crystalline silica can lead to many negative health impacts (American Thoracic Society, 1997). Respirable crystalline silica is a known carcinogen and is associated with lung cancer (Department of Health and Human Services, 2014). Exposure can also cause the lung disease silicosis, which in severe or chronic cases can increase the risk of tuberculosis (American Thoracic Society, 1997; Castranova & Vallyathan, 2000). In a study by the National Institute for Occupational Safety and Health (NIOSH) in the US, the occupational exposure to crystalline silica in eleven shale gas sites in five US states was investigated (Esswein et al., 2013). They found that the occupational exposure thresholds for a full-shift were exceeded at all 11 sites, with 31% of samples showing an exceedance of more than ten times the NIOSH recommended exposure limit (Esswein et al., 2013). This led the Occupational Safety and Health Administration (OSHA) and NIOSH to release a Hazard Alert stating that they, "identified exposure to airborne silica as a health hazard to workers conducting some hydraulic fracturing operations during recent field studies" (OSHA, 2016). This study identified seven points of dust generation that were found at all 11 work sites (Esswein et al., 2013). **Occupational exposure to respirable crystalline silica can be a serious health hazard to workers during shale gas exploration and development (Exploration Only, and Small and Big Gas scenarios).**

Diesel exhaust was classified as carcinogenic to humans by the IARC that is part of the WHO (IARC, 2012). This finding was based mostly on occupational exposure to diesel exhaust; however, the committee commented that exposure to workers and the general public should be reduced. The quantitative relationship between cancer risk and distance from source is not yet clear. Exposure to NO_2, which can be elevated in concentration by roadways, can have negative effects on the respiratory system including inflammation and reduced lung function growth (WHO, 2005). The results of a systematic review on outdoor air pollution and asthma concluded in part that, prevalence of asthma is associated with reported exposure to truck traffic. The evidence does suggest that this association only exists in those living very close to the roadside, however, the proximity to roads was less consistently and strongly associated with asthma prevalence than the exposure to heavy good vehicle traffic (Gowers et al., 2012 and references therein).

Increased PM is associated with increased hospital admissions, chronic respiratory and cardiovascular diseases, decreased lung function, and premature mortality, with the health impacts of $PM_{2.5}$ exceeding those associated with PM_{10} (Kim et al., 2015). In 2013, IARC classified outdoor air pollution and PM from outdoor air pollution as carcinogenic to humans (IARC, 2013). It was highlighted by the panel that almost all of the studies that showed an association between increased health risk and exposure to outdoor air pollution were performed in areas with annual average $PM_{2.5}$

concentrations in the range of 10-30 $\mu g/m^3$ (IARC, 2013). VOC emissions, also known as petroleum hydrocarbons, include aromatic and aliphatic compounds emitted during exploration, production and distribution stages (Adgate et al., 2014 and references therein). Health effects are compound specific, but many known shale gas-related VOCs are carcinogenic, while some cause eye irritation, headaches, and asthma. **The use of heavy diesel trucks, stationary engines and associated rig equipment for SGD, as well as some VOCs emitted from the fracking process and use of silica, leads to occupational health exposure assessed as high risk at the well site without mitigation due to emissions of diesel exhaust, NO_2, PM, and VOCs.**

There is a potential risk from H_2S emissions, if it is present. H_2S is flammable and has a strong smell of rotten eggs that becomes obvious at concentrations of 0.01 -1.5 ppm (OSHA, 2005). People who are exposed to low to moderate levels of H_2S can experience symptoms such as irritation to eyes, nose and throat, headaches, tiredness, poor memory, and nausea (Agency for Toxic Substances and Disease Registry (ATSDR), 2014; OSHA, 2005). Asthmatics may also experience difficulty in breathing, at higher concentrations, people can lose consciousness, and exposure can lead to death (ATSDR, 2014). Oil and gas companies in the US do use mitigation measures to reduce worker exposure to H_2S, however the frequency of worker exposure to H_2S from SGD in the US is not known (Witter et al., 2014). **If H_2S is present in the geological formation, there is a risk of it being released at various stages during the shale gas exploration and development process, leading to occupational exposure.**

The occupational risks are assessed as ‘very likely’ for the Exploration Only and Small and Big Gas scenarios, as once a wellpad is established there will be workers exposed to air pollutants. The consequence is considered severe in all three cases with no mitigation due to the high likelihood of workers being exposed to pollutant levels that exceed regulatory limits, leading to a high risk of occupational exposure in these three scenarios. However, the consecutive increase in the number of wellpads from the Exploration Only scenario through to the Big Gas scenario does not increase the consequence, as the workers are only exposed to wellpad emissions from the site they work on, and the increase in the number of sites in the region does not increase the potential for risks related to occupational exposure.

With mitigation measures, the high risk of occupational health exposure assessed for the three scenarios decreases to moderate risk. While there were high levels of crystalline silica sampled at sites in the US (Esswein et al., 2013), the study also developed a management plan to mitigate the potential impact. This is attached in Digital Addendum 3b. Thus, occupational exposure to respirable silica could be decreased through the application of these mitigation measures, which should include a combination of the appropriate use of personal protection equipment, and engineering and administrative controls. However, exposure to diesel exhaust and VOCs will be harder to mitigate. Different fuels could be used to mitigate diesel exhaust (e.g. the natural gas itself in CNG vehicles), however, VOCs would still be released. The VOCs will be difficult to mitigate as they are emitted at source as part of the process. The potential risk to health will be easier to evaluate once the composition of the VOCs are known. **The risk to occupational health can be mitigated to a moderate risk by decreasing respirable crystalline silica emissions using best practice. It is more difficult to mitigate the risk from diesel exhaust and VOCs.**

3.2.4.3 Local community exposure to air pollutants

The risks associated with local community health due to emissions of diesel exhaust, NO_2, PM, and VOCs need to be considered. As discussed in Section 3.2.2.5, the ambient concentrations of PM in the study area are already above NAAQS standards. As such, there already exists likely exposure to PM for local communities with a moderate consequence, and therefore a low risk is assessed in the Reference Case (with and without mitigation). Local community exposure derives from a production block being placed within 10 km of a community, regardless of the population size of that community. In Digital Addendum 3a the spatial distribution of risks is only shown for existing communities; however, the risk assessment would be for any person within 10 km of a production block.

The average hourly ambient concentrations of NO_x at the Karoo background monitoring site (0-12.6 $\mu g/m^3$) are more than 25 times lower than the South African hourly standard. In the Small Gas scenario, the increase in emissions leads to NO_x concentrations increasing near wellpad activity (estimated maximum increase of 9 $\mu g/m^3$; section 3.2.2.5.1). Even with this maximum increase, the NO_x concentrations would likely remain well below the NAAQS threshold for NO_2, which results in an overall low risk. The Small and Big Gas scenarios lead to order of magnitude increases in all emissions. For NO_x, with the maximum increase in ambient concentrations estimated at 43 $\mu g/m^3$, the NAAQS threshold for NO_2 would not be exceeded. However, with larger increases in PM direct emissions and PM precursors (e.g., VOCs that can react and condense to increase PM mass concentrations), the risk to local health is assessed as a moderate risk with no mitigation.

In addition, NO_2 can react to form ozone and PM, which can in turn have negative health impacts locally. Exposure to ozone is linked to asthma, decreased lung function, and premature mortality (Levy et al., 2001). The WHO has stated that for PM and ozone exposure there is not clear evidence of a lower threshold where adverse health effects do not occur, with some evidence suggesting that the guideline and standards cannot fully protect public health (WHO, 2005). Thus, it is likely that ozone concentrations would increase (both locally and regionally); however, it is unlikely that these increases would be large considering 1) the estimated emission levels of NO_x and VOCs (Table 3.3), and 2) the current ambient ozone concentrations measured near the study area are well below the NAAQS thresholds.

Local community exposure to emissions of diesel exhaust, NO_2, PM, and VOCs is assessed as a low to moderate risk without mitigation.

Mitigation technologies can significantly reduce local community exposure to air pollutants. According to Burns et al. (2016), flaring will be used to minimize VOC emissions from the completion venting process, however, green completions are the recommended standard for emissions reductions as this also minimises GHG emissions (Field et al., 2014). Emissions modelling from the Marcellus shale play in the USA demonstrated that NO_x emissions could be reduced by 85% if control methods were used for all equipment, while VOC emissions could be reduced by 88% (Roy et al., 2014). Assuming control measures are successfully implemented for NO_x and VOCs, the drilling emissions in Table 3.3 can be significantly reduced (Table 3.5). This assessment assumes a roughly linear response to decreasing consequence (and thus risk) with decreasing emissions. Thus, the local community exposure to air pollutants can be mitigated to a low risk for all scenarios.

Table 3.5: Emissions assuming a reduction of 85% of NOx emissions and 88% of VOC emissions using best available control technologies

tons/day	Exploration Only	Small Gas	Big Gas
NO_x	0.08	0.30	1.41
VOC	0.03	0.12	0.85

Drilling, fracking and trucking emissions can be mitigated using ignition timing retard and selective catalytic reduction for NO_x, diesel particulate filters for PM, and diesel oxidation catalysts for VOCs (Grant et al., 2009; Roy et al., 2014). With mitigation, local community exposure is assessed as low risk.

3.2.4.4 Regional community exposure to air pollutants

Community exposure at the regional scale may occur due to emissions of diesel exhaust, NO_2, PM, VOCs, and resultant formation of ozone, associated with SGD regardless of the population size within the study area. Similar to the risk to local communities, the risk of exposure to air pollutants for the region is assessed to be a low risk in the Reference Case (with and without mitigation), because currently only PM concentrations are above the NAAQS threshold (Section 3.2.2.5). Diesel exhaust, ozone, and PM (both directly emitted and secondary particles produced from gaseous emissions) are the main pollutants that are considered for regional air quality. There is a risk of exposure to diesel exhaust if communities are close to roads where the long-haul trucks will travel, with the risk decreasing with distance from the road (potential health risks are summarised in Section 3.2.4.2). Without mitigation, increases in regional ozone and PM ambient concentrations would be expected due to the increase in emissions of precursors and direct emission of PM. The relationship between health impact and both PM and ozone concentrations is linear (WHO, 2005), however the relationship between precursor emissions and resultant ambient concentrations of ozone and PM is not. This non-linearity makes it difficult to quantify the potential resultant ozone and PM concentrations on a regional level.

The Exploration Only scenario is assessed as low risk (with and without mitigation), as it is not likely that the increases in emissions will have a marked impact on air pollution at the regional scale. In the Small and Big Gas scenarios, even though emissions increase as compared to the Exploration Only scenario, it is not likely that on a regional scale the ambient PM and ozone concentrations will see great increases as the dispersion of the pollutants over the region will dilute the average exposure of people in the region. The Small and Big Gas scenarios do have large increases in truck traffic volume and the amount of the study area that will experience increases in truck traffic; as such the Small and Big Gas scenarios are assessed as moderate risk without mitigation. **The use of heavy diesel trucks increases the potential for people within the region to be exposed to increased levels of air pollution. This risk can be mitigated by routing trucks away from communities.**

Gas phase species and particles can scatter and absorb light, thus deteriorating visibility. However, in general, particles have the greatest impact on visibility as they can scatter significant amount of light (Seinfeld & Pandis, 2006). The impact that particles have on visibility is related properties such as the particles’ size, shape, optical properties, composition, and ability to take up water. It is difficult to assess the potential risk to visibility without information on these characteristics, and thus visibility is not considered further in this chapter (see Oberholzer et al. 2016).

<u>Agriculture and ecosystem exposure to air pollutants</u>

With increasing SGD, it is increasingly likely that forage will be exposed to increasing ozone levels. A critical level for accumulated ozone (AOT40, see above) of 3000 ppb hours is associated with a 5% reduction in yield of wheat cultivars; plant sensitivity does vary and it is not known how sensitive the forage or the grazing animals will be to ozone in the study area (CLRTAP, 2015). In this assessment, it is not likely that there will be large increases in ambient ozone concentrations in the study area in the Exploration Only and Small and Big Gas scenarios. Currently, the background ozone concentrations are low (~40-60 $\mu g\ m^{-3}$), and thus it is not likely that the small increase in ozone would be a risk to agriculture. As the spatial extent of SGD increases in the Small and Big Gas scenarios, the likelihood of plants across the study area being exposure was assessed to increase to likely, with the consequence slight but noticeable. **Overall, agricultural exposure (with and without SGD) is assessed as very low risk.** Ozone can impact the yield and nutritional content of grass and shrubs for foraging, which in turn can have nutritional impacts on the grazing animals (Booker et al., 2009).

3.2.5 Summary of risks to air quality

In summary, SGD provides a potential opportunity to reduce indoor air pollutants, if the gas displaces other fuels such as wood, coal and paraffin, especially in poor households. The risk assessment matrix in Table 3.6 summarises the main risks to deterioration of air quality. Occupational exposure refers to workers on the production block or wellpad. Local exposure refers to communities near the 30x30 km production block (within 10 km). Regional refers to the entire study area, defined in Burns et al. (2016). Opportunities are addressed in Section 3.2.4.1 and mitigation of risks in Section 3.4, considering how they might apply in the South African context. It is important to note that the total emissions as calculated based on the scenarios here are much smaller than emissions in the USA (Section 3.2.2.5 and Figure 3.2), which has resulted in significant impacts on air quality in the US that are not anticipated to be as severe in the South African context. In reading the table, note that “with specified mitigation” assumes that good practice, governance and enforcement are implemented.

Figure 3.4 presents a risk map of local community exposure to air pollutants across four SGD scenarios, with- and without mitigation.

Table 3.6: Risk assessment matrix for air quality

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Occupational exposure to air pollutants	Reference Case	On wellpad	None	Very unlikely	Very low	None	Very unlikely	Very low
	Exploration Only		Severe	Very likely	High	Substantial	Very likely	Moderate
	Small gas		Severe	Very likely	High	Substantial	Very likely	Moderate
	Big gas		Severe	Very likely	High	Substantial	Very likely	Moderate
Local community exposure to air pollutants	Reference Case	Local (a production block placed within 10 km of a town)	Moderate	Likely	Low	Moderate	Likely	Low
	Exploration Only		Moderate	Likely	Low	Moderate	Likely	Low
	Small gas		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Big gas		Substantial	Very likely	Moderate	Moderate	Very likely	Low
Regional community exposure to air pollutants	Reference Case	Regional (production blocks placed anywhere within study area)	Moderate	Likely	Low	Moderate	Likely	Low
	Exploration Only		Moderate	Likely	Low	Moderate	Likely	Low
	Small gas		Substantial	Very likely	Moderate	Moderate	Likely	Low
	Big gas		Substantial	Very likely	Moderate	Moderate	Likely	Low
Agriculture and ecosystems exposure to air pollutants	Reference Case	Regional	Slight but noticeable	Extremely unlikely	Very low	Slight but noticeable	Extremely unlikely	Very low
	Exploration Only		Slight but noticeable	Extremely unlikely	Very low	Slight but noticeable	Extremely unlikely	Very low
	Small gas		Slight but noticeable	Likely	Very low	Slight but noticeable	Likely	Very low
	Big gas		Slight but noticeable	Likely	Very low	Slight but noticeable		Very low

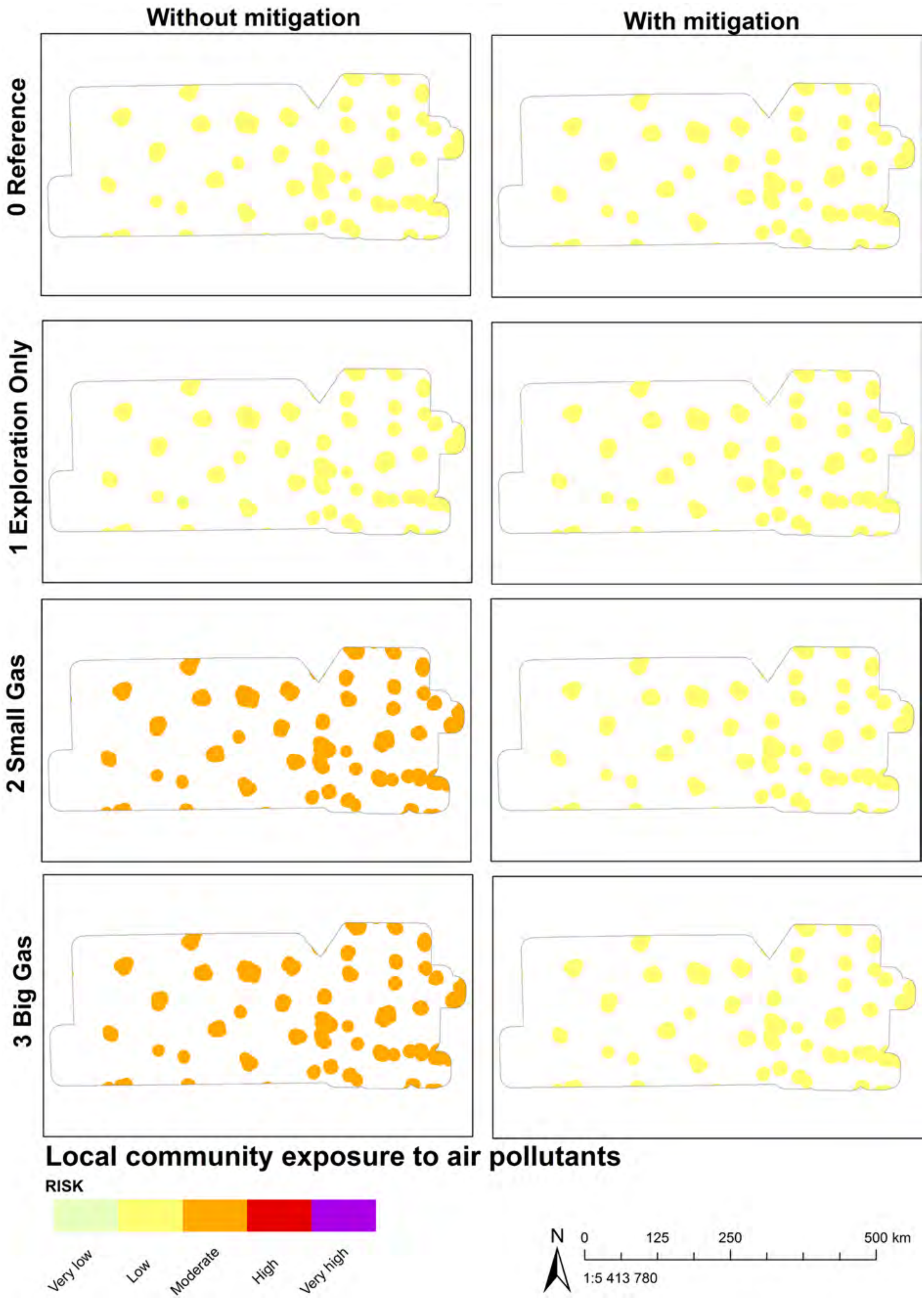


Figure 3.4: Map indicating the risk of local community exposure to air pollutants across four SGD scenarios, with- and without mitigation.

Without mitigation, most risks to human health from local and regional community exposure in the Exploration Only and Small and Big Gas scenarios are assessed as low or moderate risk, with occupational exposure assessed as high risk. With mitigation using control technologies – suitably enforced by capable regulatory institutions and systems – the air quality risks decrease across both community and occupational exposure.

The risk of workers being exposed to air pollution is driven by emissions of respirable crystalline silica, diesel exhaust and VOCs. It is anticipated that the risk of silica exposure can be effectively mitigated, although exposure to VOCs and diesel exhaust will be harder to mitigate. Thus even with mitigation, occupational exposure is still assessed as a moderate risk.

For local communities, the risk of exposure to air pollution is driven by the increase in ambient PM concentrations, which already exceeds NAAQS. For communities that are more than 10 km from a wellpad, the risk is driven by the potential exposure to increased truck traffic, which can be mitigated by routing trucks away from communities or by treating the road surface.

The air quality impacts on agriculture and ecosystems are assessed as very low (with and without mitigation). While ozone can impact the yield and nutritional content of grass and shrubs for foraging, which in turn can have nutritional impacts on the grazing animals; it is not likely that there will be such large increases in regional ozone to begin to put agriculture at risk.

3.3 Greenhouse gas emissions

3.3.1 Scope

Key SGD activities pertinent to GHG emissions include vertical and horizontal drilling; fracking; and well completion, with upstream fugitive emissions of methane the most material concern (Burns et al., 2016). The major potential risks and opportunities are elaborated in Section 3.3.1. The scope of GHGs includes CO_2, methane (CH_4; especially fugitive emissions) and nitrous oxide (N_2O). Perfluorocarbons, hydrofluorocarbons, and sulphur hexafluoride are not included in the scope, as they are not considered material in shale gas and also considered less material in South Africa’s Intended Nationally Determined Contribution (INDC) (RSA, 2015b). Short-lived climate forcers (SLCFs) are not considered as GHGs, though they are receiving some attention internationally (United Nations Environment Programme (UNEP), 2011). However, two SLCFs, being ozone and PM, are considered in the air quality assessment as air pollutants.

The biggest challenge is South Africa's energy economy which is GHG-intensive (DOE, 2015a) due to extensive use of coal. Seventy-seven percent (77%) of the total primary energy supply and 90% of electricity supply are provided by coal (DOE, 2015a). The largest sources of GHG emissions in South Africa are from activities in the energy sector – electricity generation, liquid fuel from coal and energy use in industry and transport, with smaller shares of national emissions from land use and waste (Department of Environmental Affairs (DEA), 2014c). GHG emissions from residential, commercial and industrial use of shale gas will be smaller, as is energy demand (see Wright et al., 2016); the current literature does not provide a basis for assessing shale gas use in these sectors.

A different energy path will be required to make any dent in South Africa's emissions (Winkler & Marquard, 2009). Gas is less emissions-intensive than coal at the point of combustion, but emits more GHGs than renewable energy or nuclear power (GEA, 2012). The Department of Energy's (DoE's) Integrated Energy Plan (IEP) and Integrated Resource Plan (IRP) (DOE, 2011, 2015b) considers GHG emissions, and provides opportunities to revisit our energy mix (see Wright et al., 2016).

3.3.2 Key potential impacts on GHG emissions

The opportunities of reducing, and risks of increasing GHG emissions from shale gas depend on:

- The extent of fugitive emissions, i.e. physical leakage of methane to the atmosphere;
- Which other fuels would have been used instead of gas;
- Global warming potential (GWP) values; and
- Extent to which control technologies and good practice are employed.

These are also key uncertainties. Given the uncertainties, a careful assessment should compare shale gas against different scenarios (as described by Burns et al., 2016). Different findings in the literature to a significant extent reflect different assumptions about the uncertainties, including scenarios of different uses of shale gas, in each case compared to other fuels. The extent of use of shale gas is considered in Wright et al. (2016), which assumes expansion plans will be based on the IRP for 2010-2030 and an update in 2013 for electricity supply (DOE, 2011; 2013), while projections for liquid fuel supply are consistent with the IEP (DOE, 2015b[7]; see Wright et al.; 2016).

Among the hotly debated concerns associated with shale gas is the cumulative impact that shale gas may have on global GHG emissions compared with conventional fuel use and, as such, on global climate change (Bradbury et al., 2013). In assessing the literature, it is important to distinguish two

[7] Note that the IEP has draft status, is not ready for publication nor has been officially adopted by government. The IRP 2013 Update was published, but not officially adopted.

aspects, firstly the overall effect of gas, and which other fuels it displaces, and secondly, the emissions intensity of shale gas.

3.3.2.1 Overall effects

Some researchers have observed that abundant natural gas substituting for coal could reduce CO_2 emissions globally (Hultman et al., 2011; Levi, 2013; Moniz et al., 2011). For example, certain studies show shale gas as having a lower emissions intensity compared with conventional fuels (particularly coal) (e.g. Broomfield, 2012; Burnham et al., 2012; Cathles et al., 2012) and thus having the potential to reduce global emissions should the gas replace conventional fuels. On the other hand, there are studies that suggest that shale gas has, under certain circumstances, a greater GHG emissions intensity than that of conventional fuels (e.g. Howarth et al., 2011; Wigley 2011[8]; Jiang et al., 2011[9]).

Many comparisons in the literature on the GHG 'value' of the various fuels assume other fuels are displaced, and in South Africa with increasing demand, it is also possible that shale gas may be used in addition to existing fuels – in which case there is an emissions increase, though less than business-as-usual (Cohen & Winkler, 2014). Wood et al. (2011) show that there is little evidence to suggest that shale gas is currently or is expected to substitute coal in a significant manner. Indeed, suggestions indicate that it will continue to be used in addition to coal in order to meet increasing energy demand (Wood et al., 2011). McJeon et al. (2014) show that market-driven increases in global supplies of unconventional natural gas do not discernibly reduce the trajectory of GHG emissions or climate forcing. Feng et al. (2015) show that from 2007 to 2009, when carbon emissions in the USA declined the most, 83% was due to economic factors, including consumption and production changes. Just 17% of the decline was due to changes in the USA's fuel mix.

Shale gas is considered by some to be a 'transition' or 'bridge' fuel that will allow time for energy systems to adapt from carbon-intensive fuels to renewables (Bradbury et al., 2013). However, others disagree with the need for a 'transition' fuel by debating that present technology could allow for an immediate shift to a 100% renewable energy system if energy systems were reconceptualised[10]

[8] This study considered a scenario where a portion of coal usage was replaced with shale gas usage (considering a methane leakage rate) over a period of time. The findings suggest that the methane leakage counteracted the reduction in carbon associated with a switch from coal combustion to gas combustion.

[9] When comparing shale gas to conventional natural gas. Their results show shale gas has approximately 3% more emissions than conventional gas but they conclude that this is '*likely within the uncertainty bounds of the study*'.

[10] An example of an alternative strategy to energy systems that would make an energy system entirely renewable is to include various energy storage systems, such as pumped storage hydroelectric power plants, and molten salt storage for concentrated solar power, in the system, to maintain the baseline load of energy without the need of fossil fuels (Glasnovic & Margeta, 2011).

(Glasnovic & Margeta, 2011; Lund & Mathiesen, 2009). The scale of investment required will depend on the existing infrastructure and South Africa does not have extensive transmission and distribution networks for gas (see Wright et al., 2016).

3.3.2.2 GHG intensity and emission factors

There is little doubt that, at the point of combustion, natural gas, including from fracking, emits lower quantities of GHG emissions per unit of energy produced than other fossil fuels (Alvarez et al., 2012). There is less certainty when broadening the assessment beyond the point of combustion, to include particularly fugitive methane emissions (see Section 3.3.4.1). Figure 3.5 shows GHG emission factors for different fossil fuels, illustrating that gas is comparatively better relative to other fossil fuels, but is higher than renewable energy, which has zero GHG emissions in operation. Because of this, using natural gas in favour of other fossil fuels should result in less GHG emissions, with positive implications for global climate change (Wigley, 2011). Figure 3.5, however, does not provide an illustration of the GHG impacts of the various fuels across the full life cycle; key points during shale gas exploration and production are discussed in Section 3.3.2.3, and various end-uses of shale gas in Section 3.3.2.5.

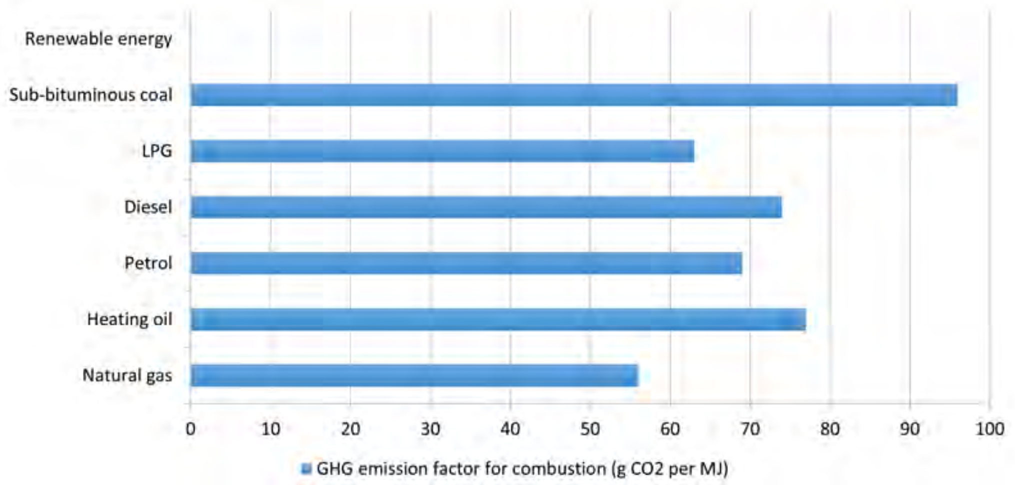


Figure 3.5: GHG emissions factors for different types of fuels

Source: Based on data in (IPCC, 2006)

The differences in opinion are often linked to system leakage rates of methane, which has a high global warming potential, further explored in the sub measured oil and gas methane emissions - section on fugitive methane emissions of Section 3.3.2.3 below.

3.3.2.3 GHG emissions during shale gas exploration and production

The GHG emissions prior to use or conversion, primarily from fugitive methane emissions, are likely the biggest contributor to overall GHG emissions. In the absence of appropriate controls, fugitive emissions as a result of leaks, and flaring and venting during extraction, production and transportation have the potential to be high, which can increase the life cycle GHG emissions profile of shale gas (Bradbury et al., 2013; Stephenson et al., 2011). The risks of increasing, and opportunities to reduce GHG emissions are explored further in the risk assessment (see Section 3.4.2).

Detail on the typical phases of a SGD includes exploration, appraisal, development, production and decommissioning. The primary GHG emissions during these phases (i.e. all activities prior to use of the shale gas) include, but are not restricted to:

- Carbon losses and GHG emissions resulting from changes in land use type (e.g. the removal of vegetation/ carbon stocks) (Forster, Perks, & AEA, 2012).
- Combustion of fuel for transport of the fracturing materials needed, including water, chemicals and sand, to the well site (Broderick et al., 2011);
- Combustion of fuel associated with the prime mover, the power source of the shale gas extraction rig, which can be run on diesel, petrol, electricity or natural gas (Broderick et al., 2011).
- Combustion of fuel for compression and injection of the base fluid into and out of the well (Broderick et al., 2011);
- Fugitive emissions resulting from flowback. After the process of fracking, the base fluid injected at pressure into the well returns to the surface, which is known as 'flowback' (Broderick et al., 2011). Natural gas flows to the surface within the flowback at increasing concentrations over time. The gas is not immediately of adequate quantity or quality for sale and, as such, quantities of the gas are often initially vented or flared (Barcella et al., 2011). The GHG emissions associated with flowback can be high (Bradbury et al., 2013; Jiang et al., 2011), but estimates vary across studies;
- Flaring, which involves purposely burning the methane in an open flame through a flare stack, emitting CO_2 instead of CH_4 to the atmosphere (noting the GWP100 of CH_4 is 34 times that of CO_2);
- Fugitive emissions via leaks and fuel usage involved to enable the assembly of equipment during well completion, which involves bringing the gas well into production after the completion of drilling and fracking operations (Branosky et al., 2012);
- The processes associated with gas plant operations and maintenance, which involves the drainage of hydrocarbons from a gas field, are significant sources of GHG emissions (Branosky et al., 2012). These processes include both venting and flaring during workovers

(where shale plays are fractured again) and liquids unloading as well as methane leakage and routine venting from equipment (includes pumps, valves, connectors, compressors, pneumatic devices, acid gas removal units, and dehydrators);

- Off-site processing, which involves the removal of liquid hydrocarbons and impurities from the extracted gas (Branosky et al., 2012) generates fugitive emissions from the equipment components, and GHG emissions from the combustion needed to operate the processing system. Such components include pumps, valves, connectors, compressors, pneumatic devices, acid gas removal units, and dehydrators;
- Temporary storage of the gas and distribution to the compressor stations generates fugitive emissions resulting from leaks and vented GHG emissions from pipeline or compressor blow down, as well as combustion GHG emissions from engines that drive the compressors that push the gas through the system.

In relation to the emissions intensity of shale gas, the balance of evidence suggests that shale gas is less emissions-intensive than coal, though much depends on methane leakage rates (see Section 3.3.2.4 below). Even with the worst leakage rates, the 'worst shale gas' is roughly as emissions intensive as the 'best coal'. In terms of the overall effect on GHG emissions in a country, key factors include which energy sources are displaced, and how much electricity or liquid fuel is produced from each source.

3.3.2.4 Fugitive methane emissions, leakage rates and GWP values

Fugitive emissions of methane pose a key risk of increased GHG emissions with SGD and production (Howarth et al., 2011; Jiang et al., 2011; Wigley, 2011). Estimates of gas leakage rates are expressed as a percentage of total production and a range of leakage rates are found in the literature. A study based on direct measurements of fugitive emissions by Allen et al. (2013) reports the rate as lower than commonly reported (0.42% of gross shale gas production). Fugitive emissions rates of between 3.6 – 7.9% were estimated in some earlier literature (Howarth et al., 2011). Reviewing the international literature to draw lessons for South Africa, the DEA (2014b) study considered the different ranges (mainly due to different assumptions and methodologies, see Section 3.4.1) and noted that a "commonly cited rate of fugitive emissions is 2.3% of total natural gas production as reported on by the US EPA in their 2011 National Greenhouse Gas Inventory" (DEA, 2014b). This was then updated in the 2013 National Greenhouse Gas Inventory to 1.4%. Zavala-Araiza et al. (2015) showed that measured oil and gas methane emissions are 90% larger than estimates based on the US EPA's Greenhouse Gas Inventory and correspond to 1.5% of natural gas production. Brandt et al. (2014) also demonstrated that measurements at all scales show that official inventories consistently underestimate actual methane emissions.

Some of the key estimates of methane leakage rates, building on the analysis by Hope (2014), are shown in Figure 3.6.

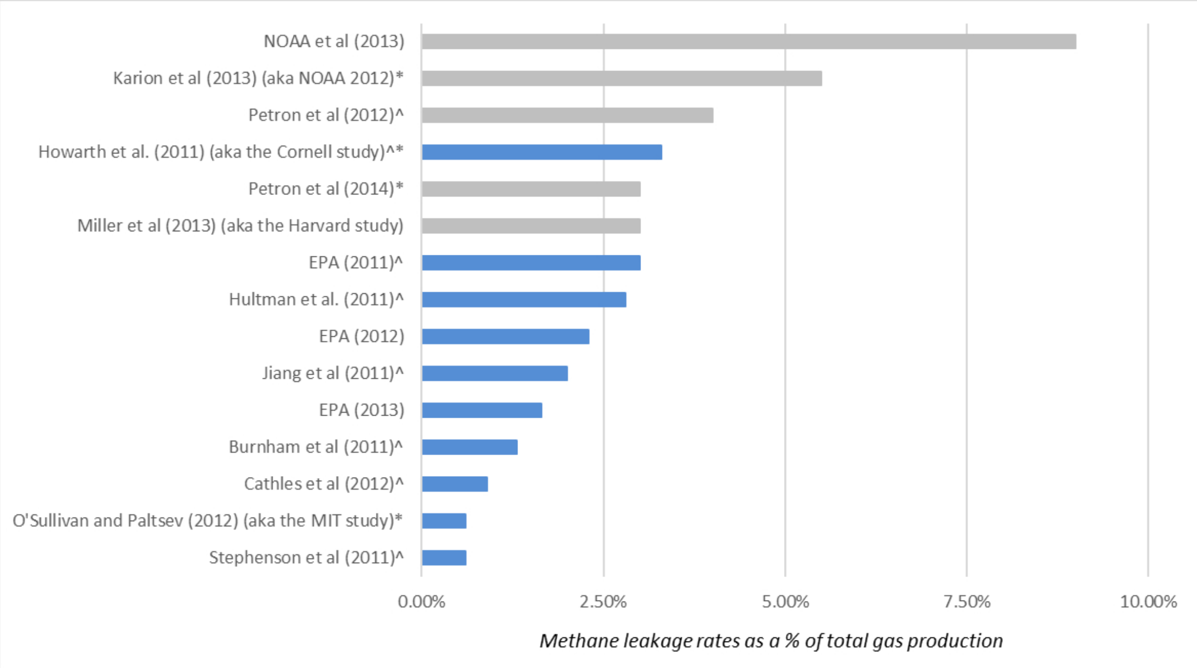


Figure 3.6: Estimate of methane leakage rates in literature, with both bottom-up and top-down approaches.

Source: cited in figure and drawing on literature (Hope, 2014) from top-down (grey bars) and bottom-up (blue bars) approaches, as described in text.
Note: ^ means value is for unconventional - i.e. shale - gas wells only, * means the value in the graph is the mid-estimate or mean of a range where a 'best estimate' is not given.

There are a number of reasons the results have such a wide range. Perhaps the most important is how the data were collected (Hope, 2014). Broadly speaking, there are two approaches to measuring fugitive emissions: bottom up and top down. Bottom-up approaches, using on-site measurement equipment - the blue bars on the chart above, are better at measuring emissions from a particular well, but do not necessarily accurately reflect the emissions of the whole production process. Top-down approaches, using for example aeroplanes, tend to come out with higher measurements - the grey bars, as they potentially capture a wider source of emissions (e.g. methane emissions from livestock and landfills).

Recent evidence related to ‘super-emitters’ suggests that bottom-up approaches may under-estimate leakage rates, but that the bottom-up and top-down estimates can be reconciled when the ‘super-emitters’ are taken into account, and that reconciled figures still lie within the 1.4 - 2.3% of production estimates. More recent literature on super-emitters has a mode (2.2%) falling within that range, but a long tail pushing the mean up to 4.1% (Zimmerle et al., 2015), seeking to reconcile diverging estimates (Zavala-Araiza et al., 2015). Actual leakage rates are significant to the risk (or reduced opportunity) and would warrant monitoring under SA conditions, should SGD proceed. The formal definition of super-emitters also would allow for focused management measures for these sources to be implemented (Zavala-Araiza et al., 2015).

From the assessment of the literature, it is clear that leakage rates of fugitive methane have major implications for GHG emissions. Figure 3.7 relates various leakage rates to national GHG emissions (as a share of the "peak, plateau and decline GHG emissions trajectory range" (PPD; see RSA 2011a, 2015b)), with ranges of leakage rates of fugitive methane from the earlier literature and adding the range from the super-emitter literature. Depending on the leakage rate of methane, this has the potential to reduce or even negate any climate benefit associated with replacing conventional fuels with shale gas (Alvarez et al., 2012; Bradbury et al., 2013).

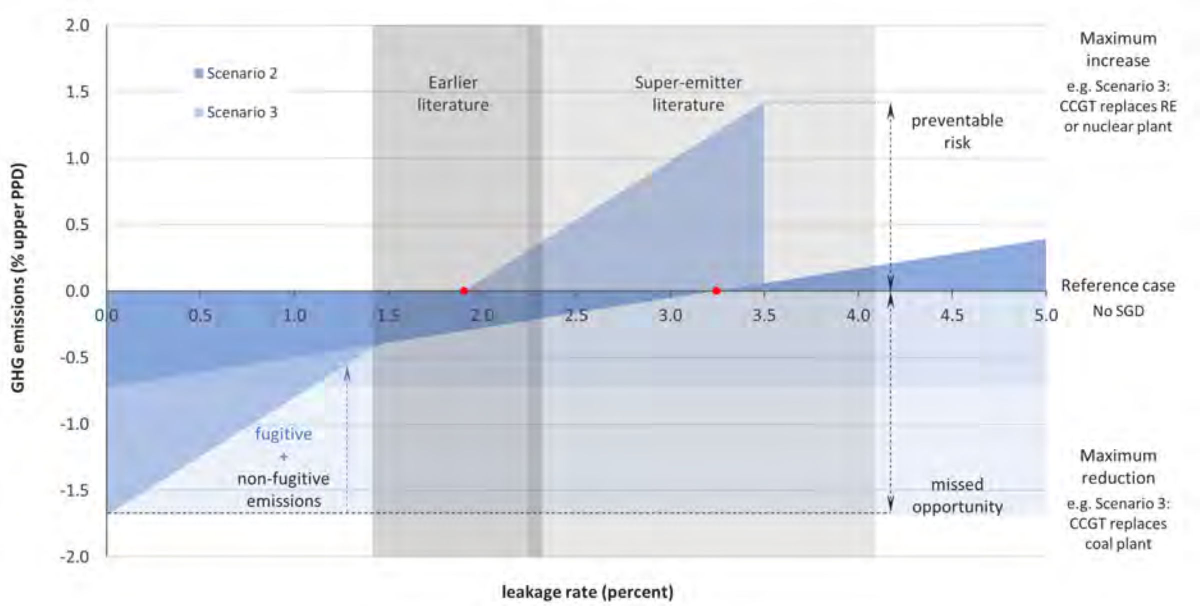


Figure 3.7: Ranges of leakage rates of fugitive methane from earlier and recent literature, for Small and Big Gas scenarios, and points where opportunity to reduce turn to risks of increased GHG emissions.

Figure 3.7 shows that the opportunity to reduce GHG emissions is reduced, as leakage rates increase. At some point, the opportunity turns into a risk of increased emissions. The cross-overs are not as precisely known as the single red dots in the figure might suggest, given uncertainties.

Leakage rates cannot be known for South Africa, until SGD takes place. For this assessment, a leakage rate of fugitive methane between 1.4 and 2.3% is assumed, noting that more recent literature has assessed low-frequency, high-impact events with a mode in this range, but a mean shifted up to 4.1%.

Another key factor in assessing the risks of increased GHG emissions from shale gas is GWP value used. Methane is a particularly potent GHG with a greater effect than the same amount of CO_2.

Text Box B: Global warming potential - GWP

GWP is defined as the global mean radiative forcing per unit mass emitted over a particular timescale relative to the forcing from CO_2 (IPCC, 2013), or the total amount of heat absorbed by a GHG over a particular timescale compared with the amount of heat absorbed by CO_2 over the same timescale (IPCC, 2007). Essentially, GWP looks to compare the relative radiative impacts of different GHGs against that of CO_2 (Burnham et al., 2012). The GWP of a GHG depends on the timescale considered (typically 20, 100 or 500 years) because atmospheric lifespans of GHGs differ. Over a 100-year timescale, for example, methane has an estimated GWP of 34 times that of CO_2 whereas over a timescale of 20 years methane's GWP is estimated to be 86 times that of CO_2 (IPCC, 2013). Without climate-carbon feedback, the GWP_{100} of methane is equivalent to 28 tons of CO_2 (ibid, Table 8.7). A local study also suggests that a 100-year GWP is appropriate for climate change (Cohen & Winkler, 2014). GWP100 is applied in this assessment.

3.3.2.5 Various uses of shale gas and associated GHG emissions

Both conventional and unconventional gas has a number of different end uses, with different GHG intensities per unit of energy used (e.g. kg CO_2-eq per kWh or per litre of fuel used). Common uses of shale gas include electricity generation; conversion to transport fuels; direct use in industry or households (for heating and cooking), and conversion to LNG for export.

The key points at which GHGs are emitted during shale gas use are described in this section, with opportunities and risks being quantified to the extent supported by existing literature in Section 3.3.4). A summary of risks and opportunities related to GHG emissions is presented in Section 3.3.5 and the risk matrix in Table 3.9.

Electricity generation: Electricity generation using natural gas involves combustion, which is the process of igniting the natural gas to release energy in the form of heat (Branosky et al., 2012). This process has been assessed internationally the greatest amount of GHG emissions among all of the stages of the life cycle of shale gas. Indeed, Bradbury et al. (2013) estimate combustion to comprise approximately 80% of the total GHG emissions associated with SGD over a 100-year timescale when the end use is electricity; AEA (2012) estimate the share to be as high as 90%.

Coal is often compared to shale gas in GHG Life Cycle Assessment (LCA) studies because of the focus on the shift away from coal for energy generation due to its GHG emissions-intensive nature. Despite the influence of different assumptions employed regarding fugitive emissions, GWP and energy conversion efficiencies, the literature generally finds shale gas to be less GHG emissions-intensive than coal, when considering electricity generation (Broderick et al., 2011; Chang et al., 2015; Cohen & Winkler, 2014; Heath et al., 2014).

Regarding energy conversion efficiency, natural gas-fired power plants are typically more efficient than coal-fired power plants (Bradbury et al., 2013). For example, electricity generation using a boiler using shale gas resulted in 31% fewer GHG emissions than a coal-fired boiler over the 100-year timescale (Burnham et al., 2012). The reduction in GHG emissions is estimated to be as high as 52% when considering a natural gas closed cycle plant (compared to a coal boiler) (Burnham et al., 2012). The UK Department of Energy and Climate Change (UK DECC, 2013), estimates the GHG emissions of shale gas when used for electricity generation to be in the range of 117.5 – 148.6 g CO_2e per MJ[11], while the GHG emissions of coal (for electricity generation) are estimated to be between 232.5 – 313.9 g CO_2e per MJ. Considering electricity generation in South Africa, and depending on the control of fugitive emissions (and which other factors relating to coal are assumed); Cohen & Winkler (2014) found a specific emissions intensity between 0.3 tCO_2/MWh and 0.6 tCO_2/MWh, compared with about 1 tCO_2/MWh for coal-fired electricity in South Africa.

Conversion to transport fuel and chemicals using GTL processes: Substituting imported fuel produced from crude oil refineries, whether located outside of South Africa or within our borders, with fuel produced from the GTL process in South Africa with shale gas as a feedstock will likely increase GHG emissions associated with liquid fuel supply in the country. The reason is that the upstream emissions from crude oil refining of the imported fuel are not accounted for as they occur outside of South Africa's boundaries. GTL is approximately 50% less emissions-intensive than CTL processes. This is assessed further in Table 3.7 below.

A straight comparison of GTL versus an oil refinery, ignoring the geographical location of where the emissions take place, presents conflicting results; likely a result of the different assumptions employed in the different studies. Edwards et al. (2011) for example, concludes that the life cycle GHG emissions of GTL-produced diesel marginally exceed those related to conventional diesel production, when considering the gas source as a field site close to the plant (note; a conventional gas source). On the other hand, Forman et al. (2011) found that the life cycle GHG emissions associated

[11] Original in g CO_2-eq per kWh.

with GTL-derived diesel (using conventional natural gas) were lower than those associated with the production of oil-refinery diesel.

Liquefaction to LNG: LNG is natural gas that has been converted to liquid form for ease of storage or transport. Natural gas is typically converted to LNG in order to transport the gas long distances, e.g. for export purposes. At the receiving end, LNG has to be re-gasified for use. LNG is distinct from GTL process, which produces diesoline or naphtha. The use of shale gas for the production of LNG may increase South Africa's GHG emissions assuming that all of the LNG is exported out of the country and is not used to substitute other fossil fuels that would have been combusted in South Africa.

Direct use in the residential, commercial and industrial sectors: The use of shale gas as a direct source of energy for heating and cooking may have GHG mitigation benefits if it is substituting coal based electricity. However, if shale gas were to displace electricity from low-GHG-emitting sources (e.g. renewable energy or nuclear power), then it would add to GHG emissions. In industry, shale gas could support fuel switching, for example from coal- to gas-fired boilers. This would assume sufficient gas (so more likely in the Big Gas scenario) and pipeline infrastructure being installed.

3.3.3 Metrics to compare GHG emissions and limits of acceptable change

In 2015, all countries signed an agreement under the United Nations Framework Convention on Climate Change (UNFCCC, 1992), for the first time committing each one to reduce their GHG emissions[12]. The aggregate of countries' INDCs falls short of the emission reductions required to keep temperature below 2°C (UNEP, 2015), and the total effect of all INDCs is likely to exceed the small remaining global carbon budget (Rogelj et al., 2016).

In absolute volumes of GHG, South Africa is a relatively small emitter albeit among the top 20 in the world (World Resources Institute (WRI), 2015). South Africa's contribution to the collective climate challenge is framed by our National Development Plan (National Planning Commission (NPC), 2012) and the National Climate Change Response White Paper (RSA, 2011a). Based on the PPD emissions trajectory range in the White Paper, South Africa's INDC (RSA, 2015b) states that the country's emissions as of 2025 and 2030 will fall between 398 and 614 Mt CO_2–eq.

[12] Reducing GHG emissions is known as 'mitigation' in the climate change literature. However, in this scientific assessment, mitigation means reducing impacts, as in the environmental management literature. The phrase "climate change mitigation" is used in this Chapter, where it is necessary to refer to the sense of reducing GHGs. The impacts of climate change are not in the scope of this Chapter; addressing the adverse impacts in the climate change literature is known as 'adaptation'.

Economic and regulatory instruments, and sectoral plans, are being developed to remain within the PPD emission trajectory range. Six GHG are being declared 'priority pollutants' under the NEMAQA; companies which directly emit over 100 000 tonnes of GHG (expressed as a CO_2 equivalent) annually must produce a regular 'pollution prevention plan' (DEA, 2016a); the DEA will allocate company-level 'carbon budgets'; and Treasury plans a carbon tax (RSA, 2015a). The Industrial Policy Action Plans (IPAP) (Department of Trade and Industry (DTI), 2015) and the New Growth Path (NGP) (RSA, 2011b) consider GHG reductions.

The GHG emissions associated with a particular set of activities can be expressed as an absolute volume of emissions per year, or as an emissions intensity, that is GHG emissions per unit of output. The latter appears frequently in the literature.

National climate policy envisages reporting of GHG emissions that is "mandatory for entities (companies and installations) that emit more than 0.1 Mt of GHGs annually" (RSA, 2011a). DEA has published for comment draft regulations declaring GHGs as priority air pollutants (DEA, 2016a), regulations requiring the submission of Pollution Prevention Plans (DEA, 2016b) and GHG reporting guidelines (DEA, 2015, 2016b). With SGD likely to exceed 0.1 Mt CO_2-eq per year, it is expected that developers will be subject to these and any further regulations, including possible company-level carbon budgets. Such reporting will contribute to South Africa's reporting on the implementation and achievements of its NDC (RSA, 2015b), as required under the Paris Agreement (UNFCCC, 2015).

3.3.4 Quantifying risks and opportunities in relation to GHG emissions

SGD presents both a risk of increased GHG emissions, and opportunities to reduce GHG emissions. The opportunity of emission reductions depends crucially on whether gas displaces coal (the main fuel in South Africa), gas displaces even lower-emission alternatives (such as renewable energy, nuclear, imported or domestically refined fuel), or gas is the fuel and technology chosen to meet increasing energy demand. Wright et al. (2016) assesses projections of growing energy demand, and the fuels and technology mix for energy supply. The use of shale gas leads to an increase in emissions measured in *absolute* units (e.g. Mt CO_2-eq), when gas adds to existing capacity to meet increasing demand, but that same case may reduce GHG emissions relative to a Reference Case. Both risks and opportunities are part of balanced approach to risk management. The following text includes quantification of opportunities, with the risks of increases in GHG emissions summarised in Table 3.9.

3.3.4.1 Risk of fugitive methane emissions

Studies indicate conflicting results regarding the percentage of fugitive methane emissions (leakage) and the value applied for global warming potential. Depending on the leakage rate of methane, this has the potential to reduce or even negate any climate benefit associated with replacing conventional fuels with shale gas (Alvarez et al., 2012; Bradbury et al., 2013). Leakage rates cannot be known for South Africa, until SGD takes place. For this assessment, a leakage rate of fugitive methane between 1.4 and 2.3% is assumed, noting that more recent literature has assessed low-frequency, high-impact events with a mode in this range, but a mean shifted up to 4.1%. Applying the 1.4%-2.3% range to the Small and Big Gas scenarios over a period of 24 years (middle of the 13-35-year range, see Burns et al., 2016) of production and development, as well as a GWP_{100} of 34, then the Exploration Only scenario might increase GHG emissions by 46 -75 Mt CO_2-eq over the 24-year period, or 1.9 - 3.1 Mt CO_2-eq per year (lower and higher leakage rate respectively[13]), which are considered 'moderate' consequences. The Big Gas scenario has a 'substantial' to 'severe' consequence of 8 – 13 Mt CO_2-eq each year, with and without mitigation, or 184 – 302 Mt CO_2-eq over the quarter-century. The occurrence of fugitive emissions is very likely, though consequences can be reduced from severe to substantial with mitigation, i.e. better control technologies to reduce leakage rates. **For the Big Gas scenario, the risk of fugitive methane emissions is assessed as high without mitigation, which might be reduced to moderate with mitigation and use of good practice in control technologies** (see Section 3.4). The assessment is based on the Big Gas scenario being limited to 20 tcf and implicitly assuming that relatively few operators introduce rigs in a well-planned fashion. Should the economic potential be a larger share of the technical potential than identified in Burns et al. (2016), the consequences would be more severe. For SGD beyond 20 tcf, the risks might be very high in the no-mitigation scenario. However, this chapter assesses the common scenarios as identified in Burns et al. (2016). For the Small Gas scenario, the risk is of increased GHG emissions is assessed as low. For exploration, the risks are very low, given only slight but noticeable consequences.

3.3.4.2 Other GHG emissions prior to transmission

In addition to fugitive methane emissions as discussed above, there are exploration and production activities that also lead to upstream GHG emissions prior to shale gas transmission and use, denoted as "other GHG emissions prior to transmission." These exploration and production processes involve both fugitive and deliberate industrial methane emissions and it is important that fugitive components are not counted twice. There is, however, considerable uncertainty surrounding the scale and likelihood of other upstream GHG emissions from SGD. In their assessment of the literature on the

[13] If the actual leakage rate for fugitive methane emissions turned out to be 4.1% (median for the super-emitter literature), then the emissions would 5.6 and 22.4 Mt CO_2-eq for the Small and Big Gas scenarios, respectively.

life cycle carbon footprint of shale gas, Weber & Clavin (2012) indicate that reworking might occur once in 10 years; perhaps not at all. Similarly, the US EPA reports CH_4 emissions from liquids loading of 3 and 96 Mt per year for sites comprising 1,379 and 1,784 wells respectively (US EPA, 2014), though Weber & Clavin (2012) (also see the supplementary information to their article) indicate that these are intermittent fugitive emissions associated with conventional gas wells only.

3.3.4.3 GHG from electricity generation – shale gas compared to alternatives

Shale gas used for electricity would displace other fuels used for electricity generation. CCGT could displace either existing plants (below the line 'existing capacity' in Figure 3.8); or add to existing capacity to meet growing demand in a Reference Case (see Wright et al., 2016). So what might be displaced can be divided into cases:

1. Coal for electricity generation, compared to shale gas ('gas displaces coal'), replacing either existing or new coal plants, both with a higher emissions intensity; or
2. Two options with lower emissions intensity than CCGT using shale gas, that is
    a. renewable energy (RE) technologies (wind, solar, others; 'gas displaces RE'); or
    b. nuclear power ('gas displaces nuclear').

Figure 3.8 illustrates how CCGT might replace other electricity generation technologies, and their difference in terms of GHG emissions-intensity. CCGT either displaces existing plant (mostly coal) below the line indicating existing capacity (the 'gas displaces coal' case). The area between the two arrowed lines assumes new capacity is built, and either displaces new coal plant with a higher emissions intensity; or options with lower emissions intensity – 'gas displaces RE' or 'gas displaces nuclear'.

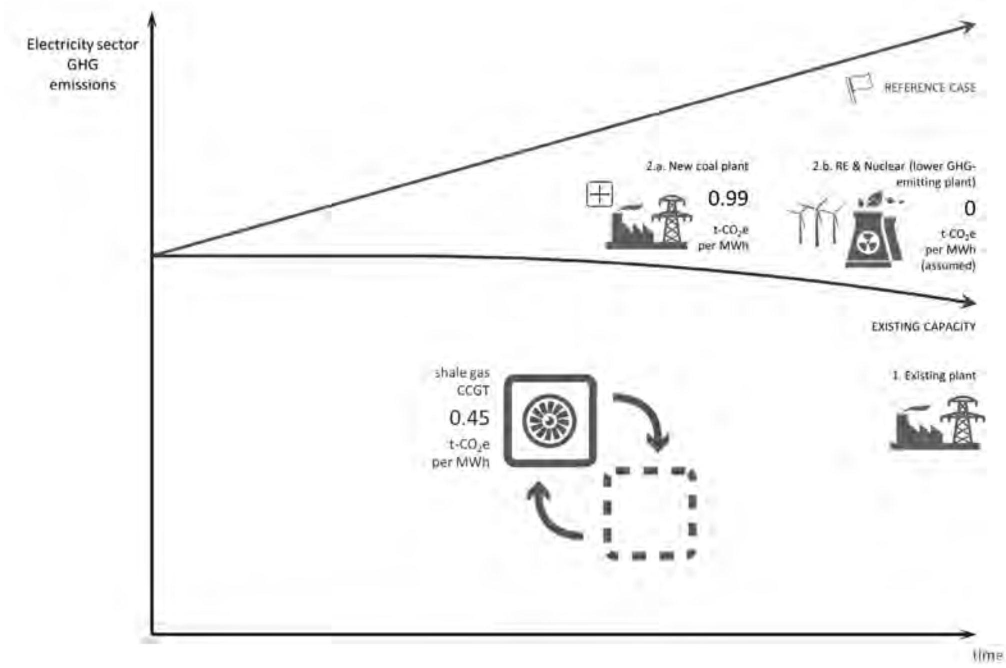


Figure 3.8: GHG implications of shale gas used in CCGT displacing other fuels for electricity generation[14].

With regards to shale gas for electricity generation, an average emissions intensity of 0.45 t CO_2-eq per MWh is used, noting the ranges reported between a maximum of 0.31 and 0.59 t CO_2-eq per MWh (Cohen & Winkler, 2014) depend significantly on fugitive methane emissions, the risk of which is separately assessed here. Coal-fired electricity in South Africa is assumed to be 0.99 t CO_2-eq per MWh as reported in Eskom annual reports; earlier studies had a slightly lower factor, 0.957 t CO_2-eq per MWh (Spalding-Fecher, 2011), but with recent challenges in the electricity system, a figure close to 1 seems appropriate. A difference of 0.54 t CO_2-eq per MWh is multiplied by assumed production for the Small and Big Gas scenarios. Nuclear power and renewable energy are assumed to have no GHG emissions during operation; there is literature on non-zero life cycle GHG emissions (GEA, 2012), but the other technologies do not factor in up- and down-stream emissions either. An increase of 0.45 t CO_2-eq per MWh for shale gas compared to nuclear and renewable energy is assumed.

Conversely, if shale gas were used to add power plants to the existing fleet, and provide additional total electricity consumed and produced – for whatever reason, then the same 0.45 t CO_2-eq per MWh would be added. **In terms of emissions intensity, shale gas would reduce GHG emissions compared to coal by 0.54 t CO_2-eq per MWh, whereas if shale gas were added to the grid or replaced electricity from nuclear or renewable energy sources, this would increase emissions**

[14] "Flag" icon by Alexander Smith, "add" icon by Designify.me, "Power Plant" icon by Dimitry Sunseifer, "wind turbines" icon by Tina Rataj-Berard, "nuclear power" icon by Siwat Vatatiyaporn, "replace" icon by Didzis Gruznovs, "jet engine" icon by Arthur Shlain from thenounproject.com

intensity by +0.45 t CO_2-eq per MWh (see Figure 3.8); note the numbers are similar but the one is a negative (reduction) the other a positive (increase). No mitigation is assessed for renewable energy or nuclear power, considered zero GHG emissions in operation for this assessment; mitigation of coal emissions is considered.

Note that Figure 3.8 shows GHG intensities (in CO_2-eq per kWh). The absolute emissions reductions or increases would depend on the amount of electricity generated from each source, and analysis of energy system modelling is beyond the scope of this Chapter (see Wright et al., 2016). It might be that electricity from shale gas was additional to existing generation. In the 'additional gas power' case, taking the 1000 and 4000 MW of CCGT (Burns et al., 2016), respectively, and further assuming a typical load factor of 55% (run as mid-merit plant) electricity generated would be 4818 GWh per year in the Small Gas scenario and 19,272 GWh per year in the Big Gas scenario[15].

In the 'gas displaces coal' case, diversifying the energy mix has long been a goal of SA's energy policy (DME, 1998), new capacity is needed with an ageing fleet of power plants and gas is potentially more available – both as LNG and shale gas. Using the same assumptions about OCGT in the Small and Big Gas scenarios, and multiplying by the difference in GHG emission intensity, there would be a reduction in emissions (shale gas relative to coal) of 2.6 Mt CO_2-eq per year for Small Gas and 10.4 Mt CO_2-eq per year for Big Gas, a slight but noticeable reduction. To put this in some context, these reductions are expressed as shares of national emissions limits under upper limit of 'peak, plateau and decline' (upper PPD), as in national policy and communicated in the INDC: so reductions in the Small Gas scenario are 0.4% of upper PPD and 1.7% in the Big Gas scenario, for both 2025 and 2030. **Shale gas for electricity provides a likely opportunity to reduce GHG emissions when displacing coal, but the scale of reductions is slight in relation to the national emissions trajectory.** Further research would be helpful to put GHG emission reductions from shale gas in the context of overall mitigation potential (as distinct from GHG emissions).

The 'gas displaces nuclear' and 'gas displaces RE' cases have very similar consequence in terms of increases of GHG emissions; they are therefore discussed together. Using shale gas for electricity generation, rather than renewable energy sources or nuclear power, is very likely to increase GHG emissions. For the Small Gas scenario, this might add 2.2 Mt CO_2-eq per year, and 8.7 Mt CO_2-eq per year for the Big Gas scenario; considered 'moderate' to 'substantial' consequences. It is very likely that the substantial consequence would occur, so that in the Big Gas scenario the risk is assessed as moderate. Emissions of 8.7 Mt CO_2-eq in the Big Gas scenario are equivalent to 1.4% of the national

[15] See calculations, the supplementary material in Excel file, worksheet 'Scale of GHG' in Digital Addenda.

emission limits represented by upper PPD, and 2.2% of the lower PPD limit. **If shale gas displaces electricity from nuclear or renewable energy, it will very likely increase GHG emissions, assessed as 'moderate' risk with Big Gas or 'low' in the Small Gas scenario.**

Mitigation is considered only for coal-fired electricity, in that a control technology of carbon capture and storage (CCS) may be applied. Adding CCS could reduce emissions (to say 0.22 t CO_2-eq per MWh (IPCC, 2014a)), but the technology is less likely to be implemented at the scale required and in time-frames considered here, than coal without CCS. A demonstration plant of CCS technology might only be available in South Africa in 2025. Emission would likely increase by 1.1 and 4.4 Mt CO_2-eq per year for the Small and Big Gas scenarios respectively, which are 'slight but noticeable' and 'moderate' consequences. **If shale gas displaces electricity from coal with CCS, it will likely increase GHG emissions, 'very low' to 'low' risk for Small and Big Gas scenarios.**

3.3.4.4 GHG from liquid fuels

Shale gas may be used in GTL plants under the Big Gas scenario (see Burns et al., 2016). Shale gas for GTL would displace other liquid fuel supply. As for electricity, this might be either existing plants; or new supply to meet rising liquid fuel demand (see Wright et al., 2016). Three options are considered in the risk assessment, illustrated in Figure 3.9 below:

1. The fuel and associated emissions from the GTL process substitute an equivalent amount of fuel produced from the CTL process ('GTL displaces CTL').
2. The fuel and associated emissions from the GTL process substitute an equivalent amount of fuel produced from importing crude oil and refining it locally ('GTL displaces refinery').
3. Imported petroleum products, in which case the associated emission are outside of South Africa's borders and in that sense considered zero ('GTL displaces imported fuel').

Figure 3.9 shows the different options, with GTL displacing one of the above options. As for electricity, the area between the two arrowed lines represents additions to existing capacity (but within a Reference Case, see Wright et al. (2016)), which is below the line.

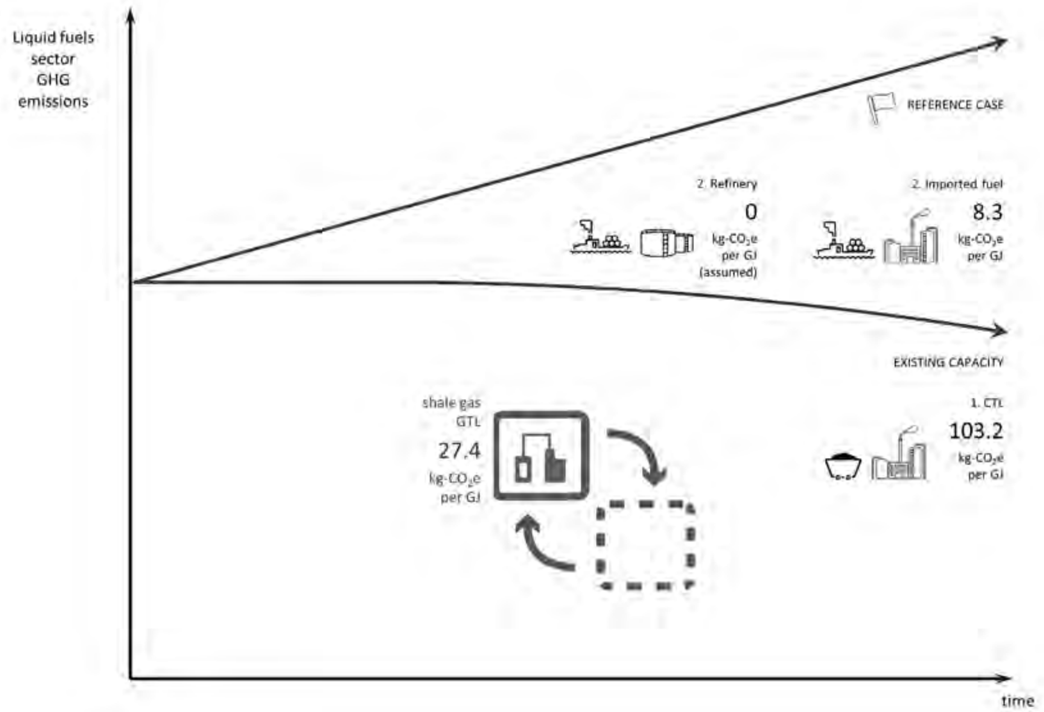


Figure 3.9 GHG implications of shale gas used for GTL displacing other liquid fuel supply[16].

In the case of 'GTL displaces CTL' is the main situation in replacing existing capacity, with an opportunity for lower GHG emissions intensity. The two new options are not quite the same intensity, with imported fuels being zero (in South Africa) compared to some GHG intensity in the 'GTL replaces refinery' case – but both are lower in emissions-intensity than GTL. New CTL is not an option assessed as there are no plans for such facilities.

In the case of 'GTL replaces CTL', all of the petrol and diesel products produced locally from CTL are replaced by locally produced syn-fuels manufactured through the GTL process using local shale gas as the feedstock. The GTL and CTL processes have different product slates, whose combustion downstream would have different GHG implications. There is insufficient literature including life cycle analyses to assess the downstream risks. The difference in emissions intensities at plant level is derived as reported in Table 3.7.

Table 3.7: Emission intensities for shale gas for GTL, CTL and oil refinery.

Emissions intensity	kg CO2e/GJ	Difference vs. shale gas
Shale gas for GTL	27.4	
Coal to liquids	103.2	-76
Oil domestically refined, imported oil	12.0	+15

Sources: Authors' calculations, drawing on (Argonne National Laboratory, 2016; Karras, 2011; National Energy Technology Laboratory et al., 2013)[17]

Given the 600 MMscf per day GTL plant envisaged in the Big Gas scenario, this would produce about 127 TJ of liquid fuel per year, with annual emissions of 13.1 Mt CO_2-eq. **In the 'GTL replaces CTL' case, emissions are reduced by 9.6 Mt CO_2-eq per year, which is a very significant opportunity**[18].

The 'GTL replaces refinery' case would increase GHG emissions by 2.4 Mt CO_2-eq per year; a 'moderate' consequence. The increases and decreases are likely, with the uncertainty lying mainly in emissions factors – with CTL not being used outside South Africa, and GTL investments occurring in few other countries. The consequences, making simplifying assumptions, may be in the range between 0.4% and 0.6% of national emissions limits under PPD for 2025 and 2030, as in national policy and communication in the INDC.

Literature on refineries in the US indicates about 100 lb of CO2 emitted per barrel of crude, though there is a range depending on technologies (Karras, 2011). Applying conversion factors (density, heat content), and assuming a range of technologies, an emissions intensity of 0.0083 t CO_2-eq GJ is derived; which is lower than the emissions intensity for GTL from shale gas (0.0274 t CO_2-eq GJ); these values are used for an assessment in the South African context (see digital addenda for calculations). **There is a low risk of increased GHG emissions with GTL displacing a refinery in a Big Gas scenario.**

The reason is that the upstream emissions from crude oil refining of the imported diesel and petrol are not accounted for as they occur outside of South Africa's boundaries. The upstream emissions from SGD and processing in the GTL process are accounted for and thus there would be additional emissions.

[17] CTL is used commercially by SASOL, but no emissions intensities are published. This assessment has drawn on the GREET model – from a US national lab - in the absence of published data on CTL in South Africa (Argonne National Laboratory, 2016).

[18] The term 'very significant' is not precisely defined, but is used here as a 9.6 Mt CO_2-eq increase in emissions which would have been called 'severe' consequence.

Shale gas can be used for the production of liquid fuels such as diesel, petrol etc. in a GTL process. This fuel can also be imported, in the 'GTL displaces imported fuel' case. Applying the consumption of 600 MMscf (Burns et al., 2016) per day in a GTL facility over a period of 24 years (13-35-year range) of production and development, then the Big Gas scenario is likely to increase GHG emissions with a 'moderate' consequence of between 2.8 Mt CO_2-eq (with mitigation) and 4.2 Mt CO_2-eq (without mitigation) per year. Here, mitigation refers to technologies and measures that can be used to prevent increased GHG emissions along the South African GTL supply chain, including the transport and distribution of gas. These may include technologies such as CO2/steam reforming or CCS during production, as well as proactive equipment maintenance and close monitoring of fugitive emissions during transport, transmission and distribution of the gas and end-products (see Figure 3.11). **The risk of increased GHG emissions from shale gas if GTL displaces imported fuel is low, with and without mitigation.** To get a sense of scale and consequence, over the 24-year period, increased emissions would add up to between 67 with mitigation and 100 Mt CO_2-eq without mitigation. Another reference is that annual emissions increases in the Big Gas scenario range from 0.5% of PPD (with mitigation, as share of upper PPD emissions, 614 Mt CO_2-eq per year) to 0.7% (without mitigation). This only applies to the Big Gas scenario as there is insufficient gas to run a GTL facility in the other scenarios and thus the risks for other scenarios are not assessed.

3.3.4.5 GHG from LNG Export

This case is a stand-alone case and differs from the other cases in that it does not require comparison. Any GHG emissions from the production of LNG would be additional to South Africa's current GHG footprint. Since LNG is exported from the country the GHG emissions associated with its combustion occur elsewhere and are not included in national GHG inventories. All the gas extracted from the Karoo is converted to LNG for export over a 24-year period. One terminal will be developed in the country to process the gas. Assuming all of the shale gas that would have been consumed in the GTL and power plants (780 MMscf per year) in the Big Gas scenario will be processed and exported as LNG. The LNG will not be combusted in South Africa and hence there are no combustion related emissions. However, the emissions produced are all additional to what is already being produced locally. The probability of an increase is thus 'very likely'. The increase in emissions, making simplifying assumptions, might be 3.2 to 4.9 Mt CO_2-eq per year, with and without mitigation – that is 'moderate' consequences, or 'substantial' ones without mitigation. The risk of increased GHG emissions can be mitigated by monitoring and controlling venting, flaring, and fugitive emissions, both during normal operation, i.e. from liquefaction to eventual regasification and transport, and during malfunctions. **The overall risk of shale gas for exported LNG is assessed as moderate for the Big Gas scenario – without any mitigation. Provided mitigation is implemented, this can reduce the risks to low for a Big Gas scenario.**

3.3.5 Overview of risks of GHG emissions

Based on the assessment for shale gas compared to various alternative uses, replacement of existing or new technologies using other fuels, and risks of fugitive emissions, a risk assessment matrix for GHG emissions is presented in Table 3.9. Note that the text above presents both opportunities (positive impacts, in this case, reductions of GHG emissions) and risks of increased GHG emissions; whereas Table 3.9 only presents the risks, consistent with general guidance for all Chapters of the risk assessment. This should not be understood to mean that there are no opportunities to reduce GHG emissions through use of shale gas. Shale gas presents both a risk of increased GHG emissions, and opportunities to reduce GHG emissions. The opportunity of emission reductions depends crucially on gas displacing coal (the main fuel in South Africa). This applies to gas rather than coal used for producing liquid fuel and electricity, which is a significant opportunity for GHG emission reduction.

The likelihood of various risks was determined by expert judgement; that is the author team's rating having assessed the relevant literature. A scale of consequences that emerged, with 'break points' established between different consequence levels with increases of GHG emissions in Mt CO_2-eq per year, is shown in Table 3.8. The table also shows the percentage of upper PPD emissions trajectory, i.e. as a share of 614 Mt CO_2-eq in 2025 to 2030 (see Section 3.3.3).

Table 3.8: Scale of consequences for GHG emissions

	Mt CO_2-eq per year	**% of upper PPD**
Slight but noticeable	0.0 - 1.1	0.0 - 0.2
Moderate	1.2 - 4.5	0.2 - 0.7
Substantial	4.6 - 8.7	0.7 - 1.4
Severe	8.8 <	1.4 <
Extreme	-	-

Given that GHG emissions are well mixed in the atmosphere in short timeframes, the location of sources is not material; the matrix therefore does not refer to area. Risks with mitigation are assessed for some but not all options, depending on control technologies available (see Section 3.4). Note that 'shale gas displaces coal' is presented only 'with specified mitigation', i.e. with CCS, as coal without CCS is an opportunity to reduce GHG emissions, and opportunities are not included in a risk matrix.

Table 3.9: Risk assessment matrix for GHG emissions

		Without mitigation			*With specified mitigation*		
Impact	**Scenario**	**Consequence**	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Fugitive emissions							
	Exploration Only	Slight but noticeable	Very likely	Very low	Slight but noticeable	Very likely	Very low
	Small Gas	Moderate	Very likely	Low	Moderate	Very likely	Low
	Big Gas	Severe	Very likely	High	Substantial	Very likely	Moderate
Use of shale gas for electricity generation, additional to existing or compared to alternative end use							
'Gas displaces RE': Electricity generation using shale gas in CCGT, displaces renewable energy	Small Gas	Moderate	Very likely	Low			
	Big Gas	Substantial	Very likely	Moderate			
'Gas displaces nuclear': Electricity generation using shale gas in CCGT, displaces nuclear power	Small Gas	Moderate	Very likely	Low			
	Big Gas	Substantial	Very likely	Moderate			
Gas displaces coal with CCS': Electricity generation using shale gas in CCGT, displaces electricity generation at coal-fired power stations with CCS	Small Gas				Slight but noticeable	Likely	Very low
	Big Gas				Moderate	Likely	Low
Use of shale gas for liquid fuel, additional or compared to alternative end use							
'GTL displaces imported fuel': Fuel from shale gas for GTL displaces imported fuel	Big Gas	Moderate	Likely	Low	Moderate	Likely	Low
'GTL displaces refinery': Fuel from shale gas using GTL displaces liquid fuels from oil imports refined in SA	Big Gas	Moderate	Likely	Low			
Export shale gas in form of LNG							
'Gas for LNG export' Shale gas liquefied to LNG and exported	Big Gas	Substantial	Very likely	Moderate	Moderate	Very likely\	Low

A high risk of increased GHG emissions is assessed for the risk of fugitive methane emissions associated with large SGD (Big Gas scenario). This can be reduced to moderate with mitigation. Good governance, ensuring that good practice and effective control technologies are implemented is therefore important, as the decreased risk due to mitigation assumes good governance.

Replacing fuel produced from importing crude oil and refining it locally with GTL from shale gas has a moderate risk of increases, given that is assessed as likely with substantial consequences. The consequence for imported fuel is moderate (4.2 Mt CO_2-eq per year) which is still the case with mitigation but at lower scale (2.8 Mt CO_2-eq per year); which comes close to the consequence for ‘GTL displaces refinery’ (2.4 Mt; see Digital Addenda for calculations). The relative emissions factors need further study.

The scale of these consequences is put into context of other cases, with indicative consequences shown in Figure 3.10. The figure shows opportunities to reduce GHG emissions as bars below the line, and risks of increases as bars above the line. The consequences were based on simple calculations drawing information from the literature and should not be taken as precise, even though the units are Mt CO_2-eq per year.

Figure 3.10: Indicative consequences of increases in GHG emission reductions and opportunities for reductions, in Mt CO_2-eq per year, as calculated for this assessment.

Considering the emissions intensity of shale gas used for electricity generation, the cases illustrated in Figure 3.8 focus on CCGT displacing coal-fired power plants (an opportunity to reduce) or even lower GHG-emitting technologies (renewable energy and nuclear power). In terms of emissions intensity, shale gas would reduce GHG emissions compared to coal by a similar amount (-0.54 t CO_2-eq per MWh) to the increase in GHG emissions (+0.45 t CO_2-eq per MWh) if shale gas were added to the grid or replaced electricity from nuclear or renewable energy sources. The likely opportunity to reduce GHG emissions is slight for a Small Gas scenario, and moderate for large SGD (Big Gas scenario), in relation to the national emissions trajectory. Shale gas displacing electricity from nuclear or renewable energy risks increasing GHG emissions, though at a scale assessed as ‘slight but noticeable’ to ‘moderate’ consequence. The changes are very likely, given well-understood emission factors, and risk of increases are low to very low.

The risk of shale gas for exported LNG is assessed as low for the Big Gas scenario – without any mitigation, very low with control technologies and effective governance.

The main risk for increased GHG emissions that is shown in Table 3.9 is from fugitive methane emissions, which is sensitive to leakage rates (see Figure 3.7).

3.4 Good practice guidelines

There are a number of approaches to minimise the impacts of the shale gas life cycle on air quality and to reduce GHG emissions. These include control technologies and engineering actions or alterations of equipment, as well as a strong emphasis on good governance, transparency and strong regulatory and enforcement frameworks. Monitoring is crucial and baselines need to be established before shale gas exploration takes place.

3.4.1 Control technologies

Control technologies to minimise air pollutant emissions are focused on vehicles, drilling rig engines, pump engines and compressors. Having a high level of fuel-efficiency standards is also a means to limit emissions (IEA, 2012). As outlined in Section 3.2.4.3, technologies such as ignition timing retard and selective catalytic reduction can limit NO_x emissions, while diesel particulate filters can limit PM emissions, and diesel oxidation catalysts can limit VOC emissions (Roy et al., 2014). Once the shale gas is produced from a well, compressed natural gas engines could be utilised in place of diesel engines, greatly reducing emissions (Burns et al., 2016). Occupational exposure to air pollutants can be greatly mitigated with best available mitigation technologies based on the EPA Oil and Gas rules, Tier four emissions standards, and silica mitigation measures (Digital Addendum 3b). It is proposed that these be used to determine environmental impacts of this activity in the absence of local rules.

Mitigation technologies can reduce local community exposure to air pollutants. According to the scenarios described in Burns et al. (2016), flaring will be used to minimize VOC emissions from the well completion process; however, green completions are the recommended standard for emissions reductions as this also minimises GHGs (Field et al., 2014). Emissions modelling from the Marcellus shale play in the USA demonstrated that NO_x emissions could be reduced by 85% if the control methods discussed above were used for all equipment, while VOC emissions could be reduced by 88% (Roy et al., 2014). Assuming control measures are implemented for NO_x and VOCs, the risk of emissions in Table 3.3 can be significantly reduced.

Mitigation efforts on SGD would not directly decrease the risks of increased ozone and PM concentrations. However, the decreased emissions of NO_x and VOCs through mitigation efforts would lead to decreases in ozone and PM concentrations, and thus a risk reduced indirectly.

In relation to GHG emissions, control technologies will be key to limit the venting of methane to the atmosphere, realising opportunities of shale gas to reduce GHG emissions, and limiting the risk of any increases. Figure 3.11 highlights specific mitigation technologies and systems identified in a South African study. The risk of fugitive methane emissions, without any mitigation or control technologies, appears very likely.

Figure 3.10/...

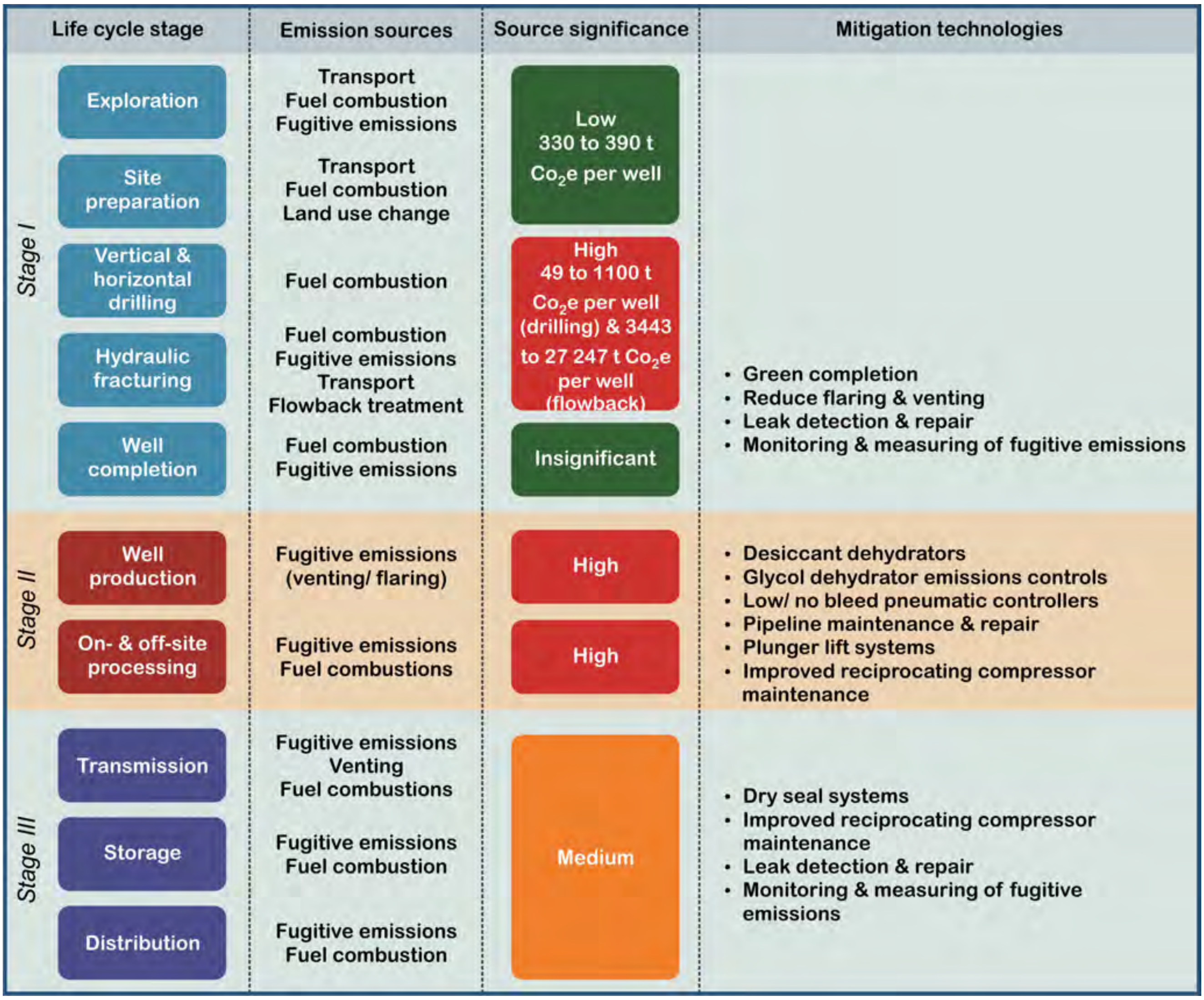


Figure 3.11: Mitigation measures for different stages of shale gas development.

Source: Figure 2.6 in DEA (2014a)

With control technologies it is suggested that up to 88% of upstream fugitive emissions (prior to combustion of the gas) can be captured by implementing mitigation efforts (Harvey et al., 2012). The literature also advises requiring best emission controls and rigorous testing for leaks (Field et al., 2014). Control technologies include improving the existing field equipment to reduce leaks; using additional technology designed to capture emissions; and minimising and monitoring fugitive emissions.

The consequences of exposure to air pollutants can be significantly mitigated in occupation, local, and regional exposure by technological interventions and best practice. An exception is occupational exposure to diesel exhaust, which are difficult to mitigate. The assumptions regarding the efficacy of mitigation depend on the adoption of strong regulatory frameworks with appropriate monitoring and enforcement. This leads to an additional risk not evaluated here, which is the risk that capable regulatory institutions and systems will not be put in place or will not be managed successfully. Indeed, the large number of sources and large spatial scale of the shale gas industry in the US has rendered effective monitoring and enforcement very challenging.

An impact specific to South African SGD is the fugitive dust related to vehicle movements on unpaved roads, which may be exacerbated by the remote locations and the requirement for transporting large quantities of water. This will require careful planning of routes and, once planned, traffic densities or traffic frequency thresholds, and then the mitigation of this source by chemical stabilisation or paving of roads. Such measures would assist in mitigation regional community exposure to truck emissions.

3.4.2 Legislation and regulation

Good practice may be required under the Mineral and Petroleum Resources Development Act (Act No. 28 of 2002; MPRDA: as amended and read with two proclamations). The Department of Mineral Resources (DMR) has gazetted regulations under the MPRDA which include a section on “management of air quality” and specifically paragraph 127 requiring license holders to minimise fugitive emissions, including natural gas during hydraulic fracturing operations by various means, or if those are not feasible, to flare the gas (DMR, 2015). These regulations seek to avoid venting methane to the atmosphere and to minimise flaring.

It is recommended that there should be an assessment of existing regulations and legal frameworks applicable to SDG across all impacts. Environmental legislation under the National Environmental Management Act No. 107 of 1998 will be applicable to SGD. A Specific Environmental Management Act (SEMA) could be passed. The regulatory mechanisms available under NEMAQA should be assessed and the most relevant options applied to SGD. It is important to note that SGD is a complex emissions source consisting of a combination of point and diffuse emissions which vary spatially and temporally.

The IEA (2012) established a set of ‘Golden Rules’ for shale gas with the aim to address environmental and social impacts. The IEA’s ‘Golden Rules’ advise to “target zero venting and minimal flaring of natural gas during well completion and seek to reduce fugitive and vented GHG emissions during the entire productive life of a well [as well as to] minimise air pollution from vehicles, drilling rig engines, pump engines and compressors” (IEA, 2012). For mitigation of venting and flaring, measures consistent with the Global Gas Flaring and Venting Reduction Voluntary Standard (part of the World Bank Group’s Global Gas Flaring Reduction Public-Private Partnership) should be adopted when considering flaring and venting options for onshore activities; again venting only for safety and listing several specific control measures when flaring (International Finance Corporation, 2007). This is consistent with regulation elsewhere (e.g. the UK, which aims to minimise venting - only for safety reasons - and it is preferable to use gas on-site and flare (UK DECC, 2014).

The IEA estimated the cost of applying its 'Golden Rules', which "could increase the overall financial cost of development a typical shale-gas well by an estimated 7%" (IEA, 2012). These relatively modest costs of mitigation, which can be offset by lower operating costs, should be included by developers in considering the full costs of the investment and its returns. Estimates for specific technologies are included in a study for South Africa (DEA, 2014d).

Legal research indicates that is "valuable to aggregate all regulatory provisions into a single set of regulations, [but] those regulations must be appropriately authorised by statute (Centre for Environmental Rights, 2013). The same point is made in a Water Research Commission (WRC) report which points to the need for "alignment and cooperative governance between different government departments and alignment between different pieces of legislation" (Esterhuyse et al., 2014). The WRC report also suggests that monitoring should ask why, what, how, where, when and who (ibid).

3.4.3 Establish baselines and monitoring of air quality and GHG emissions

The Centre for Environmental Rights (2013) recommends establishing baselines for and disclosing key environmental indicators including air quality and emissions. World Bank guidelines also recommend baseline air quality assessments and air quality models to establish potential ground level ambient air concentrations during facility design and operations planning, to avoid impacts on human health and the environment (International Finance Corporation, 2007).

There is an urgent need for at least one monitoring station for local air quality *within the study area,* well before shale gas exploration and development begins. Effective monitoring is an essential information base for management plans for both air quality and GHG. Baseline and monitoring methodologies are best designed together, as the baseline stations can be utilised as monitoring stations.

Baseline monitoring before any shale gas exploration occurs would be critical to understand the background concentrations of methane and air pollutants (NO_x, SO_2, PM, and VOCs). A baseline air quality monitoring study should be at least 12 months long in order to capture seasonal differences, however studies longer than a year are needed to understand differences between years. As noted in

Section 3.2.1, there are currently no ambient air quality monitoring stations in the study area. As more information on the location of drilling and exploration activities is made available, sites should be identified for intensive air quality monitoring. This baseline information should be made publicly available to inform stakeholders on the current status of the area.

In addition, due to the potential for regional impacts, air quality monitoring sites are needed throughout the Karoo, in addition to monitoring near the shale gas activities.

Monitoring of air pollutants on-site would be necessary throughout all stages of the shale gas life cycle (Burns et al. 2016). The on-site monitoring would include species that are an occupational risk, which would include VOCs. Well completions in particular are a potentially large source of VOCs that must be mitigated. Green completions are by far the recommended best practice for minimising VOC emissions, with flaring being a less desirable alternative. As the health impacts from VOCs are composition-specific, speciation of VOCs would be needed to understand what species are present, their associated risk and associated occupational health guidelines. Oil and gas operations can have VOC source signatures distinct from vehicles and other industrial processes. For example, propane, C_2-C_7 alkanes and C_5-C_6 cycloalkanes were used to determine the relative contribution of oil and gas operation VOCs to all ozone precursors in Colorado (Gilman et al., 2013). In addition, for local and regional air quality concerns, the speciation of VOCs will aid in modelling their ozone production and secondary aerosol production potential. In order to attribute pollution to different activities, air quality modelling that includes photochemistry and chemical transformation of pollutants would be necessary.

In order to manage the potential risks from increased emissions of air pollutants, the development of an Air Quality Management plan for the region, as well as an Occupational Health and Safety Plan for the work sites is needed. The recently published US EPA guidelines (US Federal Register, 2012) could serve as a useful reference point on good practice. The plans will identify species of concern, the necessary monitoring plan, as well as mitigation policies to be enacted to decrease exposure. A baseline air pollution emissions inventory of the region would assist in modelling not only the current atmospheric concentrations on the pollutants of concern, but also to model the impact that SGD scenarios would have on regional air quality (e.g. through ozone formation). Such scenarios could also include the potential impacts of climate change to air quality (e.g. changes in precipitation, temperature, meteorology, etc.). The potential impacts of climate change on air quality are extremely complex, but should be considered when developing a comprehensive air quality management plan.

It is important to establish a baseline to enable clear attribution of any increased GHG emissions due to SGD. Methane is the most material GHG in this context, but a baseline might also be established for CO_2 and N_2O, with little additional cost. Studies in the US state of Pennsylvania used instrumented aircraft platform to identify large sources of methane from some wellpads, with further work being required for attribution to specific sources (Caulton et al., 2014). It may be possible to use high precision measurement combined with inverse modelling, and information about local wind patterns, to improve attribution, if shale gas exploration and development takes place. The immediate priority, as for air quality, should be to establish baseline values for any methane emissions in the Karoo.

GHG monitoring methodologies should draw on both top-down and bottom-up approaches. Methane can be released naturally, and thus in order to understand at a later stage the impact of SGD on regional methane emissions, it is necessary to develop a baseline; initial approaches might use methodologies for GHG inventories. Inventory methodologies often assume average activity levels, and standard emission factors. Monitoring systems should be designed for continuous improvement, and specifically to ensure that "sampling strategy must capture the low-probability, high-emitting sources" (colloquially known as super-emitters) (Zavala-Araiza et al., 2015), including for example rare but high-emitting liquid unloading events (Heath et al., 2014). Methane leakage rates should be established soon, to avoid problems with attribution in future, where developers might claim that fugitive methane was not higher than 'natural' rates.

The DEA is declaring GHGs as priority pollutants (DEA, 2016a) and the DMR has listed fugitive emissions in the air quality section of regulations for petroleum exploration and exploitation (DMR, 2015). DEA and DMR might involve other agencies in the design, commissioning and finalisation of a baseline study.

3.4.4 Institutional responsibilities

National DEA would lead the development of policy to regulate the emissions of GHG and air pollutants from SGD.

Institutionally, the opportunities to reduce GHG emissions if substituting higher carbon fuels and risks of increased emissions when displacing even lower emission fuels (or being entirely additional to the energy system) will likely lie with the DEA, as the focal point for climate change. The DEA should work with the DoE, DMR, Science & Technology (DST) and Water & Sanitation (DWS) in developing an effective regulatory framework for GHG emissions associated with SGD. It is recommended that these departments develop and legislate domestic "best practice" emissions standards for SGD and develop appropriate human, institutional and technical capacity.

With regards to air quality impacts of SGD, DEA needs to develop policy for regulating the emissions. As indicated earlier, this could include application of NEMAQA, possible amendments of its regulations and / or a SEMA. Implementation of these would require strengthening of capacity within district municipalities to ensure licensing and implementation; especially given that district municipalities in the affected areas have had limited experience in the practice of air quality management and SGD is a unique combination of emissions hitherto unknown in South Africa. In addition, as the highest risks with regards to air pollution exposure were assessed for workers, DEA must work with the Departments of Health and Labour in order to develop and implement appropriate occupational health regulations for SGD.

Good practice guidelines are needed to minimise impacts on air quality and reduce GHG emissions, with guidelines for control technologies, consideration of effective legal regulation, early establishment of baselines and continuous monitoring and good governance enabled by coordination across several institutions.

3.5 Gaps in knowledge

The literature on SGD is largely international, particularly from the USA, with relatively few studies undertaken in South Africa. There are little data available from the rest of the world on GHG emissions specific to South Africa, only two studies specific to the South African context (DEA 2014b; Cohen & Winkler 2014) and one on air quality (Altieri & Stone, 2016). This partly reflects different levels of development of shale gas, but points to the overall need for more research, including on air quality and GHG risks under South African conditions. This also reflects on that fact that many specifics of SGD will only be known if and when exploration and development begins. At that point, empirical studies in South Africa would become possible; the current assessment can only draw on international literature for empirical findings.

Specific emission factors for CTLs in particular are needed for South Africa. Emission factors for GTL are studied slightly more widely, though specific studies under South African conditions would be beneficial; whereas analysis of emissions oil refineries are appropriately supported by international literature.

Relatively few studies undertake a full life LCA for GHG emissions from SGD, and further work should compare this to life cycle GHG emissions for other energy end uses, for both liquid fuels and electricity. Additional research is required to conclude whether the use of shale gas as a source of fuel for transport in the form of CNG is better or worse from a GHG perspective.

Further research is needed to quantify the risks and opportunities of SGD for GHG emissions, for example through energy modelling. Energy modelling would provide information on how the energy system might respond to shale gas becoming available at different scale, assumed prices and the extent to which gas might displace other fuels for various end uses. No dedicated modelling study has been undertaken recently, other than a ‘Big Gas’ scenario in the unofficial IRP 2013 update.

The majority of the gaps in understanding the risk to air quality from shale gas stem from the uncertainty in the emissions and speciation of emissions (e.g. exact chemical compositions of all VOCs) from the exact processes and activities that will occur, and what fuel source shale gas may replace. A comprehensive emissions inventory that could be used for air quality modelling for the area would assist in understanding the potential ambient air pollution impacts from shale gas, and the resultant potential health impacts. The speciation of VOCs would assist in developing appropriate mitigation measures for occupational health (the standards are species-specific) as well as their ozone and secondary aerosol production potential. This detailed emissions inventory could then be used for air quality modelling to quantify the impact that SGD has on ambient air quality, and the resultant impacts.

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3.7 Digital Addenda 3A – 3B

SEPARATE DIGITAL DOCUMENT

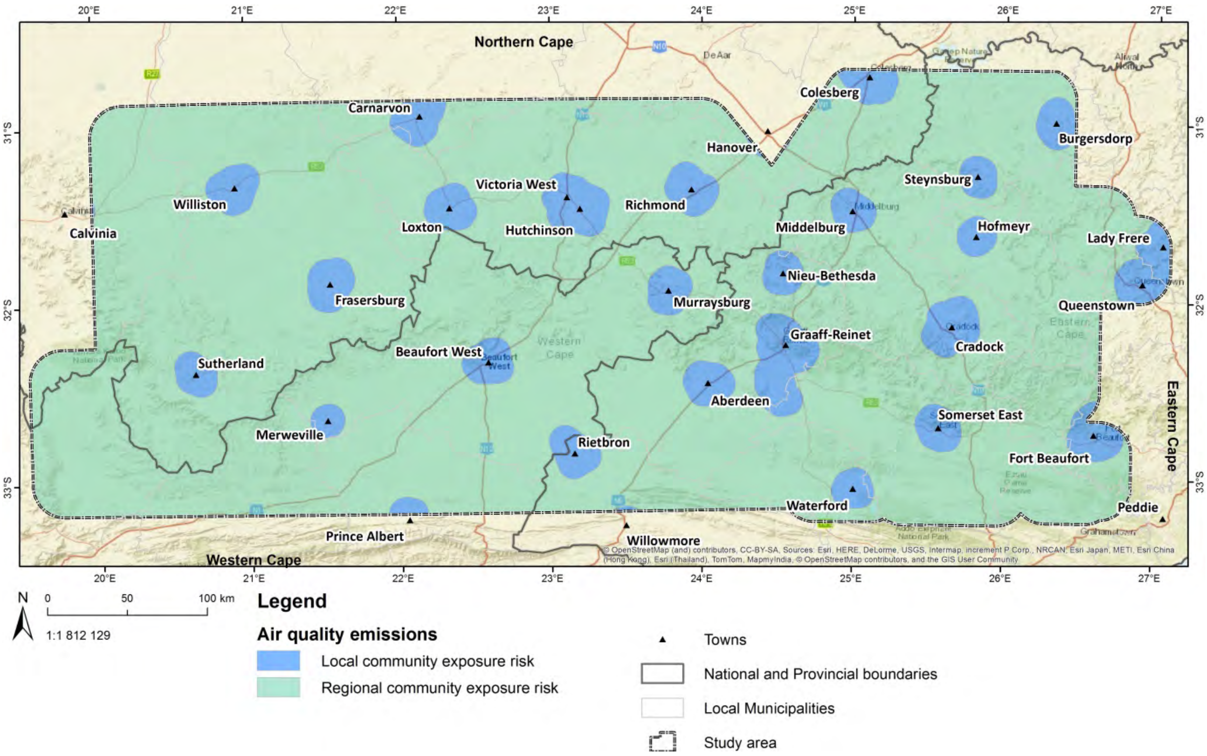
Addendum 3A: Spatial distribution of risks

Addendum 3B: Taken directly from "Controls and Recommendations to Limit Worker Exposures to Respirable Crystalline Silica at Hydraulic Fracturing Work Sites," Online Supplemental, Esswein et al., 2013

DIGITAL ADDENDA 3A – 3B

Addendum 3A: Spatial distribution of risks

If a wellpad is placed in one of the blue areas, the neighbouring town will be at risk for local community exposure. The green area represents regional community exposure, regardless of where in the study area the wellpads are placed.



Addendum 3B: Taken directly from "Controls and Recommendations to Limit Worker Exposures to Respirable Crystalline Silica at Hydraulic Fracturing Work Sites," Online Supplemental, Esswein et al., 2013

(http://www.tandfonline.com/doi/suppl/10.1080/15459624.2013.788352/suppl_file/uoeh_a_788352_sm4302.pdf)

"Engineering Controls

Based on workplace observations of various points of dust release on sand movers, NIOSH developed two engineering controls, one at the conceptual stage and one at the proof of concept stage. The first is a series of mini-bag houses that attach to the rim of a sand mover thief hatch and exploits positive pressure generated in the sand bins by the air compressor on the sand refill truck. Dust control is achieved as a filter cake develops on the inside of the bag house fabric. The design is intended to be self-cleaning as the filter cake is sloughed as the bag house fabric expands and collapses as air pressure is pulsed at the end of bin filling. This design is intended to be a “bolt-on” retrofit control option for sand movers currently operating in the field, but also could be configured in as part of original equipment manufacturer (OEM) for new models of sand movers. Figures 1 and 2 illustrate the concept of the mini-baghouse retrofit. A second control (at the conceptual stage) is a screw auger retrofit assembly to replace the sand belt on sand mover. This control requires more extensive engineering and mechanical retrofitting to existing sand movers, but could also be included in new OEM models.

An additional active control (which may currently be in production) includes use of a hood and ductwork connected to sand mover thief hatch openings connecting to a central manifold and then to a stand-alone baghouse for dust collection. Other (passive) considerations include enclosures, specifically installation of skirting or stilling curtains along the sides of the sand mover to contain particulate emissions from the sand belt. Similarly, enclosures and shrouding can be considered along the dragon tail with shrouding at the end of the dragon tail to limit dust emissions at the interface of transfer belts and blender hoppers. Keeping the dragon tail as close to the blender hopper or transfer belt to minimize the distance the proppant falls can reduce dust generation. Mandating the use of end caps on fill ports of sand movers is a simple and cost effective way to control silica dust ejected from this point source. Using dust control (magnesium or chloride amended water) on lease roads and at the wellpad area can reduce on-site dust generation. The use of well brines is not recommended as these may contain naturally occurring radioactive materials (NORM), including isotopes of Uranium, Thorium, Radium.

NIOSH recently published *Best Practices for Dust Control in Metal/Nonmetal Mining (NIOSH Informational Circular 9521)* which discusses dust control in underground mining operations.(1) Results from this document have direct relevance in hydraulic fracturing operations. Dust suppression using water misting may be acceptable and effective if misting nozzles are located in the correct locations and fine spray, atomizing nozzles are used. A recent paper found that the use of water spray application reduced respirable silica concentrations by 69-82% in outside stone crushing mills.(2)

While this study involved a systematic approach to understanding risks for work crew exposures to respirable crystalline silica, and is believed to be substantially representative, it may not address all points of dust generation or all options for effective controls.

Personal Protective Equipment

Until a variety of engineering or other controls can be conceived, developed, evaluated and confirmed to be effective for controlling respirable silica exposures to hydraulic fracturing work crews, the use of respiratory protection will be required. NIOSH approved, air-purifying, elastomeric half masks and filtering-facepiece respirators with particulate efficiencies of N-95 and greater are recommended as a minimum protection when PBZ exposures can be confirmed to be less than 10 times the relevant OELs. Because some PBZ samples exceeded either the OSHA calculated PELs or the NIOSH REL by a factor of 10 or more [the maximum use concentration (MUC) for that type of respirator], full-face, air-purifying respirators which are assigned a protection factor of 50 may need to be used in some cases. Considering the NIOSH REL of 0.05 mg/m^3 as a TWA, the MUC for a half face respirator would be an airborne concentration of respirable silica equivalent to 0.5 mg/m^3 as a TWA. In this study, respirable silica concentrations among Sand Mover and T-belt Operators notably exceeded this concentration, especially for Sand Mover Operators.

RECOMMENDATIONS

Conducting workplace exposure assessments to characterize work crew exposures to respirable crystalline silica is a recommended first step in understanding the scope of controls that may be needed. Employers should conduct full-shift worker exposure assessments, unless a decision is made to immediately implement controls and then re-evaluate the degree of exposure hazard based on use of controls. Since silica-containing dusts are generated from multiple locations, multiple types of controls (active and passive engineering controls, administrative and PPE) will be needed to prevent or mitigate workplace exposures.

Worker exposures to respirable crystalline silica should be controlled to the lowest concentrations achievable, certainly below calculated OSHA PELs and ideally below the NIOSH REL. Employers with workers at hydraulic fracturing worksites should focus on the traditional industrial hygiene hierarchy of controls, specifically: eliminate the hazard if possible and substitute less toxic proppant where feasible. Because engineering controls may not be completely effective, employers are encouraged to ensure that an effective respiratory protection program is in place that meets the criteria of the OSHA Respiratory Protection Standard (29 CFR 1910. 134).(2) and consult OSHA Directive CPL 03-00-007, National Emphasis Program–Crystalline Silica, for detailed information on silica hazards, guidelines for air sampling, guidance on calculating PELs for respirable dust containing silica, and other compliance information."

CHAPTER 4

Earthquakes

CHAPTER 4: EARTHQUAKES

Integrating Author:	Raymond Durrheim[1, 2]
Contributing Authors:	Moctar Doucouré[3], Vunganai Midzi[4]

1 Centre for Mining Innovation, Council for Scientific and Industrial Research (CSIR), Pretoria, 0184

2 University of the Witwatersrand, Johannesburg, 2000

3 Africa Earth Observatory Network- Earth Stewardship Science Research Institute (AEON-ESSRI), Nelson Mandela Metropolitan University, Port Elizabeth, 6031

4 Council for Geoscience, Pretoria, 0184

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Executive Summary

"Unconventional gas development" or "fracking" is a technology that uses high pressure fluid to create a network of fractures that extends for tens of meters from a borehole to provide pathways for the extraction of gas from low permeability rocks such as shale. The technology has greatly increased hydrocarbon production during the last decade, especially in the United States. It is believed that the Karoo Basin contains some shale strata that may contain significant resources of gas. The injection of fluids into the earth at pressures high enough and volumes great enough to cause rocks to fracture and/or faults to slip will inevitably cause seismic events. It is the purpose of this investigation to consider the potential risk posed by natural and induced seismicity in the study area, especially as many of the buildings in the Karoo, including heritage buildings, are considered to be vulnerable to shaking as they are built from adobe (mud brick) or unreinforced masonry.

Scenario 0: Reference Case

Southern Africa is a stable continental region with a low level of natural seismicity. Felt earthquakes (M>3) occur occasionally in the greater Karoo region, perhaps once or twice a year. Only two damaging events have been reported in the last century (Koffiefontein in the southern Free State, M_L6.2 in 1912; Tulbagh-Ceres in the Western Cape, M_L6.3 in 1969), both well outside the study area. Thus the occurrence of a felt earthquake within the study area is considered to be *unlikely*, and the occurrence of a damaging event to be *very unlikely*. The area is sparsely populated, apart from towns such as Beaufort West, Victoria West, Graaff-Reinet, Middelburg, Cradock and Queenstown. Most buildings, including important heritage buildings and dwellings, were built using unreinforced masonry and are thus vulnerable to damage and consequent injuries and loss of life similar to that experienced in the Tulbagh-Ceres district following the M_L6.3 earthquake in 1969 and in Khuma Township (near Orkney, North West Province) following the M_L5.5 earthquake in 2014. The first western style buildings were erected in this area around 1750 and the fact that some of these buildings have survived till today is testimony to the rarity of damaging earthquakes.

In summary, the occurrence of a damaging earthquake (say M>5) anywhere in the study area is considered to be *very unlikely*. The level of risk depends on the exposure of persons and vulnerable structures to the hazard. In the *rural parts* of the study area the exposure is *very low*, the consequences of an earthquake are likely to be *slight*, and hence the risk posed by earthquakes is considered to be *low*. While it is considered to be *very unlikely* that a damaging earthquake will occur within 20 km of a town, the consequences of such an event could be *moderate* or even *substantial*. Lives could be lost, and many buildings would need to be repaired. Hence the risk in urban areas is considered to be *moderate*.

Scenario 1: Exploration Only

Exploration activities do not involve the large scale injection of pressurised fluids. Trial injection tests will probably be carried out at a few wells. The triggering of a felt earthquake is considered to be *unlikely*, and the triggering of a damaging event to be *very unlikely*. Thus, *the risk posed by earthquakes in the study area* during the exploration and appraisal phase is considered to be *low* and not significantly different to the baseline.

Scenarios 2 and 3: Small and Big Gas

Should unconventional gas resources be developed in impermeable shale strata in the Karoo, fluid will be injected into boreholes at pressures that are high enough to cause the shale to fracture. This will cause numerous small seismic events. It is conceivable that the increase in pressure and the injection of fluids could induce slip on nearby faults and cause a felt earthquake.

Many thousands of hydraulic fracture wells have been drilled worldwide. Most only caused micro-seismic events ($M<3$) imperceptible to humans, while none of the few felt events have caused any damage (Ellsworth, 2013). To date, all damaging events associated with fluid injection are associated with the disposal of large volumes of waste water, not fracking. The disposal of waste water by injection into underground aquifers is forbidden by current South African legislation. Thus fracking is considered *very unlikely* to induce a damaging event. Providing fracking is not carried out within a distance of 20 km of a town, the consequences are considered to be *slight* and the risk *low*. The risk to persons and assets close to fracking operations in rural areas, such as workers, farm buildings and renewable energy and Square Kilometre Array (SKA) radio telescope infrastructure, should be handled on a case-by-case basis. Vulnerable structures should be reinforced and arrangements made to insure or compensate for damage. Should particularly attractive shale gas resources be found close to towns, it is essential to inform local authorities and inhabitants of any planned fracking activities and the attendant risks; enter into agreements to repair or compensate for any damage; monitor the induced seismicity; and slow or stop fracking if felt earthquakes are triggered.

It should be noted that the Earth’s crust is heterogeneous and physical processes are complex. Rock properties and geodynamic stresses are not perfectly known, and the seismic history is incomplete. Thus we cannot categorically exclude the possibility that a large and damaging earthquake may be triggered by fracking. It is thus important that seismicity is monitored for several years prior to any fracking, and that a seismic hazard assessment is performed to provide a quantitative estimate of the expected ground motion. It is also conceivable that a felt natural event may occur while shale gas development (SGD) is in progress and be linked to it by the public and the media. Monitoring should continue during SGD to investigate any causal link between SGD and earthquakes. Should any such link be established, procedures governing fluid injection practice must be re-evaluated.

We recommend that Council for Geoscience's (CGS) seismic monitoring network be densified in the study area, and that vulnerability and damage surveys of buildings and other structures (e.g. bridges, dams) be carried out before, during and following any SGD activities. At the present time (August 2016) an additional six seismograph stations were being installed by the CGS. Other mitigation measures to be considered should include: monitoring of seismicity during SGD and the slowing or stopping of fracking if felt earthquakes are induced, schemes to guarantee compensation in the case of damage, disaster insurance, reinforcement of vulnerable buildings (especially farm and heritage buildings, schools and hospitals), enforcement of building regulations, training and equipping of emergency first responders, and earthquake drills in schools and work places.

CHAPTER 4: EARTHQUAKES

4.1 Introduction and scope

"Fracking" is a popular term for a technology that is used to extract gas from impermeable rocks such as shale at depths of several kilometres (km). Known technically as "unconventional gas development", the technology uses high pressure fluid to create a network of fractures that extend for tens of meters from a borehole to provide pathways for the extraction of gas. The technology has greatly increased hydrocarbon production during the last decade, especially in the United States (US). It is believed that the Karoo Basin contains strata that may contain significant resources of shale gas.

MEASURING EARTHQUAKE SIZE AND EFFECTS

Magnitude (M) is a measure of the energy released by the earthquake and the dimensions and slip on the fault. Seismograms recorded by many widely-spread seismograph stations are integrated to assign a single magnitude to an event. The South African National Seismograph Network (SANSN) uses either the local magnitude scale (M_L) or the moment magnitude scale (M_w), which are essentially equivalent for M<6.5. The M_L scale uses the maximum amplitude of ground motion recorded at the various local stations, is quick and easy to measure, but saturates above M6.5. The M_w scale takes the entire seismogram into account and is derived from an assessment of the mass of rock moved (or work done, hence the subscript 'w') by the earthquake. M_w does not saturate and can be estimated from local, regional or global stations. It has been calibrated to match M_L for M<6.5.

Earthquakes are generally divided into the following categories: micro M<3, small 3<M<5, moderate 5<M<7 and major M>7. Natural earthquakes are generally only felt when M>3 and only cause damage when M>6. However, people unaccustomed to earthquakes may be frightened by the shaking that is produced by a M5 event, even though the amplitude of ground motion is 1/10 that of a M6 event. It should be noted that earthquakes induced by mining or fluid injection may cause damage if 5<M<6 because they occur at much shallower depths than natural events.

Intensity (I) describes the shaking experienced on the surface of the earth. Intensity generally decreases with distance from the epicentre (the point on the earth's surface above the earthquake source), but is also affected by near-surface geology. Shaking is generally amplified where there is thick layer of alluvium. Reports by many widespread observers are collated to derive Intensity Data Points (IDPs) and compile an isoseismal map.

The SANSN uses the Modified Mercalli Intensity (MMI) Scale. An intensity of III indicates ground motion that is perceptible to people, especially on the upper floors of buildings; VI is felt by all, many people are frightened and run out of doors, and a few buildings may be slightly damaged; VIII causes slight damage to earthquake-resistant structures, considerable damage to solid buildings, and great damage to poorly-built buildings; while XII indicates total destruction, with objects thrown into the air.

The injection of fluids into the earth at pressures high and volumes great enough to cause rocks to fracture and/or faults to slip will cause seismic events and, very rarely, shaking of the ground that is felt on the surface. The key issue is their magnitude. The events may range in size from micro-seismic events ($M<3$) that are barely perceptible on the surface, to events that are large enough to alarm residents and cause damage to vulnerable structures, including heritage buildings or buildings built from adobe (mud brick) or unreinforced masonry, typical of the Karoo. It must be emphasised that the felt events ($M>3$) are almost always associated with the injection of massive volumes of waste water, and very rarely with the deliberate formation of fractures to liberate gas (i.e. fracking) (Ellsworth, 2013).

The only known study of the impact of fracking on South African seismicity was conducted under the auspices of the Water Research Commission (WRC) (Kijko and Smit, 2014). Kijko and Smit (2014) conclude that fracking *"can/will lead to high levels of seismic hazard in the parts of the Western Cape, the Free State, Gauteng, and towards the eastern border of the North West Province. Moderate hazard levels can be expected in the Limpopo Province and parts of the Northern Cape. The southern part of the Eastern Cape is subject to low levels of seismic hazard."*

The purpose of this study is to assess the earthquake risk posed by shale gas exploration and development in the study area in the central Karoo region, and advise how best any risk can be mitigated. In particular, the assumptions and conclusions of the WRC report on the effect on seismic hazard (Kijko and Smit, 2014) will be assessed. Mitigation measures to be considered include restrictions on the location and intensity of fracking activity, disaster insurance, reinforcement of vulnerable buildings, enforcement of building regulations, training and equipping of emergency first responders, and earthquake drills in schools and offices.

This chapter links most closely to the following chapters of the scientific assessment:

- Chapter 5: Water Resources (Hobbs et al., 2016)
- Chapter 6: Impacts on Waste Planning and Management (Oelofse et al., 2016)
- Chapter 12: Impacts on Human Health (Genthe et al., 2016)
- Chapter 15: Impacts on Heritage (Orton et al., 2016)
- Chapter 17: Electromagnetic Interference (Tiplady et al., 2016)
- Chapter 18: Impacts on Integrated Spatial and Infrastructure Planning (Van Huyssteen et al., 2016)

4.1.1 Overview of international experience

There is a large volume of published literature on the subject of shale gas development (SGD), fluid injection and seismicity. In some instances (e.g. in Oklahoma), earthquake activity increased dramatically in areas where fluid injection was implemented. Earthquakes with magnitudes as large as M5 were triggered and caused alarm and even damage to structures that are not resistant to shaking (e.g. unreinforced masonry, adobe). However, it must be noted that almost all cases where damaging earthquakes were associated with unconventional hydrocarbon production, the earthquakes are attributed to the injection of large volumes of waste water into deep aquifers, not to fracking (Ellsworth, 2013). It should also be noted that there are also cases where damaging earthquakes are associated with the large scale extraction of oil and gas, but without any fluid injection being practiced, for example, near Gröningen in the Netherlands (Amin, 2015).

The Governing Board of the National Research Council (US) commissioned a study to "examine the scale, scope, and consequences of seismicity induced during the injection of fluids related to energy production; to identify gaps in knowledge and research needed to advance the understanding of induced seismicity; to identify gaps in induced seismic hazard assessment methodologies and the research needed to close those gaps; and to assess options for interim steps toward best practices with regard to energy development and induced seismicity potential". The comprehensive 300 page report was published in 2013 (National Research Council, 2013). Their principal conclusions relevant to SGD in the Karoo are:

1. Seismic events caused by or likely related to energy development have been measured and felt in 12 American states. However, only a very small fraction of injection and extraction activities at hundreds of thousands of energy development sites in the US have induced seismicity at levels that are noticeable to the public.
2. The process of fracking as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events. Observations and monitoring of fracking treatments indicate that generally only micro-seismic events ($M<2$) are produced because the volume of fluid injected is relatively small and the area affected by the increase in pore pressure is generally small (Figure 4.1).
3. Injection for disposal of waste water into the sub-surface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation.

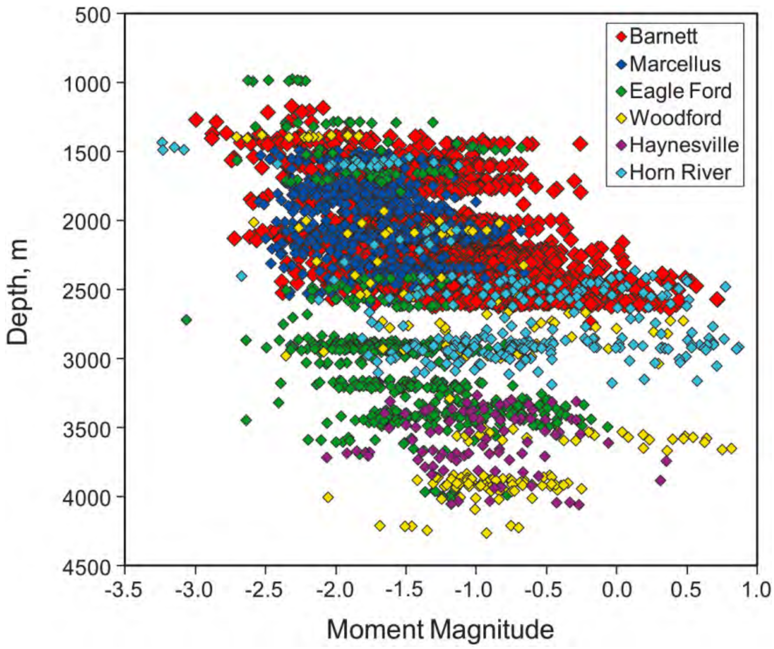

Figure 4.1: Maximum magnitude micro-earthquakes detected in six major unconventional reservoirs in the US. The micro-earthquakes are likely due to slippage along faults, natural fractures, and bedding planes, with the largest probably being fault interactions (Warpinski, 2013: 123).

Another important study was conducted by the Induced Seismicity Working Group (ISWG), a "collaborative effort of state oil and natural gas agency members and other advisory experts including industry and academia representatives to share science, research and practical experience that will equip the states with the best decision-making tools to evaluate the possible connections between seismic events and injection wells, minimise risk, and enhance appropriate readiness when seismic events occur". The ISWG published a 141 page report in 2015 (Groundwater Protection Council and Interstate Oil and Gas Compact Commission, 2015). The document focuses on seismicity induced by the underground disposal of fluids (e.g. brine) produced as a by-product of hydrocarbon extraction, as the potential for felt induced seismicity related to hydraulic fracturing was considered to be far lower than waste disposal. While fracking operations pump fluids into the well at higher rates and pressures than waste disposal wells, the procedure lasts only a short time (one to several hours) and the wellbore is fracked in stages (up to several hundred meters in length). Consequently, extended and prolonged contact with a fault is unlikely. Furthermore, the well may go into production soon after the fracking operation and thus becomes a pressure sink, drawing fluids into it and decreasing pore pressure in the vicinity of the well.

The ISWG report notes that very little ground motion data exists for the few reported incidences of seismicity associated with fracking, and no reports of damage. In the UK Bowland shale incident (De Pater & Baisch, 2011), at least one person apparently felt an M2.3 earthquake. In the Poland, Ohio, incident, some people felt the M3 earthquake and one of the smaller magnitude earthquakes. In the Horn River Basin (British Columbia Oil and Gas Commission, 2012) and the Montney trend incidents in Canada (Alberta Energy Regulator, 2015); numerous people onsite felt several earthquakes that were greater than M3.

Several moderate earthquakes (4<M<5) that occurred near Fox Creek in Alberta have been associated with fracking operations (Atkinson et al., 2016). In this case, the formations that were being fracked were close to crystalline basement. It is postulated that the increase in pressure triggered slip on pre-existing faults that extended into the basement. It should be noted that a rupture with an extent of the order of 1 km is required to produce a M4 earthquake. This is much greater than the length of fractures produced by fracking.

Several studies of seismicity induced by fluid injection have been published in prestigious refereed scientific journals in the last couple of years. For example:

- Kim (2013: 3506), in a paper in the *Journal of Geophysical Research*, reports that more than 100 small earthquakes (M_w0.4–3.9) were detected between January 2011 and February 2012 in the Youngstown, Ohio area. There were no known earthquakes in the past. The earthquakes were attributed to the disposal of waste water (brine) in Ohio produced by fracking carried out in Pennsylvania and transported to Ohio. The water was injected into deep wells at a depth range of 2.2–3.0 km under high pressure (up to 17.2 MPa).
- Walsh and Zoback (2015), in a paper published in *Science Advances*, show that the marked increases in the rate of small- to moderate-sized earthquakes in Oklahoma is associated with the injection of massive volumes of saline pore water that is coproduced with oil.
- McGarr (2014: 1008), in a paper published in the *Journal of Geophysical Research*, reports that the maximum magnitude of earthquake sequences induced by fluid injection at depth appears to be limited by the total volume of fluid injected. Similarly, the maximum seismic moment seems to have an upper bound proportional to the total volume of injected fluid (Figure 4.2). Fluid injection activities investigated by McGarr (2104: 1008) included (1) fracking of shale formations or coal seams to extract gas and oil, (2) disposal of waste water from gas and oil activities by injection into deep aquifers, and (3) the development of enhanced geothermal systems (EGS) by injecting water into hot, low-permeability rock. Of these three operations, waste water disposal is observed to be associated with the largest earthquakes, with magnitudes sometimes exceeding 5. McGarr (2014) reports that the micro-earthquakes (i.e. M<3) produced by permeability-enhancing treatments (i.e. fracking) are seldom large enough to be felt at the surface. He does, however, note that exceptions were reported by Holland (2013: 1784), De Pater & Baisch (2011), and the British Columbia Oil and Gas Commission (2012).

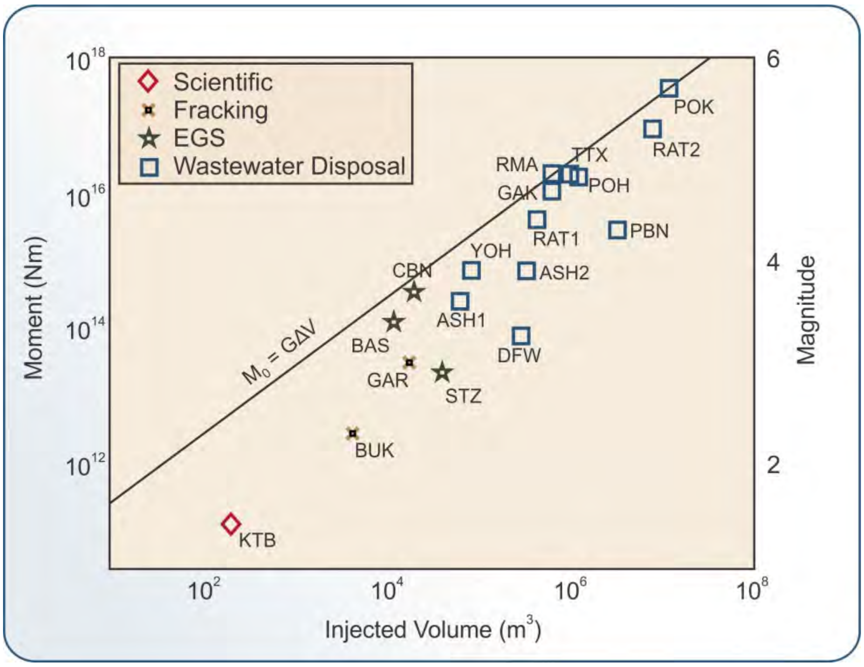

Figure 4.2: Maximum seismic moment and magnitude as functions of the total volume of injected fluid from the start of injection until the time of the largest induced earthquake. EGS denotes 'enhanced geothermal systems' (McGarr, 2014: 1008)

4.1.2 Earthquakes in the Karoo and environs

The South African Seismograph Network (SANSN) monitors local and regional seismicity (Figure 4.3). Southern Africa is, by global standards, a seismically quiet region as it is remote from the boundaries of tectonic plates. However, natural earthquakes do take place from time to time. They are driven by various tectonic forces, such as the spreading of the sea floor along the mid-Atlantic and mid-Indian ocean ridges, the propagation of the East African Rift System, and the response of the crust to erosion and uplift.

The Cape Fold Belt is seismically active. The largest instrumentally recorded earthquake was a M_L6.3 event that struck the Ceres-Tulbagh region on 29 September 1969, causing widespread damage and claiming 12 lives. It was felt as far away as Durban. Modern concrete-frame buildings sustained relatively minor damage, but some well-constructed brick houses were badly damaged and many adobe-type buildings were completely destroyed. The maximum MMI was VIII (Van Wyk & Kent, 1974). The Ceres-Tulbagh event provides a useful reference for the vulnerability of typical Karoo farmsteads and heritage buildings. On 12 January 1968 and 11 September 1969 events of magnitude M_L5.2 and M_L5.4 took place near Willowmore and Calitzdorp, respectively.

Another cluster of events north of the study area is found near Koffiefontein in the southern Free State. A M_L6.2 event that occurred on 20 February 1912 was felt over much of South Africa and assigned a maximum MMI of VIII (Brandt et al., 2005).

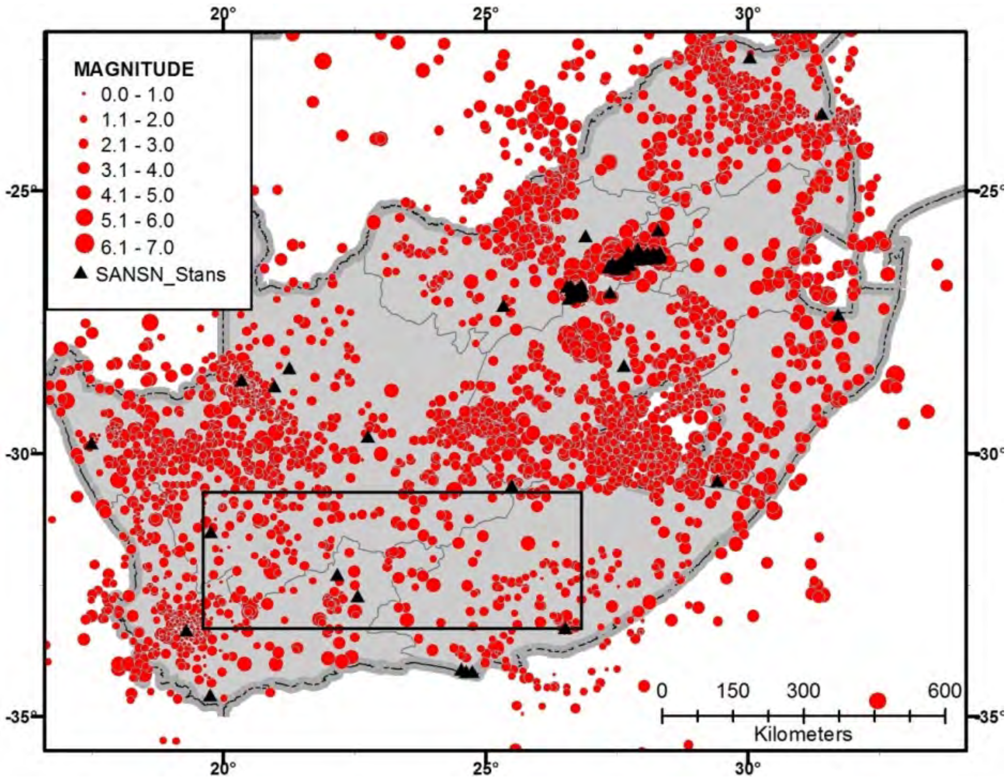

Figure 4.3: Location of recorded earthquakes in southern Africa. Black triangles indicate locations of SANSN stations; black rectangle indicates the study area. The period of data collection depicted is 7 January 1811 to 31 December 2014. (Source: Council for Geoscience, 2014).

Most seismic activity in South Africa is induced by deep level mining for gold and platinum. The largest event ever to occur in a mining region was the M_L5.5 event that struck Orkney on 5 August 2014, causing damage to numerous dwellings in nearby townships and one fatality. This event provides useful examples of the vulnerability of low-cost housing to strong ground motion.

In order to assess the risk posed by earthquakes, it is important to have a record of past earthquake activity. These parameters are best known if earthquakes are recorded by seismographs. However, the global instrumental catalogue does not go back much further than 1900, and, in many parts of the world, the recurrence time of the largest plausible earthquake is much longer than this. Thus historical records of earthquakes, while less accurate and complete, are a vital supplement to instrumental catalogues. However, the historical record in South Africa often only covers a few centuries and is inevitably incomplete. Thus palaeo-seismologists seek to extend the catalogue back in time by discovering and deciphering clues left by prehistoric earthquakes (say events occurring during the last 100 000 years). For example, geomorphological features such as fault scarps and knick points in rivers can be used to deduce the length and displacement of the rupture caused by a particular earthquake, while geochronological techniques can be used to determine the age of sediments deposited along fault scarps, and hence the minimum age of the earthquake.

Palaeo-seismic studies have been carried out as part of an investigation into the Quaternary tectonic history of the south-eastern continental margin, in support of the assessment of seismic hazard at proposed sites for nuclear power stations (Engelbrecht & Goedhart, 2009; Goedhart & Booth, 2009: 510; Midzi & Goedhart 2009). There is little seismic information for this region, and the record is too short to include the long recurrence intervals typical of large, surface-rupturing earthquakes in intraplate regions. Goedhart and Booth (2009: 510) interpreted a scarp running parallel to the Kango fault in the Cape Fold Belt to be the surface expression of an 84 km long extensional surface rupture. An 80 m long, 6 m deep and 2.5 m wide trench was dug across the fault, exposing 21 lithological units, six soil horizons, and 19 faults strands. Vertical displacement indicated a fault throw of about 2 m. Optically stimulated luminescence dating indicated that the fault was active between 12 200 and 8 800 years ago, and most probably around 10 600 years ago. Goedhart and Booth (2009: 510) used published relations between surface rupture length, displacement and magnitude to estimate the magnitude of the event at M_w7.4. It should be noted that there a fair degree of uncertainty associated with the magnitude assessment, as is the case with all palaeo-seismic investigations.

4.1.3 Relevant legislation, regulation and practice

The Minister of Mineral Resources published the “Regulations for Petroleum Exploration and Production. Notice R466” under Section 107 of the Mineral and Petroleum Resources Development Act (2002) in the Government Gazette dated 3 June 2015. [It should be noted that the validity of these regulations was being challenged in the High Court at the time of writing this report (August 2016) and they might be set aside.]

The regulations relevant to the risk posed by earthquakes induced by fracking include:

89. Assessment of related seismicity

(1) An applicant or holder must, prior to conducting hydraulic fracturing, assess the risk of potential fracking related seismicity and submit a risk assessment report and the proposed mitigation measures to the designated agency for approval and recommendation by the Council for Geoscience (CGS) and the risk assessment report must, as a minimum, identify -

(a) stressed faults which must be avoided in the fracturing process;

(b) fracture behaviour of targeted formations; and

(c) the site-specific seismic monitoring to be undertaken pre-fracturing, during operation and post fracturing including the monitoring and reporting frequency.

(2) An applicant or holder must carry out site-specific surveys prior to fracking to characterise local stress regimes and identify proximal faults and the site characterisations must at least include-

(a) desktop studies of existing geological maps;

(b) seismic reflection and refraction data, where available;

(c) available background seismicity data;

(d) stress data from proximal boreholes where available; and

(e) other relevant available geophysical data, such as gravity.

(3) The risk assessment report contemplated in sub-regulation (1) and the site-specific surveys contemplated in sub -regulation (2) must be submitted to the competent authority, for consideration, as part of the application for Environmental Authorisation.

(4) The assessment of the orientation and slip tendency of faults and bedding planes may be done once faults have been identified and geological stress regimes characterised.

(5) The holder must mitigate risks of fault movement by identifying stressed faults by preventing fracturing fluids from entering stressed faults [sic].

(6) The holder must test fracture a targeted formation in a given well by using small pre-fracturing injection tests with micro-seismic monitoring.

(7) A holder must, following pre-fracturing injection tests contemplated in sub-regulation (6), investigate whether seismic activity occurs and then modify subsequent fracking operations.

(8) The holder must undertake seismic monitoring at the site for a period of 3 years after fracking activities have ceased and include the results of the seismic monitoring in the monitoring report contemplated in sub-regulation (1)(c).

112. Mechanical integrity tests and monitoring

(8) (a) During fracking, annulus pressure, injection pressure and the rate of injection must be continuously monitored and recorded.

(b) Micro-seismicity (in real time <5 minute delay) must be monitored by a long array of accelerometers located in an offset monitoring well, situated 100 m or more away from well at a comparable depth.

(c) Micro-seismic sensors must be designed for temperatures between 175-200 degrees Celsius.

(d) Tiltmeter measurements must be taken with an array of tiltmeters, either located in shallow offset wells (10 m) at the site surface or in a more sensitive deep offset well at comparable depth to fracking depth and in fracking well which provides info on fracture orientation and direction (azimuth).

120. Post fracking report

(1) A holder must compile and submit, to the designated agency and the department responsible for water affairs, a detailed post fracking operation report, for review and recommendations, which report must include among others-

(j) data and information concerning related seismic events, in internationally accepted formats, that have been recorded including the steps taken as a result of such events;

(k) plans to continue micro-seismic monitoring; and

(l) the induced seismic events that have been recorded including the steps taken as a result of such events.

124. General

(4) Disposal to underground, including the use of re-injection disposal wells, is prohibited.

132. Well decommissioning or closure

(1) A well that is no longer active, or producing, or for which the approved suspension period determined in terms of regulation 130 (b) has passed, must be plugged and decommissioned in accordance with-

(a) a decommissioning plan approved by the designated agency; and

(b) the relevant provision of the Environmental Impact Assessment Regulations.

(2) The decommissioning plan must take into account the following factors:

(j) related seismic activity risks.

These regulations provide a sound basis for discussions between regulators and developers of shale gas wells. Several of the clauses might require clarification, be too stringent, impractical or unnecessarily prescriptive. For example, the meaning of the phrase “fracture behaviour of targeted formations” (clause 89 (1) (b)) should be explained; while the stipulation that an array of accelerometers must be installed in a monitoring well (clause 112 (8) (b)) should be reviewed, as it is possible that satisfactory measurements could be obtained from a far cheaper surface array using modern location algorithms.

4.2 Key potential impacts and their mitigation

4.2.1 Unconventional shale gas development

Beginning in the 1960s, efforts were made to enhance oil recovery by injecting high pressure fluids into reservoirs to “hydrofracture” the rock. Sometimes the fluid was heated to reduce the viscosity of the oil. About the same time, technologies were developed to “steer” drilling bits so that targets could be reliably hit. The technology advanced to the extent that the trajectory of a hole could be deviated from the vertical to horizontal, enabling a far larger sub-surface area to be explored and exploited from a single drilling pad. Beginning in the 1990s, engineers in the US combined fracking and directional drilling to explore and exploit low permeability source rocks directly on a large scale. This required a great deal of technical development, including a variety of chemical additives to enhance the flow of oil and gas, and the introduction of sand grains to “prop open” the cracks. Generally, unconventional reservoirs are at depths of several kilometres. In the case of the Karoo Basin, the depth is likely to be in the range of 3 to 4 km.

4.2.2 Triggering of earthquakes by fluid injection

The injection of fluids into the rock at pressures that exceed its tensile strength will cause the intact rock to fracture, releasing some of the stored elastic energy as vibrations. During fracking, this is done in a controlled manner. The density and length of fractures is controlled by *in situ* conditions (such as the stress field), rock properties (such as the rock strength), and the fracking process (fluid pressure, density with which the well casing is perforated, and the length of borehole where the pressure is elevated). Generally, the desired length of fractures is of the order of tens of meters, while the length of borehole that is fractured (or “stimulated”) at any one time is, at most, a few hundred meters. Rock fracturing inevitably releases elastic energy stored in the intact rock. Generally the shaking is too weak to be felt on the surface.

Some researchers (e.g. McGarr et al., 2002: 647) draw a distinction between “induced” seismicity and “triggered” seismicity. Under this distinction, induced seismicity results from human-caused stress changes in the Earth’s crust that are on the same order as the ambient stress on a fault that causes slip. Triggered seismicity results from stress changes that are a small fraction of the ambient stress on a fault that causes slip. Anthropogenic processes cannot “induce” large and potentially damaging earthquakes, but anthropogenic processes could potentially “trigger” such events. Following the report of the National Research Council (2013), we do not distinguish between the two and use the term “induced seismicity” to cover both categories.

Earthquakes related to fracking are induced by at least three mechanisms:

- (i) Cracking or rupturing of rocks in the vicinity of the wellbore that creates micro-earthquakes of very small magnitude, $M<0$;
- (ii) Interaction between fracking fractures and nearby faults, where the fracking fluid enters the fault zone. This may causes a change in pore fluid pressure that can trigger earthquakes of $0<M<3$, and rarely, but possibly, greater.
- (iii) Interaction between fracking fractures and nearby faults, through the transfer of stress through the rock. This may causes a change in the shear stress acting on the fault and trigger earthquakes of $0<M<3$, and rarely, but possibly, greater.

4.2.3 Damage caused by earthquakes

As noted above, natural earthquakes are rare in the study area, but cannot be entirely ruled out. The disposal of waste water into aquifers is forbidden in South Africa; thus the Oklahoma case of large fluid-induced earthquakes causing damage to surface structures will not occur. Fracking will cause micro-seismic events, but only a very few will be perceptible on the surface and the probability that they will cause any damage to surface structures is negligible. It is conceivable, although unlikely, that fracking might trigger slip on a pre-existing fault and cause an earthquake large enough to be felt. We cannot entirely rule out the possibility of damage and losses on the surface to:

(i) structures at fracking sites,
(ii) nearby farmsteads, villages and towns, and
(iii) nearby sensitive infrastructure (SKA radio telescopes).

However, to the best of our knowledge, no earthquake associated with fracking has caused damage to a surface structure anywhere in the world.

A significant part of damage observed from earthquakes is associated with the amplification of seismic waves due to local site effects. Local conditions can vary greatly due to variations in the thickness and properties of soil layers, which could have significant effects on the characteristics of earthquake ground motions on the ground surface to which buildings are subjected. Similar site effects are observed for structures built on hills, except the observed amplification is due to topographic effects.

Fracking and fracking-triggered earthquakes could cause damage and losses underground, even though the events might not be felt on the surface. For example:

(i) rupture of the well casing, should a slipping fault cut the casing, and
(ii) contamination of water resources, should there be interaction between aquifers, hydraulic fractures, faults and leaking casings.

As noted by Hobbs et al. (2016), there are no documented and verified cases of contamination of potable groundwater resources from the fracking process itself. Surface spills or faulty casing and poor well maintenance account for all proven contamination.

4.2.4 Mitigation of impacts

Several practical steps should be taken to mitigate earthquake risk in the region.

- Monitor seismicity before, during and after fracking. Ideally, monitoring of earthquakes should start at least 1 to 2 years before fracking (at a minimum to obtain base line seismic activity in area) and for about 3 years after fracking ends to investigate effect of fluids flowing through fractures and faults. Using the seismograph stations of the SANSN, the CGS has built a database of earthquake locations, which can form the basic baseline data for the study area (Figure 4.3). It shows that moderately sized earthquakes (M>4) have previously occurred in the region, prompting serious consideration and planning for the mitigation of earthquake effects in the region.

- Identify faults by mapping regional and local structures in the field, in boreholes and with geophysical methods.
- Measure the regional stress (e.g. from proximal boreholes) to characterise regional and local stress regime.
- Analyse seismicity data (location, source parameters) as well as stress data to identify pre-stressed and active/capable faults. Improved monitoring at regional level can assist in identifying active fault structures.
- Obtain orientations and slip tendency of identified active/capable faults.
- Mitigate risks of fault movement by preventing fluids from flowing into pre-stressed faults by informed location of fracking wells.
- Perform real-time micro-seismic monitoring during appraisal and production.
- Implement “traffic light” systems (i.e. feedback system) during fracking that will enable operators to respond quickly to induced earthquakes by either reducing the rate of fracking or stopping fracking altogether (Majer et al., 2007: 185).
- Assess seismic hazard and risk to determine (i) the expected maximum magnitude of earthquakes, and (ii) the expected maximum ground motion at the fracking site and in the region. Assessments should be conducted before (baseline), during and after fracking. The impact on ground motion at nearby towns and facilities (e.g. the SKA) should be considered.
- Assess the regional strain field through analysis of data recorded by the national geodetic network.
- Assess the building typologies in the region.
- Inspect buildings and structures prior to fracking to assess their condition.
- Reinforce vulnerable buildings and structures. Some simple measures may reduce the severity of earthquake damage. For example, buttress walls, strapping of hot water heaters (geysers) to rafters, stabilisation of towers carrying water tanks with anchor cables.
- Enforce building codes.

4.2.5 Cumulative impacts

Here we consider an extreme scenario where large scale SGD (Big Gas scenario) is accompanied by urbanisation and other industrial developments such as uranium mining and renewable energy projects. These developments will not have any effect on the seismic hazard (i.e. the likelihood of earthquakes occurring), but could affect the risk as more assets and people will be exposed to harm. We believe that it is possible to mitigate the risk posed by fracking-triggered earthquakes by ensuring that all new structures are built using modern materials and techniques to that they are able to withstand moderate intensities of shaking. Regardless of fracking, this would be a sensible precaution as a moderate natural earthquake will occasionally occur somewhere in the Karoo.

4.3 Risk assessment

4.3.1 How seismic hazard and risk is measured

Hazard assessment is the process of determining the likelihood that a given event will take place. Probabilistic seismic hazard assessment (PSHA) is generally expressed in terms of the ground motion (for example, peak ground acceleration (PGA)) that has a certain likelihood of exceedance (say 10%) in a given period (say 50 years). There are many PSHA schemes, but all require a catalogue of earthquakes (size, time, location); the characterisation of seismically active faults and areas (usually in terms of the maximum credible magnitude and recurrence periods); and a prediction of variation in ground motion with distance from the epicentre. The longer the duration of the catalogue, the smaller the magnitude of completeness, and the better the zonation, the more reliable is the PSHA.

The consequences of an earthquake depend on four main factors: the vulnerability of buildings to damage, the exposure of persons and other assets to harm, the cost of reconstruction, and the cost of lost economic production. Risk assessments are useful for raising awareness of possible disasters and motivating policies and actions to mitigate losses and avoid disasters. For example, vulnerable buildings may be reinforced, building codes enforced and insurance taken out to cover possible losses.

The moment there is human interference (i.e. fluid injection); probabilistic hazard assessment techniques cannot be used. The most reliable approach is to consider analogous situations elsewhere in the world.

Scenario 0: Reference Case

In the absence of shale gas exploration, natural events will occur from time to time. The important parameters are the maximum magnitude (M_{max}), the recurrence interval, and the likely ground motion.

These parameters are difficult to determine in a region where the seismicity is low, the instrumental catalogue is of short duration, and there are no recordings of strong ground motion.

The largest instrumentally recorded events in the region have magnitudes of M_L6.2 (Koffiefontein, 1912) and M_L6.3 (Ceres, 29 September 1969). In the absence of a lengthy and complete catalogue, it is standard practice to assume that the maximum credible magnitude is 0.5 units larger than the maximum observed event. Palaeo-seismic studies suggest that a M_w7.3 event occurred along the Kango Fault some 10 000 years ago.

The most recent published probabilistic hazard assessment is by Fernández and du Plessis (1992). They found that the PGA with a 10% probability of being exceeded in 50 years is less than 0.05 g in the study area, rising to a value greater than 0.2 g in the Ceres region. The CGS is in the process of developing new seismic hazard maps of South Africa (Midzi et al., 2016).

Based on these studies, the occurrence of a felt earthquake within the study area is considered to be *unlikely*, and the occurrence of damaging event to be *very unlikely*. The area is sparsely populated, apart from the towns such as Beaufort West, Victoria West, Middelburg, Queenstown, Cradock and Graaff-Reinet. Hence the *exposure is generally low* and the consequences of an earthquake are generally considered to be *slight*. However, very few buildings in the region were constructed to withstand strong shaking. Most buildings, including important heritage buildings and dwellings, were built using unreinforced masonry and are thus *vulnerable* to damage similar to that experienced in the Ceres-Tulbagh region in 1969 and in Khuma Township near Orkney in 2014. Thus the consequences of a shallow M>5 earthquake occurring within 20 km of a town could be *moderate* or even *substantial*. Considering the *very low likelihood of the occurrence* of a damaging earthquake and *low exposure*, the *risk* posed by earthquakes in the study area is thus considered to be *low*.

Scenario 1: Exploration Only

Exploration activities do not involve the large scale injection of pressurised fluids. Trial injection tests may be carried out at a few wells. The triggering of a felt earthquake is considered to be *unlikely*, and the triggering of a damaging event to be *very unlikely*. Thus, the risk posed by earthquakes in the study area during the exploration phase is considered to be *low* and not significantly different from the base line.

Scenarios 2 & 3: Small and Big Gas development

Should unconventional gas resources be developed in impermeable shale strata in the Karoo, fluid will be injected into boreholes at pressures that are high enough to cause the shale to fracture, thereby creating a network of pathways that enables the gas to be extracted.

In the case of limited production of a small resource (Small Gas scenario), there is likely to be localised induced seismicity, depending on the location of fracking wells in relation to faults in the region and at fracking site. It is *unlikely* that the seismicity will be felt on the surface, and *very unlikely* that it will cause any damage.

In the case of large scale production of a rich resource (Big Gas scenario), there is likely to be an increase in the frequency of felt earthquakes in the vicinity of the production wells. The likelihood of induced seismicity depends on the location of wells in relation to faults (especially faults that are close to instability) and the rate of fracking.

Many thousands of hydraulic fracture wells have been drilled worldwide. Most only caused micro-seismic events (M<3) imperceptible to humans, while none of the few felt events have caused damage. To date, all damaging events associated with fluid injection are associated with the disposal of large volumes of waste water. The disposal of waste water by injection into underground aquifers is forbidden by current South African legislation. Thus fracking is considered *very unlikely* to induce a damaging event. However, we cannot entirely exclude the possibility that a shallow M>5 event will be induced.

The damage produced by mining-related event that struck the Orkney area in the North West Province on 5 August 2014 damaging more than 600 dwellings (mostly constructed of unreinforced masonry) provides a local example of the relationship between the distance from the epicentre, the intensity of shaking and vulnerability of structures (Midzi et al., 2015). The highest intensity value obtained was VII, which was experienced at Khuma, Orkney, Stilfontein, Klerksdorp, Vaal Reef Mine and Buffelsfontein, all within 20 km of the epicentre. While acknowledging that there is a large variability in the intensity of ground motion, we have used this number as the basis for differentiating the risk posed by a shallow earthquake (<5 km depth) within 20 km of a town and that posed by a more distant earthquake.

4.3.2 Earthquake risk matrix

In order to illustrate the risk posed by earthquakes in the study area, we considered a worst case scenario, using the Ceres-Tulbagh earthquake of 29 September 1969 and the Orkney earthquake of 5 August 2014 as credible examples of natural and induced earthquakes, respectively. Should a M>6 natural earthquake or a shallow M>5 induced earthquake occur within 20 km of Graaff-Reinet, dozens or even hundreds of heritage buildings and dwellings could be damaged, some severely. Dozens of people could lose their lives. Repair costs could average perhaps 20% - 40% of the cost of the building stock, amounting to hundreds of millions of Rand, and the consequence would then be judged *moderate* to *substantial*. However, the likelihood of a natural event occurring is considered to be *very unlikely*, and the risk posed by this scenario is considered to be *low,* or at most *moderate.* Based on international experience, fracking is *highly unlikely* to induce a M>5 earthquake, but this cannot be entirely excluded, and the consequences could be *moderate* or even *substantial*. The implementation of mitigating measures would decrease the likelihood and consequences to some extent, although this is difficult to quantify (Table 4.1).

It should be noted that the Earth's crust is heterogeneous and physical processes are complex. Thus we cannot categorically exclude the possibility that a large and damaging earthquake may be triggered by fracking. It is also conceivable that a felt natural event may occur while SGD is in progress and be linked to fracking operations by the public and the media. It is thus important that seismicity is monitored for several years prior to any fracking and during SGD (say threshold of completeness M1, and with stations sufficiently dense to determine the depth of the hypocentre) to investigate any causal link between SGD and earthquakes. Should any such link be established, procedures governing fluid injection practice must be re-evaluated.

The question arises as to the limits of acceptable change with regard to ground shaking. It is well known that humans can perceive ground vibration at levels as low as 0.8 mm/s, much lower than the level of vibration that will damage even the most fragile structures (about 6 mm/s). Daily life in a family home will produce perceptible vibrations, for example: walking = 1 mm/s, jumping = 7 mm/s, and slamming the door = 12 mm/s (Scott, 1996). Experience gained from open pit mining shows that the main reason for complaints about ground vibration is not usually structural (or even cosmetic) damage, but the fear of damage and/or nuisance. Good public relations and explanations will help to reduce anxiety and complaints.

Table 4.1: Earthquake risk matrix

Impact	Scenario	Location	Without mitigation: Consequence	Without mitigation: Likelihood	Without mitigation: Risk	With specified mitigation: Consequence	With specified mitigation: Likelihood	With specified mitigation: Risk
Damaging earthquakes induced by fracking.	Reference Case	Wells within 20 km of towns	Slight	Very unlikely	Low	Slight	Very unlikely	Low
	Exploration Only		Slight	Very unlikely	Low	Slight	Very unlikely	Low
	Small Gas		Slight	Not likely	Low	Slight	Not likely	Low
	Big Gas		Moderate	Not likely	Moderate	Moderate	Not likely	Moderate
	Reference Case	Wells beyond 20 km of towns	Slight	Very unlikely	Low	Slight	Very unlikely	Low
	Exploration Only		Slight	Very unlikely	Low	Slight	Very unlikely	Low
	Small Gas		Slight	Very unlikely	Low	Slight	Very unlikely	Low
	Big Gas		Slight	Unlikely	Low	Slight	Not likely	Low

Figure 4.4 presents a risk map of damaging earthquakes across four SGD scenarios, with- and without mitigation.

4.3.3 Previous assessments of seismic hazard owing to fracking

The only known previous study of the impact of fracking on South African seismicity was conducted under the auspices of the WRC (Kijko and Smit, 2014). The report is entitled *"Possible Effect of Hydraulic Fracturing on Seismic Hazard in South Africa"*. Kijko and Smit (2014) conclude that fracking *"can/will lead to high levels of seismic hazard in the parts of the Western Cape, the Free State, Gauteng and towards the eastern border of the North West Province. Moderate hazard levels can be expected in the Limpopo Province and parts of the Northern Cape. The southern part of the Eastern Cape is subject to low levels of seismic hazard."*

It is clear that our conclusions differ significantly from those of Kijko and Smit (2014). We seek to explain why this is so.

- Kijko and Smit (2014) consider the entire region of South Africa, while our study is focused on the study area in the Karoo. The baseline hazard in study area is low compared to other parts of South Africa.
- Kijko and Smit (2014) use a methodology where they use a current probabilistic hazard assessment as a starting point, and then compute the increase in hazard should seismic activity increase by factors of 2, 5 and 10; as well as an assessment that combines the Reference Case and the three scenarios, assigning weights of 0.15, 0.50, 0.30 and 0.05 to each scenario, respectively. Kijko and Smit (2014) "strongly emphasise that the weights are very subjective; it was selected according to a wide scatter and often contradicting expert opinions on the effect of hydraulic fracturing on seismicity".

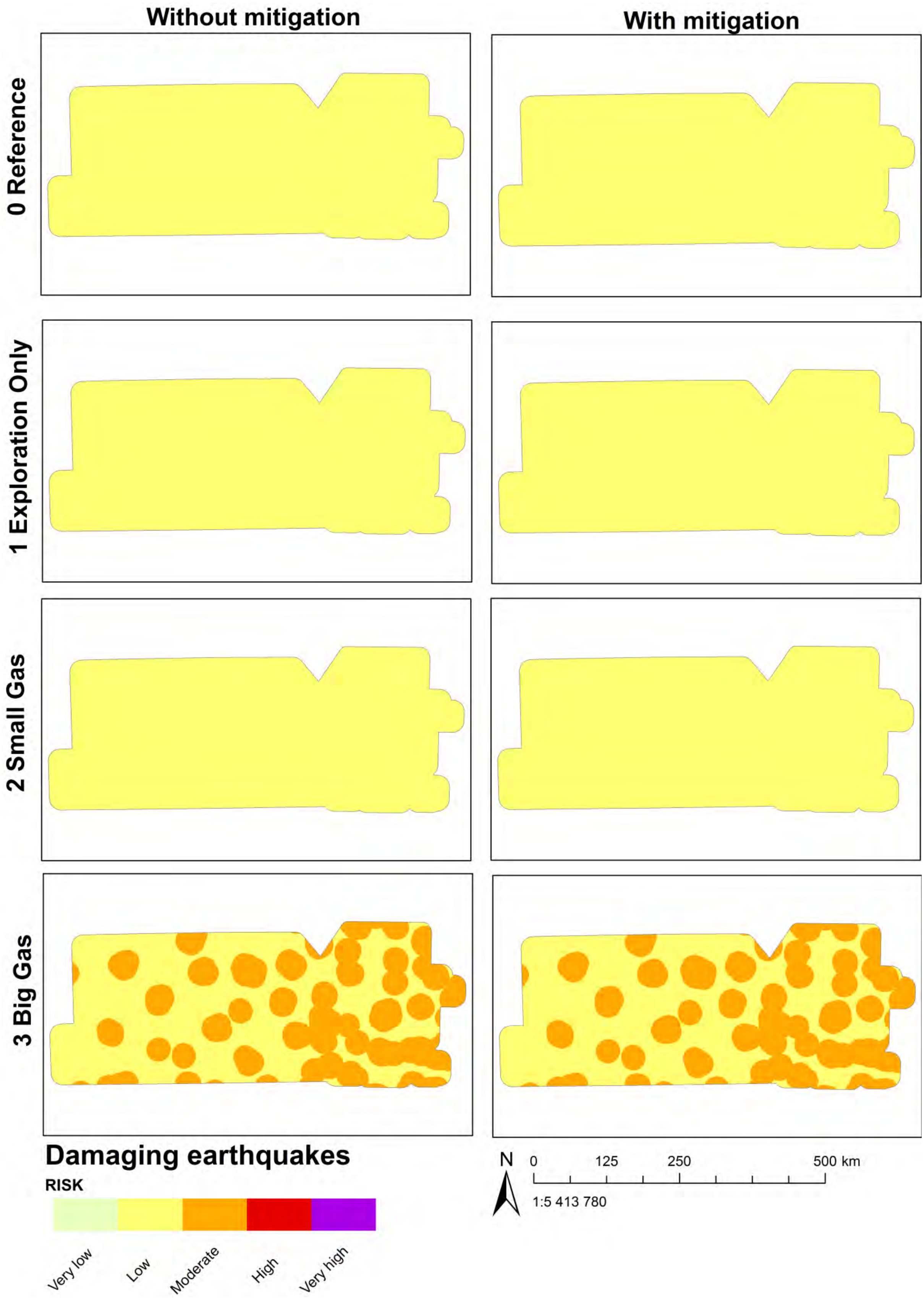

Figure 4.4: Map indicating the risk of damaging earthquakes across four SGD scenarios, with- and without mitigation.

- It is our opinion that the approach used by Kijko and Smit (2014) overstates the increase in hazard. International experience based on hundreds of thousands of fracking stimulations worldwide, indicates:
  - Seismicity induced by fracking is transient (hours to days), limited to the immediate area surrounding the wellbore (hectares to perhaps a square kilometre), and have magnitudes that are proportional to the volume of fluid that is injected. Natural seismicity is driven by tectonic forces that operate on geological time scales on crustal blocks and faults with dimensions of tens to hundreds of kilometres.
  - The vast majority of seismic events induced by hydraulic fracturing have M<0. Only a very small fraction have M>3 and are felt on the surface. No events have been reported to exceed M5. Thus the frequency-magnitude distribution of seismic events induced by fracking differs greatly from the frequency-magnitude distribution of natural seismic events.

4.4 Best practice guidelines and monitoring requirements

The regulations gazetted by the Minister of Mineral Resources on 3 June 2015 provide sound guidelines for best practice and monitoring, although, as noted above, there are some aspects that might require clarification, be unnecessarily stringent or prescriptive. It should also be noted that, at the present time (August 2016), the validity of the regulations were the subject of a High Court challenge.

Other mitigation measures to be considered should include:

- Establishment of ‘buffer zones’ around towns (say 20 km in radius) where fracking operations are either prohibited or carried out under strict control e.g. the rate of fracking controlled to limit felt seismicity,
- Reinforcement of vulnerable buildings (especially farm buildings, heritage buildings, schools and hospitals),
- Guarantees of compensation for any damage caused by fracking-induced earthquakes,
- Enforcement of building regulations,
- Disaster insurance,
- Training and equipping of emergency first responders, and
- Earthquake drills in schools and offices (drop, cover, hold on!).

We recommend that the SANSN, operated by the CGS, be densified in the study area, and that surveys of buildings and other structures (e.g. bridges, dams) be carried out before, during and following any SGD activities. The CGS currently operates only two seismograph stations within the study area, and another four stations close to its perimeter (see Figure 4.3). It is desirable that sufficient stations are installed so that all events exceeding M1 are recorded in any part of the area where SGD is likely to take place. These areas will only become apparent when the exploration and appraisal phase nears completion. At the present time (August 2016) a further six stations were being installed by the CGS in the study area. This should improve the threshold of completeness to M1 (Midzi, pers comm.)

The monitoring of seismicity at the well site is normally the responsibility of the license holder. The seismic network designed for monitoring background seismicity should calculate longitude, latitude and depth of small events (say threshold of completeness M1.0). The depth of small events has to be accurately determined in order to understand the dynamical processes that are taking place in the area of future fracking. The accuracy of location should be of the order of 100 m. The seismic arrays should be designed accordingly and advanced location algorithms used. Routine processing of seismic data should include an estimation of spectral parameters such as scalar seismic moment, seismic energy, and static stress drop, which will help to identify a stressed fault as is required by clause 89(1)(b) of the regulations (see Section 3.1.3: Relevant legislation, regulation and practice).

4.5 Gaps in knowledge

The principal lack of information with regard to the assessment of the risk posed by earthquakes is the lack of baseline information on the regional stress field, seismicity and active faults. It is clear from available information (Figure 4.3) that there is seismic activity in the region. However, given the sparse seismograph station distribution in the country, especially in the study area in the Karoo, the available data is not adequate to identify and characterise the active structure. Improved monitoring by densifying the network would certainly assist. Detailed geological and geophysical studies of identified structures would also be necessary.

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CHAPTER 5

Water Resources

CHAPTER 5: WATER RESOURCES

Integrating Authors	P. Hobbs[1] and E. Day[2]
Contributing Authors	P. Rosewarne[3] S. Esterhuyse[4], R. Schulze[5], J. Day[6], J. Ewart-Smith[2],M. Kemp[4], N. Rivers-Moore[7], H. Coetzee[8], D. Hohne[9], A. Maherry[1]
Corresponding Authors	M. Mosetsho[8]

1 Natural Resources and the Environment (NRE), Council for Scientific and Industrial Research (CSIR), Pretoria, 0001

2 Freshwater Consulting Group, Cape Town, 7800

3 Independent Consultant, Cape Town

4 Centre for Environmental Management, University of the Free State, Bloemfontein, 9300

5 Centre for Water Resources Research, University of KwaZulu-Natal, Scottsville, 3209

6 Institute for Water Studies, University of Western Cape, Bellville, 7535

7 Rivers-Moore Aquatics, Pietermaritzburg

8 Council for Geoscience, Pretoria, 0184

9 Department of Water and Sanitation, Northern Cape Regional Office, Upington, 8800

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Executive Summary

Water availability/supply for shale gas development (SGD) in the assessment study area is severely constrained. Surface water availability is generally low, with large areas of non-perennial, episodic and ephemeral streams experiencing very high inter-annual variability (Subsection 5.2.3). The surface water resources in the study area are already stressed (and in many areas over-allocated) to meet the demand of existing users. Groundwater recharge is typically low and sporadic, and where groundwater does not already supply 100% of the demand, the development of groundwater resources to meet shortfalls in surface supplies is increasing, particularly during drought years (Subsection 5.2.3.1). The availability of potable groundwater resources in the study area to meet the additional demand of full SGD (beyond exploration) is seriously constrained. There is potential to develop non-potable (brackish or brack) groundwater resources for this purpose at a limited scale (Subsection 5.2.2.2). This, however, will need to take into account potential impacts associated with the transport and storage of this water, as well as potential impacts due to wellfield development.

Water resources monitoring (especially pre-SGD baseline) is an imperative. SGD must not proceed before a comprehensive set of baseline data for the study area has been established (Section 5.8). This must include surface water availability and verification of existing use also to meet environmental requirements, as well as surface water and groundwater quality. Water resource quality monitoring including general and SGD-specific determinands during and after SGD is also important to ensure protection of the water resources. Different levels of baseline information are however required for different stages of SGD – during exploration, for example, the level of baseline data required is less extensive than is required for development activities that entail hydraulic fracturing ("fracking").

Surface spills on-site and along transport networks are the most likely source of contamination (Section 5.5). Impacts that arise from on-site (wellpad) spills and accidental spillages of noxious/toxic material during transport are inevitable. Although spills *per se* are expected to have localised and short-term impacts; their actual location in the landscape will inform the magnitude of their impact. If the spill enters a river system during flood events, downstream impacts can occur.

Cumulative impacts from other activities will compound water scarcity and quality concerns. The study area is also the focus of other potential SGD-related activities such as fracking, road building and workforce accommodation that will place an additional demand on water resources and present a risk of contamination. Unrelated activities such as uranium exploration and mining will compound this demand. These represent cumulative impacts for both water quantity and quality.

Post-SGD legacy impacts will occur. Impacts following full-scale SGD (e.g. from failing/failed spent production wells) are a cumulative and inevitable legacy issue far into the future and relate to the failure of post-SGD production well casings. Where these impacts are traceable (e.g. from monitoring data), containment is feasible following site-specific assessments to identify the most appropriate mitigation measures and monitoring to establish the success of these. However, since they may only arise long after SGD has ceased, there may be concerns over the likelihood of actual detection and the availability of funding for remediation. Such issues would need to be considered in a permit.

Concern of landowners about negative impacts on local domestic/stock water supplies is acknowledged. Local landowners are mainly reliant on groundwater resources for domestic and stock water supplies. The concern about impacts on these resources from SGD is very real and understandable. The measures recommended in the scientific assessment for protecting groundwater resources must address these concerns.

Lack of a comprehensive Reserve determination prevents SGD. A comprehensive determination of the Reserve (for groundwater, surface water and wetlands) for basic human needs and ecological requirements must be carried out before SGD occurs. The authority (Department of Water and Sanitation) responsible for Reserve determinations will not issue water use licences without a comprehensive Reserve determination having been completed (Subsection 5.4.3).

Lack of infrastructure and institutional capacity for water management is a constraint. Insufficient institutional and human resource capacity is a severe constraint to the implementation and execution of a robust and effective water resource monitoring and management programme for SGD. This constraint will apply to regulatory authorities, who often lack the necessary skills and the will to exert enforcement, and less so to the industry, which it is expected will mobilise the necessary resources to meet regulatory requirements in this regard. This constraint is particularly relevant to independent monitoring and evaluation activities directed at ensuring compliance of the SGD industry with the regulatory requirements. Environmental non-compliance could be amplified by poorly capacitated regulators.

Lack of laboratories in South Africa (RSA) for water chemistry analysis is a severe constraint. Although most accredited local (RSA) laboratories are equipped to carry out the more routine water analyses (e.g. major cations and anions), none are capable of analysing for determinands such as $\delta^{11}B$, $^{36}Cl/Cl$, ^{4}H, $^{3}H/^{4}H$, and CH_4. Sufficient lead-in time must be allowed for such facilities to be established prior to baseline monitoring requirements.

SGD provides a learning opportunity that will improve understanding of local water resources. The activities associated with SGD create a substantial opportunity to generate new geoscientific data and information. This will advance an understanding of the geoscience framework (e.g. geology, hydrogeology, geophysics, geochemistry) of the study area. The benefit will extend to the international geoscientific community. The discovery of as yet unknown groundwater resources is a further possibility. Realising this opportunity will proceed whether SGD advances to production stage or not, as the geophysics and exploration drilling will have identified this potential.

CHAPTER 5: WATER RESOURCES

5.1 Introduction and Scope

Water scarcity is a critical issue in South Africa and sources of water for shale gas development (SGD), and the possible effects thereof on water resources, are crucial factors to consider in this assessment. The demand for water would be greatest during the establishment of a production well typically comprising a wellbore with vertical and horizontal sections. The drilling process typically requires ~1 000 cubic metres (m^3), and the hydraulic fracturing ("fracking") process ~16 300 m^3 per well with no water re-use and ~11 150 m^3 with water re-use. Defined by substantial error bounds (±40 to 50%), the fracking water use values are bracketed by the median values reported in Table 5.1. Although the timeframe for this concern spans the establishment and development of each well (typically one month), its long-term impact only ends with completion of the last production well and any repeat fracking activity that may be required in its active lifespan. The availability of water and the impact of its acquisition on existing water resources therefore represent one of two primary concerns. The second revolves around the issue that a variety of chemicals is added to the water used in the drilling and fracking process. These additives serve a number of purposes all aimed at improving the efficiency of the process and the productivity of the completed production well. The escape of any of this water into the environment, either as surface spillage, flowback or as produced water via whatever pathway, as well as the possible entrainment of harmful chemicals that may occur naturally in groundwater at depth, therefore represents the second primary concern for its possible impact on the fitness for use of existing water resources. The timeframe for this concern extends well beyond the productive lifetime of the well and wellfield.

The occurrence and availability of water in the study area varies both spatially and temporally, partly in accordance with rainfall typically expressed as mean annual precipitation (MAP), but also in accordance with the water-bearing properties of the Karoo strata that host the groundwater resources. With a MAP that is generally <300 mm, the western and south-western portions are drier and more arid than the semi-arid eastern portion with a MAP of >300 mm (refer to Figure 1.4 in Burns et al., 2016). Surface water is a scarce resource in the Karoo environment characterised by ephemeral surface water drainages with periodic discharge and an associated low assurance of supply (Figure 5.1). This places a huge value and reliance on groundwater resources. At the same time, the study area straddles several major (primary) catchments (Subsection 5.2.3), which indicates that impacts of various development scenarios on water resource condition may have further-reaching implications for downstream resource users, including natural ecosystems.

The circumstances described above explain the concern for any activity that threatens this resource. The development of a shale gas industry is seen as such a threat. It is attendant on this scientific assessment to evaluate robustly the threat of SGD to the water resources environment. Such assessment must necessarily consider both the quantity and the quality aspects associated with these resources. By their nature, the quantity aspect is more easily addressed than the quality aspect for reasons that will become evident.

Although the discussion of SGD in relation to water resources is arguably one of the more prominent, contentious and emotive of the 17 topics included in the overarching scientific assessment, a focus on key issues must capture and convey the most relevant and appropriate information on this aspect of the scientific assessment within reasonable text constraints. It must necessarily present a synopsis of hydrological, geological, hydrogeological and technical material that establishes a common basis on which is developed the assessment of key potential impacts and associated risk. The scientific assessment must also necessarily rely to some extent on international experience where the shale gas industry has reached maturity and a scale that lends statistical significance and credibility to the manifestation of negative impacts on water resources. Its relevance, however, depends on the extent to which it assesses threats in the context of the existing Karoo water resources environment, e.g. factors such as current and future water availability and use, natural quality constraints, environmental requirements and other hydrophysical limitations.

5.1.1 What is included in this topic?

The ‘driving’ water resource components comprise rainfall, evaporation, evapotranspiration, runoff and stream discharge, infiltration into the sub-surface, groundwater and its replenishment, hydrological linkages (fluxes) between surface water and groundwater, as well as quality. The ‘receiving’ components comprise shallow to deep aquifers, downstream water courses including rivers, wetlands and estuaries outside of the study area that may nevertheless be affected by changes in water quality and/or water quantity in the study area, surface storage (reservoirs) containing both surface runoff and pumped groundwater, human and ecosystem dependence in terms of current and future water demand and use, and waste water generation in terms of quantity and quality. The topic also includes groundwater (possibly of poor to very poor quality) occurring at considerable depth in the sub-surface. Fracking technology is increasingly adapting to the use of poor quality water in an effort to limit the impact on better quality water supplies.

In the semi-arid to arid Karoo environment, it is likely that surface water availability for such additional uses is limited (SSI, 2012; Grimmer and Turner, 2013) even without degradation of water resource quality. This issue is discussed, along with the broad implications of alternative water uses for exploration, appraisal, development and production phases of shale gas. Alternative water uses considered include treated waste water, seawater and deep groundwater. Also included are the ancillary threats to water resources posed by industry-related transport activities such as the conveyance of fuels, chemicals and other hazardous materials to site, the storage and handling of these locally together with waste products (e.g. waste water, sludge and brine) generated by on-site activities, and the conveyance of waste products from site. Note however, that whereas the waste component of this scientific assessment (Oelofse et al., 2016) deals with the normal handling of waste passing into and out of the site, this Chapter deals only with the implications of and responses to accidental exposure of surface and/or groundwater resources to contaminants as a result of spillage, leakage or disaster events.

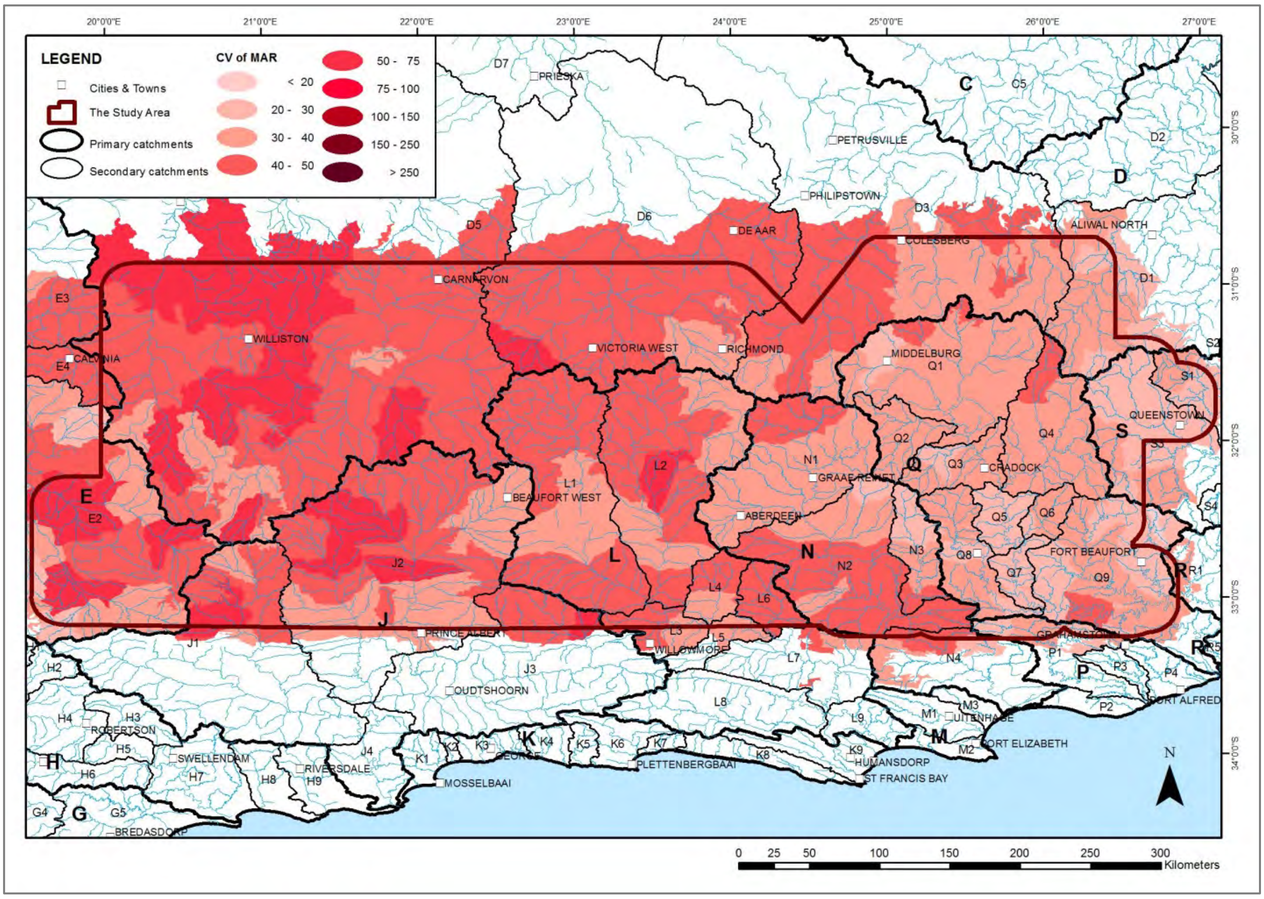

Figure 5.1: Co-efficient of variation (CV) as % of annual rainfall in the study area. The figure illustrates year-to-year rainfall assurance, as follows: the CV is a relative index of variability, expressed as a percentage (Std Dev/Mean*100), allowing a comparison of rainfall CV to streamflow CV. The higher the CV; the more variable and unreliable the year-to-year rainfall. The study area has amongst the highest CV's in SA, particularly in the western two-thirds of the site. Original data sources: Schulze et al. (2010) and Schulze (2012).

Important assumptions regarding spatial limitations for practical implementation of fracking exploration through to production activities, with particular relevance to water resources assessment, include:

- slopes steeper than 10% will not be targeted, even in the exploration phase (Burns et al., 2016); and
- legislated setbacks will be adhered to [e.g. GN R466 of 3 June 2015 in terms of the Minerals and Petroleum Resources Development Act (RSA, 2015a) (Section 122(2)].

5.1.2 Overview of international experience

International experience with SGD on a substantial scale dates back to the 1940's in the United States of America (USA). The USA and Canada currently account for virtually all of the commercially produced shale gas globally (Norton Rose Fulbright, 2013). These industries therefore attract the closest scrutiny for their learning opportunities. The scale of the industry is informed mostly by the

> ***Proppant**: Material, usually sand or ceramic particles, carried by the fracking fluid into a fracture to keep it open when hydraulic pressure is released.*

size of the resource, as technological advances have to a large extent overcome natural limitations. Examples of these are drilling techniques that have overcome constraints on the depth of extraction, directional horizontal drilling, multi-stage fracking and efficacy of drilling and fracturing fluids (including the use of waste water) and proppants to fracture the reservoir strata and release trapped oil and gas. The mature USA and Canadian industries benefitted from already existing conventional oil and gas infrastructure, allowing SGD and production to focus attention and costs on the upstream infrastructure. SGD in the Karoo does not provide such benefit. It must start from scratch, and would require extensive development of infrastructure (roads, services, etc.) along with direct development-associated activities.

Fracking varies in its water requirements (Burns et al., 2016, Subsection 4.3.2.2.1), the amount and type of chemicals used, and the quantity and quality of waste water generated (Cooley and Donnelly, 2012). These variations can occur even between neighbouring wells (Nicot et al., 2011) and, as shown by Nicot et al. (op cit), varies between four different shale gas resources in the semi-arid environment of Texas (Table 5.1). Cooley and Donnelly (2012) report the conflict between existing water use and shale gas production created by a major drought in Texas in 2011 that precipitated the imposition of mandatory water use reductions. The volume of waste water (flowback and produced water) that is generated during full scale SGD is similarly characterised by large uncertainty. Flowback can range from 10 to 80% (Broomfield, 2012; Grant and Chrisholm, 2014) of that injected during fracking. Produced water, although typically in the order of 1 to 2 m^3/d (Rahm et al., 2013), can be produced for the lifetime (many years and more) of a production well.

The scarcity of surface water resources in the semi-arid and arid Karoo landscape suggests that the learning experience from the wetter North American plays has limited relevance to this scientific assessment. The Barnett Shale in Texas and the Permian Basin of western Texas and New Mexico, both are characterised by semi-arid to arid climates, provide the closest developed international proxies for the Karoo Basin.

Table 5.1: Water requirement estimates for fracking in four Texas shale gas resources (from Cooley and Donnelly, 2012).

Shale gas resource	Water requirement (m^3 per well)[(1)]		
	Low-end estimate	Median	High-end estimate
Barnett Shale	<3 800	9 800	>30 300
Haynesville and Bossier Shale	<3 800	20 800 to 22 700	>37 900
Eagle Ford Shale	3 800	22 700 to 24 600	49 200
Woodford, Pearsall and Barnett-PB Shale	<3 800	2 800 to 3 800	<18 900
(1) Values rounded off to nearest 100			

Note however that these shale formations are at different depths to those in the Karoo, and the data presented in this table may not therefore be representative of the actual water requirements for fracking of Karoo systems, given that water requirements are a function of depth and other factors.

5.2 Characterising features of the Karoo environment

5.2.1 Geology

A description of the key geological features of the Karoo Basin is provided in Section 1.3.1 of Burns et al. (2016). Familiarisation with this description will facilitate an understanding of the concepts and relationships that inform the association between geology, shale gas and groundwater that is discussed in this Chapter. The mudstones and sandstones of the Adelaide Subgroup at the base of the Beaufort Group succession of sedimentary strata represent in surface extent the main rock types in the study area. Covering ~87% of the landscape; these strata host the shallow aquifers that provide groundwater primarily for human and livestock consumption in the semi-arid to arid environment. This function is generally enhanced in the presence of dolerite intrusions in the form of dykes and sills (Subsection 1.3.1.2 of Burns et al. (2016), and is identified as a unique feature of the Karoo Basin that has a potential impact on gas reserves and contaminant migration to surface. The sedimentary rocks of the Ecca Group cover a further ~6% of the study area.

> ***Aquifer**: Part of a formation, a formation or a group of formations that is/are capable of both storing and transmitting groundwater, by virtue of possessing sufficient saturated and interconnected porous and/or permeable material, directly to a borehole, well or spring in sufficient quantities for a required use.*

In agreement with Rosewarne et al. (2013), who recognise a western, a central and an eastern subarea; this study recognises an additional southern subarea (Figure 5.2). Each subarea is characterised by distinguishing lithological and hydrogeological attributes. The subdivision also recognises physiographic factors such as the Great Escarpment. Changes from one subarea to another are mostly gradational.

- *Western subarea.* Dolerite intrusions in the form of sills and dykes occur in abundance throughout the western area. The intrusions represent the main targets for groundwater exploration. The high ridges (inselbergs) which characterise large parts of the area are the result of erosion resistant dolerite forming a protective capping for the underlying sedimentary strata. The target shale gas horizons deepen westwards and southwards from ~500 m along the western and northern margin, to >2 000 m below surface.

- *Central subarea.* The area is characterised by horizontal to sub-horizontal strata. The horizontal bedding gives rise to the expansive landscape of flat to gently undulating plateaus. The landscape becomes more hilly east of Richmond. A greater density of dolerite sills and dykes occurs to the north and central parts of the area, again representing main targets for groundwater exploration. The topography is again the result of erosion resistant dolerite forming cappings to these features and ring complexes which give rise to circular shaped basins. The target shale gas horizons diminish in depth northwards from ~2 000 m along the southern margin to ~1 000 m along the northern margin.

- *Eastern subarea.* North of the towns of Somerset East and Adelaide dolerite intrusions (sills and dykes) occur in abundance. The target shale gas horizons occur at depths of ~3 500 m in the southern part, becoming shallower in a north-easterly direction to ~1 000 m below surface.

- *Southern subarea.* A key feature of this area is a general absence of dolerite intrusions, except in the very north-east of the area, and the proximity to the Cape Fold Belt (CFB). Proximity to the CFB resulted in this area being structurally more complex than the other three subareas, with folding and fracturing of the rock layers. The trend of the fold axes is approximately east-west, with the steepest bedding dip angles in the south, moderating rapidly to the north before the Great Escarpment. The target shale gas horizons for the most part occur >2 000 m below surface.

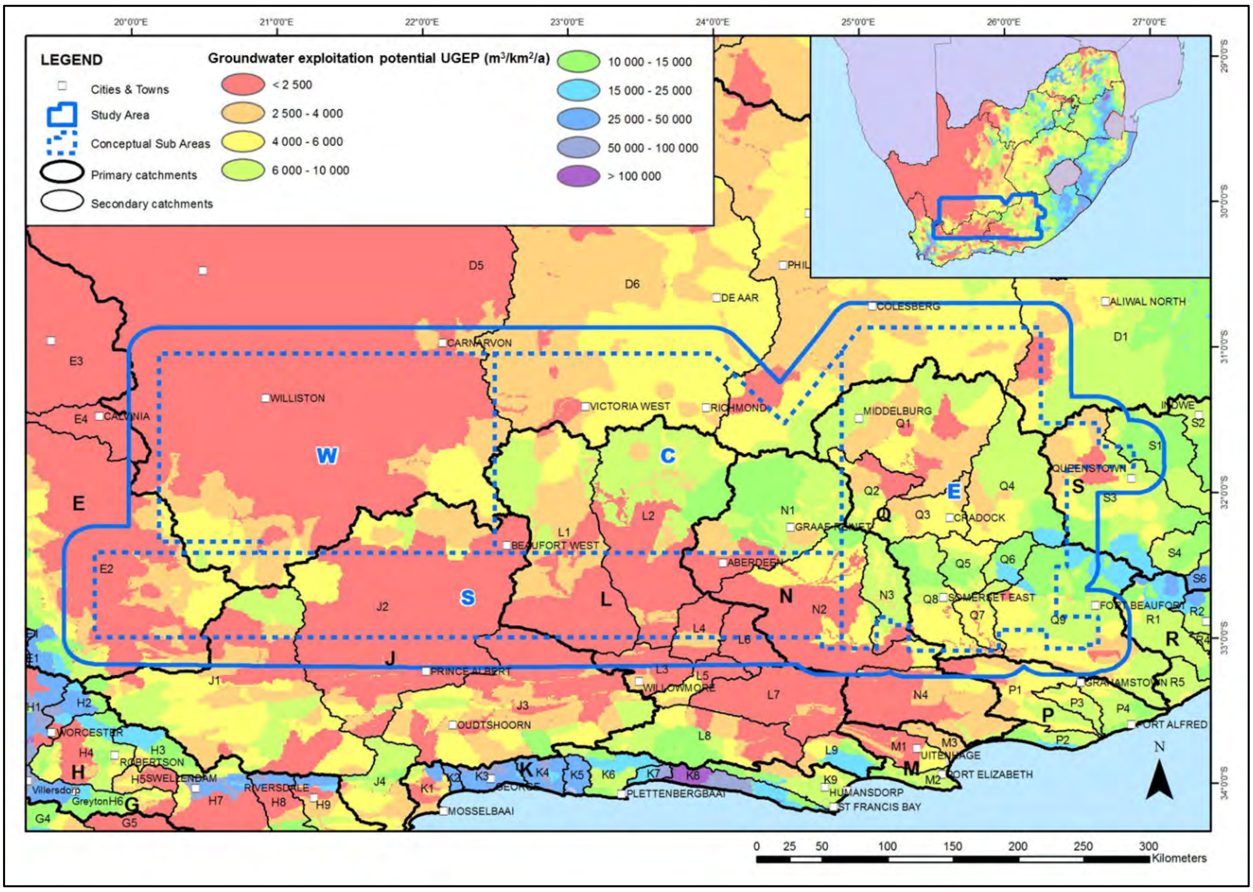

Figure 5.2: Utilisable Groundwater Exploitation Potential. The figure shows the subdivision of the study area into four subareas identified as W (western), C (central), E (eastern) and S (southern) distinguished on the basis of lithological, hydrogeological and morphological factors; boundaries are gradational (adapted from Rosewarne et al., 2013): base map shows the utilisable groundwater exploitation potential in the study area with inset map for national context (after DWAF, 2005).

5.2.2 Groundwater

5.2.2.1 Occurrence

Dolerite intrusions in the form of dykes and sills and ring complexes are intrinsic to groundwater occurrence in the broader Karoo environment (Chevallier et al., 2001). As already mentioned, these structures represent the main targets for scientific groundwater exploration, with dykes in particular being the feature most commonly targeted by landowners for successful borehole siting. These circumstances have resulted in a comprehensive assessment of these features, on the basis of which the following groupings are recognised:

- East-west striking dykes, some of which are extensive and continue over 500 km. These intruded along major lateral east-west dislocation/shear zones, and are accompanied by north-west and north-east trending sympathetic shears. They are thought to represent feeder dykes extending to the base of the Karoo Supergroup.
- North-northwest striking dykes, which are also regionally extensive and regularly spaced from east to west across the Karoo landscape. Their trend is curvilinear, varying from west-northwest in the south to north-south in the north.
- Sill and ring complexes are prominent features of both the western and eastern Karoo, where they are well developed in the upper Ecca Group sediments. The geometry of these features ranges from tabular to bowl-shaped, and may comprise a multi-level stacking in nested groupings. Many of these structures are fed by arcuate dykes (Chevallier et al., 2001). In their simplest expression, the sills form the resistant caprock that characterises the flat-topped koppies (hillocks) of the Karoo landscape.

An association between lithology and dolerite distribution is inferred from the observation by Woodford et al. (2001) of a sharp decrease in intrusion density at the boundary between the lower and upper Ecca strata. This boundary corresponds to the appearance of the first sandstone units of the Karoo Supergroup. The majority of the dykes are stratabound and concentrated in the upper Ecca and Beaufort group sandstones.

In broad terms the shallow aquifer is mainly associated with the weathered and/or fractured sedimentary strata (mudstone and sandstone) of the Beaufort Group, and the deep aquifer with fractured Ecca Group and Dwyka Group strata, and possibly also underlying basement strata. The intermediate aquifer most likely associated with the groundwater of 'mixed' chemical composition (Murray et al., 2015), is not readily positioned in lithostratigraphic terms. The aquifer yield is derived from the utilisable groundwater exploitation potential (UGEP) estimates produced by the then Department of Water Affairs and Forestry (DWAF) GRAII Project (DWAF 2005) and as shown in Figure 5.2. These estimates are based on average input values and therefore will not vary significantly over time as they are based on long-term records (i.e. mean annual rainfall, recharge, and average water levels). The UGEP provides an estimate of the maximum volume ($m^3/km^2/a$) of groundwater that is potentially available for abstraction under natural conditions (i.e. no abstraction) and normal rainfall conditions. The UGEP figures illustrate the fact

> ***Lithostratigraphic:*** *Combination of the terms lithology describing rock type, and stratigraphy describing position in the geologic record.*

that aquifer yields increase from the western to the eastern area. Water levels become shallower, recharge increases and water quality improves in this direction and also from south to north in the eastern area. These trends are reasonably attributed to factors such as the increase in rainfall, the greater proportion of sandstones relative to siltstone/mudstone strata, and the preponderance of dolerite intrusions to the east.

The windpump is synonymous with the Karoo environment, and is a constant reminder of the value of groundwater in this landscape. Successful boreholes are often associated with intrusions of dolerite into the sedimentary strata in the form of vertical to sub-vertical dykes and/or horizontal to sub-horizontal sill and ring-complex structures (Chevallier et al., 2001; Woodford and Chevallier, 2002). The hydrogeological maps 3117 Calvinia (RSA, 2002a), 3122 Beaufort West (RSA, 2002b) and 3126 Queenstown (RSA, 1997a) assign a median yield in the range 0.5 to 2 litres per second (L/s) for a successful borehole across much of these map areas in the study area, with total dissolved solids (TDS) levels in the range 500 to 2 100 milligrams per litre (mg/L) , nitrate levels >10 mg/L (as N) and fluoride levels >1.5 mg/L being a common occurrence in this groundwater. The nitrate and fluoride levels define the recommended operational limit (for N) and maximum allowable level (for F) for limited duration as given in the earlier South African National Standards (SANS) 241 national drinking water standard. The most recent revision (SANS, 2015a; 2015b) reports a standard limit of ≤11 mg/L for nitrate as N, with that for fluoride unchanged at 1.5 mg/L.

> ***Salinity:*** *A measure of the total dissolved solids (TDS) concentration expressed as electrical conductivity (EC) with the unit mS/m (milliSiemens per metre). The ratio of TDS to EC provides a useful factor to estimate TDS (as mg/L) from EC (as mS/m). The ratio for natural water typically falls in the range 5.5 to 7.5 (Hem, 1985). More acidic, poorly buffered and/or more saline water will differ from this, with higher ratio values generally associated with water containing higher sulfate levels. For example, the sulfate-rich acid mine water of the West Rand Goldfield is characterised by a ratio of 10 to 12.*

Site specific scientific groundwater investigations generally yield more productive boreholes than are reflected in the hydrogeological maps. The scientifically-based (geophysical) siting of 67 water exploration boreholes with a median depth of 240 m targeting dolerite structures around Victoria West (Chevallier et al., 2001) returned a median blowout yield of 2.4 L/s and a median TDS concentration of ~420 mg/L. Similarly, groundwater investigations carried out in the Beaufort West area in the late-1970’s (BRGM, 1977) identified an alluvial aquifer associated with the Sout River. This intergranular primary aquifer comprises unconsolidated alluvial material >10 m thick supporting borehole yields of ~5.5 L/s and an electrical conductivity (EC) of >500 mS/m. These circumstances resulted in the establishment of a wellfield. More recently, SRK Consulting (SRK, 2007; 2008) identified a productive fractured rock aquifer in the Ryst Kuil area. Developed in channel sandstone up to 45 m thick, this aquifer supported exploration boreholes with yields in the range 3.5 to 26.7 L/s (SRK, 2008) producing groundwater with a salinity of <150 mS/m. Given the arid nature of the area and the impact of drought, long-term sustainable yields are likely to be more conservative but still significant.

> ***Standard limit:*** *Acceptable health risk for consumption of an average of 2 litres of water per day for 70 years by a person weighing 60 kg (SANS, 2015a).*

The natural occurrence of groundwater in the study area is rendered in greater detail in Figure 5.3 on the basis of the aquifer classification protocol followed for the Department of Water and Sanitation (DWS) 1:500 000 scale hydrogeological map series. Figure 5.3 indicates that most of the study area is characterised as being underlain by fractured aquifers supporting boreholes with a median yield in the range 0.5 to 2 L/s. Areas of higher yielding boreholes occur around Beaufort West and Aberdeen, amongst others. Intergranular and fractured aquifers are prominent in the north-eastern and eastern portions of the study area (e.g. around Richmond and Queenstown). As the data also provide an indication of groundwater availability, this aspect is discussed in the context of demand in Subsection 5.3.1.

Understanding and evaluating the threat of SGD to the water resources of the Karoo is undoubtedly confounded by the complexity of the surface water and groundwater environments. It is therefore inevitable that a varying degree of uncertainty will apply to such understanding and evaluation, depending on the availability of data and the level of unobservable and therefore inferred complexity in the absence of monitoring data. For instance groundwater level and temperature monitoring of the Ryst Kuil aquifer in the period 2007 to 2010 (SRK, 2010) indicated recharge in some areas and no recharge in others. The areas of recharge could be linked to sites close to rivers and dams excavated to collect some surface run-off. Groundwater levels in the 3 year period of record declined in the range 0.4 to >2 m in the areas of no recharge.

DWS aquifer classification: *Four aquifer types (modes of groundwater occurrence) are recognised as follows:*

Intergranular ....a
Fractured...b
Karst c
Intergranular & fractured ....d

Five median yield ranges (excluding dry boreholes) are recognised as follows:
0 to 0.1 L/s 1
0.1 to 0.5 L/s 2
0.5 to 2 L/s 3
2 to 5 L/s 4
>5 L/s...5

The alpha-numeric combination of the above, e.g. b3, classifies both the aquifer type and groundwater availability, and lends itself to colour-coding as shown in Figure 5.3.

5.2.2.2 Water quality

Rosewarne et al. (2013) report that sodium concentrations in the shallow groundwater decrease from the drier western portion to the wetter eastern portion of the Karoo, an observation supported by Murray et al. (2015). The 'shallow' groundwater is typically characterised as cool (<24°C) and fresh to slightly saline (brackish) (RSA, 2002a; RSA, 2002b; Murray et al., 2015). The occurrence of groundwater at much greater depth (>1 000 m) is known from a handful of ultra-deep (up to ~4 000 m) boreholes. The 'deep' groundwater resources are generally characterised by warm (>24°C) to hot (>34°C) (Murray et al., 2015) and moderately saline (highly brackish) water. In some instances the confining pressure of overlying strata causes the water to rise to surface, resulting in free-flowing (artesian) borehole discharge similar to thermal springs. The hydrostatic pressure is typically shut in by fitting the borehole with a gate valve and pressure gauge. Despite such measure, the Southern oil Exploration Corporation (SOEKOR) well SA 1/66 had stopped flowing by the time Murray et al.

Groundwater temperature: *Kent (1950) proposed the following classification for groundwater temperature:*

Warm .... 25° to 37°C
Hot .... 37° to 50°C
Scalding .... >50°C

(2015) visited the site in July 2014 for sampling purposes. The Institute for Groundwater Studies (IGS) at the University of the Free State (UFS) has previously successfully sampled the well in November 2012 and September 2013. The more recent cessation of artesian flow suggests that pressure relief occurred via another pathway in the sub-surface. Murray et al. (2015) concluded that the 2013 chemistry already reflected a mixture of deep and shallow groundwater. It is not improbable that moderately saline (highly brackish) groundwater might be exploited by the shale gas industry for drilling and fracking water supply purposes, although it should be considered that the US Bureau for Land Management (BLM) attempted to set a lower TDS limit of 10 000 mg/L for such use in the Pavillion Field of Wyoming (DiGiulio and Jackson, 2016).

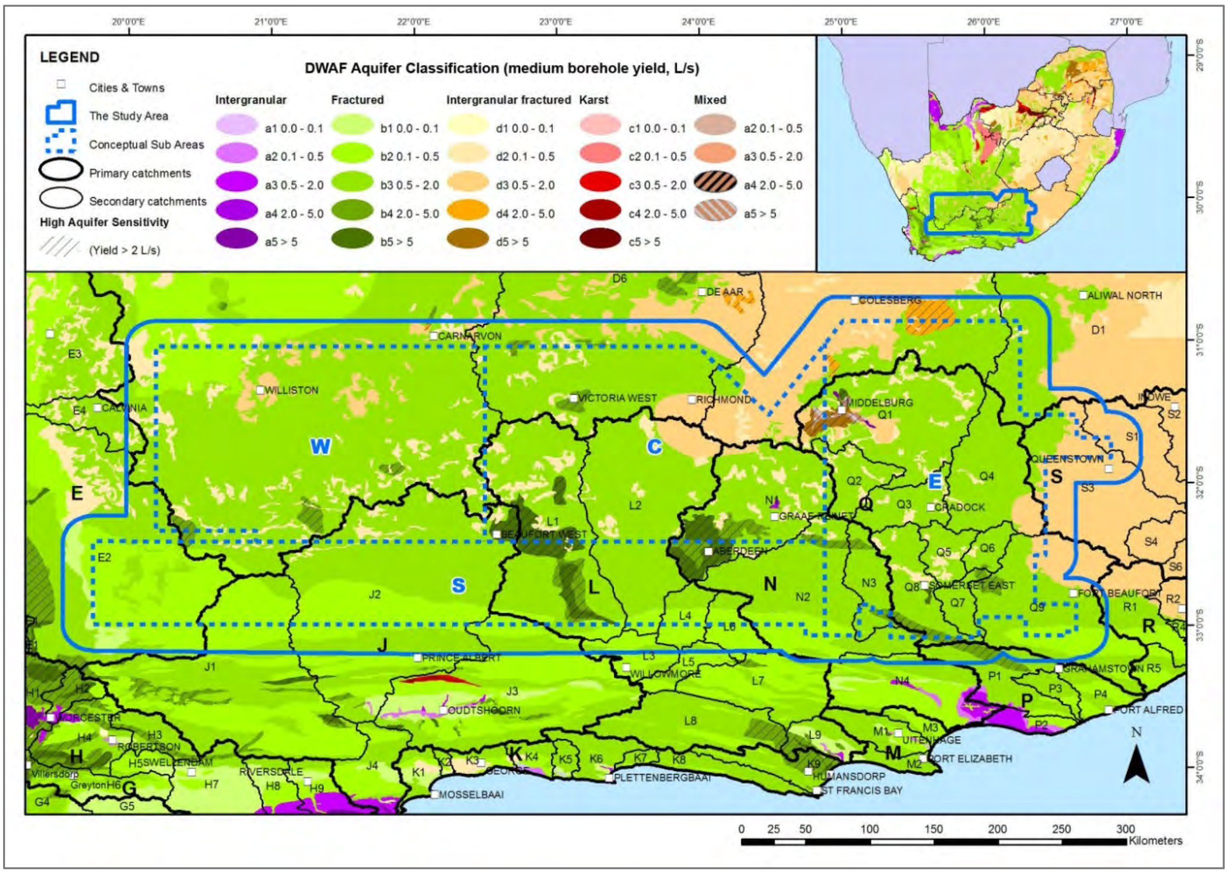

Figure 5.3: Groundwater occurrence in the study area (after RSA, 1997a; 2002a and 2002b).

Both Rosewarne et al. (2013) and Vermeulen (2012) also recognise an ‘intermediate’ aquifer arbitrarily assigned to the depth interval 300 to 1 000 m below surface. The groundwater of ‘mixed’ chemical composition recognised by Murray et al. (2015) is considered to derive from this interval. An analysis of water samples drawn from 20 boreholes/springs led Murray et al. (2015) to categorise these into three distinct groups, viz. seven deep and eight shallow with confidence, relegating five to a ‘mixed’ group on the basis of hydrochemical differences, suggesting a correlation with the similar distinction drawn between aquifers. It is not yet possible to associate the intermediate/mixed and deep aquifers with either a specific lithology (formation) or water chemistry. The ca. 1960’s SOEKOR boreholes indicate that one or more water strikes of 0.5 to 2 L/s might be encountered at any depth in the Karoo sedimentary package (Rosewarne et al., 2013). Most recently, the CIMERA-KARIN borehole KZF-1 produced 6.7 L/s of fresh (TDS ~330 mg/L) warm (34.4°C) artesian groundwater at a depth of ~671 m below surface (De Kock et al., 2016) from the Dwyka Group glacial deposits underlying the target shale gas horizon (the Whitehill Formation). The TDS of this groundwater suggests that it may derive (at least in part) from the basal quarzitic strata of the Table Mountain Group that outcrop to the west in the north-western limb of the CFB represented by the Skurweberg mountain range, amongst others. The artesian water produced by KARIN borehole KFZ-1 (De Kock et al., 2016) is an example of groundwater generated in the exploration (pre-development) phase of SGD. The chemical composition of this water will reflect the presence of naturally occurring elements associated with the formation(s) producing this water.

Brack water: *Salty tasting water caused by a higher concentration of dissolved mineral elements (e.g. calcium, magnesium, sodium, chloride) collectively described as total dissolved solids (TDS). The TDS concentration is used to describe the degree of salinity (brackishness). The following classifications are two examples of many.*

Hem (1985)	*TDS (mg/L)*
Fresh	*<1 000*
Slightly saline	*1 000 to 3 000*
Moderately saline	*3 000 to 10 000*
Very saline	*10 000 to 35 000*
Briny	*>35 000*
Sea water	*~34 000*

King (2012)	*TDS (mg/L)*
Fresh	*<1 000*
Brackish	*1 000 to 5 000*
Highly brackish	*5 000 to 15 000*
Saline	*15 000 to 30 000*
Sea water	*30 000 to 40 000*
Brine	*40 000 to >300 000*

CIMERA-KARIN: *The Centre for Excellence for Integrated Mineral and Energy Resource Analysis (CIMERA) is a Department of Science and Technology and National Research Foundation facility tasked with managing the Karoo Research Initiative (KARIN) programme. This programme is an academic study of the geology of the Karoo Supergroup, with special reference to its shale gas potential, by geoscientists from six of South Africa’s leading universities, Keele University in the United Kingdom, and the South African Council for Geosciences (De Kock et al., 2016).*

The principal aim of KARIN is to explore the southern Karoo Basin through the extraction of deep drill cores. To this end, the initiative has recently completed two deep boreholes, one near Ceres in the Tankwa Karoo (borehole KFZ-1) west of the assessment study area to a depth of 671 m, and the other near Willowvale (borehole KWV-1) in the Eastern Cape to a depth of 2 350 m.

An analysis of groundwater chemistry data associated with each of the subareas recognised in the study area (Section 5.2.1 and Figure 5.2) indicates that each of these areas might also be characterised on the basis of slightly different chemical compositions. These differences are revealed by the ‘footprints’ that encompass the position of water analyses plotted on a Piper diagram (Figure 5.4). The positions of the southern subarea analyses are shown to illustrate the derivation of the ‘footprints’. The footprints indicate a greater difference in groundwater chemistry in the eastern and western subareas compared to the central and southern areas. This is to be expected given the climatic differences that exist between these two subareas (Section 5.2.1). The ‘tighter’ grouping of the southern subarea data, including the smaller difference in chloride (compared say to the western subarea), is considered to reflect the absence of dolerite intrusion influence on groundwater chemistry. Clear separation of these footprints with that of ‘deep’ groundwater (from Murray et al., 2015) is evident.

***Uranium**: In its natural state, uranium (U) occurs mainly as the radioactive isotope uranium-238 (^{238}U), which represents ~99.3% of the natural abundance of U. It is extracted for commercial purposes from U-bearing minerals such as uraninite (pitchblende). In the Karoo, the U occurs as shallow tabular ore bodies in association with sandstones of the Adelaide Subgroup, Beaufort Group (Cole, 1998). Uranium is highly soluble in water, its dissolution, transport and precipitation in a groundwater system being controlled by changes (often small) in oxidation-reduction (redox) conditions. Uranyl species (e.g. UO_2, UO_2CO_3) are especially mobile in oxidizing environments (Domenico and Schwartz, 1998) at both alkaline and acidic pH conditions.*

Steyl et al. (2012) report that the results of various geochemical studies of fine-grained sedimentary rocks of the Karoo Supergroup show that the shales are not enriched in possibly “dangerous” elements, including uranium. Murray et al. (2015) identified higher uranium concentrations in the range 0.002 to 0.041 mg/L in the ‘shallow’ groundwater than that in warm springwaters rising from a maximum depth of ~1 000 m. Uranium occurs quite commonly in the south-western part of the Karoo Basin. The combined extent of these occurrences is sufficient to define the so-called Karoo Uranium (metallogenic) Province, described by Cole et al. (1991) as extending from the north-eastern part of the Western Cape Province across the south-eastern part of the Northern Cape into the southern Free State. Four orebodies were subject to feasibility studies in the late 1970’s. One of these, located 42 km west-southwest of Beaufort West, showed an average ore grade of 1.5 kg/t at a depth of 13 m (Cole, 1998). In a study focused specifically on the incidence of naturally occurring hazardous trace elements in groundwater nationally, Tarras-Wahlberg et al. (2008) report concentrations of up to 0.539 mg/L in groundwater taken from old uranium exploration boreholes in proximity to uranium deposits with an average grade of 4.1 kg/t around Beaufort West. Concentrations of <0.016 mg/L were found in water supply boreholes in the same area. Similarly, Vogel et al. (1980) found ^{238}U levels in the range 0.001 to 0.044 mg/L from 9 boreholes in the Beaufort West area. These values are similar to those reported by Murray et al. (2015). The national drinking water standard for uranium is ≤0.03 mg/L (SANS, 2015a; 2015b).

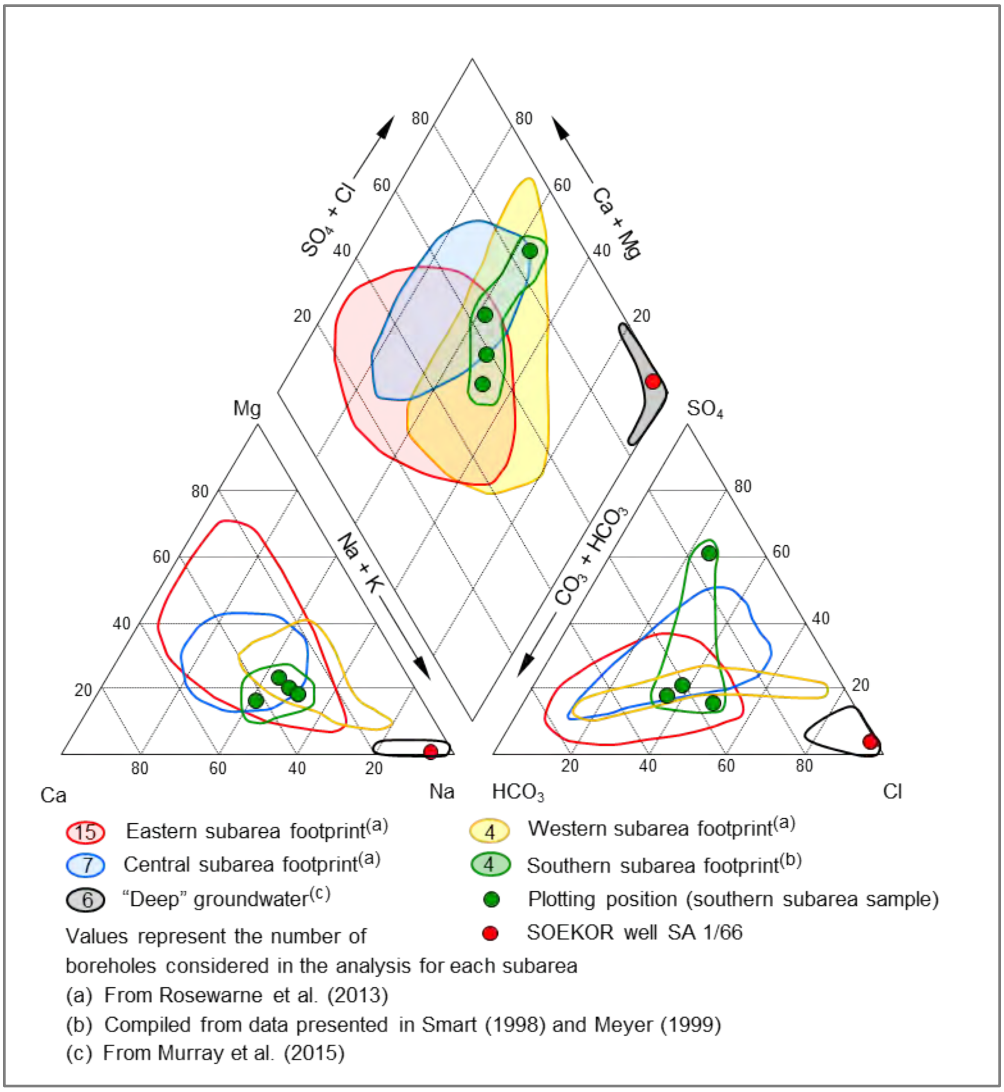

Figure 5.4: Characterisation of shallow groundwater chemical composition between the four subareas recognised in the study area compared to 'deep' groundwater as reflected in a Piper diagram; southern subarea analysis excludes groundwater from the basal Dwyka Group, which varies considerably from fresh to brack.

The uranium deposits are also associated with elevated arsenic concentrations in groundwater. Sami and Druzynski (2003) report concentrations between 0.13 and 0.3 mg/L from 9 boreholes in the south-western Karoo near Beaufort West, while Tarras-Wahlberg et al. (2008) report concentrations of up to 0.082 mg/L in water sampled from exploration boreholes near Beaufort West. These authors also report concentrations of 0.14 to 0.2 mg/L from three boreholes penetrating black carbonaceous shale (probably the Whitehill Formation) north of Calvinia. Murray et al. (2015) report concentrations of 0.001 and 0.009 mg/L in the warm (~30°C) Cradock Spa springwater, and of ~0.02 mg/L for shallow groundwater from a borehole north of Cradock. Most of these levels exceed the limit of ≤0.01 mg/L set by the national drinking water standard (SANS, 2015a; 2015b).

Similar circumstances as described for uranium apply to radon-222 (^{222}Rn), the daughter of radium-226 (^{226}Ra) in the decay chain with ^{238}U as parent. Vogel et al. (1980) report ^{222}Rn activity levels in the range 30 - 128 Bq/L from 14 boreholes in the Beaufort West area. At a more regional scale, Murray et al. (2015) report ^{222}Rn values in the range 1.3 - 58 Bq/L for deep groundwater from six sources, and 14 - 163 Bq/L for shallow groundwater from eight sources. Although the indications are that neither ^{238}U nor ^{222}Rn (and by association ^{226}Ra) represent elements of significant concern for SGD, further geochemical characterisation of the shale gas-bearing strata also in regard to these radionuclides is advisable during the “initial exploration and drilling phase” (Steyl et al., 2012). The impact of chemicals introduced during fracking on the mobility and availability of naturally occurring radioactive materials (NORMs) is, however, unknown and will require evaluation by the industry. Analysis of gross alpha activity and gross beta activity in drill cuttings, flowback and produced water serves as an adequate screening tool to assess whether further characterisation of radioactive material (e.g. for waste disposal considerations) would be required (New York State Department of Health (NYSDOH), 2009). Baseline sampling of water supply boreholes for gross alpha and gross beta activities as well as for NORMS and arsenic is equally advisable.

Talma and Esterhuyse (2015) report the fairly common occurrence of methane (CH_4), a colourless and odourless gas, in groundwater from boreholes and springs in the Karoo environment. These occurrences are associated with both deep and shallow sources (based on water temperature), and occur both north and south of the Great Escarpment. It would also appear that methane emanations are not conditional on the presence of dolerite intrusions (Talma and Esterhuyse, 2015). Methane results presented by Murray et al. (2015) indicate a mean concentration of 17.9 cm^3/kg for six ‘deep’, 6.4 cm^3/kg for five ‘mixed’ and 1.9 cm^3/kg for eight ‘shallow’ groundwater samples. A study by Siegel et al. (2015) of thousands of domestic boreholes in proximity to hundreds of pre-existing oil and gas wells concluded that there is no significant correlation between dissolved methane levels in groundwater and proximity to nearby oil and gas wells. Nevertheless, the inclusion of CH_4 and related diagnostic isotope analyses (^{12}C, ^{13}C, ^{1}H and ^{2}H, amongst others) in the recommended baseline studies is advocated.

5.2.2.3 Contextual discussion

It has been noted that SGD in the USA often appears to be associated with brines with produced water TDS values in the range of 60 000 to 180 000 mg/L (McLaughlin, 2013) and even >250 000 mg/L (Osborn et al., 2011). By contrast, the highest TDS recorded from deep drilling in the Karoo is ~10 000 mg/L (Rosewarne et al., 2013; Murray et al., 2015). This is not much higher than that of some naturally occurring moderately saline groundwater in the Karoo, and might explain why Murray et al. (2015) do not recognise TDS as an indicator of deep groundwater in the Karoo region. The differences in groundwater quality at shallow and intermediate depth is illustrated by the field results from KARIN borehole KZF-1, with groundwater from a depth of ~83 m having a pH of 8.9, a temperature of 25.8°C and an electrical conductivity of ~73 mS/m compared to the pH of 8.3, temperature of 34.4°C and electrical conductivity of ~48 mS/m for groundwater from a depth of 671 m (De Kock et al., 2016).

A flow pathway that has generated considerable attention in the shale gas debate is that of possible hydraulic linkage between the shale gas strata and ‘shallow’ groundwater resources. This debate is fuelled by the network of structures represented by the dyke and sill intrusions. Rosewarne and Goes (2012) suggests that it is unlikely that potential conduits such as faults and dykes extending from depth to surface remain unmapped. However, ‘blind’ features that terminate below or in the shallow aquifer could exist, and some mapped geophysical anomalies might correlate to these. The North American experience is based on the presence of faults rather than dykes, and is further confounded by the existence of many and more old oil and gas wells dating back decades, and which represent potential artificial pathways for upward migration of natural and introduced contaminants.

The Aliwal North thermal spring, with a temperature of 37ºC, represents the deepest known groundwater circulation of ~1 100 m below surface based on a geothermal gradient of 30ºC per 1 000 m. This spring discharges groundwater with a TDS of ~1 200 mg/L at a rate of 44 L/s. Evidence provided by the SOEKOR wells SA 1/66, KL 1/65 and VR 1/66 in the southern subarea (Figure 5.2), i.e. below the Great Escarpment, indicates open fractures at depths >4 000 m producing artesian flows of up to 3 L/s, TDS of up to 10 000 mg/L and temperature of up to 76ºC (Kent 1969). The water intercepts in the Dwyka and Witteberg Group strata suggests a more complex groundwater environment and has implications for potential migratory pathways for contaminants from depth to the near-surface (shallow aquifer) and surface environments. The drilling record of KARIN borehole KZF-1 (De Kock et al., 2016) has also proven insightful in regard to hydrogeologically significant aspects of Karoo strata with depth below surface. Beyond the expected presence of a 'typical' shallow fractured aquifer extending to a depth of ~60 m, the record shows the following:

- interception of a dry fracture at a depth of ~82 m that resulted in total circulation loss of drilling fluid;
- occurrence of fault zones at depths of ~450 m and ~480 m; and
- water strikes at depths of 558 m (freshwater), ~626 m (slightly sulphurous water) and ~670 m (6.7 L/s freshwater).

These observations reveal the hydrogeological complexity that might be encountered during SGD, and which represent a mixture of associated opportunities and threats. Opportunities take the form of 'discovered' groundwater occurrences that might be used for community water supply. Threats are embodied in all of the listed items that potentially represent horizons susceptible and vulnerable to intrusion by flowback, produced water and shale gas in the event of casing failure Subsection 5.5.1). Uncertainty also exists regarding an understanding of the stress-strain fields at depth. For example, Coblentz and Sandiford (1994) report large extensional stresses present in the lithosphere beneath southern Africa, which circumstances might have implications for the 'frackability' of proximal overlying strata such as the Whitehill Formation.

The vulnerability information of shallow groundwater resources to contamination from surface sources have been rendered nationally in the GRAII (DWAF, 2005) based on the DRASTIC algorithm (Aller et al., 1987). This is shown in Figure 5.5, which indicates a low to medium vulnerability across most of the study area, with smaller areas of high vulnerability around Beaufort West.

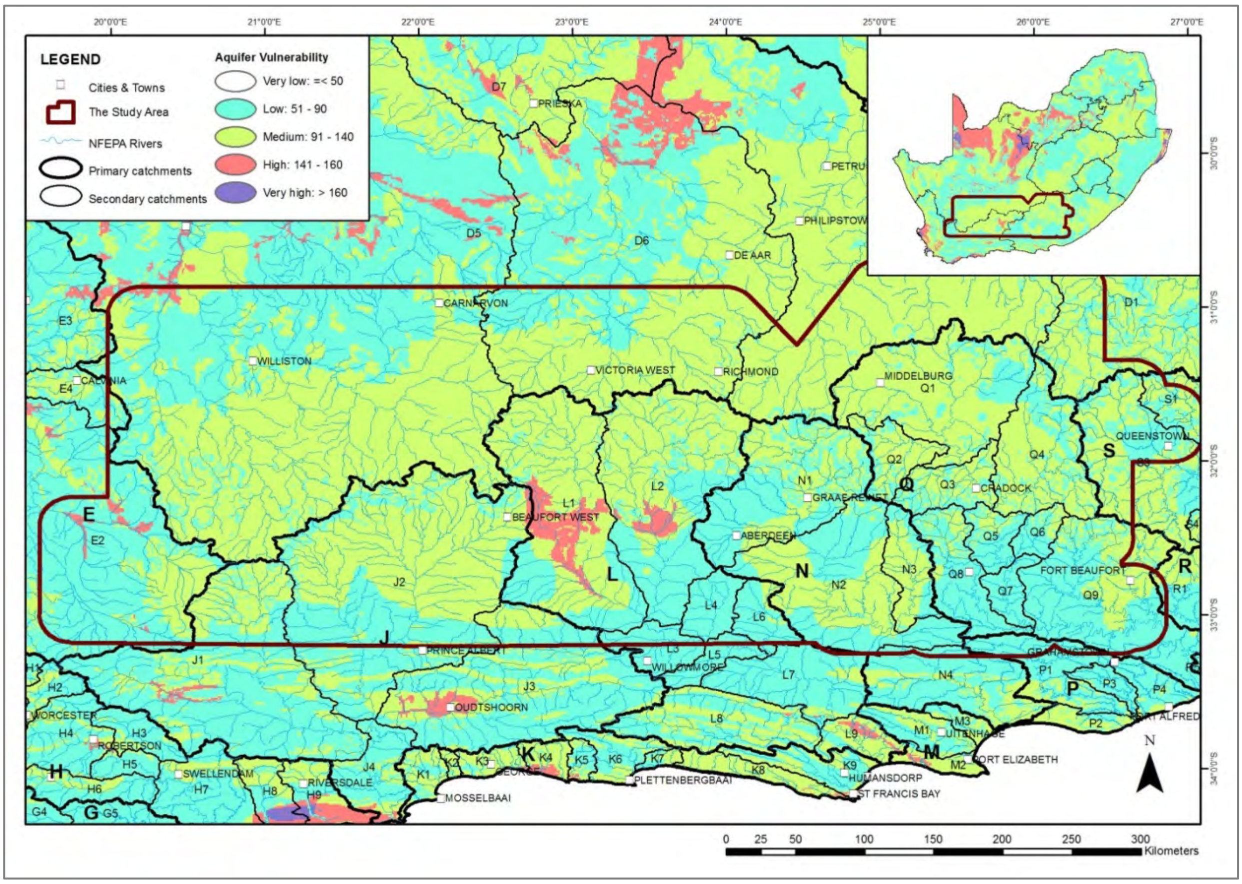

Figure 5.5: Shallow groundwater vulnerability rating (from Esterhuyse et al., 2014).

The vulnerability of the shallow groundwater resources to potential contamination from depth is rendered in Figure 5.6. In the light of sparse information regarding deep groundwater occurrence, known macro-features of the geological environment have been used to derive the qualitative vulnerability assessment based on the following considerations.

An area of **high vulnerability** in the south which is marked by the absence of dolerite intrusions. Karoo strata (including the target shale gas reservoir formations) north of the CFB (not shown) are folded and fractured, with groundwater intercepts being recorded up to a depth of >4 000 m. The Great Escarpment is taken to mark the northern limit of deep artesian flow. The area south of the Great Escarpment is underlain by rocks of the Cape Supergroup (mainly the Table Mountain Group and Witteberg Group quartzitic sandstones) from which deep groundwater is under sufficient hydrostatic and lithostatic pressure to reach the surface. This is evidenced by the SOEKOR wells that produced saline thermal groundwater from depth, as well as the KARIN borehole KZF-1. An area of **moderate vulnerability** between the southern limit of dolerite intrusions and northern limit of Cape Supergroup floor rocks, representing the Cape Basin. The presence of especially dolerite sills are likely to impede the upward migration of gas, groundwater and contaminants as evidenced by gas strikes encountered at the base of thick sills during exploration/water borehole drilling. An area of **low vulnerability** north of the Cape Basin that is characterised by a shallower target shale gas reservoir, a multitude of dolerite intrusions and a generally hotter and drier climate especially in the western portion.

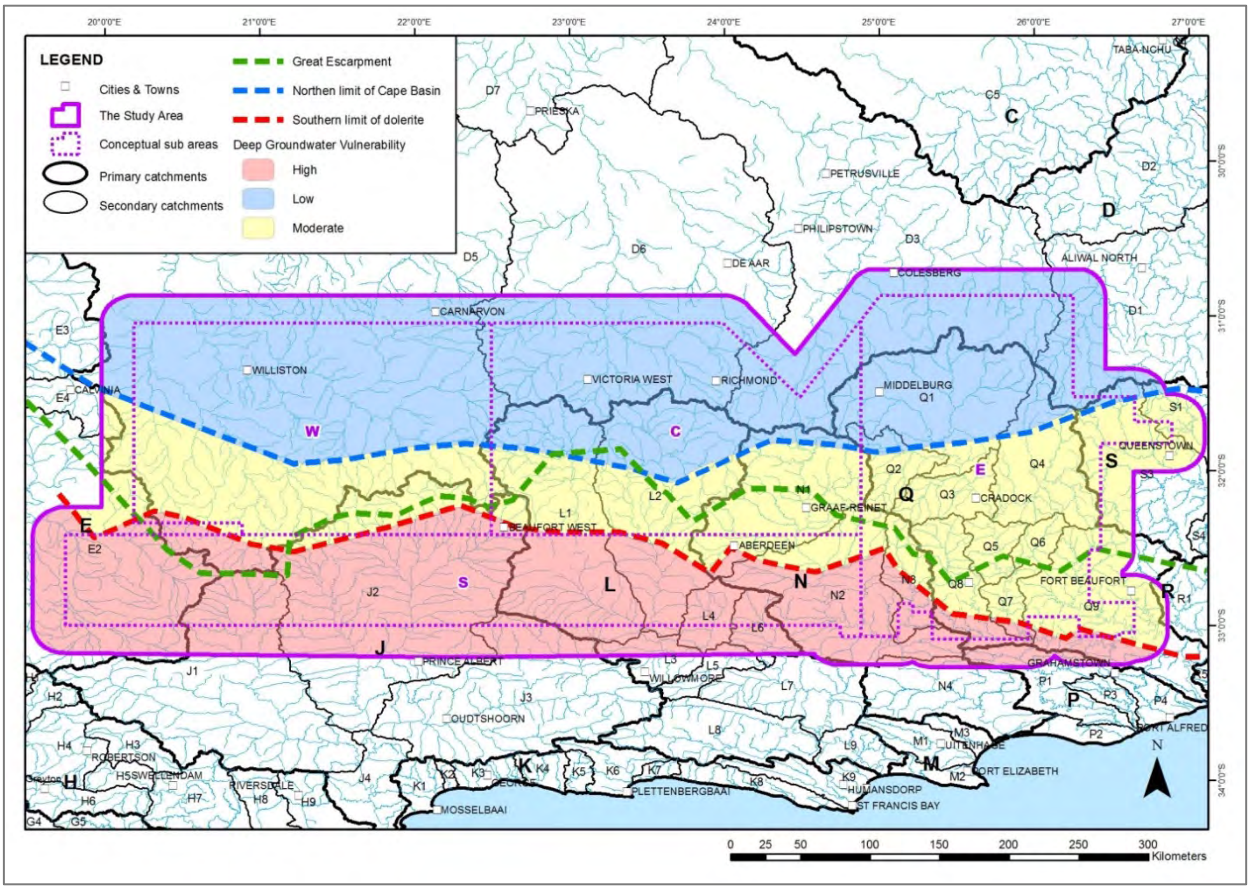

Figure 5.6: Intermediate and deep groundwater vulnerability rating (Rosewarne, 2015).

5.2.3 Surface water

5.2.3.1 <u>Occurrence</u>

The study area extends over portions of nine Primary catchments, of which the greatest areas comprise Primary catchments D (lower Orange River), J (Gouritz River), L (Gamtoos River), N (Sundays River) and Q (Great Fish River) (Figure 5.7). Relatively minor portions of the study area are drained by Primary catchments E (Olifants River) in the west, and R and S in the east (Keiskamma and Groot Kei rivers, respectively). The water resources of South Africa's Primary catchments are managed by the DWS in respect of nine Water Management Areas (WMAs), each of which is intended to be managed by a Catchment Management Authority (CMA). Not all CMAs have yet been established, but are included in the National Water Resources Strategy (NWRS, 2013), and are referred to in this Chapter as is relevant. Catchment D falls within the Orange WMA, catchment J in the Breede-Gouritz WMA (where a CMA has been established), and the remaining catchments L, N, P, Q, R and S all within the large Mzimvubu-Tsitsikamma WMA (where establishment of a CMA is imminent) (Figure 5.7).

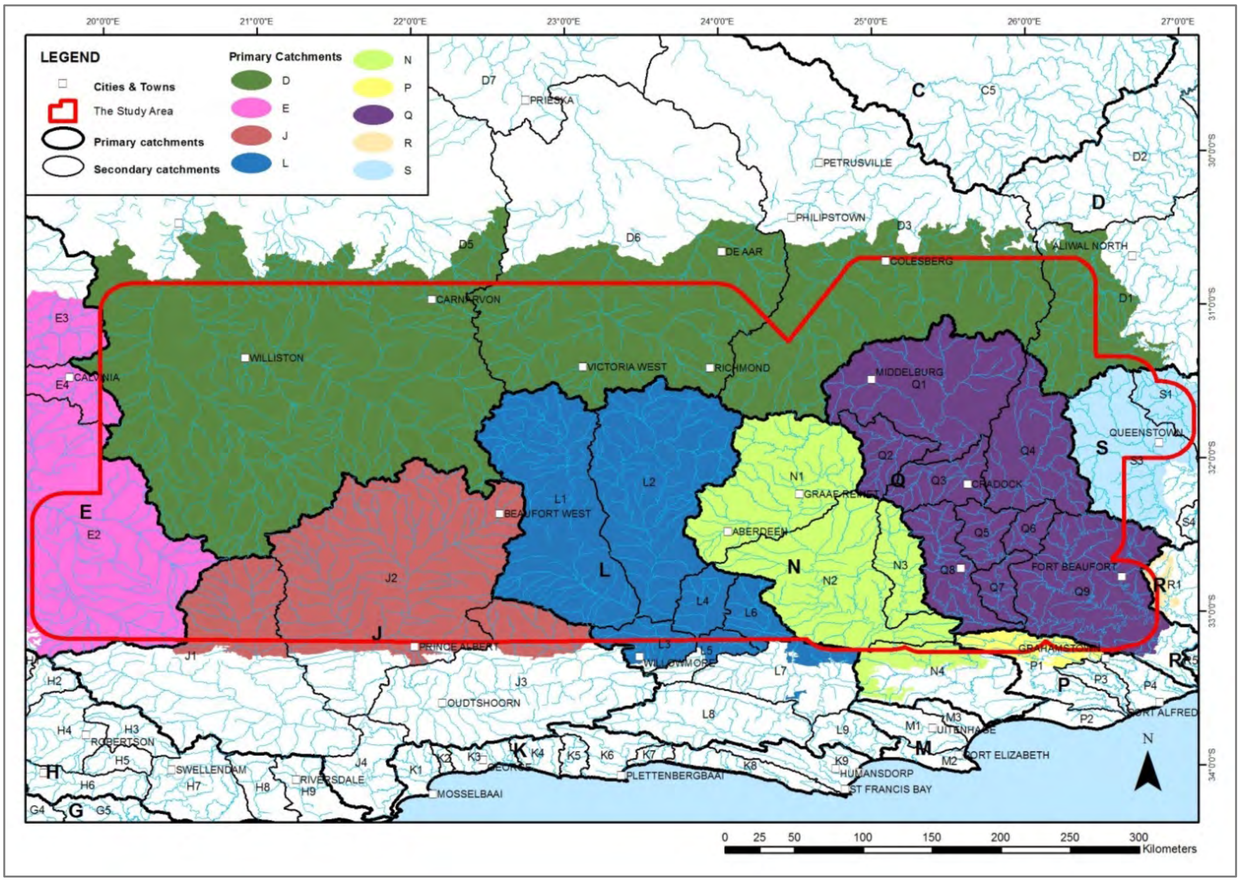

Figure 5.7: Catchment context of the study area, with Primary and Secondary catchments and Water Management Areas (WMAs) indicated: river data from Nel et al. (2011).

The Karoo is an arid area, with hydrological data modelled for Quinary catchments showing that most of the study area has an MAP of below 400 mm, with a distinct gradient of increasing MAP from the dry west (mostly <300 mm) to the east (mostly <400 mm), but with the most easterly parts of the area 400 to 600 mm and in excess of 700 mm in limited areas (refer to Figure 1.4 in Burns et al., 2016). Rainfall data (summarised in the Digital Addendum 5A – Figures 5A1.3 (A to D) illustrate a west to east gradient of increasing rainfall across the study area for data for each of the months illustrated. Rainfall is generally highest in autumn, although still <25 mm across a large proportion of the study area and <50 mm across almost all of the study area. What rainfall there is tends to be highest towards the west in winter (July) and higher in the east during the spring, summer and autumn months (Schulze, 2012). High mean potential evaporation rates at generally over 1 600 mm across the study area and in excess of 2 000 mm in the arid west (Burns et al., 2016) indicate, however, that outside of major storm events, little rainfall translates into streamflow (Figure 5.8).

> ***Primary catchment:*** *The physical catchment area completely separated from other Primary catchments by watershed boundaries. DWS notation denotes Primary catchments as letters (A, B, C etc.) and Secondary catchments as numbers (e.g. A1, B5, C3 etc.)*

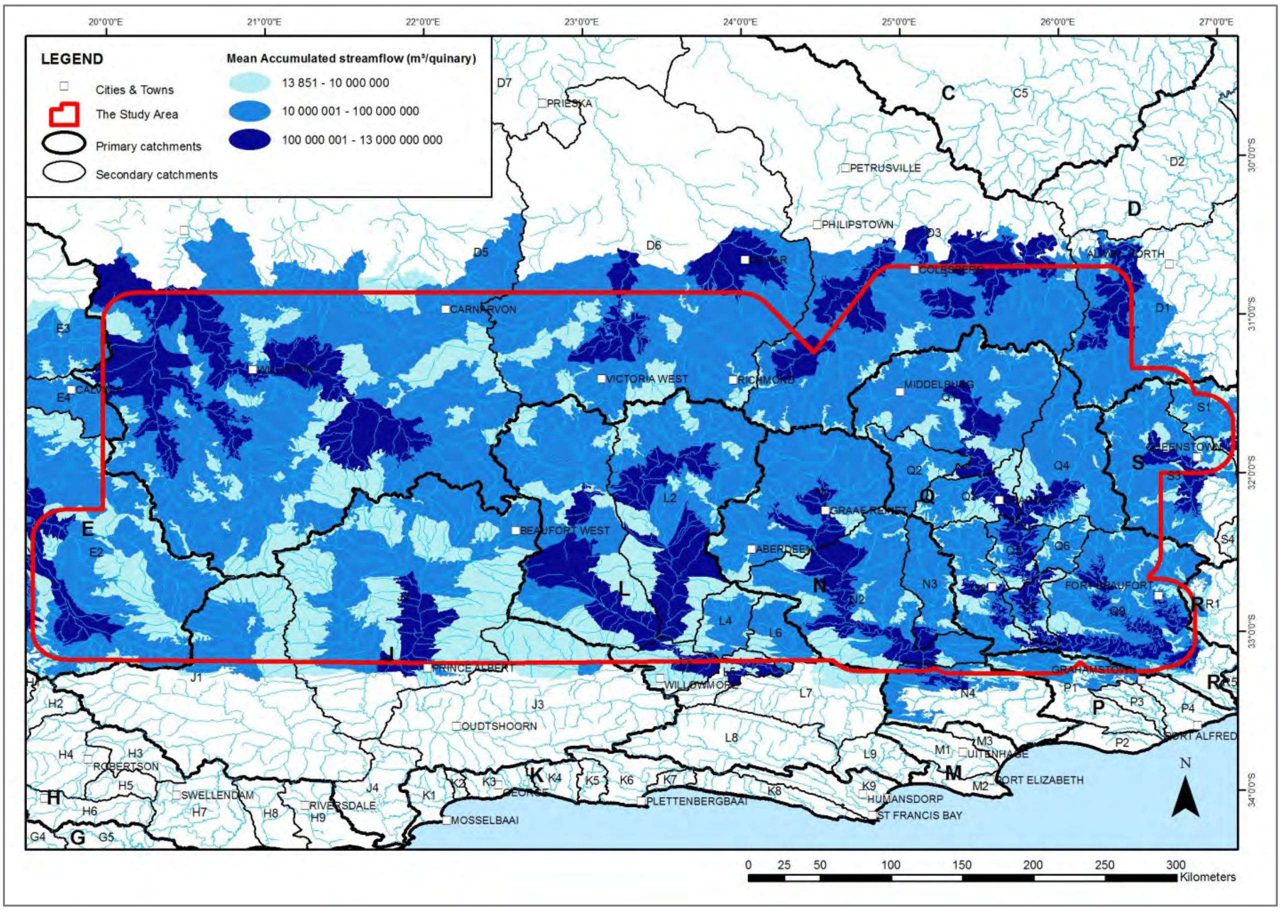

Figure 5.8: Mean annual accumulated streamflow**.** Data at quinary level. Daily runoff values were generated with the ACRU daily time-step physical-conceptual, multi-soil level and multi-purpose hydrological model (Schulze, 1995 and updates). Streamflow at Quinary exit is the runoff generated within that specific Quinary plus the accumulated runoff of all upstream Quinaries. Note that from the darker coloration one can clearly see how, for the bigger rivers, the streamflow gets larger and larger as one cascades downstream. Original data source Schulze (2012).

Rainfall is also more erratic in the south-western and central portions of the study area, as shown by high coefficients of variation (CV) in both annual precipitation (Figure 5.1) and annual accumulated streamflow (Figure 5.9). Hydrologic simulations performed as part of the scientific assessment indicate that the western/south-western portions of the study area are more prone to extreme but erratic rainfall and associated floods with high ratios of 1:10 to 1:50 year return interval for three and one day rainfall events respectively (Addendum 5A: Figures 5A1.16 to 5A1.26). In the study area the differences in flows between wet and dry years is vast, indicative of the high variability of streamflows and thus high uncertainty of assured supplies of water from local surface water sources. This amplification of variability between rainfall and streamflow (that is, an already erratic rainfall translates into greater extremes of high and low flows as a result of (*inter alia*) high potential evaporation rates) is typical of semi-arid regions (Schulze, 2012) (Figure 5.9). These extremes of high flow are further illustrated in Figure 5.11 and 5.12.

Furthermore, Figure 5.12 depicts the ratio of the 1:50 to 1:10 year extreme 3-day streamflow events. This ratio identifies areas that are particularly vulnerable to such events, with a high ratio of the very rare event to the less rare event indicating periodic “shock” events. The highest ratios are in the south-west of the study area. These data have relevance to the SGD assessment, in that the location of such activities in areas identified as of high risk in terms of severe but rare storm events would be potentially problematic from both the perspective of the resource and the development itself.

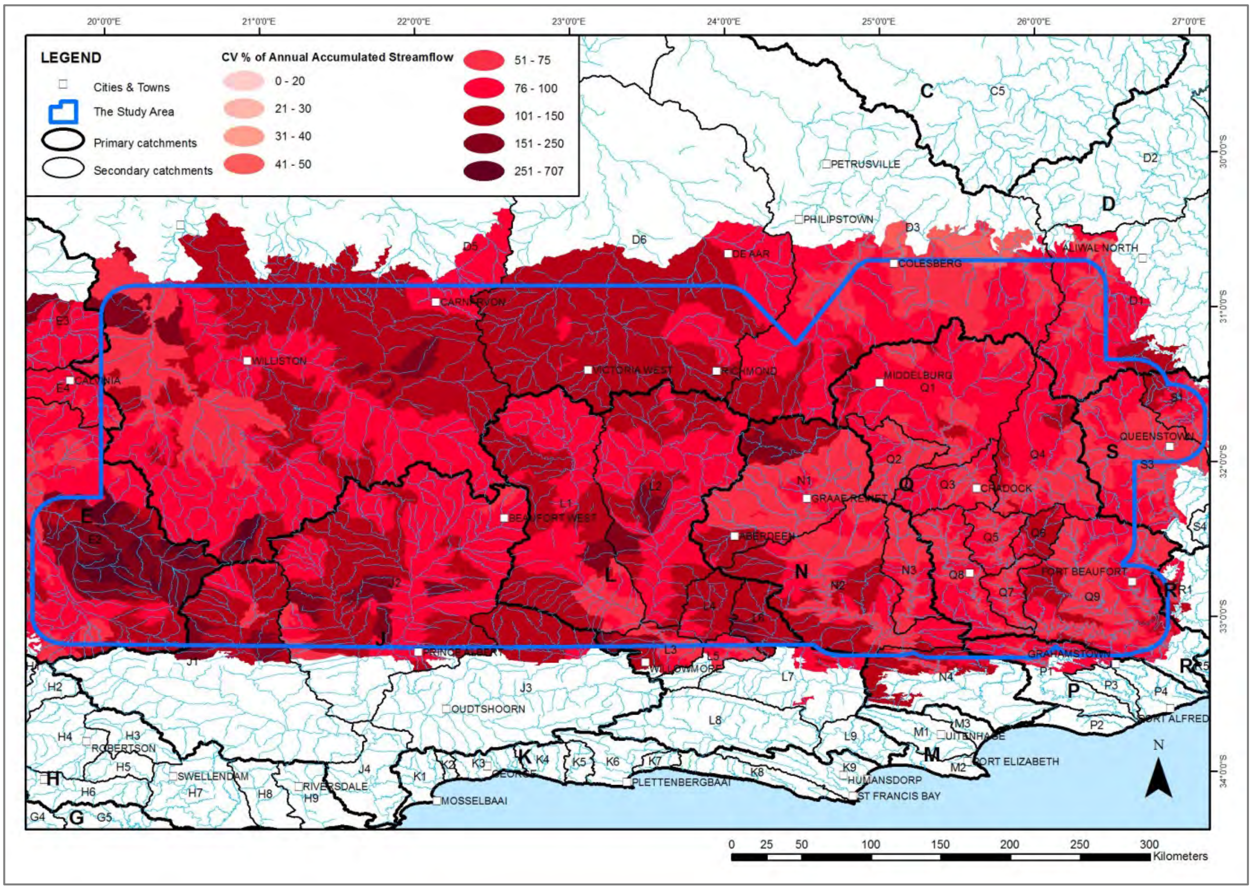

Figure 5.9: Coefficient of variation (CV) of annual accumulated streamflows CVs in the range 50–250% show high inter-annual variability in streamflows. Original data source Schulze (2012).

Figure 5.10: Spate conditions in the ephemeral (seasonal) Theekloof River north-east of Beaufort West in January 2016 (photo courtesy D. Hohne, source unknown).

Figure 5.11: Aerial view showing wide spread of flows in the episodic Renoster River in the north-western part of the study area (Orange River WMA) in April 2016 (photo courtesy D. van Rooyen).

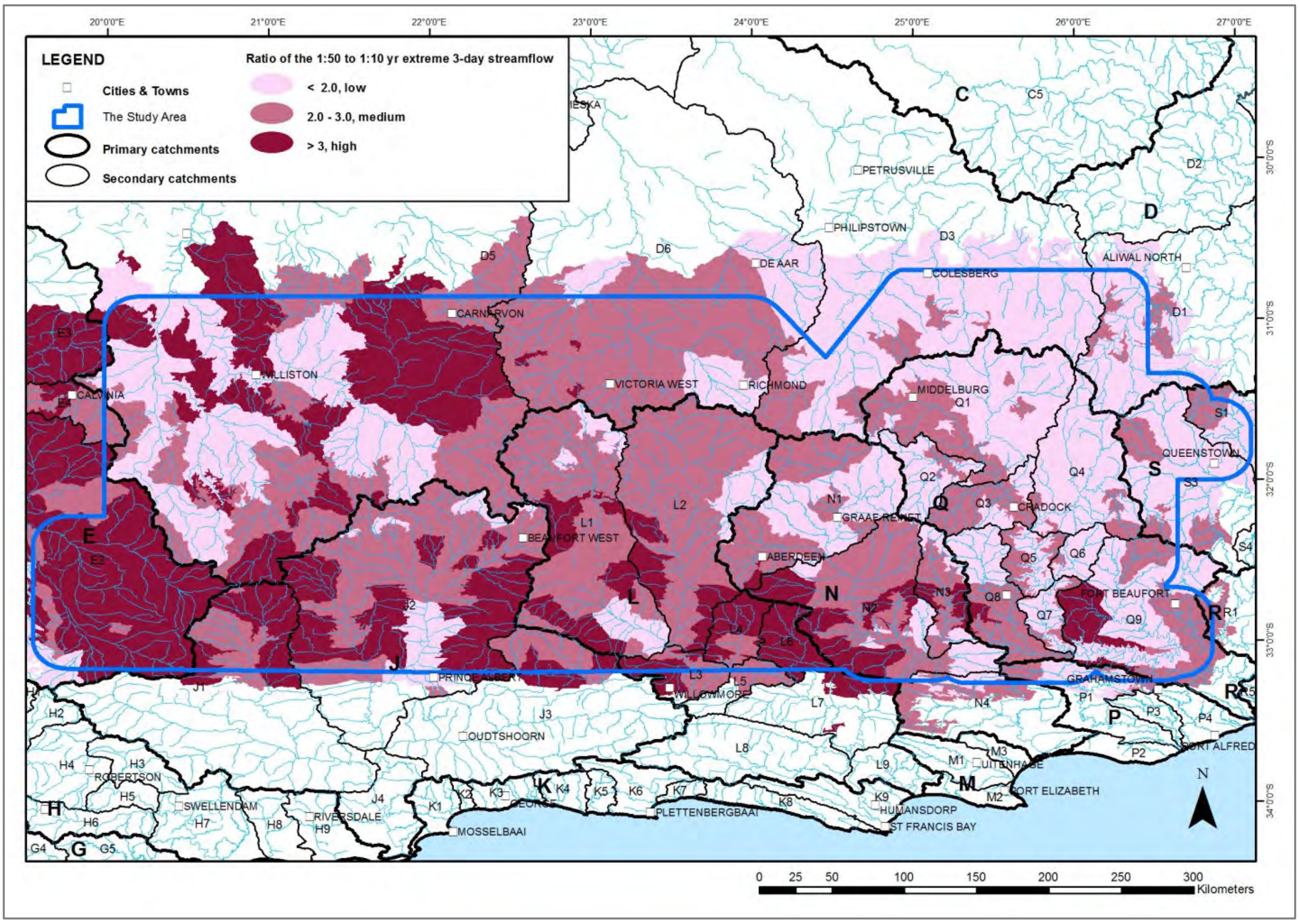

Figure 5.12: Ratio of the 1:50 to 1:10 year extreme 3 day streamflow. These data indicate areas prone to rare but highly damaging floods. Original data source Schulze (2012).

The area is also prone to drought, and the implications of a 'severe drought' (Burns et al., 2016) are that around 60% of the study area would receive less than 100 mm in such a year, indicative of the harsh climatic conditions existing in this region. This has a bearing on the importance of the availability of water resources to "buffer" existing users through periods of extreme drought. The World Wide Fund for Nature (WWF, 2015) note that while currently under-utilised farm dams, for example, may seem to present a possible water supply for activities such as shale gas exploration and production, these resources, where they exist, are often a critical buffer during drought. Mean accumulated streamflow volumes [which take account of the effect of evaporation and infiltration on mean annual runoff (MAR)] also generally increase toward the east (Figure 5.8), and SSI (2012) present hydrographs that show zero flows over most months of the year for selected quaternaries in the western area.

> ***Classifying river flow types:***
> *Perennial rivers flow 11 to 12 months/year;*
> *Ephemeral (or seasonal) rivers flow usually 3 to 10 months/year;*
> *Episodic rivers flow less than two months per year, and sometimes not at all.*

These aspects explain the fact that many of the rivers in the study area are seasonal (ephemeral) or episodic, with Quinary catchments dominated by perennial flow largely being restricted to the eastern part of the study area and along high mountain areas extending through the central zone of the site (along the Great Escarpment) and to the west. Extensive areas of only episodic flow occur particularly in the central, north and south of the site (Figure 5.13).

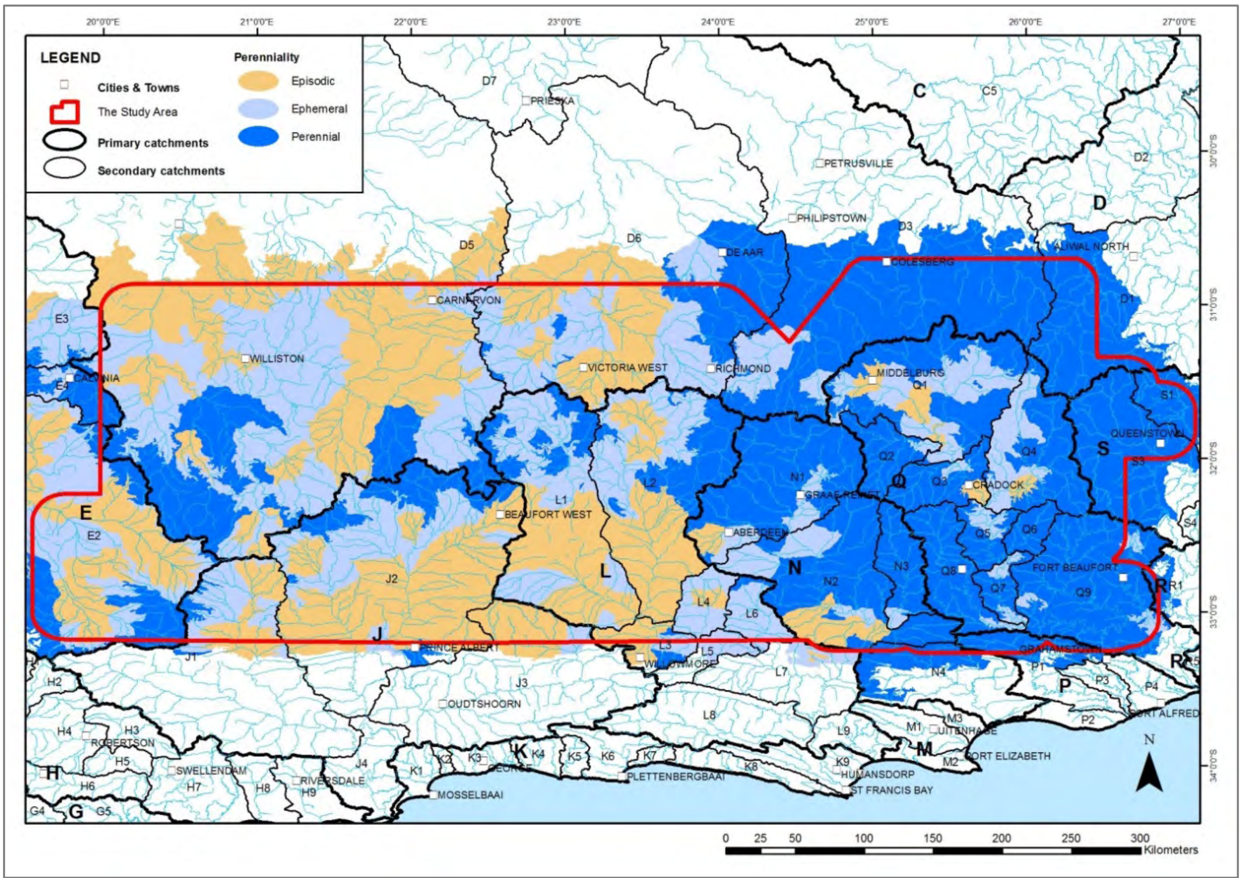

Figure 5.13: Areas of perennial, ephemeral (or seasonal) and episodic flows. Data shown as effective runoff (i.e. runoff generated minus channel flow losses to evaporation) from individual Quinaries. Information source new unpublished research by Schulze and Schütte (2016).

The low levels of perenniality in rivers in the study area, relative to those at a national level, are indicated in Figure 5.14. The significance of these from a scientific assessment perspective is that they do not provide an assured source of water for activities associated with proposed shale gas exploration to production activities, but do provide potential surface conveyance pathways through the study area for pollutants.

5.2.3.2 Water quality

The region of the Karoo under investigation is arid, and more so in the west than in the east. Very few major rivers traverse the area, and most of these are seasonal or ephemeral. The few data sets from the DWS database[1] show that the rivers are low in dissolved solids in their headwaters (within high-lying areas), becoming more saline further downstream, and that surface waters are more saline in the west of the region than in the east. High salinity values (e.g. a median conductivity of 504 mS/m in the Sak River at Williston Commonage, 1973-1988: DWS water chemistry database) in some of these systems

[1] DWS database available at: https://www.dwa.gov.za/iwqs/wms/data/000key.asp

are natural (Basson and Rossouw, 2003). Others have become more saline over time as a result of evaporative concentration of slightly saline irrigation water (Van Rensburg et al., 2011). In the Groot Vis River catchment for example (Figure 5.5), high natural salinity in rivers such as the Groot Brak River is artificially reduced for agricultural and other uses by dilution with inter-catchment transfers of fresher water from the Orange River (Basson and Rossouw, 2003; see Section 5.3).

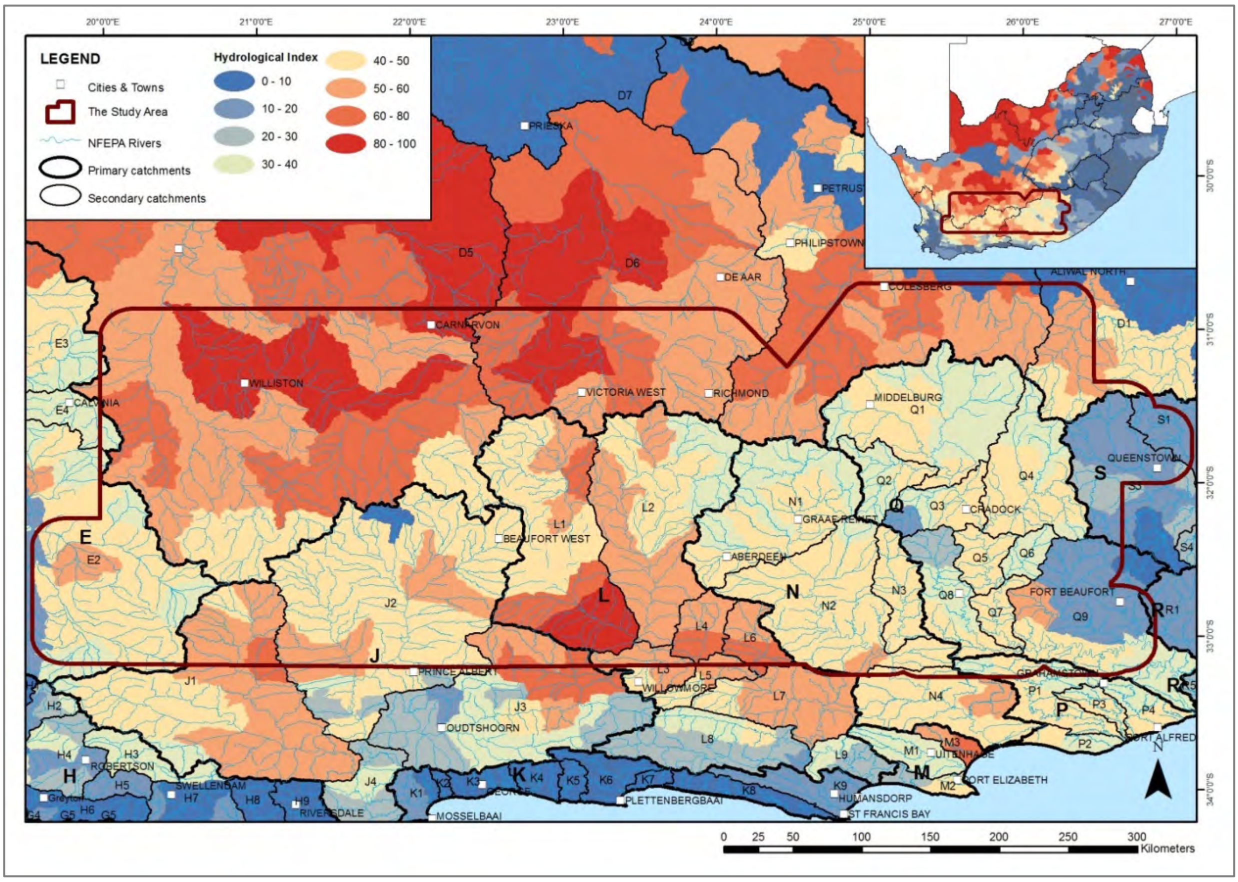

Figure 5.14: Hydrological Index (HI) data**.** Assessment of the study area in a national context, using the hydrological index (HI) of Hughes and Munster (1993) to highlight differences in flow regime through consideration of flow variability and the strength of base flow; strongly perennial systems have a low HI and ephemeral systems a low HI. [unlike the Quinary-level data shown in Figure 5.12, HI data are based on Quaternary catchments.]

Although the rivers in the study area are mainly dry, under high flow or flood conditions, large volumes of sediment can be mobilised both from the surrounding catchment and the river channels and floodplains themselves, and transported downstream in turbid flows (Basson and Rossouw, 2003a; 2003b). Although this is a natural characteristic of much of the Karoo region, it is exacerbated by poor land use practices (e.g. overgrazing, disturbance to river corridors and their floodplains, inadequately sized culverts and bridges), leading to erosion in large flow events. In-channel dams are thus prone to sedimentation, and associated loss in dam capacity. Boardman and Foster (2011) for example estimate a rate of sediment input into the Nqweba Dam on the Sundays River, near Graaff-Reinet, of approximately 1 million m^3 per year and note that in this area almost 50% of small dams are fully silted up.

The sparse population across most of the study area means that sources of pollution into surface waters are generally limited and mainly comprise waste water discharges. The DWS water quality database[2] indicates that of the fifteen waste water treatment works (WWTW's) shown in the study area, four discharge directly into rivers in the study area and three discharge variously into the Orange River and Gariep Dam to the north of the study area (Table 5.2).

Table 5.2: Disposal of effluent from waste water treatment works in the study area

Name of works	Primary catchment	Manner of effluent disposal
Beaufort West	J2	Kuilsrivier – tributary of the Gamka River
Aberdeen	N1	Irrigation
Graaff- Reinet	N1	Sundays River
Grootfontein College of Agriculture	Q1	Irrigation
Middelburg	Q1	Tributary of the Klein Brak River
Burgersdorp	D1	Unspecified – assumed to be irrigation
Somerset East	Q5	Irrigation
Venterstad	D3	Orange River
Oviston	D3	Gariep Dam
Van der Kloof	D3	Gariep Dam
Nou Poort	D3	Unspecified – assumed to be irrigation
Zastron	D3	Unspecified – assumed to be irrigation
Tarkastad	Q4	Irrigation
Bedford	Q7	Irrigation
Adelaide	Q9	Koonap River

Effluent from the other WWTW's is used in irrigation, and is likely to contribute nutrients and other pollutants from this source into rivers as diffuse runoff from these areas. These effluent discharges convey loads of nutrient enriched water into these systems, with phosphorus and nitrogen nutrients usually considered of most concern from a water quality perspective, along with bacterial contamination and the effects of low oxygen as a result of decomposition of high organic loads. Effluent from the remaining WWTW's is used in irrigation, and is likely to contribute nutrients and other pollutants from this source into rivers or groundwater respectively as diffuse surface flows following rains and/or through infiltration to shallow aquifers.

Pollution of episodic and ephemeral river systems or their catchments can be highly problematic. Continuous discharges of effluent, for example, may for a large proportion of the year constitute the full flow of water in the river, rendered more concentrated by high rates of evaporation. Episodic contamination of these rivers or their catchment areas may also be of great concern, as intermittent flows may result in extended residence times for pollutants in isolated pools which, in perennial systems, would often be able to move "plugs" of pollution downstream.

Apart from the above localised and mainly point source impacts, water quality in rivers in the study area is not considered highly impacted and the State of the Rivers Report for the Gouritz WMA (River Health Programme (RHP), 2007) allocated 'Good' to 'Natural' water quality scores to assessed rivers in the study area (albeit limited to only five monitoring sites that fell within the study area).

[2] DWS water quality database available at: https://www.dwa.gov.za/iwqs/wms/data

Groundwater in the region daylights in several areas as springs (known locally as "eyes") some of which produce hot water, indicating that they are produced at substantial depths (Murray et al., 2015). Their water chemistry is expected to reflect that of the deep aquifers from where they rise (Subsection 5.2.2.2).

5.2.3.3 Aquatic ecosystems

The aquatic ecosystems in the study area reflect their particular hydrological, climatological and geological conditions within this area, and comprise natural rivers, wetlands and springs and artificial features such as in- and off-channel impoundments (dams). Chapter 7 of the scientific assessment, by Holness et al. (2016) describes the biodiversity aspects of these systems. The present Chapter focuses on their roles in the hydrological cycle, where they function both as ecosystem drivers and as conduits between surface and groundwater systems (vertical linkages) and between the activities in any particular part of the study area and downstream receiving areas.

> ***Watercourses** and **wetlands** are defined in this study as per the following definitions of the National Water Act (NWA) (RSA, 1998a):*
> ***"watercourse"** means -*
> *(a) a river or spring;*
> *(b) a natural channel in which water flows regularly or intermittently;*
> *(c) a wetland, lake or dam into which, or from which, water flows; and*
> *(d) any collection of water which the Minister may, by notice in the Gazette, declare to be watercourse, and a reference to a watercourse includes, where relevant, its bed and banks;*
> ***"wetland"** means -*
> *land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.*

Figure 5.15 shows the spatial distribution and mapped extent of known watercourses (rivers and wetlands) and other wetland types (i.e. those not associated with channelled inflow) in the study area, with rivers mapped at a scale of 1:500 000, based on river and wetland data from the National Freshwater Ecosystem Priority Area (NFEPA) data (Nel et al., 2011), but including an updated wetland layer developed by Holness et al. (2016).

Many of the riverbeds in Karoo valleys are sandy, reflecting both alluvial and aeolian deposits, and support primary aquifers (Colvin et al., 2007), with water sometimes occurring in these river beds primarily below the surface. Figure 5.15 shows extensive areas of sandy river bed features ("dry rivers") in parts of the study area, as mapped by Holness et al. (2016). For intermittent rivers in the Karoo, Colvin et al. (2007) refer to the classification of Vegter and Pitman (1996) that considers both surface and groundwater contributions to flow, describing how short-term (intermittent) discharges into such watercourses occur when the primary aquifer intersects with the river channel, driven by groundwater recharge through precipitation at higher elevations (Colvin et al., 2007). During dry periods, groundwater storage is depleted by such effluent, exacerbated by evapotranspiration and evaporation. Surface flow in the rivers from local stormwater runoff may also discharge into the primary aquifer, locally replenishing groundwater (Colvin et al., 2007). Streams in the Karoo, such as the upper reaches of the Salt River (Beaufort West), the Kamdeboo, Sundays and Brak Rivers (De Aar) are cited by Colvin et al. (2007) (after Vegter and Pitman, 1996) as examples of this kind of system.

> ***Aquifer dependent ecosystems (ADE's)*** *are ecosystems that depend on groundwater in or discharging from, an aquifer (Colvin et al., 2007). They may occur where groundwater discharges from an aquifer to the surface, forming aquatic features such as springs or wetland seeps, or where aquifers contribute to the baseflow of rivers.*

The wetlands indicated in Figure 5.15 comprise valley bottom wetlands along river channels, seeps, and by far the most dominant wetland type; pans (see Holness et al., 2016). The latter are for the most part shallow depressions in the landscape in many cases connected to highly ephemeral systems only, which overtop into the pans, leaving them to dry out slowly through the combined effects of infiltration and evaporation. These features often represent aquifer dependent ecosystems (ADE's) in the landscape. The largest of these pans include the Grootvloer-Verneukpan complex, which plays an important role during migrations of biota, enabling them to have access to breeding grounds in the upper reaches of the Sak River (Esterhuizen et al., 2014). Verneukpan and Grootvloerpan (both located just north of the study area, along the Sak River, reach depths of up to 1.2 m during wet periods, though this happens rarely (Thieme et al., 2005), with Baard et al. (1985) noting that Verneukpan contained substantial water only five times during the period from 1885 to 1985 (Baard et al., 1985). Within the study area itself, Swartkolkvloer and Blombergsevloer form part of the same extended system of pans along the Sak River (Mucina and Rutherford, 2006).

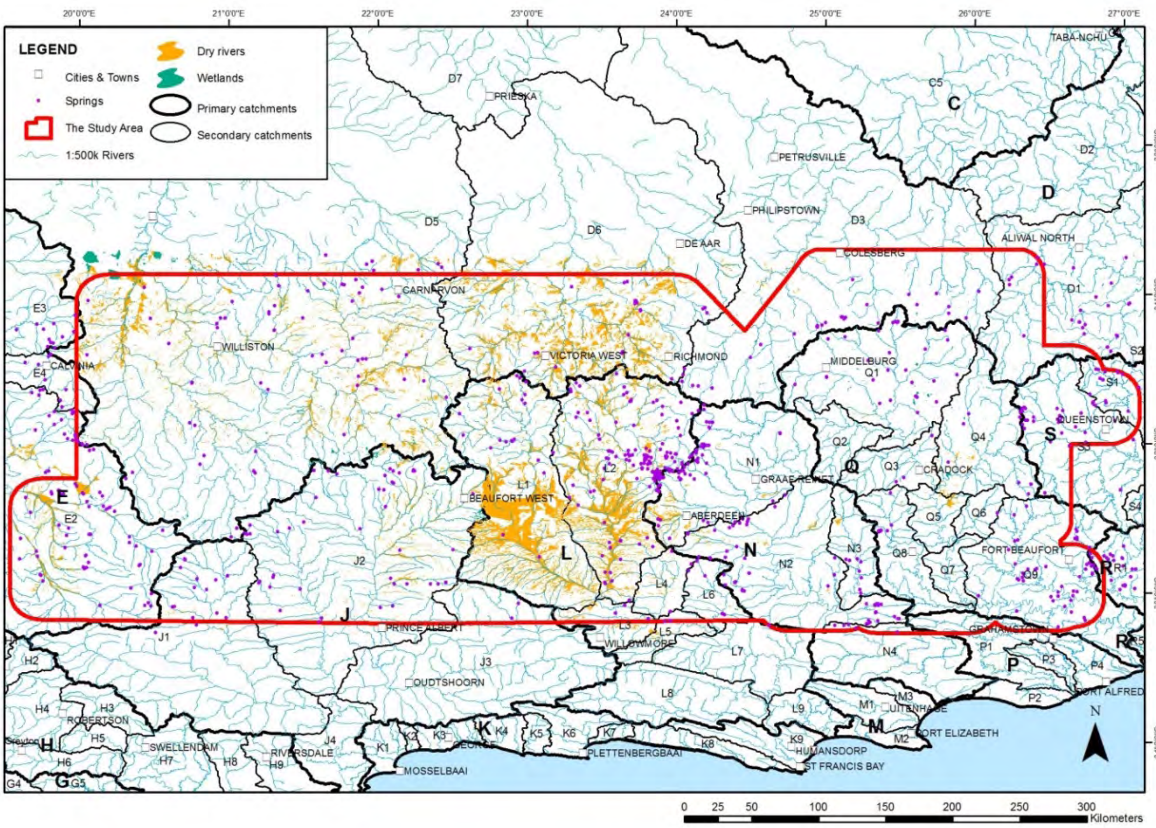

Figure 5.15: Natural and artificial river and wetland extent. Figure based on NFEPA river and wetland data (Nel et al., 2015) with "dry rivers" added as a layer for the scientific assessment (Holness et al., 2016) and with DWS Primary and Secondary catchments shown.

From a hydrological perspective, such pans provide localised attenuation and storage of runoff. Their value as a water resource for local populations is however usually low, due to their characteristically high salinities, as a result of the high rates of evaporative concentration in the region, particularly with distance west and north. To a degree, the pans thus also accumulate chemically stable nutrients, salts and other constituents carried into them by surface runoff. Transport of these substances out of the pans occurs either by wind action on dry pans or, in the case of those linked to channels, during flood events.

While pans usually are associated with flatter portions of the study area, where drainage lines overtop and flood broad depressions, non-thermal springs and wetland seeps are associated with Karoo dolerite dykes and sills. These wetlands are typically situated at the base of dolerite cliffs or on dolerite slopes, in depressions along fractures or topographical breaks, and are fed by groundwater seeping from deep, fractured aquifers or unconfined alluvial aquifers (Nhleko, 2003). They are one of five types of secondary aquifer associated with ADE's recognised in South Africa (Colvin et al., 2009). Colvin et al. (2007) note that the most hydrogeologically vulnerable ecosystems are the seeps occurring on the lower slopes, which depend on spring discharges from the upper unconfined aquifer. In the event that activities such as upslope abstraction occurs; drawing down the aquifer water level, these systems would be highly affected. The distribution of springs in the study area is shown separately as unscaled spot points in Figure 5.16, and these reflect direct links to groundwater.

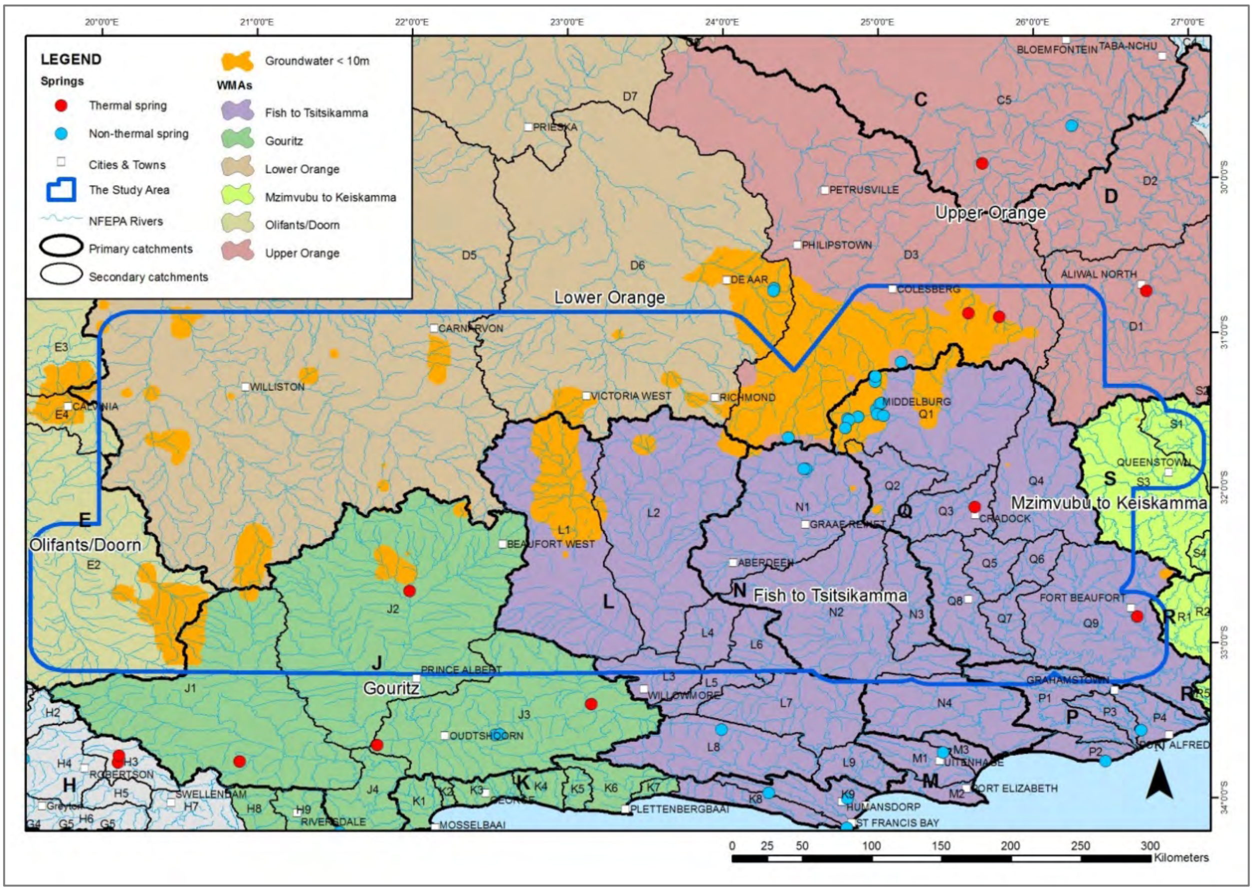

Figure 5.16: Location of known cool and warm/thermal springs in and around the study area. The figure also indicates where groundwater is expected to be shallow (<10 m below surface); data from DWA (2005). Note that springs are shown as unscaled points and not spatially representative polygons.

Watercourses downstream and at the outlet of springs are considered at least partially groundwater-dependent. In this scientific assessment, the potential for groundwater-dependent ecosystems (GDE's) associated with shallow aquifers is considered to include areas where groundwater lies within 10 m of the surface, and is presented in subsequent sections of this Chapter. Note that this assumption is conservative, with Colvin et al. (2007) classifying groundwater-dependent wetlands on the basis of depth-to-groundwater of <5 m. The amendment to <10 m takes cognisance of uncertainties regarding the actual spatial extent of groundwater/surface ecosystem interactions, and thus the need for a precautionary approach in the present study, as well as the fact that Colvin et al. (2007) used the presence of groundwater <30 m as shown by hydrocensus data as a coarse estimate of possible groundwater dependent ecosystems. Most of the non-thermal springs shown in Figure 5.16 in the study area occur in areas where groundwater has been mapped at distances <10 m from the surface. The figure also reflects available data relating to the known location of springs in and around the study area, with four hot spring areas included. These ecosystems are highly dependent on groundwater.

The study area also includes numerous farm dams as well as several large impoundments (e.g. Nqweba Dam on the Sundays River, the Gamka Dam on the Gamka River and the Grassridge Dam on the Grootbrak River), which contribute to water supplies for various towns (e.g. Graaff Reinet, Beaufort West and Cradock) and agricultural users. Like natural pans, these too act as depressions in the landscape and may thus also accumulate chemically stable nutrients, salts and other constituents over time. Many of the farm dams are however fed by wind-pumped groundwater, providing a direct surface-groundwater link.

The importance of the ephemeral aquatic ecosystems of the Karoo

In contrast to perennial rivers and wetlands, surface water in the rivers and wetlands occurring in the study area are predominantly ephemeral in nature. These systems are event driven, being either dry or in flood. The onset, duration, frequency and magnitude of low and high flows are highly variable, unpredictable and mostly unknown. The variability of flows is due to low mean annual precipitation, high potential evaporation which exceeds rainfall in most of the study area, and is also dependent on land use management.

Knowledge of environmental water requirements in non-perennial rivers is still in its infancy compared to perennial rivers, and has contributed globally to the poor ecological state of these systems (Acuña et al. 2014). In South Africa, understanding of the functioning of non-perennial rivers and streams has increased markedly over the last decade (Seaman et al., 2010; 2013). These studies emphasised the important role of pools, the connectivity between them, and the interaction between surface and sub-surface water play in maintaining the ecological integrity of these rivers. Pools act as important refugia during dry periods, not only for aquatic biota and riparia, but also for other organisms associated with freshwater like amphibians, birds and small mammals during dry periods. The lack of good quality hydrological data and suitable integrative hydrological models make it very difficult to predict how these organisms, associated with the pools, will react to changes in water quantity and quality over time under non-perennial conditions. Neither is there baseline data on how these species will react to change. Furthermore, the species that occur in these rivers are generalists that are able to survive the harsh conditions, making them less sensitive to change compared with species occurring in perennial rivers. That being said, these species might become extinct by the time change is detected, as the limits of acceptable change are currently unknown.

Groundwater plays an important role in the persistence of pools after flow ceases. Understanding of surface water and groundwater interaction is mostly conceptual and needs to be tested. Rivers in the study area are all classified as groundwater dependent ecosystems (Colvin et al., 2003) from a groundwater perspective, and can be described as ecosystems that depend significantly on groundwater for their hydrological functioning. The effect that additional groundwater extraction for SGD might have on the sustainability of these rivers, is unknown and of great concern. It is possible that over-abstraction could damage these GDE's beyond repair. An added uncertainty is that recharge data is only available for localised areas, but is lacking on a regional scale. Recharge is influenced by land use changes and it is expected that the study area, because of its arid nature, will be very sensitive to a change in land use. A change in land use from natural to agriculture/industrial could result in more pronounced erosion, sedimentation, floods, less infiltration from precipitation and higher rates of evapotranspiration. This uncertainty is aggravated by the limited rainfall and poor/limited distribution of gauging stations in the study area.

The knowledge uncertainties and gaps regarding surface water systems in semi-arid to arid areas hamper the ability to manage these resources in a sustainable manner. In the light of climate change, an increasing human population and the possible impacts of SGD, it is imperative that resources for question-driven research are made available to address the attendant uncertainties.

5.2.3.4 Resource condition

Water resources in the catchments over which the study area partially extends have been classified in terms of their present ecological state (PES) as part of a national assessment, using a combination of expert knowledge, desktop assessments and ground-truthing, with PES status being determined for rivers and, to a limited extent, valley bottom wetlands (DWS, 2014).

PES data for the study area and its downstream catchments are shown in Figure 5.17. These data indicate that PES for rivers in Quaternary catchments in the study area are in their most natural condition in Primary catchments J and E, with large sections of river in a category A or B. Rivers in catchments L, N, Q, R and S tend to be in a more degraded condition, with few category A reaches and more category C and D reaches. Excluding the Orange River sub-catchments, the lower reaches (outside of the study area) are generally categorised as more impacted than the upper reaches. In addition, more (mainly main stem) rivers in the eastern third of the site are classified as PES Category D or worse than in the western two thirds. This apparent west-east gradient of increasing degradation probably reflects in part the low levels of usability of many of the rivers in these arid Karoo regions, where salinity and poor flow assurance mean that such rivers may not have been affected by impacts that degrade many less saline or perennial systems (e.g. abstraction, grazing and impoundment). Reliance on groundwater resources in many areas of the Karoo thus means that many of these surface systems remain in a near-intact condition.

Present ecological state (PES)

PES is a measure of river condition that is used to set so-called Ecological Specifications (EcoSpecs), on the basis of which the Ecological Reserve for different river reaches is calculated, and from which remaining water resources can be allocated, after accounting for the Basic Human Needs Reserve.

PES assessments assign river reaches to one of six PES categories, ranging from A to F, with A representing rivers in a natural or pristine condition and F representing rivers in a Critically Modified condition or state. PES categories of E (Seriously Modified) or F are not considered sustainable (Kleynhans et al., 2005). Since sustainable resource use is an important tenet underpinning the NWA (RSA, 1998a), aquatic ecosystems need to be managed in a condition that is above (better than) Category E. Thus the management objective for all aquatic ecosystems needs to be in an overall state that is better than Category E – that is, Category D or better.

From a resource allocation perspective, such systems are unlikely to be further affected by increased water allocation pressures, as available water is limited. With distance east, as the resource quality improves for human requirements (e.g. irrigation and domestic supply), so river condition appears to deteriorate, reflecting a reduction in natural flows. Figure 5.17 shows that many of the southern rivers downstream of the study area are already in a PES Category D, highlighting the fact that additional water resource allocations from these systems might reduce their condition to below sustainable levels. Note however that a detailed interrogation of Quaternary level PES with regard to water quantity and the effects of reduced water quality on future PES category are beyond the scope of this assessment. An example of ephemeral flow is shown in Figure 5.18.

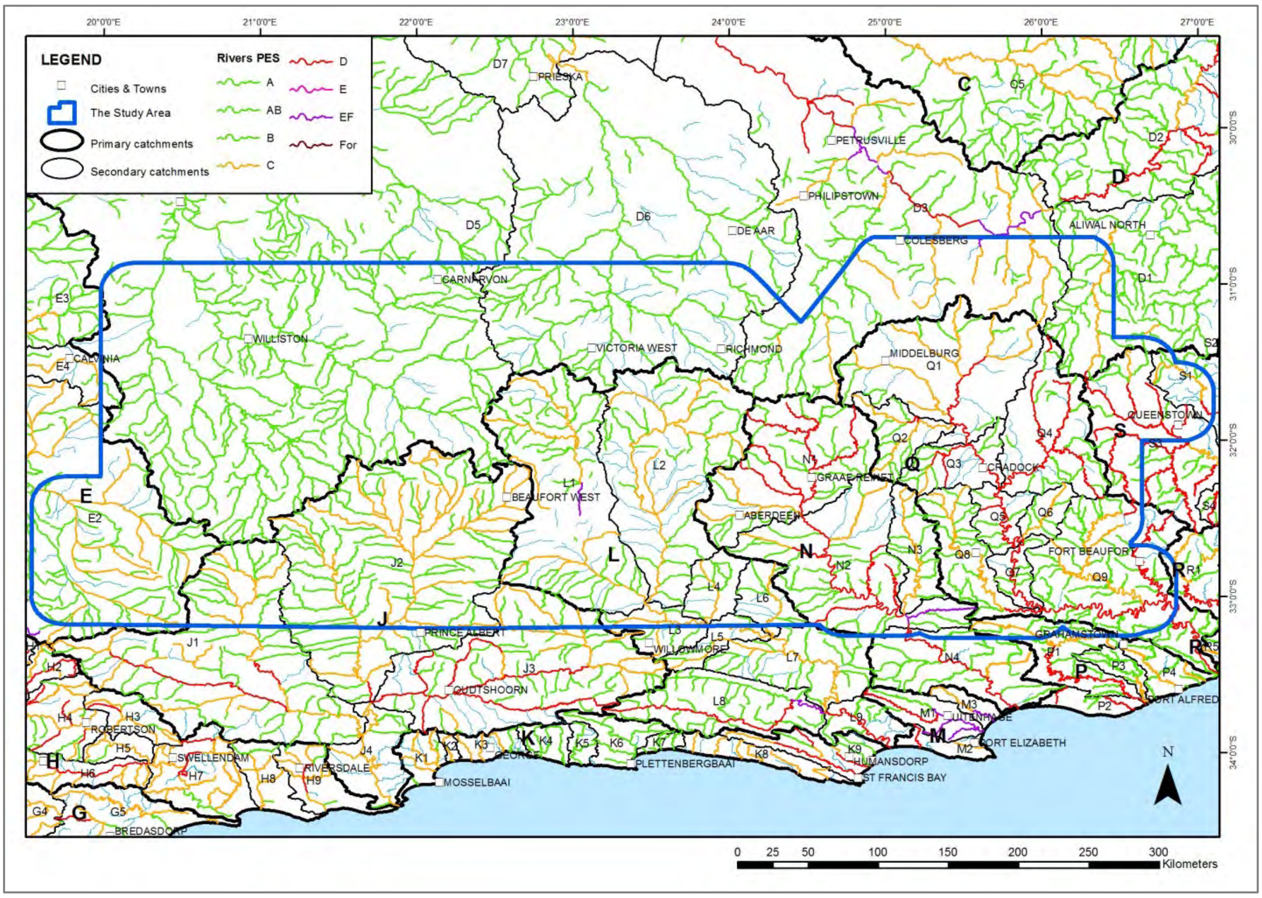

Figure 5.17: Present ecological state (PES) data for Quaternary rivers (data from DWS, 2014).

Figure 5.18: Flows in the ephemeral Vis River, April 2016 (photo courtesy D. Hohne).

5.2.4 Surface and groundwater interaction

The sporadic flow regime that characterises stream and river discharges in the Karoo environment generates a significant interaction with groundwater resources via channel transmission losses. In the majority of instances, the stream and river courses occupy channels filled with unconsolidated sediments ranging from clays and muds through fine-grained to coarse-grained sands and gravels. The extent of these alluvial deposits is often limited in depth (<10 m) and lateral extent (<100 m), but is nevertheless sufficient to serve as a reservoir to collect infiltrated water, restrict its loss to evaporation, and release it gradually to the underlying shallow aquifer. In Botswana and Namibia, such features are known as sand rivers.

The loss of groundwater to streams and rivers generates baseflow, which in the Karoo environment is very seldom perennial. The hydraulic linkage between surface water and groundwater therefore does not represent a flux where a channel transmission loss upstream is balanced by a channel transmission gain (resurgence) further downstream. Groundwater losses to streams/rivers are likely to occur mainly where springs and seeps daylight in the landscape, and include a limited number of assumed deep aquifer discharges ('thermal springs') and shallow aquifer outlets (springs), the known locations of which are shown in Figure 5.16. An example of seep and spring wetland features in the landscape is provided in Figure 5.19.

Figure 5.19: Illustrative examples (a) of a spring located at centre left of image daylighting into a hillslope seep wetland, and (b) into a valley bottom wetland located at centre of image; the vegetation and associated aquatic components in each image represent groundwater dependent ecosystems.

The study area experiences a mean annual evaporation (MAE) from open water surfaces of >1 600 mm. These circumstances and the low rainfall together have a more direct influence on surface water resources than on groundwater resources. Part of the precipitation infiltrates the sub-surface to replenish groundwater resources. This quantity varies both spatially and temporally, depending on various factors such as vegetation cover, the nature of the soil profile and underlying geologic strata, the depth to water table, and the magnitude and intensity of rainfall. Recharge is typically expressed as a percentage of MAP. Although ranging from 1 to 5%, a value of 3% is generally accepted as approaching the upper limit for 'shallow' aquifers typically located within 150 m of the surface in the Karoo environment (Van Tonder and Kirchner, 1990). For the purposes of SGD, the maximum depth of these resources is conservatively set at 300 m (Rosewarne and Goes, 2012; Vermeulen, 2012) to meet the precautionary principle.

Groundwater recharge might reasonably be expected to be lower in the drier western portion of the study area than in the wetter eastern portion. In quantitative terms, 3% recharge from 300 mm of rainfall is equivalent to 9 000 m^3 per square kilometre per annum ($m^3/km^2/a$), or 90 m^3/a per hectare. In the context of livestock watering, a requirement of 5 L/d/LSU (litres per day per large stock unit) means that recharge on 1 ha can water ~50 adult sheep per year. At a carrying capacity of 7 ha/LSU (Du Toit, 2002), this would require 350 ha of grazing veld to capture 31 500 m^3/a of recharge. These indicative values will vary considerably across the study area depending on differences in climate and physiography, which complicates recommendations for the sustainable abstraction and management of groundwater resources.

Artificial recharge (AR) of aquifers has been successfully used at a number of sites in South Africa, most notably at Atlantis on the West Coast for the past 30 years (DWA, 2010). Artificial recharge is a very attractive option to maximise the value of groundwater resources. Within the study area, AR is practiced at Williston, and the DWS intends developing an AR scheme at Saaipoort located 10 km from Carnarvon and 70 km from Vanwyksvlei to supply both these towns with groundwater (Fourie et al., 2016) in the coming year (2017). Artificial recharge areas are defined differently to natural recharge areas, although parts of the former could overlap with the latter in shallow aquifer areas. Natural recharge of deep confined aquifers often occurs at distal and elevated locations many kilometres or more from where these aquifers might be tapped by a borehole. Artificial recharge of these systems might be similarly accomplished.

5.3 Water resources

5.3.1 Availability and demand

Water demand for SGD involves both the direct operational requirements for gas extraction as well as the ancillary requirements for infrastructural developments to support shale gas operations. The most obvious of these include infrastructural developments such as road construction and wellpad construction.

One of the key indirect demands on water resources that is often overlooked is the increased requirements for domestic use associated with the local influx of people to support the industry either directly or indirectly. Whereas water resources for the operation itself may be sourced from seawater or boreholes that produce low quality groundwater, increased domestic demands for potable water are an important consideration, particularly in the Karoo, an area that is currently sparsely populated, largely due to water scarcity.

For the purpose of this scientific assessment, water availability was evaluated by determining the ratio of current water use to water supply at a Quaternary catchment level. This calculation essentially provides an index of water scarcity that describes the surplus (or deficit) of water available for further development. In the case of surface water resources, nearly half of the Quaternary catchments are in deficit indicating no surplus for further development. (i.e. WSI >100%; Figure 5.20). Catchments with the greatest stress are those draining the Fish River within the Mzimvubu-Tsitsikamma WMA (Figure 5.7). Although Figure 5.20 indicates some water resource availability in the study area (mainly in the Orange WMA); these figures do not take into consideration the requirements for meeting the Ecological Reserve. Indeed, in their study of Water Resources Availability and Utilisation at the WMA, the DWA (2003) found that once existing users had been accommodated, and the requirements for meeting the Ecological Reserve had been met, there was no surplus water in the Orange WMA where water requirements already exceeded available supply (and where NWRS (2013) note that the ecological Reserve is not being fully met either). In the (then) Fish-to-Tsitsikamma WMA, surface waters had already been highly developed with limited potential for further development, and with requirements for urban and irrigation use expected to rise from the time of the DWA (2003) study to 2015 (summarised by SSI, 2012). In 2003, water resources in the Sundays River were already fully developed with no excess availability, while small volumes remained available after accounting for existing requirements in the Gamtoos and Great Fish catchments.

Index of Water scarcity (WSI): *a measure of water stress in a catchment where water use is expressed a percentage of water available as follows:*

$$For\ Surface\ Water: \frac{Water\ Use}{(nMAR)}$$

$$For\ Ground\ Water: \frac{Water\ Use}{(GW\ recharge)}$$

Where:

Water Use *includes the total annual water withdrawals (municipal, industrial and agricultural).* ***nMAR*** *is the naturalised mean annual runoff taken from the WR2012 dataset; GW recharge = groundwater recharge taken from the GRAII dataset.*

The ***Ecological Reserve*** *is defined in the National Water Act (Act 36 of 1998) as "… the quantity and quality of water required … to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource".*

Based on registered groundwater use provided in the Water Authorisation Management System (WARMS) database, ~35% of Quaternary catchments (particularly those within the Breede-Gouritz WMA and the western extent of the Mzimvubu- Tsitsikamma WMA) are currently over-utilised and thus represent extreme groundwater stress (Figure 5.19). Unlike surface water resources, >50% of the catchments within the study area utilise <25% of available groundwater (Figure 5.21), suggesting that groundwater resources within the study area offer a surplus for development. However, water use from the WARMS database is based on registered water use. In most instances municipal groundwater use is unlicensed and unquantified, despite ~20 towns in the study area being totally dependent on groundwater for municipal supply, and a further 14 relying in part on this resource. Furthermore, Schedule 1 use for reasonable domestic, gardening and stock watering purposes is not licensable. Cumulatively, such use probably represents a substantial volume.

Combined groundwater and surface water scarcity for each catchment is given in Figure 5.22. This spatial expression of water resource stress emphasises the deficit of either surface or groundwater resources throughout the study area. Collectively, the most water stressed catchments include those within the northern region of the Breede-Gouritz WMA, the south western extent of the Mzimvubu-Tsitsikamma WMA as well as the drainage area for the Great Fish River (Figure 5.22).

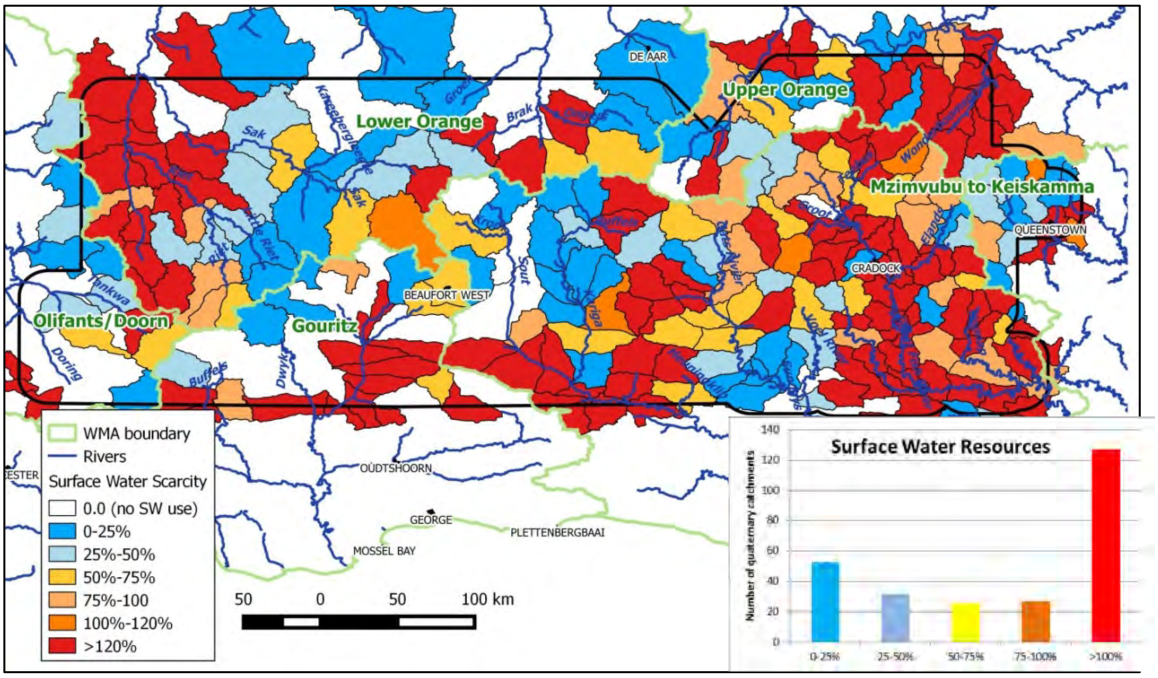

Figure 5.20: Water scarcity as an indicator of water stress at a Quaternary catchment scale for surface water resources. Catchments with a value ≥100% are those where the resource is either fully utilised or in deficit. Note that WARMS data exclude Schedule 1 Water Uses in terms of the National Water Act (NWA), and the figures shown here are thus conservative (i.e. they overstate resource availability).

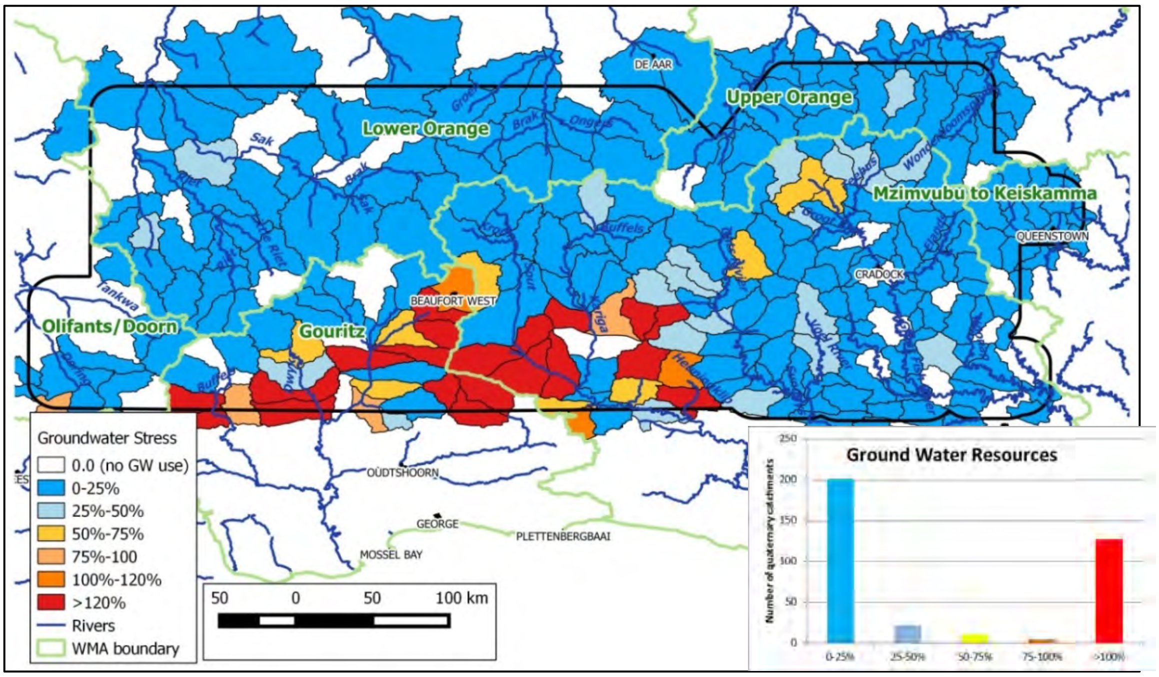

Figure 5.21: Water scarcity as an indicator of water stress at a Quaternary catchment scale for groundwater resources. Catchments with a value ≥100% are as for Figure 5.20. The bar graph summarises water use per WMA. Note that WARMS data exclude Schedule 1 Water Uses in terms of the NWA, and the figures shown here are thus conservative (i.e. they overstate resource availability).

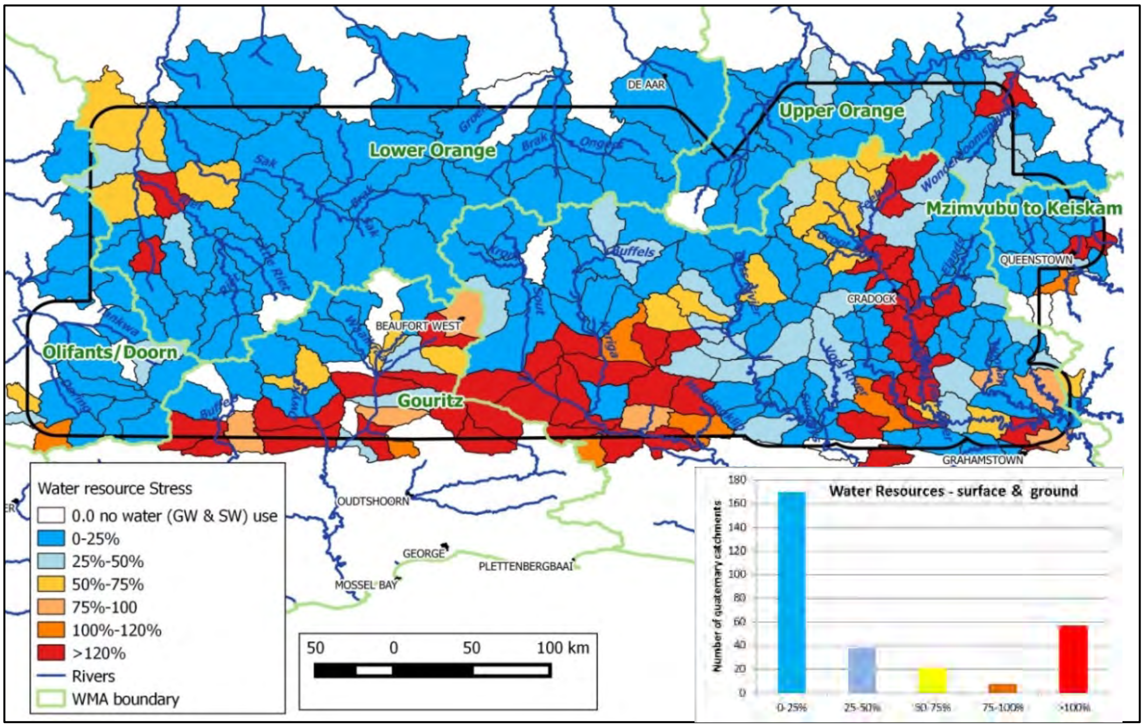

Figure 5.22: Water scarcity as in indicator of water stress at a Quaternary catchment scale for both surface and groundwater resources. Catchments with a value ≥100% are as for Figure 5.20. The bar graph summarises water use per WMA. Note that WARMS data exclude Schedule 1 Water Uses in terms of the NWA, and the figures shown here are thus conservative (i.e. they overstate resource availability).

Besides the water stress situation presented in Figure 5.21 to 5.23, the "All Towns" dataset developed as part of the DWS's water reconciliation strategy undertaken at a national scale, provides an indication of water availability for towns, villages and clusters of villages, together with a projection of the water shortage situation over the next 10 years (Figure 5.23). Although the data used in this assessment was based on 2008 data, these data provide a useful indication of those towns or settlements which are most vulnerable to water shortages should further demand increase. While these data suggest that there are no predicted shortages in the Orange WMA, water resources in the other two main WMA's considered in this scientific assessment are either in deficit already, or water shortages are expected in the near future. These assessments do not, moreover, take into account the projected decreases in streamflow in large parts of the study area, as described in Section 5.3.3.

On the basis of the above, it is apparent that additional surface water resources are unlikely to be available for direct utilisation for SGD in the Karoo, without impacting on existing user groups including aquatic ecosystems. The low assurance of yield means moreover that abstraction from non-perennial rivers will be difficult. For the purposes of this scientific assessment, it is assumed therefore that surface water abstraction to support new development in the study area is not a viable option. Even if water for the industry itself is sourced outside of this area, the increase in domestic demands for potable water are likely to impose impacts on both groundwater and surface water resources and there is a high risk of water shortages in large parts of the study area.

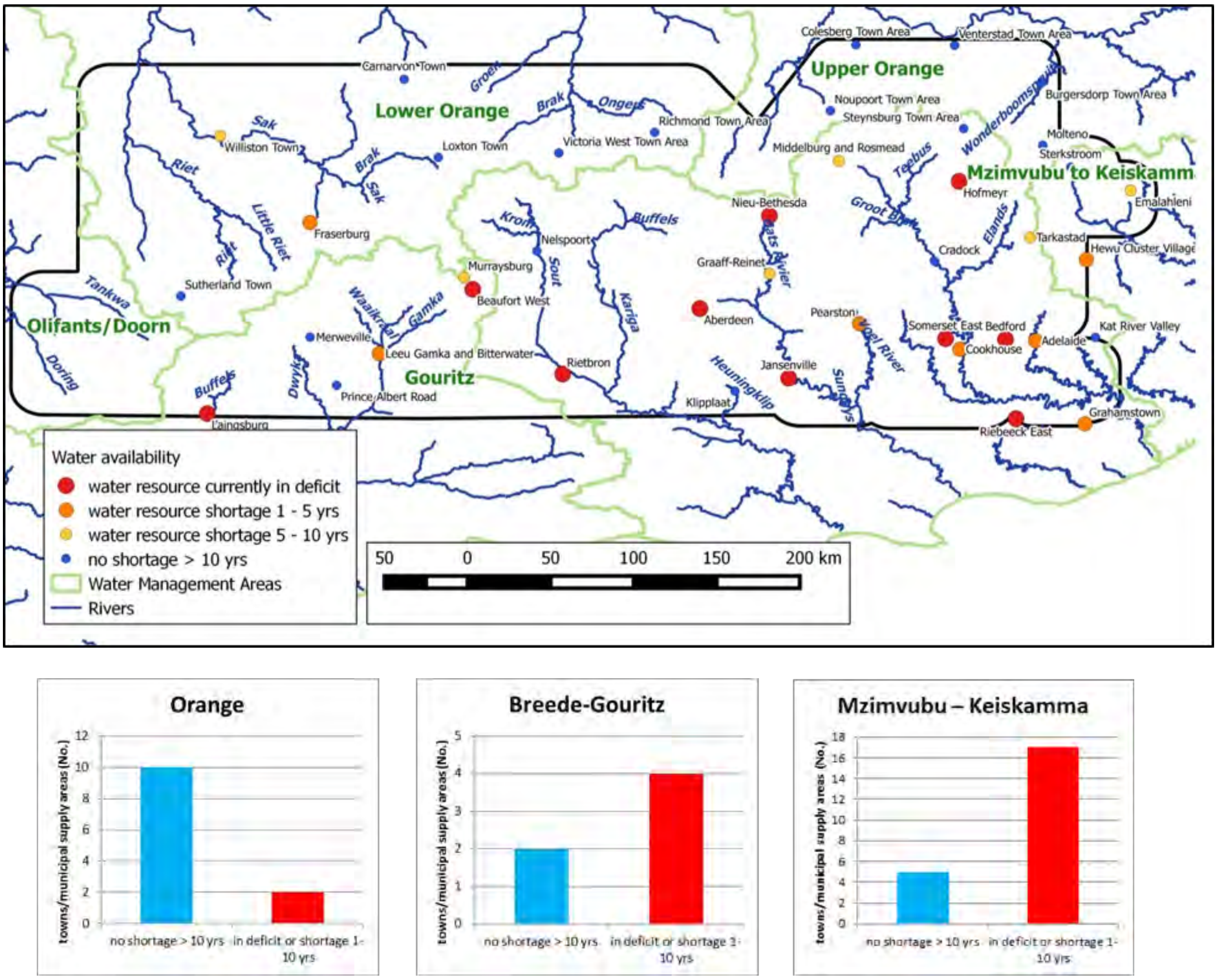

Figure 5.23: "All Towns" data from the DWS showing current water availability and predicted shortages for each town or settlement in the study area. Each point represents a municipal supply scheme which, depending on the municipality includes domestic, industrial and agricultural use. Bar graphs summarise water use per WMA.

Groundwater use in the study area is considered underestimated because a substantial portion of the resource is either not licensed in terms of the National Water Act 36 of 1998 (NWA) (RSA, 1998a) or is considered Schedule 1 use which does not require licensing. It is therefore recommended that a study which validates and verifies water use be initiated as a priority within the study area. Furthermore, it is imperative that the Ecological Reserve is quantified where such information gaps exist within the study area such that resource availability in terms of both surface and groundwater is more accurately estimated.

5.3.2 Inter-catchment water transfers

The Gariep Dam, located on the Orange or Gariep River just north of the boundary and ~50 km east of Colesberg (Figure 5.24), is the largest dam in the country and transfers water into the study area, via the Orange-Fish tunnel. This supplementary water passes into the Grassridge Dam on the Groot Brak River, a tributary of the Great Fish River. It is used both to augment scarce local resources as well as for water quality management purposes to reduce river salinity (SSI, 2012). It passes through the Fish to Tsitsikamma WMA as far south as the coastal areas and forms part of the Algoa Water

Supply System, which provides water to the Gamtoos Irrigation Board, 1.1 million people in the Nelson Mandela Bay Municipality (NMBM) for domestic use and for use by more than 373 industries, the Coega Industrial Development Zone and several smaller towns within the Kouga Municipality area (DWS website).

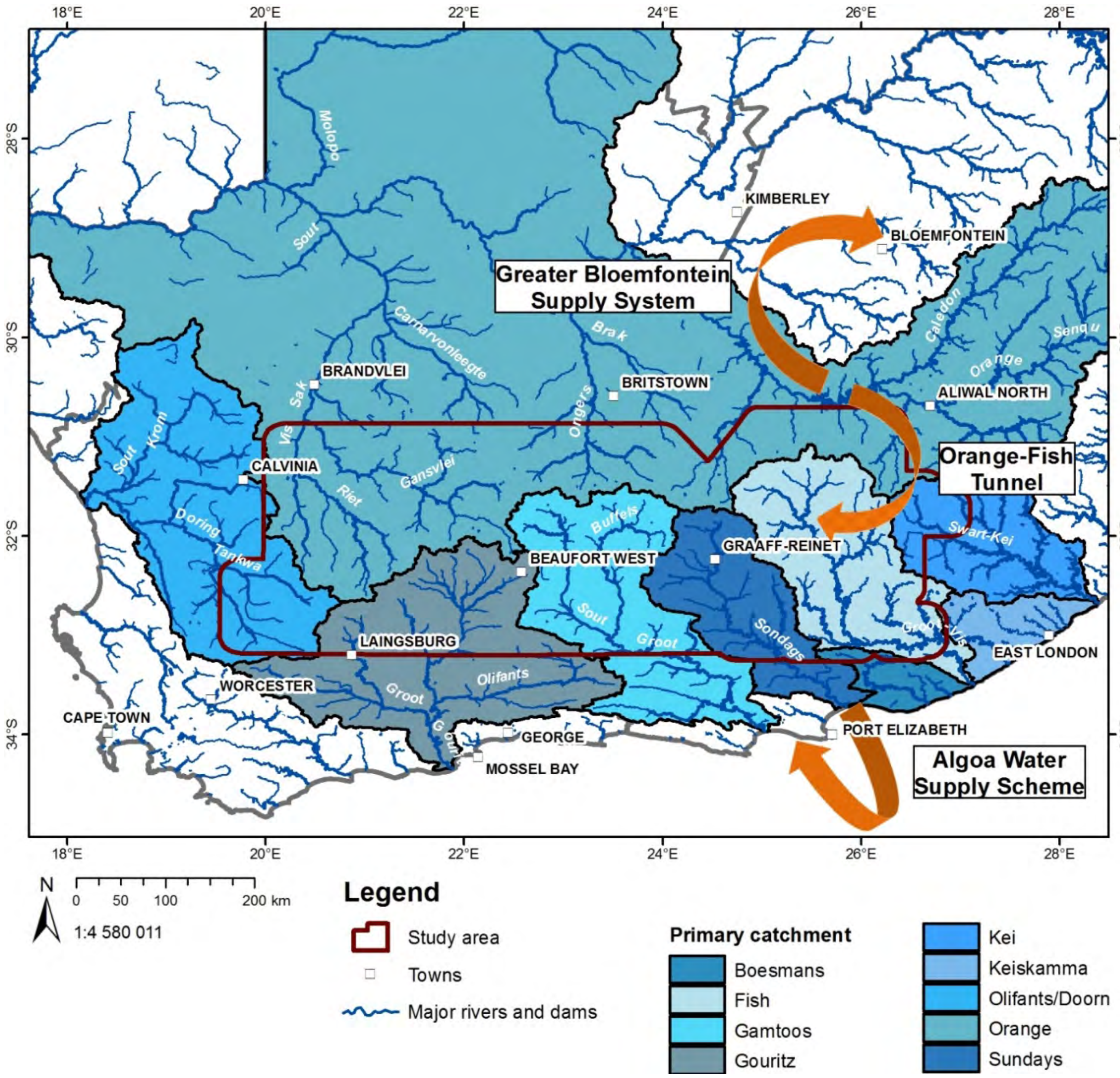

Figure 5.24: Inter-catchment transfers between the Orange and the Fish-Tsitsikamma Water Management Areas, traversing the study area.

The relevance of these water resource transfers through the study area is that they create potential flow pathways for contaminants generated in their catchment, including those potentially associated with shale gas exploration and/or production (Section 5.5.2).

5.3.3 Climate change and water resources

An assessment of the effects of projected climate change on streamflows in the study area was undertaken as part of this scientific assessment, and the results are indicated in Figure 5.26 and 5.27.

Figure 5.25, which presents projected streamflow changes in mm equivalents, shows marked decreases in streamflows in the east, moderate decreases to negligible changes in the central areas, and slight increases in the south-western corner. It should, however, be borne in mind that these projected changes come off a very low base of streamflows in this semi-arid area, and when the projected changes are expressed as percentage changes (Figure 5.26), the map shows decreases over 80% of the study area, varying from 15 to 60% of Mean Total Streamflow. These are significant projected decreases over much of the study area in an environment experiencing already stressed surface water resources.

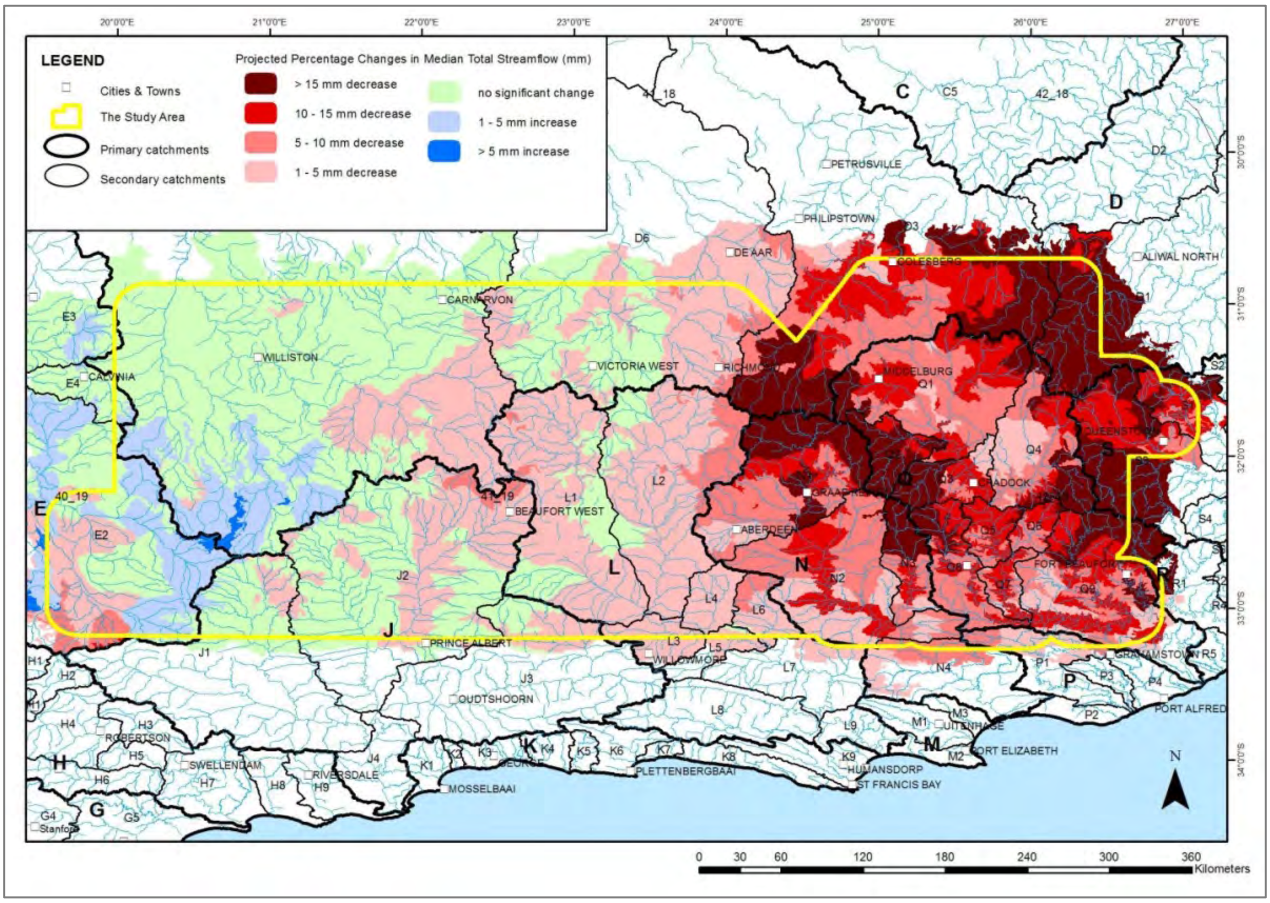

Figure 5.25: Projected changes in Median Total Streamflow (mm), showing differences between present (1976-2005) and intermediate future (2016-2045) climate scenarios, with data based on averages of changes from five GCMs (i.e. CCCma, CNRM, ICHEC, NCC, NOAA). Data derived for this study by R.E. Schulze.

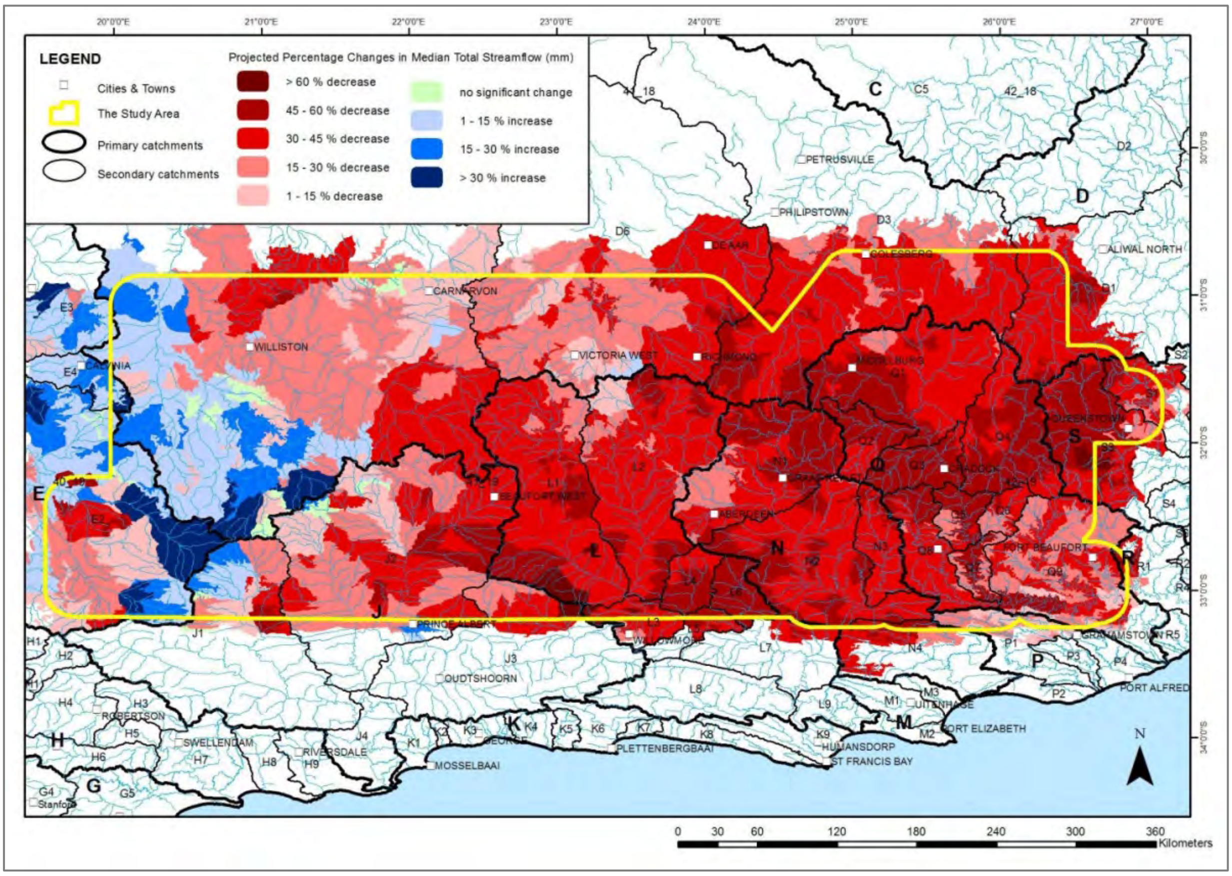

Figure 5.26: Projected percentage changes in Median Total Streamflow, showing differences between present (1976-2005) and intermediate future (2016-2045) climate scenarios, with data based on averages of changes from five GCMs (i.e. CCCma, CNRM, ICHEC, NCC, NOAA). Data derived for this study by R.E. Schulze.

5.3.4 Summary of water resource availability for SGD

It has been shown in Section 5.3.1 that while the projection of water demands for the next decade in regard to the Orange WMA predict shortages in only a few of its municipal areas/towns, those for the Breede-Gouritz and Mzimvubu-Tsitsikamma WMAs that span the study area present greater concerns. The water resources in these WMAs are either already in deficit, or water shortages are expected in the near future. This finding is exacerbated by the observation in Section 5.3.3 that streamflow in large parts of the study area is projected to decrease as a result of climate change.

It is apparent, therefore, that additional surface water resources are unlikely to be available for direct utilisation in a developing shale gas industry in the Karoo, without impacting on existing users including aquatic ecosystems.

The impression given in Figure 5.21 that many of the Quaternary catchments in the study area experience a low (<25%) level of groundwater stress must be tempered by consideration of the fact that the quantum of groundwater use outside of the formal town water supply systems served by motorised and metered production boreholes is not known. Produced by windpumps, the aggregate volume of groundwater supplied from these sources mainly for livestock watering purposes (Schedule

1 use) is indeterminable. The various factors that inform the veracity of any attempted quantification of this use are described in the Agriculture Chapter by Oettle et al. (2016), and apart from a reliable value for the total number of functional boreholes in the study area, it is hampered mainly by a paucity of borehole yield data. These circumstances indicate that a different approach is required to arrive at even a coarse estimate of this use.

Oettle et al. (2016) reports a population of ~7 million sheep as underpinning the Karoo's economy. If only a third of this population occurs in the study area, then applying the per capita demand of 5 L/d per large stock unit (Section 5.2.4) returns a daily water requirement of ~11 700 m^3 per day, or ~4.26 million m^3 per annum. To this must be added the municipal water requirements that in many instances are solely provided from groundwater sources, and account in the main for the cluster of groundwater stressed Quaternary catchments in the south-central part of the study area (Figure 5.21).

Using a strict livestock watering versus shale gas production well comparison, just 21 of the latter (at 0.2 million m^3 per annum each as per Table 5.4) will consume the coarse estimate (~4.26 million m^3 per annum) of Schedule 1 use for livestock watering in the whole study area. It is apparent, therefore, that a similar prognosis as for surface water availability applies also to the availability of groundwater resources within the context of SGD.

5.4 Relevant legislation, regulation and practice

The following discussion only addresses legislation of direct relevance to this Chapter. Other legislation which may also address water resources, e.g. in regard to the environment (Holness et al., 2016), waste (Oelofse et al., 2016) and agriculture (Oettle et al., 2016), are addressed in those respective Chapters where these are most relevant. In this Chapter, legislation and regulations relevant to water *per se* are discussed in the context of international law, the Constitution and other relevant laws in South Africa (in this order).

5.4.1 International law

International customary law and international conventions and treaties are important in the South African context. International customary law principles such as the polluter pays principle, the precautionary principle and the preventive principle have been enumerated in Section 2 of the National Environmental Management Act 107 of 1998 (NEMA, RSA, 1998b). In South Africa these principles apply to 'the actions of all organs of state that may significantly affect the environment', and not just the Department of Environmental Affairs (DEA), which administers this particular statute.

In terms of international convention, South Africa is party to the international convention on wetlands of international importance especially as waterfowl habitat, 'the Ramsar Convention', which provides for the designation of wetlands of international significance by state parties to the convention. South Africa has designated 20 wetlands under the treaty.

The South African Development Community (SADC) revised protocol on shared watercourses of 2000 and the United Nations Convention on the Law of the Non-navigational uses of international watercourses of 1997, are other relevant treaties for the Orange River that traverses the study area.

In terms of the SADC protocol, the Orange River is an international watercourse and Lesotho, South Africa, Namibia and Botswana are all watercourse states with respect to this river. According to this protocol, the State Parties recognise the principle of the unity and coherence of each shared watercourse and in accordance with this principle, undertake to harmonise the water uses in the shared watercourses and to ensure that all necessary interventions are consistent with the sustainable development of all Watercourse States and observe the objectives of regional integration and harmonisation of their socio-economic policies and plans.

The UN Convention of 1997 codified international water law and is a framework agreement, which allows for ad hoc watercourse agreements to be adopted for specific international watercourses. The substantive obligations of the UN convention are that watercourse states (a) may utilise an international watercourse in an equitable and reasonable manner, (b) should not cause significant harm to other states using the same watercourse, and (c) have to protect international watercourses and their ecosystems.

5.4.2 Constitution of the Republic of South Africa

The Constitution of the Republic of South Africa (Act 108 of 1996) (the Constitution) is the supreme law of South Africa and the Bill of Rights, contained within it, is the cornerstone of democracy in South Africa. The Constitution, with its environmental right, is a crucial enactment, as are a number of other acts that regulate the following inter-related areas of environmental concern.

5.4.3 Relevant South African laws

5.4.3.1 The National Water Act

The National Water Act 36 of 1998 (NWA) (RSA, 1998a) provides legislation to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate. The act defines a "water resource" to include a watercourse, surface water, estuary, or aquifer; and watercourses include rivers, springs, wetlands, dams or any collection of water that the Minister declares to be a watercourse. This Act is administered by the DWS. Sections 2 (g) and (h) specifies the "protection of the aquatic and associated ecosystems and their biological diversity" and "reducing and preventing pollution and degradation of water resources" respectively (RSA, 1998a).Water resources are primarily managed and protected in the NWA by the need to obtain a license for permissible 'water use', except in cases where a license is not required, for example where a 'General Authorisation' (GA) or 'schedule 1 use' has been issued. Water use is defined in Section 21 of the NWA and includes:

- (*a*) taking water from a water resource;
- (*b*) storing water;
- (*c*) impeding or diverting the flow of water in a watercourse;
- (*d*) engaging in a stream flow reduction activity contemplated in Section 36;
- (*e*) engaging in a controlled activity identified as such in Section 37(1) or declared under Section 38(1);
- (*f*) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
- (*g*) disposing of waste in a manner which may detrimentally impact on a water resource;

(*h*) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
(*i*) altering the bed, banks, course or characteristics of a watercourse;
(*j*) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
(*k*) using water for recreational purposes.

Once an applicant falls into any one or more of the items listed above the Minister may issue conditions for the granting of a license. Section 29 of the NWA sets out conditions that can be attached to GA's and licenses, relating to the protection of the water resource, to water management and to return flow, to discharge or disposal of waste, in the case of a controlled activity, in the case of taking or storage of water and in the case of a license.

The DWS is in the process of formulating its own regulations regarding oil and gas exploration and development (thus including SGD). It has invoked Section 38 of the NWA (RSA, 1998a) to declare "The exploration and or production of onshore naturally occurring hydrocarbons that requires stimulation, including but not limited to fracking and or underground gasification, to extract, and any activity incidental thereto that may impact detrimentally on the water resource." as a controlled activity. This was published in General Notice No. 999 (RSA, 2015b) as Section 37 (e) of the NWA (RSA, 1998a). Declaration of unconventional oil and gas extraction as a controlled activity means that water use licenses will be required for SGD.

It is important to note that Part 3 of Chapter 3 of the NWA provides for the determination of a Reserve and related matters (Sections 16 to 18), before the issuing of a license. This means that Reserve determinations on groundwater and surface water resources in the SGD areas would be required. Sections 19 and 20 of the NWA require shale gas operators to prevent pollution incidents and emergency incidents and outlines how operators should act in the case of an emergency incident.

Lastly, Chapter 14 of the NWA (Sections 137 to 145) titled Monitoring, Assessment and Information is particularly relevant to fracking. Monitoring, recording, assessing and disseminating information on water resources is critically important for achieving the objects of the Act. The Minister of DWS must establish national monitoring systems and national information systems, each covering a different aspect of water resources, such as a national register of water use authorisations, or an information system on the quantity and quality of all water resources. The Minister must also establish mechanisms and procedures to coordinate the monitoring of water resources after consultation with the relevant organs of state including water management institutions and existing and potential users of water. Key regulations important for fracking under the NWA, includes GN 704. The regulations on use of water for mining and related activities aimed at the protection of water resources (GN 704/1999 in Government Gazette of 4 June 1999) is aimed at protecting water resources. The following regulations of GN 704 are relevant:

- *Regulation 4*, with restrictions on locality, specifies that no person in control of a mine or activity may <u>locate or place any residue deposit, dam, reservoir. together with any associated structure or any other facility within the 1:100 year floodline or within a horizontal distance of 100 m from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground</u>

likely to become water-logged, undermined, unstable or cracked. It then goes on to specify more details on locality.

- *Regulation 5* restricts the use of materials and specifies that no person in control of a mine or activity may use any residue or substance which causes or is likely to cause pollution of a water resource for the construction of any dam or other impoundment or any embankment, road or railway, or for any other purpose which is likely to cause pollution of a water resource.
- *Regulation 6* specifies capacity requirements for clean and dirty water systems; and
- *Regulation 7* sets out specific requirements for the protection of water resources.

Other relevant regulations are GN 1199 (18 December 2009), which specifies conditions for impeding or diverting flow or altering the bed, banks, course or characteristics of a watercourse to persons using water under Sections 21 (c) and (i) of the NWA. In these regulations, no water use is allowed within a 500 m radius from the boundary of a wetland. Also, altering the bed, banks, course or characteristics of a watercourse is not allowed within the 1:100 floodline or within the riparian habitat, whichever is the greatest.

5.4.3.2 The Water Services Act

The Water Services Act 108 of 1997 (WSA) (RSA, 1997b) governs the provision of water services in the country. This act is also administered by the DWS. Section 2 (j) seeks to promote "…… effective water resource management and conservation."

According to the WSA, Water Services Providers (i.e. the municipalities that are supplying their communities with water) must ensure that water of a specific quality is provided (SANS, 2015a: 2015b), must ensure assurance of supply and must also ensure sanitation in their jurisdictions. If SGD occurs in a specific area, there will be an additional strain on the infrastructure and resources for water services delivery and sanitation when there is an influx of people. Additionally, the issue of waste water treatment at waste water treatment works (WWTW's) should be considered, as these works do not currently have the capacity to treat received waste water. Treatment of fracking waste water would also not be possible at these plants due to the fact that the type of waste water emanating from fracking operations is different from waste water streams currently treated at the WWTW's. This aspect is dealt with in more detail by Oelofse et al. (2016). These are important strategic issues to take into consideration.

5.4.3.3 The Mineral Petroleum Resources Development Act

The exploration and development of mineral and petroleum resources is legislated for in the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) (RSA, 2002). All environmental management aspects, however, are dealt with in terms of the "One Environmental System" which became effective on 14 December 2014. The relevant principal features of the One Environmental System with respect to exploration and mining are:

- that all environment related aspects are to be regulated through one environmental system under NEMA and all environmental provisions are to be repealed from the MPRDA; and
- the Minister of Mineral Resources will issue environmental authorisations under NEMA.

It must be noted however, that the companies involved in SGD in the Karoo have all submitted their applications for exploration rights in terms of the MPRDA in 2011. At the time, Section 39 of the MPRDA required that an Environmental Management Plan (EMP) must be submitted as part of an application for a gas exploration right. These EMP's were submitted in 2011 as part of the applications for exploration rights. The applications are still pending, and even though Section 39 of the MPRDA was repealed, all pending applications must be finalised as if Section 39 was not repealed. Subsequently, in 2015, the Department of Mineral Resources (DMR) requested the applicant companies to carry out a review of their EMP reports to determine whether they comply with the requirements set out in Section 39(3) of the MPRDA. In terms of the One Environmental System, the environmental aspects associated with any new applications related to exploration and production of shale gas resources will be dealt with in terms of the provisions of NEMA, with DMR being the competent authority.

Section 2 (h) seeks to ensure "…... that the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner while promoting justifiable social and economic development" in accordance with Section 24 of the Constitution. Environmental management is addressed in Section 39, and sets out in Section 39(3) the requirements attendant on an Environmental Management Programme (EMPr) or an environmental management plan (EMP). It is important to note that the mining industry is a long established industry in South Africa; while the petroleum resources industry, particularly land based extraction is still in its infancy. As a result, while the MPRDA tackles both, much associated regulation, particularly that which covers environmental matters and water, tends to focus on mining activities and are silent on petroleum production activities.

Environmental Authorisations (EA's) are one of the key features of both the mining and petroleum regulatory regimes. Section 37 of the MPRDA states that all prospecting and mining operations must adhere to the environmental management principles of the NEMA while Section 38 states that any operator has a responsibility to manage environmental impacts and must as far as possible rehabilitate the environment affected by the operations. Section 39 calls for operators to conduct an EIA and submit an EMP where baseline information of the affected environment to determine protection and remedial measures must be established. Section 41 calls for operators to make financial provision for the remediation of environmental damage. An operator remains responsible for any environmental liability, pollution or ecological degradation and its management until the Minister of Mineral Resources has issued a closure certificate and no closure certificate may be issued until the Minister of Water and Sanitation has confirmed in writing that the provisions relating to health and safety and the management of potential pollution to water resources have been addressed (Section 43).

In 2015 specific regulations to govern petroleum exploration and production has been promulgated under the MPRDA – i.e. Regulations for Petroleum Exploration and Production, 2015 (GN R466). These petroleum exploration and production regulations prescribe standards and practices to ensure the safe exploration and production of oil (petroleum and other liquid hydrocarbons) and gas (coal bed methane (CBM) and shale gas). GN R466 is listed in Digital Addendum 5B for ease of reference. GN R466 specifies that an EIA be performed in potential areas of petroleum exploration and extraction, with specifics relating to water resource monitoring (sub-regulation 88), the management of drilling fluids (sub-regulation 109), fracking fluid disclosure (sub-regulation 113), fracture and fracturing fluid containment (sub-regulation 114), the management of fracturing fluids and flowback and produced fluids (sub-regulations 115 and 116) as well as regulations on the transportation and storage of fluids (sub-regulations 117 and 118).Sub-regulations 121 to 123 focuses on the management of water specifically while sub-regulations 124 to 126 focuses on waste management and spillage management. Sub-regulations 122(2) and 122(3) specify setback distances from water resources, which are discussed in more detail in Section 6. Sub-regulations 130 to 132 focus on well suspension and decommissioning, which are in the respectful view of the authors, inadequate. Disappointingly, no penalties are specified for non-compliance with these regulations, meaning that operators will not face any consequences for not complying with any of the provisions set out in these regulations.

5.4.3.4 The National Environmental Management Act

The requirements for Environmental Impact Assessment (EIA) under the National Environmental Act 107 of 1998 (NEMA) (RSA, 1998b) are also applicable in a water context. The principles in Section 2 of the NEMA apply to both the MPRDA and the NWA. An important principle is the precautionary ("risk-averse and cautious") approach, specifying that a risk-averse cautious approach is applied to development, which takes into account the limits of current knowledge about the consequences of decisions and actions. Another important principle is that the costs for remedying pollution, environmental degradation and consequent adverse health effects must be paid for by those responsible for harming the environment. Chapter 3 of the NEMA requires co-operative governance, which would be important if fracking is to be managed effectively between different spheres of government.

5.4.4 Regulatory water quality guidelines and standards

Water quality management in South Africa is based on two separate concepts: water quality guidelines, and water quality standards. The South African Water Quality Guidelines “serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems” (DWAF, 1996). Recognising that suitable quality may differ for different water users, separate guidelines are provided for domestic, recreational, industrial and agricultural (irrigation and livestock watering) use, as well as for maintenance of aquatic ecosystems. As the name implies, these are guidelines for best practice and are not legally binding.

In contrast, standards for drinking water and purification of waste waters and effluents are legislated and should therefore be binding. The SANS specifies the minimal quality of drinking water, defined in terms of microbiological, physical, chemical, and taste-and odour parameters at the point of delivery to the consumer. The assumption is that water of this quality will present an acceptable health risk for lifetime consumption. The Water Services Act 108 of 1997, updated as SANS (2015a: 2015b), requires that water provided by water services authorities such as municipalities meets the specified standards. It should be noted that these standards apply only to water to be delivered to the consumer, and not to water in rivers or aquifers, where only the relevant guidelines apply.

Standards were set in the 1956 Water Act for some 23 constituents in effluents and waste waters entering a stream. While the updated version (DWA, 2013) modifies the legal limits of some constituents, no additional constituents are considered. The values set for most or all of the constituents listed in the current list are derived from the South African Guidelines for Aquatic Ecosystems (DWAF, 1996).

5.5 Key potential impacts and their mitigation

Any discussion of key potential impacts on water resources and their mitigation must be prefaced by a discussion of the hydrologic, geologic, hydrogeologic and relevant technological aspects that frame the development of a shale gas industry. To this end, the following material provides a synthesis of the geologic environment to aid conceptualisation of the key potential impacts of specific relevance to the Karoo Basin. It is followed by a similar synthesis of the other aspects attendant on the development of shale gas resources. This necessarily draws to some extent on international experience.

The following assumptions regarding each scenario form an important backdrop to the description of potential impacts associated with each scenario, and feed into the later risk assessment associated with each impact:

- Scenario 0 (Reference Case): It is assumed that in this “no shale gas development” scenario, water resources in the Karoo region remain largely unchanged in terms of resource allocation, especially given that surface waters in the region are considered over-allocated in any case, but that water in the region will be affected by climate change. Climate change models suggest that climate change will result in increased frequency of extreme events such as droughts and floods. In this context it is assumed with low confidence levels (because detailed climate change scenarios have not been run for the study area), that water resources are highly sensitive to climate change, primarily because any change in rainfall, be it positive or negative, is amplified in the streamflow response and flow variability, and is further amplified in the groundwater recharge response. In the case of surface water, as rain intensities increase, this may in some areas translate into higher levels of erosion and sediment transport, and higher siltation rates within impoundments. It is also likely that the value of groundwater resources in an increasingly arid Karoo environment will become greater compared to surface water. Climate change impacts would apply to all scenarios.
- Scenario 1 (Exploration Only): In this scenario, limited seismic exploration only occurs, with vertical stratigraphic and appraisal wells being drilled.
- Scenario 2 (Small Gas): Seismic exploration, vertical stratigraphic wells and limited fracking in horizontal sections, with a 110 ha footprint for each of 55 wellpads describes this scenario.
- Scenario 3 (Big Gas): Seismic exploration, vertical stratigraphic wells and fracking in horizontal sections, with a 820 ha area wellpad coverage; 410 wellpads constructed.

In all of the above, it is assumed that activities would be governed by a responsibly authorised EMPr but that, as stated in Burns et al. (2016), 30 years after the start of exploration, abandoned wellpads would be audited and if found to have achieved required rehabilitation targets in accordance with relevant legislation and regulations, monitoring to verify this compliance will continue for at least another 10 years. Importantly, it is assumed that further auditing of these wellpads then ceases.

5.5.1 Groundwater issues

The primary issues of concern with respect to SGD are the contamination of shallow groundwater resources and the supply of water for drilling and fracking activities. Associated with the former is possible hydraulic connectivity between deep and shallow formations and the disposal of flowback and produced water. Vengosh et al. (2013) identified the management of waste waters as one of the main issues confronting the shale gas industry, with post-fracking incidents related to surface spills or faulty casing and poor well maintenance accounting for all proven contamination to date.

The growth of the USA shale gas industry proceeded in the absence of baseline water resources monitoring studies to establish a reference of 'pre-industry' water quality. This compromises any subsequent attempt to link observed instances of impaired water resources quality (especially sub-surface) with the industry itself. This makes it very difficult to prove that certain elevated constituents in water are as a result of SGD/production (Stephens, 2015). The situation is exacerbated in instances where SGD proceeds in an area where the existence and position of 'historical' deep wells was not required to be documented; Davies (2011) reports >180 000 such wells in Pennsylvania. It is reasonable to presume that a proportion of these were improperly abandoned, providing connecting pathways to shallower aquifers. This is not the case in the study area, where existing boreholes established for water supply purposes, including those that have been abandoned, seldom exceed a depth of 150 m.

Vengosh et al. (2014) investigated stray gas contamination of shallow aquifers, contamination of groundwater and surface water from spills, leaks and waste water, the accumulation of toxic or radioactive contaminants in soils and stream sediments near disposal or spill sites and the over-exploitation of water resources to supply drilling and fracking operations. Evidence was found of stray gas migration, contamination of water from surface spills and leaks and accumulation of contaminants in soils/sediments but conclude that contamination of water resources by fracking itself "remains controversial".

Migration of contaminants from the 'fracked zone' along natural or induced pathways seems to be the least likely cause of water contamination according to a number of researchers (Osborn et al., 2011; RS&RAE, 2012; Brantley et al., 2014). Atangana and Van Tonder (2014) suggest rather drastically and on purely theoretical grounds, however, that "…... in the case of the Karoo, fracking will only be successful if and only if the upward methane and fracking fluid migration can be controlled, for example, by plugging the entire fracked reservoir with cement." This opinion is shared by Van Tonder et al. (n.d.). It is also worth noting that Warner et al. (2012) report the natural migration of brines (TDS of 10 000 to 343 000 mg/L) from the Marcellus Shale Formation through >1 200 m of sedimentary strata into shallow aquifers in north-eastern Pennsylvania. Nevertheless, the main possible causes of contamination are considered to be the following:

- surface spills and leaks (Metzger, 2011), which should be of short-term duration and relatively easy to identify and quickly remedied;
- compromised production well integrity associated with leaky casings and annular seals (Ingraffea 2013), which are more difficult to identify and result in longer-term contamination; and
- spent production wells that develop structural defects following decommissioning (Ingraffea, 2013), and represent an insidious long-term threat.

The pathways represented by the afore-mentioned 'threats' are illustrated in Figure 5.27. It is the cumulative impact of many wells in various phases of development in comparatively small areas (greater density) that represents the greater concern and risk profile (Kibble et al., 2013).

The data presented in Burns et al. (2016) have been evaluated to derive a typical value of water use required for the drilling and construction of various types of wells associated with SGD. The results are presented in Table 5.3. If it is assumed that a fracked well is completed in 30 days, then the total water use of 16 330 m^3 (without re-use) is in reasonable agreement with the average per well of ~17 600 m^3 reported by King (2012), and comfortably in the ranges 13 000 to 19 000 m^3 reported by Osborn et al. (2011) for the Marcellus Shale, the 9 800 to 24 600 m^3 reported in Table 5.1, and the 10 000 to 30 000 m^3 reported in Burns et al. (2016).

The values presented in Table 5.3 are readily aggregated to a variety of situations, e.g. per annum, per campaign, per scenario (Small or Big Gas) using the number of wells as multiplier. It is on this basis that the water use per drill rig and the total water use for a Small Gas scenario and a Big Gas scenario campaign as presented in Table 5.4 is derived.

Table 5.3: Summary of water use by shale gas well type.

Type of well	**Depth/length (m)**	**Water use**					
		Without re-use			**With re-use**		
		L/s	**m^3/d**	**m^3/m[(1)]**	**L/s**	**m^3/d**	**m^3/m[(1)]**
Stratigraphic well[(2)]	3 000	0.3	26	778	0.2	17	518
Vertical well[(3)]	3 000	0.3	26	778	0.2	17	518
Fracked vertical + horizontal well[(4)]	3 000 + 1 500	6.3	544	16 330	4.3	372	11 146

(1) m^3 per month
(2) Type “X” well illustrated in Figure 1.24 (Burns et al., 2016)
(3) Type “Y” well illustrated in Figure 1.24 (Burns et al., 2016)
(4) Type “Y” + “Z” well illustrated in Figure 1.24 (Burns et al., 2016)

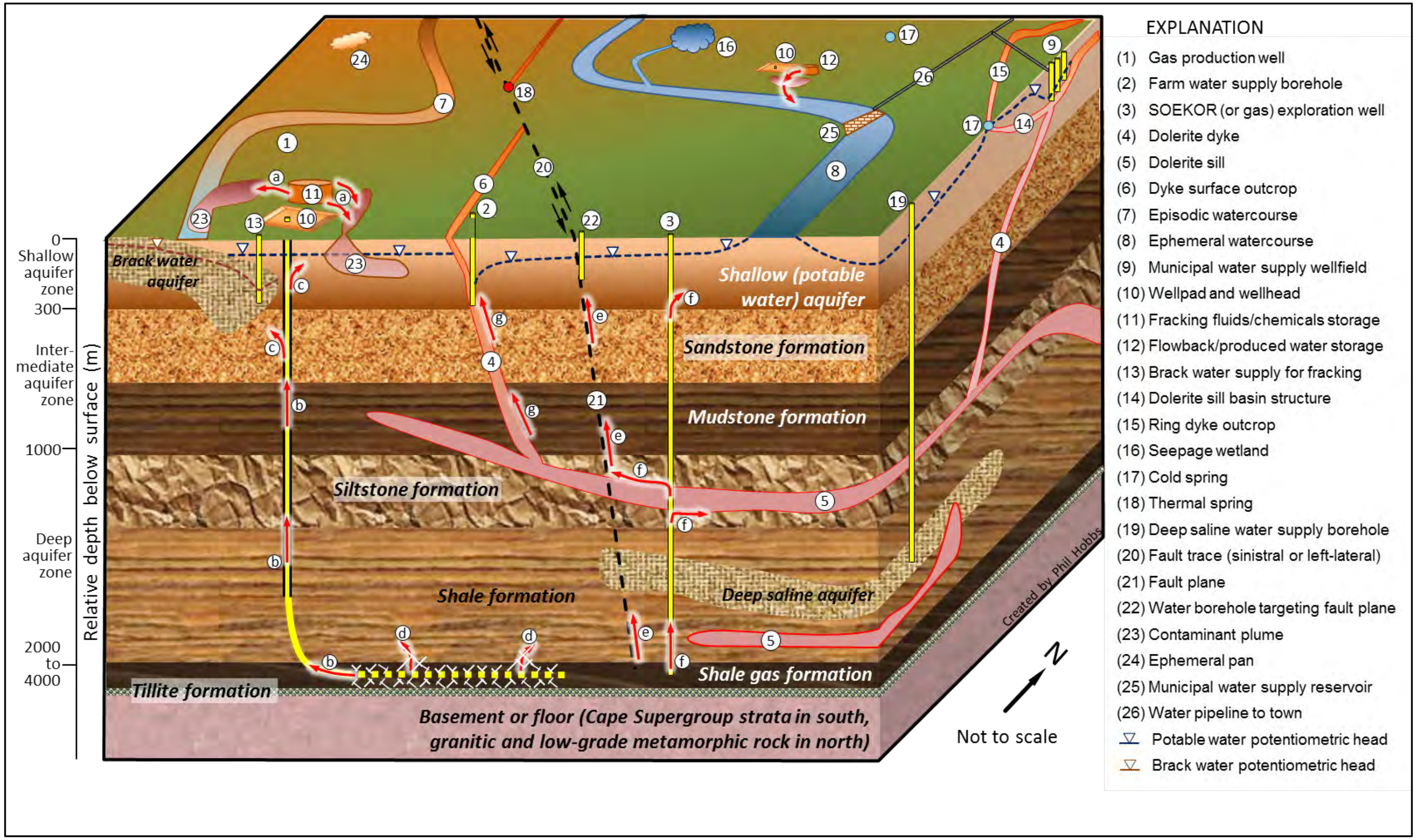

Figure 5.27: Schematic block diagram illustrating various features associated with the surface water and groundwater environments as these relate to SGD activities. The possible contaminant pathways (red arrows) and plumes (feature 23) are conceptual and exaggerated for explanatory purposes. The lithostratigraphic succession is similarly for illustrative purposes, whereas in reality the various formations comprise a mixture of sedimentary rock types, and are also not uniformly thick or necessarily horizontal. Features 3 and 19 might be artesian. The possible contaminant pathways are identified as (a) surface spills at the wellpad, (b) flowback and produced water via a production well, (c) leakage via faulty annular seals in production wells, (d) migration via hydraulic fractures, (e) preferential migration along fault planes, (f) escape/leakage via old (possibly uncased) oil and gas exploration wells, and (g) preferential migration along dyke/sill contact zones.

Table 5.4: Summary of water use per drill rig by type of shale gas campaign.

Water use application (campaign)	Period (years)	Per drill rig		Total	
		Without re-use m^3	With re-use m^3	Without re-use m^3	With re-use m^3
Exploration only	2	103 770	70 140	518 850	350 700
				5 drill rigs	
Small Gas	17	3 283 500	2 237 400	9 850 500	6 712 400
				3 drill rigs	
Big Gas	21	4 104 375	2 796 750	82 087 500	55 935 000
				20 drill rigs	

5.5.1.1 Exploration activities

The key impact of shale gas exploration activities is on water use. The water requirements, typically for activities such as geophysical exploration and stratigraphic drilling, are comparatively low. Water is required for purposes such as personnel/crew 'domestic' use (e.g. drinking/cooking water and ablutions), for access road construction and in the drilling of stratigraphic wells.

Impact: The water requirements for exploration activities can, in most instances, be readily met from groundwater resources in the vicinity of the exploration activities. For example, the water use for a geophysical campaign is mainly for personnel/crew 'domestic use'. Assuming a staff complement of 100 people, then their requirement of 150 L/d/capita amounts to 15 m^3/d. This can be met from a borehole delivering ~0.4 L/s in a 12-hour day. Similarly, the water requirement for stratigraphic drilling (without re-use), including that of 100 crew, amounts to ~26 m^3/d (Table 5.3). This again can be met from a borehole delivering 0.6 L/s per 12-hour day. The water requirement for road construction is estimated at ~30 m^3/d including 30 crew and sundry other use such as washing of vehicles. A single borehole delivering ~1 L/s per 12-hour day might therefore reasonably meet all of these requirements.

Mitigation: The impact of utilising groundwater at this scale for exploration activities is readily assessed by carrying out a hydrocensus (borehole survey) within a radius around the water supply borehole that is sufficient to encompass the likely area of influence (whether radial in the case of a homogeneous and isotropic aquifer, or linear in the case of a structural, e.g. dyke or fault, feature). The hydrocensus must include a quantitative assessment of water use from groundwater sources in the likely area of influence. Mitigation is indicated in instances where a reduction in water availability from a source is attributable to groundwater use for SGD activities, in which case the deficit must be compensated for based on the results of a groundwater use monitoring programme.

5.5.1.2 Appraisal activities

Shale gas appraisal activities have a higher water demand as these activities include the fracking of appraisal wells (Burns et al., 2016, Subsection 1.4.3.2.2.1). The fracking itself poses a greater risk to the environment than stratigraphic drilling, and is therefore identified as having a key potential impact. The associated risks are identified in Subsection 5.5.1 and illustrated in Figure 5.27. These comprise mainly the storage and handling of chemicals (used in the fracking process) on the wellpad, and the escape of flowback and produced water from the fracked section of bore via a number of pathways.

Impact: The water requirement for a fracked well is estimated at 544 m^3/d (without re-use). This amounts to a borehole yield of ~13 L/s per 12-hour day. Water supply boreholes of this class in the Karoo environment are scarce, and would likely produce groundwater with a quality suitable for most other uses, SGD, rendering their application for SGD highly contentious.

The storage and handling of chemicals on the wellpad poses a risk of their accidental spillage and escape into the environment if not contained.

The fracking of appraisal wells will not occur on the same scale as that of potential production wells with multiple horizontal sections, and the risk from this activity is therefore not considered as great as in the latter instance. Nevertheless, the risk is not inconsequential, and must be mitigated.

Mitigation: The water requirement is readily mitigated by sourcing water outside of the study area, necessarily requiring its importation into the study area. A possible alternative is the use of municipal waste water procured from local municipalities or, less likely, the utilisation of saline groundwater resources in the study area.

The comparatively short duration and smaller scale of the chemicals storage and handling activity provides a measure of risk reduction in addition to the wellpad protection measures advocated in Table 5.9. The latter include on-surface practices such as lining the wellpad with impermeable material and storing chemicals in bunded tanks that are regularly inspected for leakage.

The impact of fracking is mitigated by the implementation of the raft of measures described in Table 5.9. The most important of these are adherence to sound well construction practices to ensure the integrity of annular seals, and the setback of wells and their horizontal sections from geological structures (mainly faults and dykes), springs and municipal wellfields.

5.5.1.3 Development and production activities

SGD and production comprises similar activities as are associated with appraisal (Subsection 5.5.1.2), but at a significantly larger scale and intensity. The impacts as identified for appraisal activities are therefore equally relevant to development and production, but are an order of magnitude or even greater in terms of potential risk and impact. For example, a production gas well may comprise multiple fracked horizontal sections (laterals) radiating from one vertical bore (although it should be noted that there are multiple configurations for drilling horizontal wells from a wellpad). Further, the duration and geographic footprint of development and production is much longer and wider, respectively, than that of appraisal activities. Amongst other factors, this requires the establishment of a denser access road network. The volume of chemicals stored and handled on the wellpad are similarly much greater.

Impact: The substantial water requirement for either a Small or Big Gas scenario can realistically only be met by sourcing and importing water from outside of the study area.

The greater and more prolonged level of activity spent on a production well increases the risk of unintended accidental spillage on the wellpad.

The scale of fracking associated with the establishment of a gas production well indicates the return of substantially greater volumes of flowback and produced water to surface via the wellbore, compared to an appraisal well. The risk of leakage of contaminated water into the sub-surface via a compromised annular seal (resulting in a loss of well integrity) is therefore significant, and escalates with the scale and duration of SGD.

Mitigation: Water re-use and an advance to techniques that are not water-dependent provide a measure of mitigation for the reliance on an adequate water supply.

The facilities for chemicals storage (e.g. tanks on surface with retaining bunds) required by appropriate regulations (Oelofse et al., 2016) and handling provides a measure of risk reduction. Together with other wellpad protection measures such as lining of the wellpad with impermeable material provides for mitigation of this risk and impact.

As in the case of appraisal wells; the impact of fracking is mitigated by the implementation of numerous measures described in Table 5.9. The most important of these are adherence to sound well construction practices to ensure the integrity of annular seals, and the setback of wells and their horizontal sections from geological structures (mainly faults and dykes), springs, wetlands and municipal wellfields. Further mitigation is provided by the hydrocensus (borehole survey) and baseline data collection activity as well as the intensive geophysical investigations, both of which precede production well drilling and development.

5.5.1.4 <u>Post-development and -production activities</u>

These activities address the legacy of SGD once production ceases. The key potential impact at this stage will be the long-term risk of contamination to groundwater resources from defunct production wells.

Impact: The risk of failure of production well annular seals resulting in the leakage of contaminated produced water in the sub-surface increases with the age of a well. It also increases with the number of such wells in the environment.

Mitigation: The impact associated with the failure of defunct production wells requires the implementation of an effective adaptive management plan based on the results of a groundwater monitoring programme that will be maintained in this stage. Such monitoring will target not only the ageing production wells, but also dedicated monitoring wells constructed for the purpose of detection of contamination. The baseline groundwater chemistry data collected prior to SGD will serve as reference for such detection.

Funding for long-term monitoring and maintenance interventions must be assured at the outset of SGD involving fracking. Possible mechanisms whereby this might be achieved would be via a long-term, dedicated Trust Fund, or alternatively through bond/insurance schemes covering long-term liabilities in case of catastrophic failure.

5.5.2 Indirect groundwater impacts

Indirect impacts are mainly associated with unintended accidental spillage of chemicals and waste water in transit to/from the wellpad along the transport routes that will include public roads. The impact of such incidents will depend on factors such as the magnitude of the spill, the nature of the spilled material, and the location in the landscape. For example, a spillage in proximity to a dolerite dyke or fault (where these intersect the transport route) is of greater hydrogeological significance and risk than were it to occur away from such features.

Impact: The occurrence of accidental spillage is not readily quantified beyond the observation that such incidents will occur.

Mitigation: Mitigation of the impact from unintended accidental spillages must be provided by suitably trained 'hazmat' teams that can be alerted to such incidents and that are equipped to contain the spillage within the environmental setting it occurs.

5.5.3 Surface water issues

5.5.3.1 <u>Overview of issues</u>

This section provides a broad overview of some of the issues associated with SGD that are most likely to be of concern from a surface water perspective. These are assessed in a more structured manner in the sections that follow, as well as in the Risk Assessment of Section 5.6.

Given the close interactions between surface and groundwater already described in Subsections 5.2.3 and 5.2.4, it is clear that some impacts to groundwater will affect surface water resources and *vice versa*. Clear pathways between these systems are illustrated conceptually in Figure 5.27, *inter alia,* in the form of springs, unconfined alluvial aquifers, water supply boreholes and faults.

The main pathways for groundwater-to-surface water contamination include:

- **Vertical pathways directly associated with stimulation wells**, as a result of flowback or produced water that discharges into surface systems. Such impacts are considered unlikely, on a site by site basis, as they would be associated with accidental spills or overflows that bypassed collection devices already included in site design. They would however be more likely as the density and scale of operations increased, and their occurrence would potentially be more likely in extreme conditions such as storm events. EPA (2015) notes that the most significant spill causes in the USA include equipment failure, human error, failure of container integrity, and other causes (e.g., weather and vandalism). The most common cause was equipment failure, specifically blowout preventer failure, corrosion, and failed valves. More than 30% of the 151 fracturing fluid or chemical spills cited were from fluid storage units (e.g. tanks, totes, and trailers). Enforced adherence by operators to legislation that requires the storage of waste in sealed systems would considerably reduce the likelihood of such impacts taking place.

  The main concern with flowback that enters surface water resources (e.g. passes into watercourses) would be from a **water quality** perspective. While Subsection 5.2.2.2 notes that water from deep aquifers is unlikely to have the high TDS concentrations reported from brines in the Marcellus Shale formations for example (TDS of 10 000 to 343 000 mg/L reported by Warner et al. (2012), limited data from deep (> 1000 m) boreholes in the Karoo described in Subsection 5.2.2.2 indicate that this water (classified as "moderately saline" and with a TDS range of 3 000 to 10 000 mg/L) would still have a significantly higher salinity than the range for Karoo surface waters (the DWS water chemistry database cited in Subsection 5.2.3.2 lists a median conductivity of 504 mS/m, which is a TDS of approximately 2850 mg /L for one of the more saline systems in the study area). Inflows of moderately saline produced water into such systems would (depending on the volume discharged compared to natural flows) result in a substantial increase in salinity, well beyond the natural tolerance ranges for aquatic and riparian species, as well as fitness for use in agriculture and as drinking water. Vengosh et al. (2014) commented too that spills of saline flowback and/or produced water could have permanent effects on soil quality, potentially areas in which vegetation could not establish. Such effects could increase soil erosion, particularly in areas prone to high runoff.

Naturally occurring chemicals in produced water included in flowback might include chemicals from deep formations, such as brines, metals, metalloids and volatile organic compounds, again with negative implications for surface water resources in the event that they passed into these systems – high uncertainty exists however as to the kinds of chemicals expected in produced water. Data presented in Subsection 5.2.2.2 note the presence of naturally occurring uranium, radon, arsenic and methane in groundwater samples from some areas of the Karoo and these might well therefore be present in produced water.

Since large volumes of the fluids are utilised, and increase in direct relation to the number of wells, substantial downstream loading of aquatic resources by these chemicals would be possible in an accidental release scenario. Where such releases were the result of floods, dilution by floodwaters might reduce short term toxicity but in the case of conservative (i.e. chemically stable over time) chemicals, they could accumulate in downstream areas such as dams, where evapo-concentration would occur.

Although contamination during flood events would be somewhat diluted, downstream loading would potentially still be high and flood flows would increase the rate of transport through the system as well as potentially exposing shallow water aquifers along flow pathways to infiltration with contaminated water. Brantley et al. (2014), discussing the impacts of fracking on water resources in Pennsylvania, noted that surface leakage into bedrock fractures poses a high risk for contaminant transport into groundwater, and is a more likely transport mechanism than upflows from deep aquifers through geological media.

- **Vertical pathways linking zones of contaminated groundwater with surface resources** – these might include springs (warm and cold) as well as artesian wells and surface supply boreholes, although researchers including RS&RAE (2012) and Brantley et al. (2014) suggest that these pathways seem to be the least likely cause of water contamination, Brantley et al. (2014) did show tracer migration over a distance of 1.3 km perpendicular to the hillslope, from a wellpad to springs.

Even where vertical surface-to- groundwater pathways are not compromised, there are other aspects of SGD that may impact directly on surface resources, with potential knock-on effects in downstream areas and even external catchments, as well as on groundwater (dealt with in Subsection 5.5.1).

Those aspects linked primarily with surface water quality issues centre largely on **waste management and disposal**. Although this Chapter is not concerned with the actual processing and storage of waste (see Oelofse et al., 2016), it is concerned with the potential ultimate discharge of treated waste into watercourses or other surface water resources, the outcomes of illegal discharges of untreated waste into water resources and the potential for accidental spillage of contained waste in transit between wellpads and treatment plants. Hoffman et al. (2014) for example noted instances where tankers transporting waste leaked or overturned on roadways, resulting in discharges onto roadsides that were transported into watercourses, as well as cases of illegal dumping of waste into surface water bodies. Other waste-related impacts to surface waters revolve around their ultimate disposal and treatment, with reduction of TDS being a significant challenge face by Waste Water Treatment Facilities, while the alternative permanent storage of waste water may not be feasible in the long term.

Among the more contentious aspects of SGD in the Karoo region is the issue of **increased water demand** associated with these activities. Section 5.3.1 highlights the fact that surface water resources in the region are already generally over-utilised, with water being imported from the Orange River catchment to provide salinity-dilution services for irrigation in saline upstream areas as well as to supply urban and agricultural areas downstream and south of the study area (Figure 5.24). Given this, it is assumed that no additional surface water resources would be available to support the direct water requirements for SGD or alternatively, surface water resources could be targeted for such additional requirements only at the expense of existing users, including the environment.

This said, development, or even the perception of development of the industry may also prompt the migration of large numbers of job-seekers from major towns, as well as an increase in population numbers from actual employees engaged in the industry. While there is no legal imperative to supply water to meet the direct demands of the SGD industry, there is a requirement in terms of the NWA, to supply water to meet the basic human needs reserve. In the event of a major influx of people into a water scarce Karoo, there will be an increased demand for the provision of water as well as for the provision of sewage treatment and its discharge, either directly into watercourses or by way of irrigation of agricultural or other areas. Meeting such needs may compromise the capacity to meet either the Basic Human Needs or the Ecological Reserve, or both. The Reserve is already compromised in some areas (see Subsection 5.3.1) and potentially under further threat either in catchments within the study area or in catchments outside of the study area, such as the Orange River Catchment (see Subsection 5.3.2).

The previous concerns raised in this section have revolved around direct threats to surface water quality and quantity. **Landscape-scale disturbance** associated with SGD would potentially also impact on surface water resource condition, from exploration phase seismic activity assessments through to extensive road networks and their associated water course crossings, as well as to localised catchment hardening associated with site development. These activities all potentially contribute to increased flood peaks. In areas where the ratio of streamflow generated from large rainfall events is high (e.g. ratio of 1:50 to 1:10 year flood event for a 3 day storm – Figure 5.12), such impacts may significantly increase flooding and flood damage (e.g. erosion and downstream sedimentation). These have been described as common impacts associated with wellpad and pipeline construction in shale gas exploration and production (Brantley et al., 2014). It is noted however that flooding due to hardened surfaces would tend to be localised and can usually be easily mitigated by providing infrastructure.

Finally, the risk posed by SGD activities to **downstream dependent systems** including urban and agricultural users as well as environmental resources such as important estuaries is poorly understood and inadequately quantified. Figure 5.7 illustrates the catchments that are downstream of the present study area, and thus potentially in any surface contamination stream.

The following sections draw on the preceding discussion, in summarising impacts to surface water resources likely to be associated with various activities associated with SGD, and in terms of the scenarios described in Chapter 1 (Burns et al., 2016) in the Preface (Scholes et al., 2016). Mitigation measures are outlined where possible, with avoidance mitigation being highlighted as preferable with regard to a potentially high risk activity being carried out under conditions of (often) low levels of information and/or poor data quality.

5.5.3.2 Assessment of likely impacts resulting from SGD activities

Reference Case

At the outset, it is noted that the Reference Case does not entail any SGD. The Reference Case does, however take cognisance of likely climate change impacts, as well as impacts to surface water ecosystems namely ongoing and increasing water scarcity with climate change likely to result in an increased frequency of extreme events such as drought and floods (Burns et al., 2016). Figure 5A1.15 in Digital Addendum 5A) shows that, in a severe drought, 60% of the study area would receive less than 100 mm rainfall per year. Figure 5.26 shows moreover that in a climate change scenario, runoff would decrease over 80% of the study area, with decreases varying between 15% and 60% of Mean Total Streamflow. These are significant projected decreases, in an environment experiencing already stressed surface water resources. Assuming, as already described in Section 5.3, that fresh water resources are already limited in the study area and limit development, such limitations are likely to become more significant in the future.

Increased assignment of land to the development of renewable energy (e.g. solar power) could trigger catchment hardening and landscaping fragmentation, with concomitant impacts to surface water resources, although the anticipated large-scale influx of jobseekers and its associated likely significant increase in demand for water resources in the case of SGD is probably unlikely.

Direct impacts to surface water resources associated with the Exploration Only, and Small and Big Gas scenarios

Impact A: ***Degradation of watercourses as a result of physical disturbance during exploration.*** It is assumed that additional water demand during the exploration phase would be met through increased groundwater abstraction (see Subsection 5.5.1). **S**eismic exploration could however include disturbance to numerous watercourses and potentially pans and wetlands as well. Resultant compaction and surface disturbance both within watercourses and their catchments would potentially affect infiltration rates (e.g. in alluvial gravels and sands) and increase runoff rates across disturbed compacted surfaces. Such impacts would result in degradation in overall river condition, and where pans and other wetlands were affected by sedimentation and/or high runoff, would decrease the condition of these systems as well. While the biodiversity implications of these impacts are dealt with in Holness et al. (2016), general degradation of surface resource quality is relevant to the present assessment. A decrease in PES category could well result, particularly in rivers to the west of the study area, where high PES categories (A and B) are assumed to reflect low levels of physical disturbance in an arid landscape. The physical activities associated with seismic exploration would be short-lived in all scenarios – however, their effects would potentially be long-term, given the arid environment in which they occur and the slow associated rates of geomorphological recovery.

Mitigation: Mitigation would require avoidance of water courses and pans, and particular attention to disturbance avoidance and remediation in areas prone to extreme rainfall and associated (amplified) runoff (see Figure 5.12). The setbacks from surface water resources cited for Ancillary Activities in Table 5.10 (Subsection 5.7.3) should be implemented, to avoid such impacts.

Impact B: ***Contamination of surface water resources as a result of accidental flowback or production water discharge into surface systems or illegal discharge of waste into surface resources.*** Such impacts, including the accidental passage of saline waste into surface water systems could have significant negative impacts on surface water resource quality, as described in Subsection 5.5.1.1. The likelihood of accidental contaminant release as a result of flooding or storm events would be higher in areas associated with more severe flood events (e.g. as shown in Figure 5.12), and particularly along waste transport routes (e.g. overturning of waste transport trucks and the direct or indirect passage of waste into watercourses). However, since the origins of such incidents are often human error or malice, they are likely to occur outside of storm events as well.

Mitigation: Risk avoidance mitigation is recommended, and the setback areas from all surface water resource components listed in Table 5.10 must be implemented, as these setbacks serve to separate the resource from zones of potential contamination, including roads. In addition, Best Practice measures outlined in Subsections 5.7.1and 5.7.2 and Table 5.9 in particular, including both on-site bunding and in-transit bunding, must be included in all activities involving the storage, transport or other handling of contaminated waste.

Impact C: ***Contamination of surface resources as a result of contact with contaminated groundwater.*** In the event that such contamination occurred, and while a similar range of chemicals to that described in the case of accidental spillage or leaks from flowback water could be anticipated, the duration of exposure could be long-term and immitigable. Nevertheless, the likelihood of occurrence would be very low. The onset of such an impact might also only be at some time far into the future, and thus more difficult to identify.

Alternative pathways for the kinds of groundwater-to-surface water contamination would include active pumping of contaminated water via boreholes supplying reservoirs and dams, as well as degradation of well seals/liners in the long-term, which allow contaminated water to mix between aquifers. This is considered likely in the long term – that is, over timescales of up to hundreds of years.

Mitigation: Mitigation would need to take the form of avoidance of areas in which surface-groundwater linkages are likely (thus reducing vulnerability), and of enforced long-term (permanent) maintenance and management schedules for all wells, on a permanent basis after decommissioning. This means that sufficient long-term funding for such activities must be set aside in trust at the outset of any exploration phase involving deep aquifer penetration and/or fracking, regardless of the profitability of such ventures from a shale gas production perspective. The mitigation measures outlined for long-term groundwater protection are recommended for surface water protection, and include recommendations for high levels of assurance of long-term monitoring and maintenance interventions from the outset of SGD involving fracking. Possible mechanisms whereby this might be achieved would be via a long term, dedicated Trust Fund, or alternatively through insurance schemes covering long-term liabilities in case of catastrophic failure.

The setback areas recommended to ensure the protection of surface water resources outlined in Table 5.10 should be implemented, with areas outside of the mapped setbacks associated with the least risk of surface/groundwater impacts being incurred.

Impact D: **Changes in the characteristics of surface water resources as a result of imports of alternative water sources into the study area to meet drilling and fracking requirements**. Given that the surface resource is considered utilised to its full potential already, it is assumed that additional direct water demand during the exploration phase would be met through sources other than surface waters.

SSI (2012) identifies sea water, desalinated water and treated sewage as potential alternative water sources. Large volumes of these water sources would be required (Table 5.3 and 5.4) and, particularly in the Big Gas scenario where the density of operations would be high, it is possible that point source passage of waste water into surface water courses could occur. Depending on the quality of water used, such waste streams could include nutrient enrichment as well as increased salinities, both of which would degrade surface water resources, if they entered as waste streams or accidentally through spills, overflows or leakages.

Mitigation: Avoidance of ecologically important watercourses or watercourses upstream of catchments with high sensitivity to increased nutrients or salinisation, depending on the source of water, would be required. Detailed assessments of any proposed imports of water resources into the study area would be required to inform adequate mitigation and/or avoidance of significant negative impacts.

Indirect impacts to surface water resources associated with the Exploration Only, and Small and Big Gas scenarios

It is likely that SGD in the study area would have indirect impacts on water resources at a regional level, as a result of the likely associated influx of additional people into the area. The magnitude of such impacts would increase between the Exploration Only and Big Gas scenarios. Three main indirect impacts are considered here.

Impact A: **Changes in surface resource characteristics and stresses as a result of population influxes into water scarce towns and an associated requirement in terms of the NWA for the provision of adequate water to meet their basic water requirements, as well as the reality that actual water demands by an increasing population are likely in practice to exceed such volumes**. It is assumed that increased water demand would need to be met by sourcing alternative water supplies. Since South Africa is already a water-stressed country, the indirect environmental and developmental opportunity costs of sourcing such water would need to be considered, including the ecological costs of enabling activities such as the construction of additional dams on the Orange River, as already discussed in NWRS (2013).

Mitigation: Mitigation would need to consider proposed approaches at a strategic and then detailed impact assessment level. The risks associated with this impact are not therefore assessed in this study "with mitigation".

Impact B: **Changes in surface resource characteristics and stresses as a result of increases in requirements for sewage treatment and effluent discharge, as a result of population increases.** In the event that effluents, possibly with a high salt content if influenced by SGD brines as well, were discharged into watercourses, there would be possible changes in instream hydro-period at least locally, resulting in changes in plant and faunal composition along these systems, which might in turn affect resource quality. Given the scarcity of water resources in the study area, and the likelihood that this will be exacerbated over time as a result of climate change, such discharge into surface water systems is however considered unlikely, given the availability of alternative uses for effluent such as for irrigation. However, if short-term storage and conveyance relied on the use of storage dams and in-channel conveyance, then significant changes might occur, particularly if the use of nutrient enriched or saline water was considered.

In the event that insufficient facilities were available for the treatment of increased sewage loads to adequate standards, then bacterial contamination and significant degradation of affected surface resources could occur, including possible permanent salinisation of soils in affected watercourses as a result of inadequate treatment to remove brine.

Mitigation: Mitigation would need to be at a strategic level – while obvious forms of mitigation would include allowance for adequate waste treatment, for both direct SGD-derived waste (e.g. brines) and indirect waste (e.g. sewage), and its beneficial reuse (ideally) or its alternative benign disposal so as not to disrupt natural surface water ecosystems, allowance for such facilities would need to be undertaken at a Municipal level, rather than by individual developers. Long-term strategic interventions would thus need to be undertaken timeously, and not simply at the start of SGD activities. The disposal of sewage effluent would, in particular, need to avoid disrupting the natural seasonality of Karoo watercourses.

Given the complexity of mitigation at a strategic level and the number of unknowns at this stage, the risks associated with this impact have not been assessed in this study "with mitigation".

Impact C: **Increased peak discharges and associated erosion and watercourse degradation from increased road crossings and catchment hardening**. An inevitable consequence of the kind of activities associated with the proposed exploration, appraisal and production phases of SGD in a largely undeveloped region such as the Karoo is that additional infrastructural development requirements would be high, including the need for roads, pipelines, and possibly other service infrastructure such as electricity and communication networks (e.g. fibre-optic cables etc.). At a large-scale (e.g. Big Gas scenario) such activities would entail multiple and permanent changes at a landscape level, affecting watercourses by fragmentation (multiple crossings), which increase the risk of flood-event driven damage such as erosion, which usually concentrates at road crossings. Such impacts are, it is assumed, also assessed in Holness et al. (2016).

Mitigation: While mitigation of the above would be possible to some degree, such impacts would be an inevitable component of extensive development, and would contribute to potential lowering of presently high PES categories for rivers across affected parts of the study area.

Nevertheless, the setback areas recommended to ensure the protection of surface water resources outlined in Table 5.10 for “Ancillary Activities” should be implemented, with areas outside of the mapped setbacks associated with the least risk of surface/groundwater impacts being incurred.

Impact D: **Failure of mitigation and best practice measures as a result of poor institutional capacity and/or will to effect compliance with legislation and required conditions of authorisation.** This is considered a high risk in South Africa’s current climate, where the water resources sector is often characterised by a lack of institutional capacity, poor levels of experience and training amongst implementing officials, a limited capacity to undertake effective audits, poor training in and ability to implement existing legislation, and poor records in effecting visible and consistent application of legislation.

Mitigation: Mitigation requires a significant *a priori* investment into the water resources and affiliated sectors, around ensuring high standards in setting legally defendable licensing conditions for SGD, ensuring adequate collection of pre-impact baseline data, effective policing of developer and State compliance in both the short- and the long-term, and ensuring that monitoring is carried out in a scientifically and technically rigorous manner, with sound interpretation of results and their implications, and adequate allowance for effective interventions in the event of critical thresholds being approached (see Section 5.6).

5.6 Risk Assessment

5.6.1 Identification of sensitive areas

Assessment of the risks to ground- and surface water resources as a result of both direct and indirect impacts derived from SGD and associated activities has been based on the methodology and assumptions outlined in the Preface to this scientific assessment (Scholes et al., 2016). In order to provide a spatial representation of the study area in terms of Risk, two approaches were followed.

- First, Figure 5.12 was used as the basis on which to assign levels of risk in the placement of SGD within the study area – Quinary catchments in which the ratio of the 1:50 to 1:10 year extreme 3 day streamflow event is >3 are considered to be **High Risk areas** for undertaking any of the activities associated with SGD, given the severe levels of external disturbance to which they are likely to be exposed over the life of the development, increasing the probability of resource contamination and other sources of degradation.

- Secondly, the setbacks developed during the course of this scientific assessment (see Section 5.7.3) and detailed in Table 5.10, were applied to all aspects of geology, geohydrology and surface water resources considered necessary to assure the protection of water resources in a SGD context. The mitigation measures outlined in Section 5.5 and assumed in the assignment of risk ratings “with mitigation” (Table 5.5 and 5.6) are based largely on achieving these setbacks. The setbacks themselves do not necessarily represent areas of certain high sensitivity. Rather, in a field with high levels of uncertainty, they have been developed to exclude areas where SGD activities could pose a risk to the resource, and thus indicate areas where there is at least moderate confidence that SGD activities could proceed without incurring such risk. In some instances, further investigation within the setback areas might show less actual risk than that based on small-scale maps and coarse data, and such refinement might indicate additional areas for development.

At the level of the current assessment, a conservative, risk-averse approach is however considered warranted. Two sets of maps were developed through this process. They are shown as summary overlays in Figure 5.28 to 5.31, but detailed in Digital Addendum 5E, allowing the contribution of individual criteria to overall setback definition to be gauged. The figures indicate (separately) setbacks that should be applied in siting any activities involving fracking, and those that must be applied in the siting of so-called “Ancillary Activities” – that is, all other activities and infrastructure that do not include fracking. In this regard, it must be stressed that Figure 5.28 to 5.31 showing areas of particular significance with regard to surface and groundwater resources, have been mapped mostly at a small scale (e.g. 1:500 000), and actual site-specific conditions within various categories of classification are liable to vary quite widely. These figures must therefore be interpreted strictly with this limitation in mind.

5.6.2 *How are risks measured?*

The determination of risk in this scientific assessment was derived from a matrix of the likelihood of occurrence and the consequences if a particular event occurred. This matrix is presented in the Preface (Scholes et al., 2016), and is common to all of the risk assessments presented in the different Chapters of the scientific assessment. Different levels of certainty encompassed in the likelihood ratings have also been clearly defined in the Preface Scholes et al. (2016). By contrast, the levels of consequence that are used in the risk matrix require calibration and/or definition with regard to Surface and Groundwater Resources. The definitions developed for the purposes of this Chapter are outlined in Table 5.5, where:

- **Duration** is categorised as short-, medium- and long-term, as follows:
    - Short-term (<3 years)
    - Medium-term (3 to 40 years)
    - Long-term (>40 years and in some cases extending hundreds of years into the future)
- **Extent** is categorised as Local/site specific, Medium and Regional, as follows:
    - Local/site specific (defined as local/site specific for surface water resources and occurring at a local level and/or the level of a wellpad for groundwater resources);
    - Medium (occurring within a defined reach level/Quaternary catchment(s)/pan or wetland cluster or system for surface water resources and at the level of a groundwater system of aquifer for groundwater resources);
    - Regional (occurring at a catchment scale or across catchments (that is, upstream/downstream longitudinally at a catchment level (primary river) and/or adjacent primary or secondary catchments for surface water resources and at a trans-system/trans-basinal scale for groundwater resources).

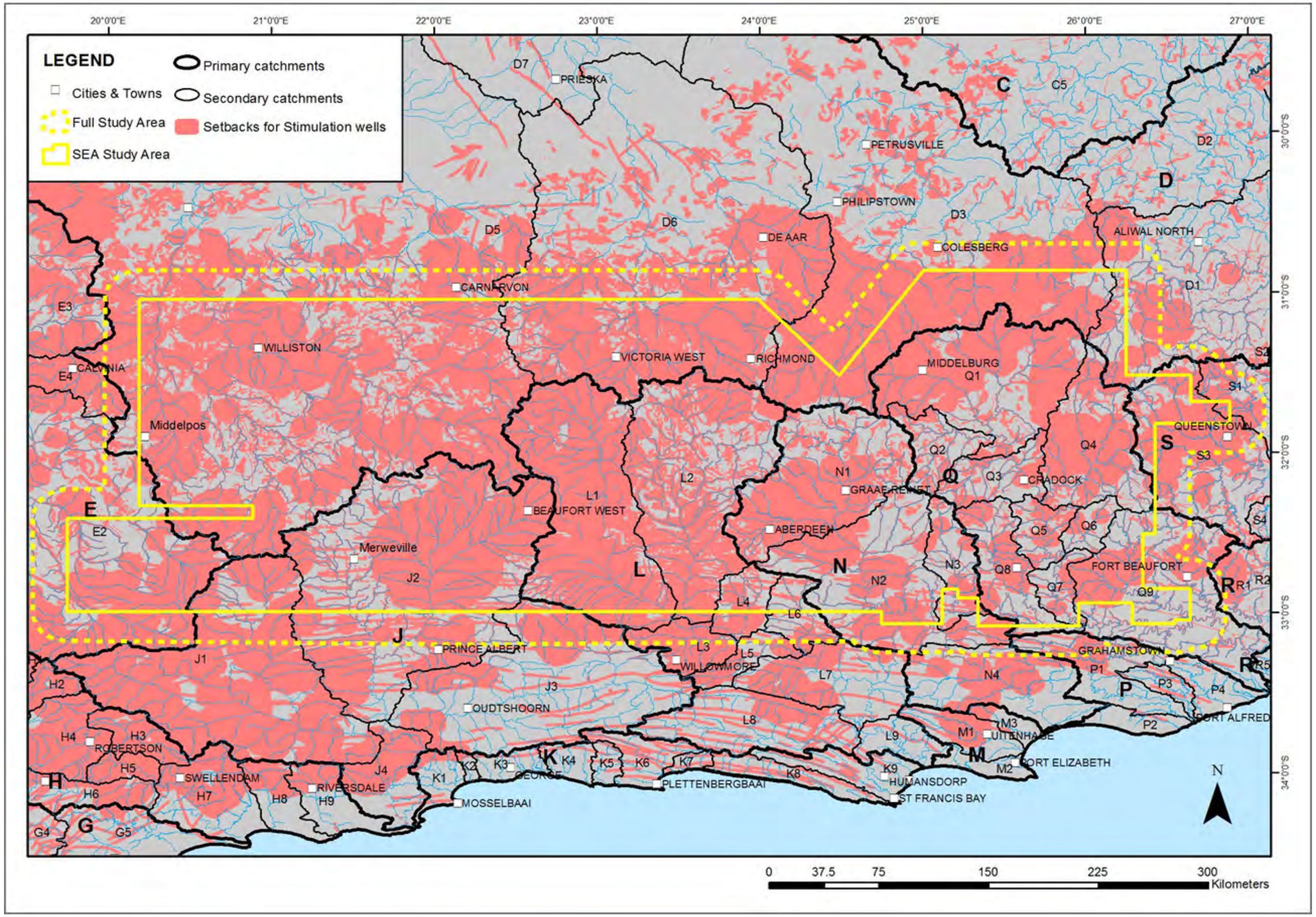

Figure 5.28: Combined sensitivity map for stimulation well activities.

In the grey areas (medium sensitivity) well stimulation (fracking) activities might take place with at least medium confidence (given concerns regarding scale of mapping) that it will not impact significantly on known surface and/or groundwater resources. Highlighted pink areas of high sensitivity comprise areas in which impacts to water resources is possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). In addition, dolerite dykes have been accorded a minimum sensitivity of 250 m which might not always apply - dolerite dyke spatial data require better resolution than at present. Sensitivity shown here is determined from setback distances recommended in Table 5.10. Note: Not all features in this table are represented in this figure, only features for which spatial data was available at the time.

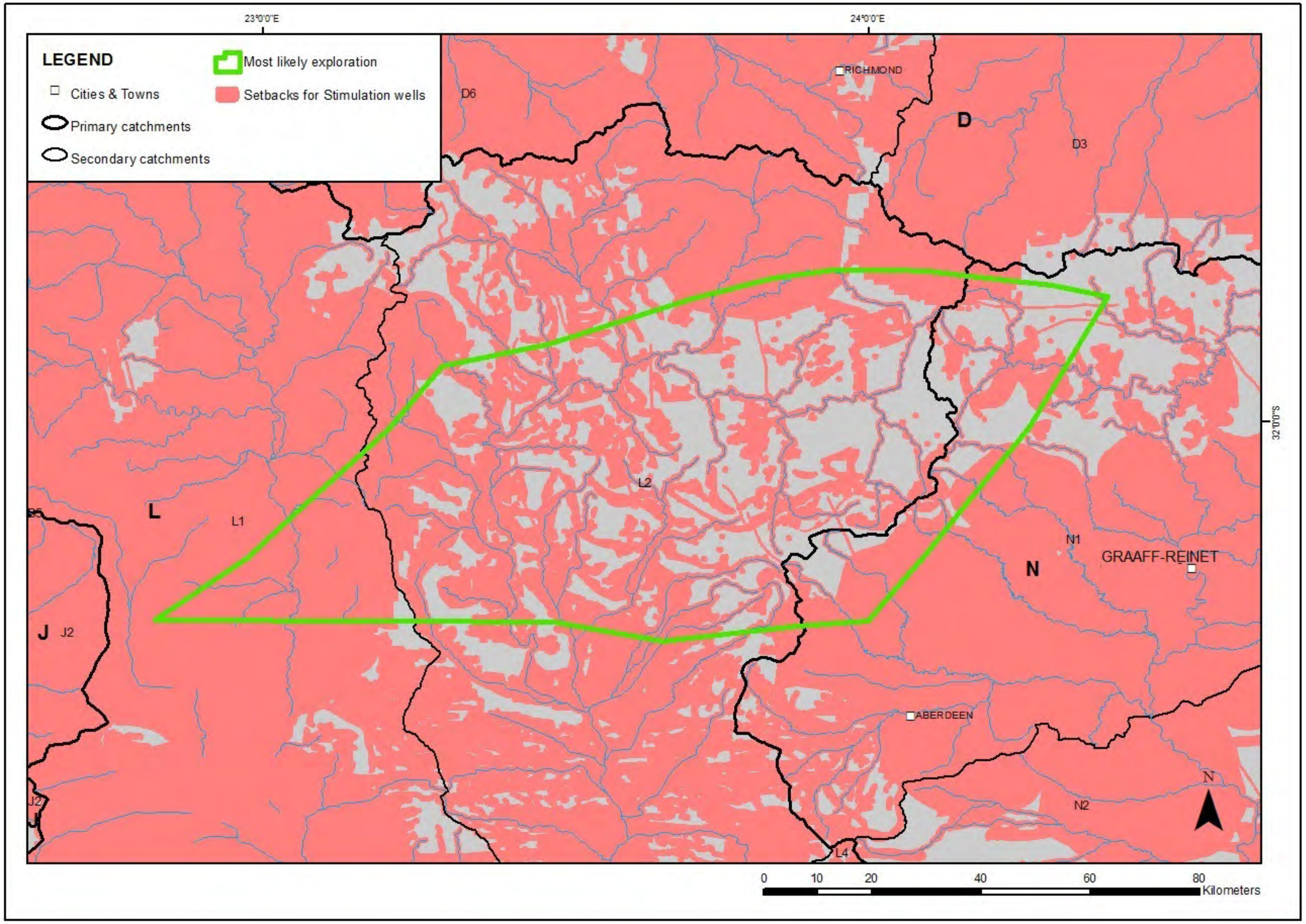

Figure 5.29: Combined sensitivity for stimulation well activities: focus on assumed most likely exploration zone, to illustrate high sensitivity areas at a larger scale than in Figure 5.28.

Map showing medium sensitivity areas (grey) in which well stimulation (fracking) activities might take place with at least medium confidence (given concerns regarding scale of mapping) that it will not impact significantly on known surface and/or groundwater resources. Highlighted (pink) high sensitivity areas comprise those areas in which some risk to water resources is potentially possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). In addition, dolerite dykes have been accorded a minimum setback of 250 m which might not always apply dolerite dyke spatial data require better resolution than at present. Setbacks shown here illustrate the combined setback distances recommended in Table 5.10. Note: Not all features in this table are represented in this figure, only features for which spatial data was available at the time of compilation of this Chapter, are shown.

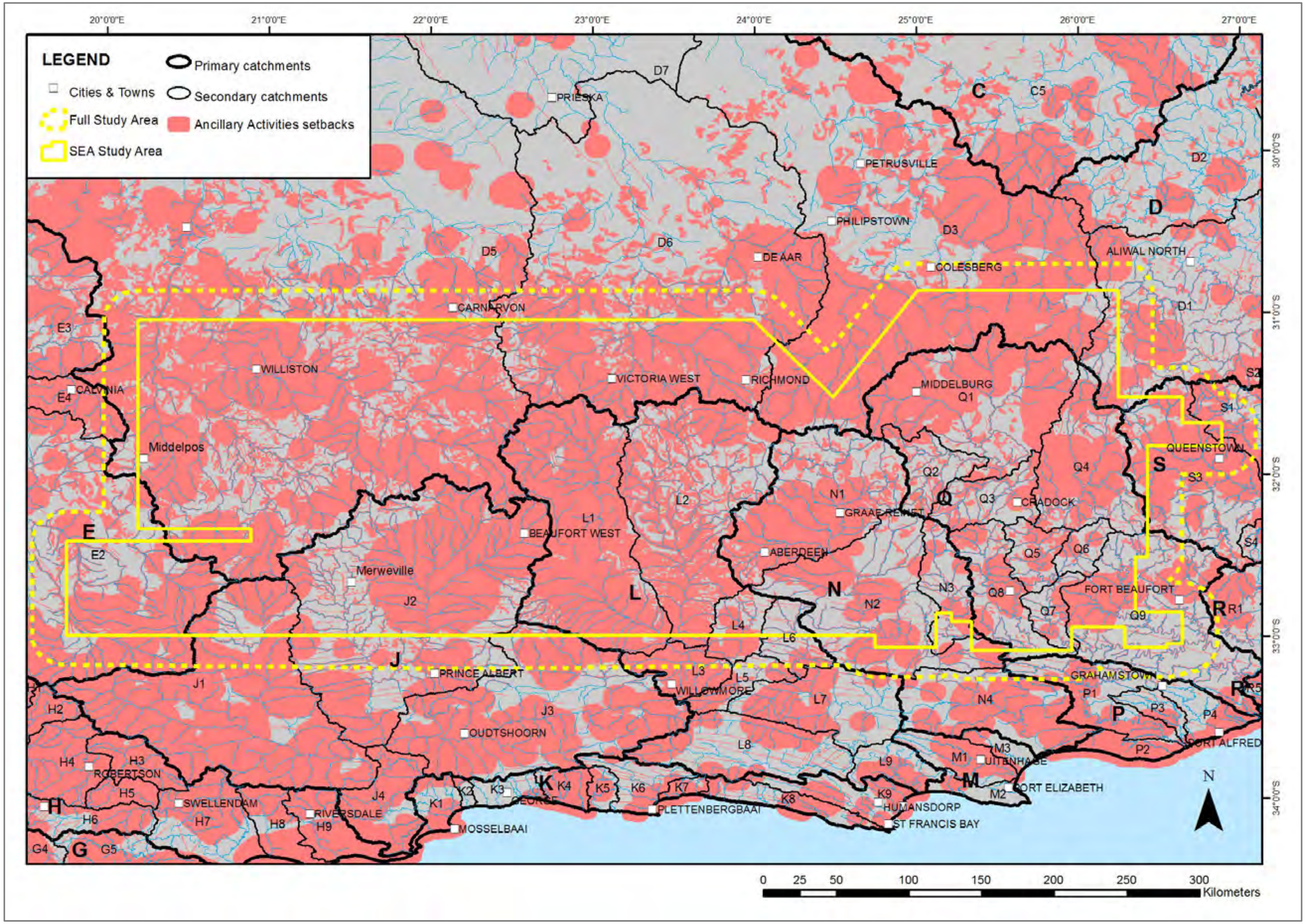

Figure 5.30: Combined sensitivity for so-called "Ancillary Activities" (as defined in Table 5.10).

Map showing remaining grey areas (medium sensitivity) in which ancillary activities might take place with at least medium confidence (given concerns regarding scale of mapping) that it will not impact significantly on known surface and/or groundwater resources. Highlighted pink areas of high sensitivity comprise those areas in which some risk to water resources is possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). In addition, dolerite dykes have been accorded a minimum setback of 250 m which might not always apply – dolerite dyke spatial data require better resolution than at present. Setbacks shown here illustrate the combined setback distances recommended in Table 5.10. Note: Not all features in this table are represented in this figure, only features for which spatial data were available at the time of compilation of this Chapter, are shown.

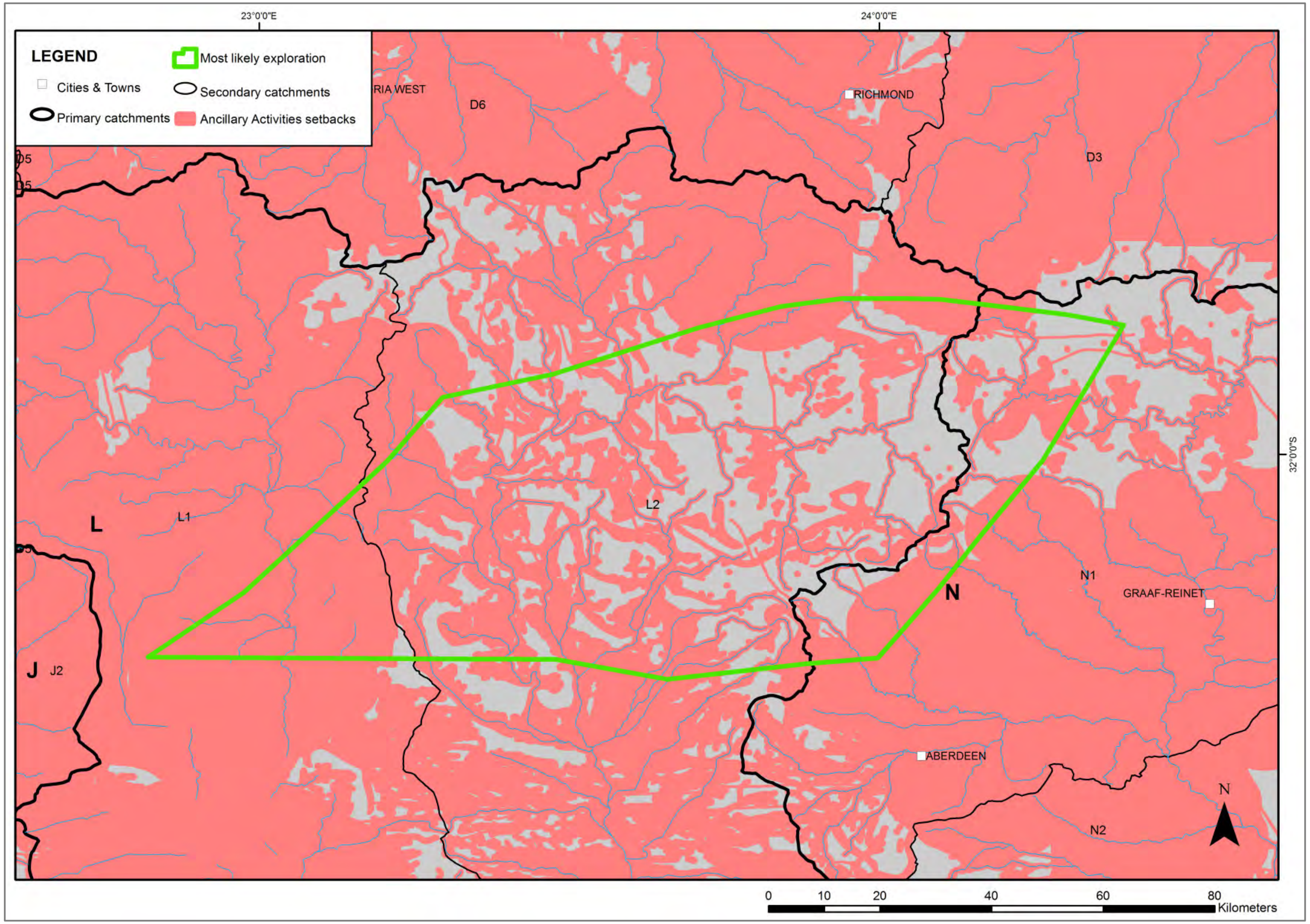

Figure 5.31: Combined sensitivity for so-called "Ancillary Activities" (as defined in Table 5.10): focus on assumed most likely exploration zone, to illustrate setbacks at a larger scale than in Figure 5.30.

Map showing grey areas (medium sensitivity) in which ancillary activities might take place without impacting significantly on known surface and/or groundwater resources. Highlighted (pink) areas comprise high sensitivity areas in which some risk to water resources is possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). In addition, dolerite dykes have been accorded a minimum setback of 250 m which might not always apply - dolerite dyke spatial data require better resolution than at present. The sensitivities shown here illustrate the combined setback distances recommended in Table 5.10. Note: Not all features in this table are represented in this figure, only features for which spatial data was available at the time of compilation of this Chapter, are shown.

Table 5.5: Consequence levels developed for use in assignment of risk to water resources.

<table>
<tr><th>Consequence Level</th><th>Description</th></tr>
<tr><td>Slight</td><td>Impacts reduce risk or do not change it in a way that is discernible
No thresholds of concern[3] (see Box for definition) are exceeded
Resource ecostatus class would not change
Limited in extent: Site specific
Readily reversible at any time and/or of short-term duration</td></tr>
<tr><td colspan="2">The impact should not have an influence on the decision, provided that recommended measures to mitigate negative impacts are implemented.
A slight consequence level would be accorded to the following ratings:
EITHER of low intensity at a local extent and endure in the medium-term;
OR of low intensity with medium extent and endure in the short-term;
OR of low to medium intensity at a local extent and endure in the short-term</td></tr>
<tr><td>Moderate</td><td>Some degradation in resource status/possible change in class
Thresholds of concern may be exceeded
Readily reversible once activity ceased
Impacts will be well within the tolerance levels or adaptive capacity of the users (NWA) relying on the resource</td></tr>
<tr><td colspan="2">The impact should not have an influence on, or require to be significantly accommodated in the development design.
A moderate consequence level would result from the following categories of impacts:
EITHER of low intensity at a medium extent and endure in the medium-term;
OR of high intensity at a local extent and endure in the short-term;
OR of medium intensity at a regional extent in the short-term;
OR of low intensity at a local extent and endure in the long-term;
OR of medium intensity at a local extent in the short-term (excluding cumulative impacts);</td></tr>
<tr><td>Substantial</td><td>Marked degradation in resource status
Thresholds of concern are exceeded
Surface water impacts potentially reversible once activity ceases
Groundwater impacts reversible only with significant human intervention over decades
Beyond the adaptive capacity of the users relying on the resource</td></tr>
<tr><td colspan="2">The impact could have an influence on the environment which will require modification of the development design or alternative mitigation.</td></tr>
</table>

[3] Thresholds of Concern (usually referred to as Thresholds of Potential Concern (TPCs) or Stress Tipping Points) are numerically defendable nodes after which damage to ecosystems is expected to be irreversible (Rogers and Bestbier, 1997). Such thresholds would need to be defined for the variables of concern in a SGD scenario.

<table>
<tr><th>Consequence Level</th><th>Description</th></tr>
<tr><td colspan="2">A substantial consequence level would result from the following categories of impacts:
• EITHER of high intensity at a local level and endure in the medium-term;
• OR medium intensity at a medium level in the medium-term;
• OR of high intensity at a medium level in the short-term;
• OR of medium intensity at a regional level and endure in the short-term;
• OR of medium intensity at a local level and endure in the long-term;
• OR of low intensity at a regional level in the medium-term;
• OR of low intensity at a medium level in the long-term</td></tr>
<tr><td>Severe</td><td>Considerable degradation in resource status
Thresholds of concern significantly exceeded, approaching system-state tipping point
Surface water impacts reversible only with human intervention over decades
Groundwater impacts are effectively irreversible</td></tr>
<tr><td colspan="2">The impact could have a no-go implication for the development or a component of the development, regardless of any possible mitigation).
A severe level of consequence would result from the following categories of impact:
• EITHER of medium intensity at a medium extent in the medium-term;
• OR of high intensity at a regional extent in the short-term;
• OR of medium intensity at a regional extent in the medium-term;
• OR of low intensity at a regional extent in the long-term;
• OR of high intensity at a local extent in the long-term;
• OR of medium intensity at a medium extent in the long-term</td></tr>
<tr><td>Extreme</td><td>Significant degradation in resource status
Thresholds of concern are exceeded beyond critical system-state tipping point/irreversible change
Resource impacts irreversible and remediation impractical
Sole source groundwater resource that would be rendered unusable</td></tr>
<tr><td colspan="2">The impact would strongly influence the decision and further steps should be investigated to avoid the impact).
An extreme consequence level would result from the following categories of impact:
• EITHER of high intensity at a medium extent and endure in the medium-term;
• OR of high intensity at a regional extent in the medium-term;
• OR of medium intensity at a regional extent in the long-term</td></tr>
</table>

5.6.2 Defining limits of acceptable change

The limits of acceptable change in different aspects of surface and groundwater resources, as considered in this Chapter, refers to the degree to which some change in resource characteristics as a result of direct or indirect impacts of SGD may be acceptable from a resource sustainability perspective. Beyond a certain point (limit or threshold), the impacts are likely to exceed sustainability levels.

The following "limits of acceptable change" are put forward in this scientific assessment:

- Any impact that would result in degradation of any aspect of the resource to a level less than the Desired Management Class for that resource component – note that the Desired Management Class has not yet been set for the study area, and would need to be set before any SGD-associated resource use is considered in this area;
- Any impact that results in a deterioration in resource quality would be an impact of high negative significance – even if associated with only one attribute or one water quality variable. The water quality guidelines for aquatic ecosystems and agriculture, as listed in Table 5.6, should be used as a guide to what constitutes a significant change in a water quality variable, bearing in mind that pre-SGD conditions might already exceed some of these thresholds. This emphasises the importance of undertaking extensive pre-development monitoring (see Section 5.8).

Management Class and the Water Resource Classification System (WRCS)
(after Dollar et al., 2006)

The WRCS is a set of guidelines and procedures for determining the different classes of water resources.

The Management Class (MC) represents the desired characteristics of the resource and outlines those attributes that the custodian (DWS) and society require of different water resources. The outcome of the Classification Process will be the setting of the Management Class, Reserve and Resource Quality Objectives (RQO's) for every significant water resource. The aim of this process is therefore to help facilitate a balance between protection and use of the nation's water resources. The WRCS is required by the National Water Act (NWA) (No. 36 of 1998 (Chapter 3, Part 1, Section 2(a)).

Table 5.6: Target water quality ranges for surface water use, with values taken from DWAF (1996a, b and c) unless otherwise specified. Concentrations are of dissolved, usually ionic, species of the elements listed. [ ] = concentration.

Chemical substance or Physical property	DWAF target water quality range for irrigation (after DWAF, 1996a)	DWAF target water quality range for stock watering (after DWAF, 1996b)	DWAF Target Water Quality Range for aquatic ecosystems (after DWAF, 1996c)	Acute toxicity values and comments (after DWAF, 1996c unless specified otherwise)
Electrical conductivity (mS/m) (=TDS)	≤40	≤300	TDS concentrations should not vary by >15% from normal cycles in the water body at any time of the year and the amplitude and frequency of natural cycles in [TDS] should not change.	
pH	6.5-8.4		pH should not vary from the range of background pH values for a specific site and time of day by >0.5 of a pH unit or by >5%, whichever is the more conservative. [nb: pH values in natural waters in the south-western Cape may be as low as 4.0 because of the presence of humic substances.]	
Suspended solids (mg/L)	≤50		Increases should be <10% of background [TSS] at a specific site and time. This criterion refers only to the physical presence of particulate material and not any potential toxic effects.	
Temperature			Species and site-dependent: should not vary from natural conditions for the specific site and time of day by >2°C.	
Aluminium (mg/L)	≤5.0	≤5.0	pH ≤6.5, 0.005	pH ≤6.5, 0.1 (DWAF (1996C)); pH ≤6.5, 0.75 (EPA) Aluminium is extremely toxic at low pH values (<6) and is the prime cause of biodiversity loss in acidified water
Ammonia (mg/L)			≤0.007 mg/l un-ionised ammonia (i.e. NH_3, pH >8.4)	0.1 mg/L un-ionised ammonia (i.e. NH_3, pH >8.4) (DWAF, 1996C); 2.9 mg/L N: EPA https://www.regulations.gov/document?d=epa-hq-ow-2009-0921-0001 Ammonia (NH_3) is very toxic but ionised ammonium ions (NH_4^+) are not.
Arsenic (mg/L)	≤0.1	≤1	≤0.01	0.13 (DWAF (1996C)); 0.34 (EPA) Arsenic is toxic and carcinogenic.
Beryllium (mg/L)	≤0.1 mg/L			Beryllium is extremely toxic but is found in natural waters only at very low concentrations.
Boron (mg/L)	≤0.5	≤5.0		Although boron is an essential plant nutrient, many of its compounds are toxic to plants at relatively low concentrations
Cadmium (mg/L)	≤0.01	≤0.01	**≤0.00015-0.00040	**0.003-0.013 Cadmium is toxic at very low concentrations; it can accumulate in plants and soils, making them toxic too.
Chlorine, free (mg/L)			≤0.0002	0.013 (EPA) While chloride ions (Cl^-) are not toxic, free chlorine (Cl_2, HOCl) is extremely toxic.
Chromium (vi) (mg/L)	≤0.1	≤1	≤0.007 Cr(vi)	0.200 (DWAF, 1996C); 0.016 (EPA)

Chemical substance or Physical property	DWAF target water quality range for irrigation (after DWAF, 1996a)	DWAF target water quality range for stock watering (after DWAF, 1996b)	DWAF Target Water Quality Range for aquatic ecosystems (after DWAF, 1996c)	Acute toxicity values and comments (after DWAF, 1996c unless specified otherwise)
			≤0.012 Cr(iii)	The chemical species of chromium vary in toxicity, the highly oxidised Cr (vi) being most toxic.
Cobalt (mg/L)	≤0.05	≤1		**0.34-1.0 (Diamond et al., 1992) Cobalt is toxic at low concentrations but more so in soft than hard waters.
Copper (mg/L)	≤0.2	≤0.5	**≤0.0003 –0.0014	**0.0016-0.012 Copper is a micronutrient but is toxic even at low concentrations. It is commonly used to suppress algal growth.
Cadmium (mg/L)			**0.15-0.4	**0.003-0.013 (DWAF, 1996c); 0.002 (EPA) Cadmiumd is potentially harmful to most forms of life (EPA)
Cyanide (mg/L)			≤0.001	0.110 (DWAF, 1996c); 0.022 (EPA)
Fluoride(mg/L)	≤2	≤2	≤0.750	2.540 While fluoride is necessary for bones and teeth of vertebrates, it is toxic at fairly low concentrations
Iron (mg/L)	≤5	≤10	Concentrations should not vary by >10% of the background concentration at a specific site and time	
Lead (mg/L)	≤0.2	≤0.1	**≤0.0002 – 0.0012	**0.004 – 0.016 (DWAF, 1996C), 0.065 (EPA) Lead is a very toxic element.
Manganese (mg/L)	≤0.02	≤10	0.180	1.300 Manganese is more toxic at low than at high pH values
Mercury (mg/L)		≤0.001	≤0.00004	0.0017 (DWAF, 1996c); 0.001(EPA) - both methyl mercury. Mercury, especially in the form of methyl mercury, is extremely toxic
Nickel (mg/L)	≤0.2	≤1		**0.47 (EPA) Nickel is toxic and carcinogenic.
Nitrate/nitrite as N (mg/L)	≤5	≤100		Nitrates and nitrites are not normally directly toxic in the aquatic environment
Phosphorus (as orthophosphate (mg/L)			Inorganic phosphorus concentrations should not be changed by >15% from that of the water body under local, un-impacted conditions.	
Selenium (mg/L)	≤0.02	≤50 micrograms	≤0.002	0.030 (DWAF, 1996c); 0.005 (EPA: https://www.epa.gov/sites/production/files/2016-06/documents/se_2016_fact_sheet_final.pdf) Selenium is a micronutrient but is toxic at higher concentrations; it also accumulates up the food-chain.
Uranium (mg/L)	≤0.01			As well as radiation effects, uranium is known to be toxic to humans and,

Chemical substance or Physical property	DWAF target water quality range for irrigation (after DWAF, 1996a)	DWAF target water quality range for stock watering (after DWAF, 1996b)	DWAF Target Water Quality Range for aquatic ecosystems (after DWAF, 1996c)	Acute toxicity values and comments (after DWAF, 1996c unless specified otherwise)
				by implication, to many other living organisms
Vanadium (mg/L)	≤0.1	≤1		Vanadium is accumulated by some marine organisms but is toxic to most organisms at relatively low concentrations.
Zinc (mg/L)	≤1	≤20	≤0.002	0.036 (DWAF, 1996c); 0.120 (EPA) Zinc is an essential micronutrient but is also toxic at fairly low concentrations in the environment.

** Dependent on hardness of water: range from soft to hard water

EPA data from national recommended water quality criteria - aquatic life criteria table, https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#a, updated 28.07.2016. Aquatic life criteria for toxic chemicals are "the highest concentration of specific pollutants or parameters in water that are not expected to pose a significant risk to the majority of species in a given environment".

Exact chronic effect values vary from species to species, so DWAF (1996c) and EPA values listed under "acute toxicity values" are not identical because they are based on toxicological experiments with different species, or include a "safety factor" where insufficient data are available. The values for each element are nonetheless usually well within the same order of magnitude.

Concentrations of the divalent cations Ca^{2+} and Mg^{2+} are low in "soft" waters and high in "hard" waters.

5.6.3 Results of Risk Assessment

The outcomes of the Risk Assessments are presented in the following tables. [Note: The tables have deliberately not been allowed to break across pages in order to facilitate the reading thereof.]

Table 5.7: Groundwater risk assessment

Note that assessments "with mitigation" in all cases included the assumption that SGD occurs outside of high sensitivity areas shown in Figure 5.28.

Direct impact	Scenario	Location	*Without mitigation*			*With mitigation (incl. avoidance of high sensitivity areas)*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Reduced water availability for people and other economic activities	Reference Case	In vicinity of wellfield or region where water is sourced	Moderate	Likely	Low	Moderate	Not likely	Low
	Exploration Only		Moderate	Likely	Moderate	Slight	Likely	Low
	Small Gas		Severe	Likely	High	Substantial	Likely	High
	Big Gas		Extreme	Very likely	Very high	Severe	Likely	High
Contamination of groundwater resources through surface spills and discharge	Reference Case	High sensitivity	Slight	Extremely unlikely	Very Low	Slight	Extremely unlikely	Very Low
	Exploration Only		Moderate	Likely	Low	Moderate	Not likely	Low
	Small Gas		Moderate	Likely	Low	Moderate	Not likely	Low
	Big Gas		Moderate	Likely	Moderate	Moderate	Not likely	Low
	Reference Case	Medium sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Moderate	Likely	Low	Slight	Extremely unlikely	Very low
	Small Gas		Moderate	Likely	Low	Moderate	Likely	Low
	Big Gas		Moderate	Likely	Low	Moderate	Likely	Low
Contamination of groundwater resources caused by a loss of well integrity and via preferential pathways caused by fracking	Reference Case	High sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Moderate	Likely	Low	Moderate	Not likely	Low
	Small Gas		Moderate	Likely	Low	Moderate	Likely	Low
	Big Gas		Substantial	Very likely	Moderate	Substantial	Likely	Moderate
	Reference Case	Medium sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Small Gas		Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Big Gas		Moderate	Likely	Low	Slight	Extremely unlikely	Very low

Figures 5.32 to 5.33 present risk maps of contamination of groundwater across four SGD scenarios, with- and without mitigation.

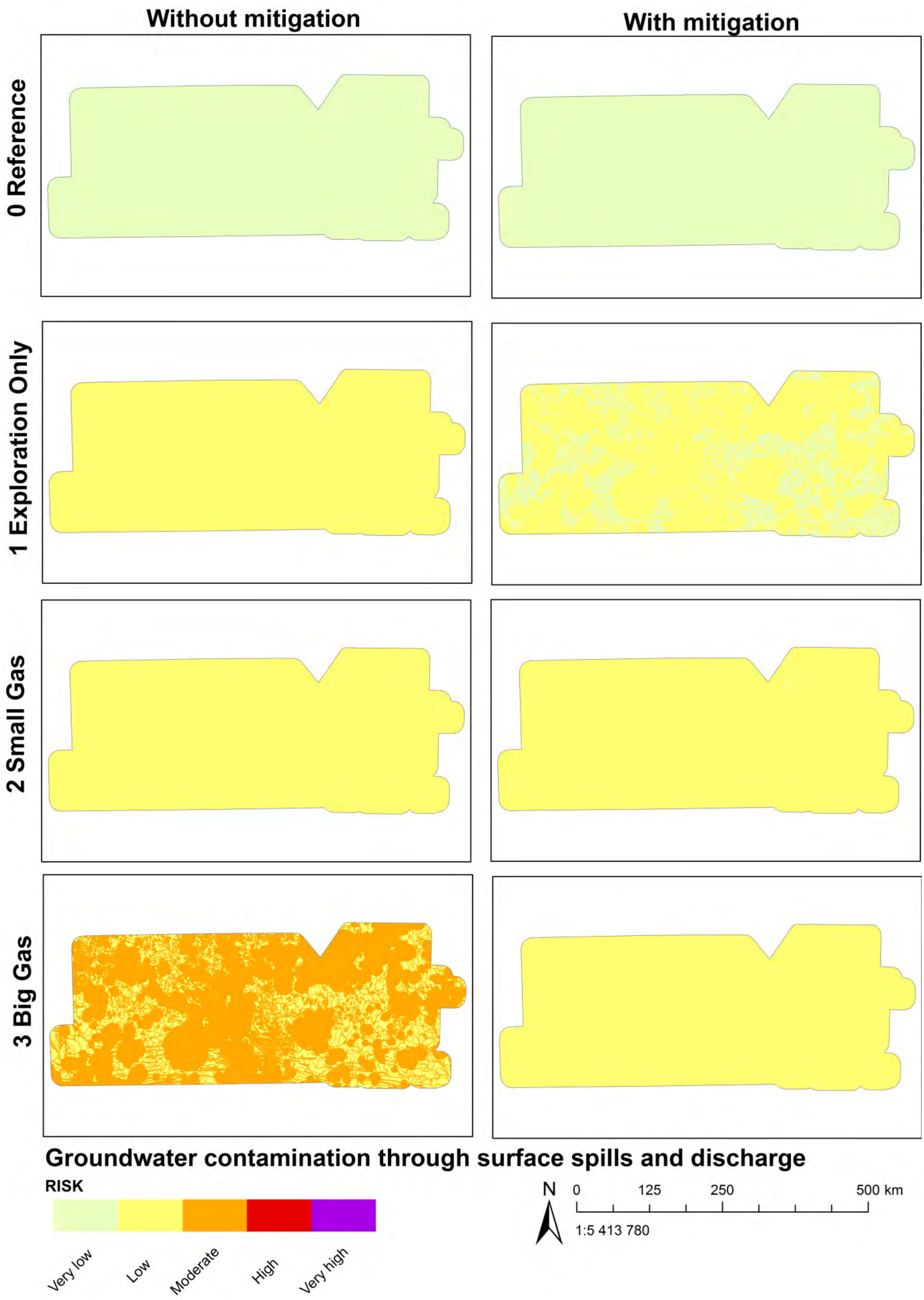

Figure 5.32: Map indicating the risk of groundwater contamination through surface spills and discharge across four SGD scenarios, with- and without mitigation.

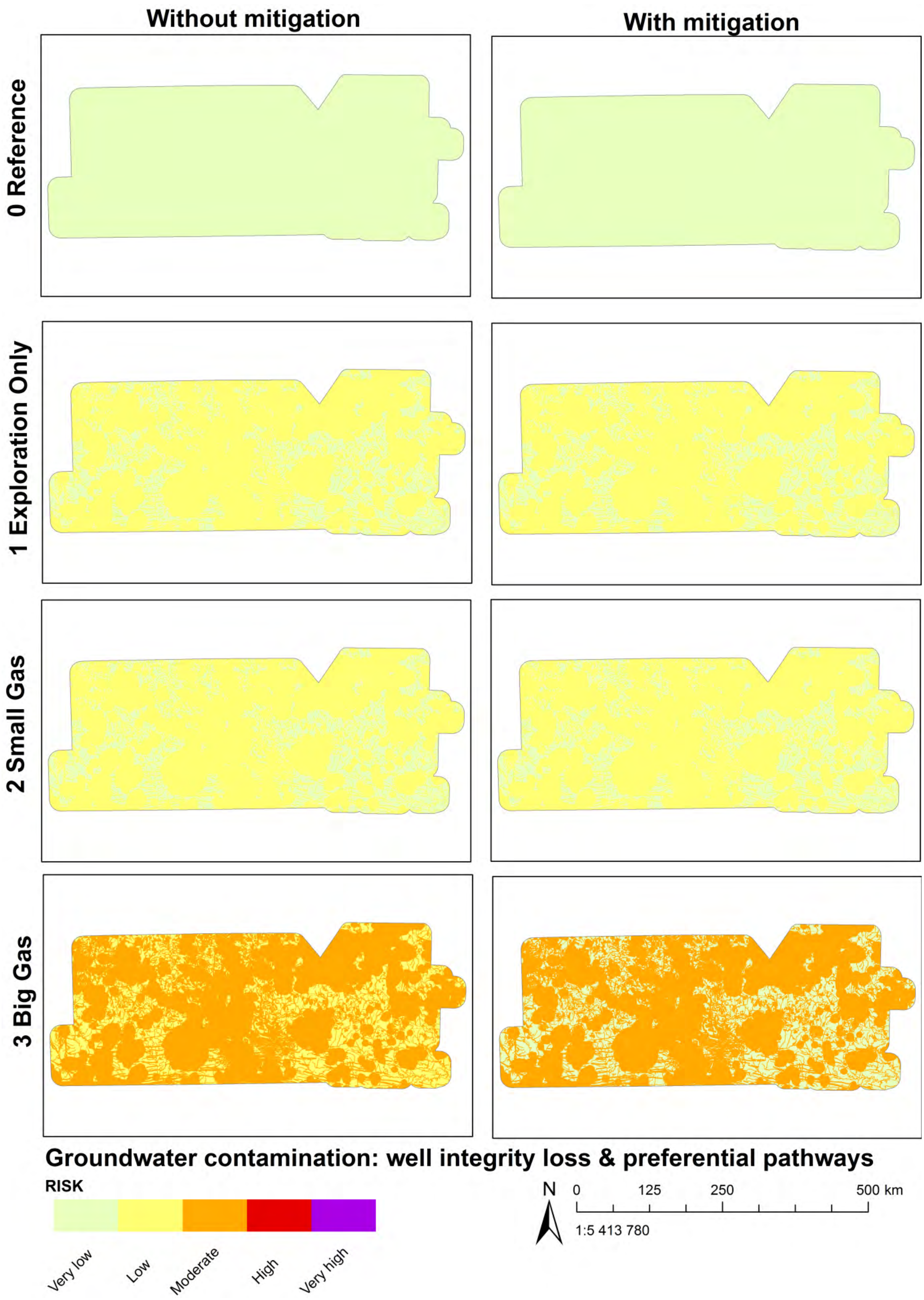

Figure 5.33: Map indicating the risk of groundwater contamination through the loss of well integrity and preferential pathways caused by fracking across four SGD scenarios, with- and without mitigation.

Table 5.8a: Surface water risk assessment of direct impacts.

Note that assessments "with mitigation" in all cases included the assumption that SGD occurs outside of high sensitivity areas shown in Figure 5.28.

Direct impact	Scenario	Location	*Without mitigation*			*With mitigation (incl. avoidance of high sensitivity areas)*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Physical disturbance to watercourses and contamination of surface water resources through flowback discharge and contact with contaminated groundwater	Reference Case	High sensitivity	Slight	Not likely	Low	Slight	Extremely unlikely	Very low
	Exploration Only		Moderate	Very likely	Moderate	Slight	Likely	Low
	Small Gas		Severe	Very likely	High	Moderate	Likely	Moderate
	Big Gas		Severe	Very likely	High	Moderate	Likely	Moderate
	Reference Case	Medium sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Slight	Not likely	Low	Slight	Extremely unlikely	Very low
	Small Gas		Moderate	Likely	Moderate	Slight	Not likely	Low
	Big Gas		Moderate	Likely	Moderate	Slight	Not likely	Low
Changes in the characteristics of surface water resources as a result of imports of alternative water sources into the study area to meet drilling and fracking requirements	Reference Case	Extensive within and potentially downstream of areas developed for SGD areas	Slight	Not likely	Low	Slight	Extremely unlikely	Very low
	Exploration Only		Slight	Not likely	Low	Slight	Not likely	Low
	Small Gas		Moderate	Not likely	Low	Moderate	Not likely	Low
	Big Gas		Moderate	Not likely	Low	Moderate	Not likely	Low

Figures 5.34 present risk maps of physical disturbance to watercourses and contamination of surface water resources through flowback discharge and contact with contaminated groundwater across four SGD scenarios, with- and without mitigation.

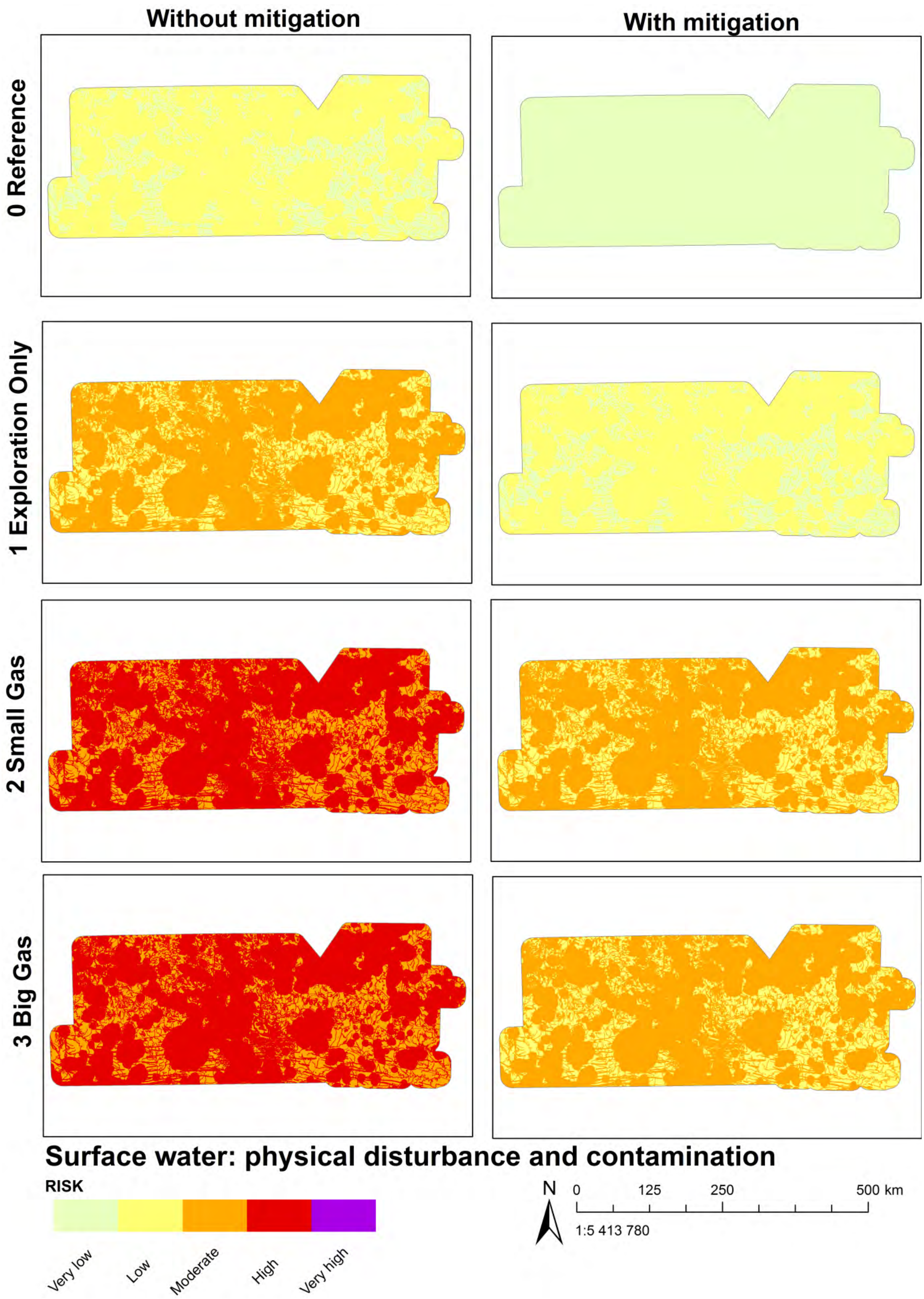

Figure 5.34: Map indicating the risk of physical disturbance to watercourses and contamination of surface water resources through flowback discharge and contact with contaminated groundwater across four SGD scenarios, with- and without mitigation.

Table 5.8b: Surface water risk assessment of indirect impacts.

Note that assessments "with mitigation" in all cases included the assumption that SGD occurs outside of high sensitivity areas shown in Figure 5.28.

Indirect impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Effects of increased water demand as a result of population growth	Reference Case	Watercourses including reservoirs in and outside of the study area	Slight	Likely	Low	Mitigation would need to consider proposed approaches at a strategic and then detailed impact assessment level. The risks associated with this impact are not therefore assessed in this study "with mitigation"		
	Exploration Only		Slight	Likely	Low			
	Small Gas		Moderate	Very likely	Moderate			
	Big Gas		Moderate	Very likely	Moderate			
Effects of increased sewage treatment requirements	Reference Case	Watercourses including reservoirs affected by WWTW effluent from new and existing settlements affected by population growth	Slight	Likely	Low	Given the complexity of mitigation at a strategic level and the number of unknowns at this stage, the risks associated with this impact have not been assessed in this study "with mitigation".		
	Exploration Only		Slight	Likely	Low			
	Small Gas		Moderate	Very likely	Moderate			
	Big Gas		Moderate	Very likely	Moderate			

5.7 Best practice and mitigation guidelines

5.7.1 Overview of Best Practice Guidelines

Stephens (2015) presents an insightful analysis of the US EPA Pavillion groundwater investigation that sought to investigate the impacts of fracking on groundwater in the Pavillion natural gas field. The Pavilion investigations attracted considerable criticism from all quarters, exposing in particular deficiencies in its field methods, transparency of its reporting, clarity of its communication and peer review process. This learning experience unequivocally identified the collection of baseline groundwater quality data prior to initiating fracking as an effective way to evaluate potential impacts. Esterhuyse et al. (2014) provide a detailed assessment of monitoring requirements and protocols to ensure responsible SGD by means of fracking.

Applying relevant local and international best practice guidelines (BPG's) is an important mitigation measure as outlined in Section 5.6. The then DWAF drafted extensive BPGs for mining, including Hierarchy guidelines, General guidelines and Activity guidelines. Although developed for mining, many of their principles are also relevant to oil and gas exploration and extraction, as outlined below.

The following hierarchy guidelines are relevant to fracking:

- BPG H1 (Integrated mine water management) (DWAF, 2008a),
- BPG H2 (Pollution prevention and minimisation of impacts) (DWAF, 2007a),
- BPG H3 (Water reuse and reclamation) (DWAF, 2006a) and
- BPG H4 (Water treatment) (DWAF, 2007b).

General guidelines that are relevant include:

- BPG G1 (Storm water management) (DWAF, 2006b),
- BPG G2 (Water and salt balances) (DWAF, 2006c),
- BPG G3 (Water monitoring systems) (DWAF, 2006d) and
- BPG G4 (Impact prediction) (DWAF, 2008b).

Activity guidelines that are relevant include:

- BPG A2 (Water management for mine residue deposits) (DWAF, 2007c) and
- BPG A4 (Pollution control dams) (DWAF, 2007d).

Various candidate technologies and practices for reducing impacts on water resources can be implemented and are listed in Table 5.9 as examples of practices that could be included when formulating policies around SGD mitigation.

Table 5.9: Candidate technologies and practices to reduce the impacts of SGD on water resources (data from Mauter et al., 2013). Scale of benefit: scale(s) at which environmental benefits of technology are most applicable; Adoption: prevalence of technology (legally required in some places, widely used and/or emerging); Type: T = discrete technologies, M = shifts in management decisions, R = feasible regulatory intervention points.

Measure	Scale of implementation	Scale of benefits	Degree of adoption	Potential environmental benefits	Type
Laying impermeable liner over wellpad site	Stimulation well	Local	Wide	Reduces risk of soil and surface water contamination	TR
Laying re-usable mats over wellpad site and planned access routes, rather than laying gravel		Local Regional	Emerging	Reduces risk of soil and surface water contamination; speeds reclamation process once well is put on production; reduces risk of erosion damage	TR
Installing containment walls or dikes around all equipment used to store hydrocarbons		Local	Wide Legal	Contains potential spills and fires	TR
Setting surface casing at greater depths (API recommendation is 100 foot below the deepest aquifer)		Local	Wide Legal	Provides additional separation of groundwater from drilling activities	MR
Cementing intermediate casing, if present, to surface		Local	Wide Legal	Provides additional layer of pipe and cement between borehole and the aquifers it passes through *(may not be applicable for all wells)*	MR
Extending cementing on production casing further above the fracturing zone – to the surface if practicable (API recommends 500 foot above the highest formation to be fractured)		Local	Wide Legal	Reduces risk of interzone migration of sub-surface hydrocarbons	MR

Measure	Scale of implementation	Scale of benefits	Degree of adoption	Potential environmental benefits	Type
Collection and analysis of surface and sub-surface data, used to inform planning and real-time management of fracking		Local Regional	Emerging	Optimises fracturing programme, reducing water use and waste water associated with non-productive fractures, thereby also decreasing truck trips required per well; reduces risk of fracturing beyond desired zone; enables detection of wellbore instability induced by high pressures, reducing risk of rupture and leakage of fluids	TMR
Transitioning to more environmentally benign fracking fluids		Local Regional	Emerging Wide	Reduces chemical hazard of waste water **May conflict with water re-use strategies*	TR
Including non-radioactive tracers in injected proppant		Local	Emerging	Facilitates monitoring of fracture locations and fluid flow within them, detection of communication with aquifers	TR
Conducting small-scale test run (mini-frack) before commencing full fracking job		Local	Emerging Wide	Reduces risk of casing and cement failure under fracturing pressures	TMR
Installing remote-controlled downhole system of permanent monitors, packers and sealing elements, used to optimise flow rates of hydrocarbons and waste water (intelligent completion)		Global	Emerging	Allows dynamic adjustment of in-hole equipment throughout the life of the well, increasing production trade-off for drilling operation	TM
Air and water quality sampling throughout the life of the well (including baseline), used to inform operations.		Local Regional	Wide Legal	Enables immediate detection and mitigation of spills and leaks	TMR

Measure	Scale of implementation	Scale of benefits	Degree of adoption	Potential environmental benefits	Type
Waste water recycling and re-use, through blending and/or treatment	Stimulation well & Surrounding area	Local Regional	Emerging Wide	Reduces volumes of freshwater input and waste water output of each well (requires coordinated completions scheduled across development area and may require alteration of fracking fluid composition to accommodate higher concentrations of dissolved minerals)	TMR
Reuse of drilling fluids and muds (closed-loop drilling)		Local Regional	Emerging Legal	Reduces solid waste; for 100% recycling, requires coordinated drilling schedule and/or large-volume storage capacity across the development area to make use of fluids	TMR
Using double-ditching (preserving topsoil layering) when burying equipment in undisturbed areas		Local Regional	Emerging Legal	Reduces land use impact by preserving soil integrity, native plant root structure and seedstock, and existing microfauna	MR
Capturing fugitive methane by implementing reduced emission completions (green completions) replacing high-bleed valves, installing vapor-recovery units on tanks, etc.		Local Regional Global	Emerging Wide Legal	Reduces carbon footprint of individual wells and development area; reduces emissions of ozone precursor compounds, such as VOC's and NO_x from wells, flares and equipment	TMR
Implementing an inspection plan on a set schedule for all pipes and equipment		Local Regional	Emerging Wide	Enables immediate detection and mitigation of spills and leaks	MR
Clustering wells around a centralised water supply of sufficient volume	Surrounding area	Local Regional	Emerging	Reduces freshwater transport distances; with planning, reduces flow reduction impact of water sourcing on small- surface waters by allowing small withdrawals over time rather than larger ones at the time of use	M
Centralised pumps and impoundments with pipes, used to frack multiple surrounding sites *(centralised fracturing)*		Local Regional	Emerging	Reduces truck trips needed to move fluids and equipment to individual sites	TM

Measure	Scale of implementation	Scale of benefits	Degree of adoption	Potential environmental benefits	Type
Installing temporary pipes to transport large volumes of water for short-term needs (e.g. fracking)		Local Regional	Wide	Reduces truck trips required for freshwater	TMR
Burying corrosion-resistant lines and pipes for longer-term operations		Local Regional	Emerging Wide Legal	Reduces truck trips where used as an alternative; reduces collective surface impacts of infrastructure within greater development area; may reduce the risk of rupture relative to above-ground lines	TMR
Planning multiple wells per pad		Local Regional Global		Reduces collective land use footprint of operation; reduces trucking distances (equipment centralised); maximises production trade-off for wellpad	MR
Surveying and data collection to choose the least environmentally sensitive site from which the target formation may be effectively accessed		Local Regional	Emerging Legal	Reduces land use conflicts and/or absolute magnitude of ecological impact	TMR

5.7.2 Technologies and practices to mitigate SGD impacts on water resources

- **Water re-use and reclamation**: These practices; also specified in Table 5.8 and BPG H3, would help ensure sustainable use of water if this principle is also applied to fracking. The development of water reuse and reclamation plans for fracking operations is encouraged, as well as using alternative processes (e.g. using carbon dioxide or gels for fracking procedures instead of water), as additional mitigation measures. To minimise the impact of accidents or spillages linked to chemicals and waste water management, provision should be made for extreme flood events of the Karoo environment (Figure 5.12). Constructed fracking fluid and waste water containment tanks should be appropriately lined with materials that will not be susceptible to chemical attack or deterioration, and should make provision for the 1 in 50 year flood event. GN R446 does not allow for any storage of fracking fluids or waste water in open pits. In terms of stormwater management BPG G3 outlines basic principles such as separating clean and dirty water systems and collecting and containing dirty water.

- **Regulatory tools and performance standards**: These approaches allow the industry to internalise externalities. Regulatory tools such as casing/cementing depth regulations (Table 5.8), specified in GN R466 in production wells "…… to a depth of 60 m below the base of the deepest freshwater or at least 100 m above the top of expected petroleum bearing zones, whichever comes first ....…" is an example of a "command and control" regulatory tool. Performance standards by contrast may for example require that concentrations of specified pollutants in streams near drilling sites not exceed a certain level or that a pressure test on casing cement not exceed a given reading. GNR 466 specifies such boundaries for pressure test results. Case-by-case permits requires that operators comply with regulator specifications per activity (on a case-by-case basis), similar to specifying licence conditions for a specific activity. Government may use a hybrid of all these approaches in managing oil and gas to minimise environmental impacts. According to Richardson et al. (2013), command-and-control was the predominant regulatory tool and it is possible that this would also be the case in South Africa.

- **Establishing baseline conditions and monitoring:** Water resources monitoring (see Section 5.8 and Digital Addendum 5F) is another important contributory measure to assist in the protection of water resources. For groundwater monitoring, a baseline system of deep and shallow monitoring wells and piezometers should be established in areas expecting significant development, before that development begins. Surface water resources similarly need baseline monitoring (discussed in more detail in the monitoring section). The DWA BPG G3 monitoring guideline specifies the development of environmental and water management plans based on impact and incident monitoring as well as the generation of baseline data before project implementation. Baseline data must as a minimum be relevant to the operation under consideration – if fracking is required, then detailed baseline monitoring of surface and shallow to deep aquifers is required, addressing the full suite of parameters outlined in Section 5.8 and identifying the features outlined in Table 5.10 and Section 5.7 from which activity-based setbacks would be required. The hydraulic properties of the geological formation in the vicinity of initial exploration wells in any new fracking block should be established before additional fracking wells are created as this provides information as to likely geological conditions as well as groundwater quality and distribution. The use of tracers to assist in establishing the direction of groundwater movement from wells may be included in geohydrological assessments, to assist with the optimum siting of groundwater and surface water monitoring points, noting however the limitations of tracer tests, particularly at depth, where the rate of groundwater movement may be very slow. Monitoring should occur before, during and after SGD, and monitoring during well suspension and after well decommissioning is especially important to detect any failure in well construction with possible resultant leakages after fracking occurred. **It is important to note, however, that post-closure monitoring in itself does not constitute mitigation for groundwater contamination**; it is a tool to detect groundwater contamination and initiate rehabilitation measures and should be linked to a management plan to address detected pollution events. Specific recommendations related to monitoring are discussed in the section on monitoring framework and requirements.

Setbacks as a precautionary tool

It is difficult to mitigate for the failure of well integrity after well decommissioning. Although GN R466 specifies that a well must have a decommissioning plan that must consider amongst other factors the current condition and design of the well, the difficulties in injecting cement into the annulus and future monitoring of the integrity of the plug before being decommissioned, there are no guarantees that over time (decades and longer) decommissioned wells would not leak. This is a serious concern to the authors and is also highlighted as a concern internationally (Davies et al., 2014; ANU, 2012; Bishop, 2011; DEP, 2009).

This aspect underlines the importance of the precautionary approach and the application of stringent setback distances from valuable water resources and possible pathways.

5.7.3 Potential setbacks

The most general way to protect vulnerable water resources is by using command-and-control regulatory tools in the form of setbacks i.e. "no-go" areas. The aim of setbacks would be to establish sufficient distance between sources of impact associated with fracking and its ancillary activities, to prevent contamination or other effects on high sensitivity water resources or pathways to such resources. At the same time, the use of setbacks would also allow for the protection of fracking-associated activities, development and infrastructure, by ensuring that these are sufficiently distanced from areas where aspects of the water resource (e.g. floods) might impact on their safety or operation.

In recommending setbacks, the following considerations have been made, and provide the rationale for setback recommendations outlined in Table 5.10.

- **Identifying relevant geological structures:** The sub-surface should be mapped prior to fracking operations for the presence of faults, shear zones, fold axis, dolerite dykes and sills, kimberlites and diatremes and the measurement of their properties as well as other relevant structures of concern. Artesian features and hot springs must also be mapped, noting that geological structures plotted on the 1:1 000 000 scale data from the Council for Geoscience (CGS) does not show all possible geological features that are present, and need to be identified on a more localised scale. During the EIA, 1:50 000 geological structure data should be used to determine setback distances for these features. Seismic data may also be used to determine sensitive geological structures, and the CGS has deployed six new seismic stations in the proposed Shell SGD areas, of which three, near Graaff- Reinet, are already operational (Saunders, pers. comm. 2016). The setback distance should be based on a reasonable risk analysis of fracking increasing the pressures within the fault/fracture. The properties of the target shale gas formation and upper bounding formations should be verified, post-fracking, to assess how the hydrogeology will change.

- **Considering Karoo dolerite dykes:** The following aspects are important in the determination of setbacks from Karoo dolerite dykes, with buffer widths being calculated as per the method outlined in Digital Addendum 5D, as recommended by Woodford (pers. comm., 2012):

    - Dolerite dykes typically range in width from 3 to 15 m and are seldom wider than 20 m. Dykes with widths <3 m usually represent short, shallow-seated intrusions, whilst the more extensive, regional dykes are typically significantly thicker (i.e. an E-W 'shear' dyke north of Victoria West is ~65 m wide, the width of the 'Gap' dykes in the eastern Karoo Basin often exceed 100 m) and can extend over lengths in excess of 300 km. Dolerite dykes represent groundwater provisioning targets in the Karoo and also represent areas of possible recharge. They are thus also potential pathways between contaminants occurring in both surface and groundwater activities during fracking and associated activities.

    - The regional E-W orientated dykes of the western and central Karoo Basin, as well as the associated N110º, N150º and N70º fracture systems, display a pattern in accordance with a typical right lateral shear zone. During emplacement of these dykes the maximum compressive stress was vertical, and therefore all fracture orientations could potentially be 'open'.

    - Dykes are often not mapped as continuous features as they are often 'masked' by overburden, exhibit small scale offsets, etc. Each dyke must be reviewed and if necessary all co-linear dyke segments must be manually 'joined' to form a single contiguous dyke feature (i.e. a single poly-line) to estimate the 'actual' length of the dyke (or dyke 'corridor' in the case an en-échelon dyke system).

- **Identifying thermal springs:** Groundwater temperatures may be used as an indicator of the depth of groundwater circulation and therefore the relative scale of flow within the aquifer system. In reality, the depth may be greater because cooling typically takes places during upward flow along fractures to the surface. Jones (1992) found that the geothermal gradients in South Africa vary from as low as 8°C/km to as much as 40°C/km, whilst a value of 30°C/km is more typical for Karoo rocks. Woodford (2012) suggested a method for calculating thermal spring setbacks (see Digital Addendum 5D), and this is used in deriving the setback recommendations outlined in Table 5.10.

- **Identifying aquatic resources**: Proposed sites for shale gas exploration and/or appraisal wells should be subjected to in-depth EIA studies, that allow for ground-truthing of the proposed fracking blocks and their surrounds, with particular attention paid to the need for and siting of exploration boreholes, as well as the identification and characterisation of watercourses, springs, isolated pans and other wetland types, and groundwater-linked artificial systems such as windpump-operated dams and reservoirs. A full inventory of such systems should be required, with the study area extending at least one kilometre in all directions outside of and including the proposed fracking block. High value water resource landscapes and waters (such as surface water and groundwater source zones, groundwater recharge areas and zones identified for artificial recharge) should be protected for future use and to ensure sustainability of water resource use. The following issues have a bearing on the setbacks outlined in Table 5.10 for these aspects, namely:

    - Current water supply wellfields are regulated in GN R466 to have a setback of 5 km around these areas. In this assessment, it is advocated that artificial recharge (AR) sites should also be protected with a similar setback, as these sites are equivalent to wellfields and can possibly in future be used as abstraction wellfields (in the absence of excess surface water for storage) or as AR areas (DWA, 2009). Protecting AR areas with horizontal setbacks in addition to the vertical protection zones based on the fact that shale gas horizons are thousands of metres away from sensitive shallow water source features, as well as the protection of geological features with setbacks within the AR areas, is an example of the application of the precautionary principle.

    - With regard to the establishment of setback lines from surface water resources, it is noted first that horizontal distance from a well may be irrelevant as a mechanism to ensure protection from groundwater contamination or accidental drainage of wetlands as a result of groundwater drawdown through puncturing of perched layers. Actual setback lines would need to be determined on a site by site basis, with reference to geohydrological modelling. However, some setback requirements should be regarded as mandatory in all cases, and would need to be inherent in any application, regardless of the outcomes of geohydrological assessment. These include:

        - floodplain setbacks based on reducing the risk of flooding of fracking infrastructure including waste storage;
        - reducing the risk of drawdown of, or the creation of new surface/groundwater pathways between watercourses, pans or other water resources, by using setbacks

that take cognisance of the likely extension of sub-surface fracturing beyond wellbores – it is mentioned in Burns et al. (2016) that fractures may extend outwards for distances of up to 300 m from the wellbore;

* consideration of downstream storage devices such as dams and their role in possible broader contamination pathways (e.g. through the export of water);
* consideration of the need to maintain or improve watercourse resilience against adjacent impacts likely to impact on natural runoff, sediment transport and water quality patterns; and
* consideration of known/visible zones of surface/groundwater interactions in the form of areas of recharge or daylighting of springs (hot or cold) or seeps. Cold and hot springs with associated seismic activity would need a greater setback than normal, as drilling and well stimulation activities may trigger earth tremors in these areas. Springs with known seismic activity include Middelburg and Leeu-Gamka (Saunders, pers. comm. 2016; Fynn et al., 2016).

Table 5.10 outlines multiple setbacks that could be applied at an EIA-level investigation to reduce risk associated with proposed SGD activities, and includes reference to existing South African regulations that currently specify setbacks. It should be noted that these setbacks are deliberately conservative, taking cognisance of the low confidence associated with identification of impacts associated with many aspects of the anticipated activities. For example, there are uncertainties as to actual aquifer extent; mapping of many geological features and important geohydrological attributes has been carried out at a very coarse scale (1: 1 000 000 in some cases); mapping of watercourse and isolated wetland features is not necessarily of a high degree of accuracy and the floodlines of most watercourses in the study area have not been determined. Given that the consequences of contamination or other impacts to surface and groundwater resources might be considerable and possibly permanent and irreversible (Section 5.6), it is appropriate to err on the side of caution in the formulation of spatial depictions of setback and exclusion areas.

The actual spatial implications of the recommendations outlined in Table 5.10 for the present study area are presented in Figure 5.25 to 5.28, while Digital Addendum 5E presents a breakdown of these data for individual components specified in Table 5.10. The most useful application of these figures is in their indication of relatively high confidence that the areas NOT outlined as setback areas could be targeted for SGD activities (i.e. areas of medium sensitivity), with a low risk of impact to surface or groundwater resources. By contrast, not all areas included in these setback zones need be regarded as 'no-go' areas. The mapped zones in some cases indicate setbacks within which more detailed information would be required to determine likely impacts and appropriate levels of mitigation. For example, watercourses have been buffered by a setback of 500 m for "ancillary activities" (that is, activities associated with SGD excluding actual fracking). This setback is simply a trigger for further investigations in terms of both the NEMA and the NWA, to determine an appropriate setback for the actual site in question. In other cases, the setbacks are conservative in the absence of detailed mapping information – dolerite dyke buffers, for example, have been calculated for curvilinear rather than straight dykes across the study area, given that the setback calculations outlined in Digital Addendum 5D allow for these to be wider than for alternative straight dykes. The figures outlined below need to be interpreted from the perspective of highlighting areas where SGD might proceed with low risk of incurring direct impacts to water resources, rather than as implying that all areas mapped are considered absolute 'no-go' zones from the outset. Detailed investigations would be required to elucidate whether additional areas may be exploited without risk to water resources, and by implication to their associated dependent ecosystems and human communities.

Table 5.10: Recommended setback distances which were used to develop the sensitivity map. Specified separately for (1) stimulation well activities and (2) ancillary activities including stratigraphic wells, horizontal wells and the establishment of roads, wellpads, waste stores and other activities.

Concern	Sensitivity / Setback aspect		Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
Stimulation well (with associated fracking)	Water source features	Municipal water well fields, artificial recharge areas, areas of shallow groundwater (<10m) or groundwater source zones.	Not within 5 km, measured horizontally, from the surface location of an existing municipal water wellfield and identified future wellfields and sources and directional drilling may not be within 2.5 km of municipal wellfields[1]	Agree with GR R466 setback distance. Apply this setback distance for artificial recharge areas and groundwater source zones as well. Where town wellfield is not known, identify town water source, if groundwater or a combination of groundwater and surface water, then use built-up area of town and buffer by 5 km, in accordance with precautionary principle. Exclusion area: Exclude areas where the wet season water table lies at or closer to 10 m from the surface.	Five (5) km between a stimulation well and 2.5 km distance between directional drilling and municipal water wellfields are sufficient based on known hydraulic properties of shallow Karoo aquifers. Where information regarding the presence of municipal water wellfields is limited but the settlement is shown in 'All Towns' data as having groundwater or combined groundwater and surface water dependence, there is also a precautionary need to buffer these areas from SGD activities. These shallow groundwater areas are considered of high sensitivity to SGD activities.
		Water supply boreholes or water storage dams	Not within 500 m, measured horizontally, from the surface location of an existing water borehole and directional drilling may not be within 500 m of the borehole[1]	No closer than 1 000 m from any domestic, stock watering or irrigation supply borehole or downslope storage dam, and directional drilling may not be within 500 m of the borehole.	The setback distance recommended in GN R466 is not stringent enough for fractured rock, which represent preferential pathways for contamination migration in the Karoo. Water scarcity in the Karoo and the high dependence on groundwater resources also necessitates a more stringent setback distance.
		Watercourses	Not within 500 m, measured horizontally, from the edge of a riparian area or within the 1:100 year floodline of a watercourse. No structure or facility within 1:100 floodline or within a horizontal distance of 100 m from a watercourse, estuary, borehole or well[2]	No closer than 500 m from the 1:100 year floodline or outer edge of the riparian zone (whichever is the greater) of any watercourse or from the temporary or other outer edges of any other wetland type	This value is based on a horizontal safety factor of 200 m, over and above the estimated 300 m to which horizontal fractures are likely to extend from fracking wells (Burns et al., 2016). This setback is conservative, and driven by the high risks associated with these activities.

Concern	Sensitivity / Setback aspect		Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
		Pans (isolated wetlands)	None	No closer than 300 m from the delineated temporary edge of any perched, isolated seasonal pan (i.e. not on a drainage line)	Such pans are not expected to be in direct contact with groundwater nor do they form part of significant conveyance corridors for sediment and contaminants. The 300 m setback derives from the 300 m to which horizontal fractures are likely to extend from fracking wells (Burns et al., 2016).
		Cold springs	None	No closer than 1 000 m from the upslope delineated outer edge of any cold spring, and no closer than 300 m downslope Setback distance = 5 000 m from springs within region of known seismic activity. Example: Middelburg cold springs area.	Springs represent zones where there is probable vertical/horizontal connectivity between surface and groundwater resources. Springs with associated seismic activity may be associated with active geological structures where drilling and well stimulation may trigger earthquakes, and would need a larger setback. The downslope setback derives from the 300 m to which horizontal fractures are likely to extend from fracking wells (Burns et al., 2016).

Concern	Sensitivity / Setback aspect		Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
		Thermal springs (water temperature >25º C), artesian boreholes, artesian aquifer zones and artesian SOEKOR wells.	None	Calculate buffer zone (Woodford, 2012) $EZ_{SP} = \frac{T_{GW} - T_{MA}}{G_T} \times \arctan(\phi)$ Where: EZ_{SP} - Radius of the circular Buffer Zone at the surface. T_{GW} - Temperature (ºC) of thermal spring. T_{MA} - Mean annual air (ºC) (possibly use Schulze's climatological dataset)/Possibly use average temperature of the shallow (5-10 m below water table) groundwater. G_T - Geothermal gradient (ºC/m) for Karoo Basin (assumed 0.03ºC/m) Ø - Angle (Digital Addendum 5D), currently assumed to be 30º, to take account of potential dip/width of fracture system (tortuous preferential flow path) from source to surface. Investigate structures linked to springs in detail during EIA to delineate any previously unidentified flowpaths and buffer such zones. Setback distance = 1 000 m from centre point where no temperatures available. Setback distance = 5 000 m from thermal springs within region with known seismic activity. Example: Thermal springs in the Leeu-Gamka seismic zone.	Thermal springs specifically are associated closely with deeper geological structures (Kent, 1969), usually with faults and folds (Olivier et al., 2011) as well as dykes. High water temperatures as well as thermogenic methane associated with some thermal springs indicates definite deep connections (Talma and Esterhuyse, 2013). Thermal springs are likely to have source recharge areas many kilometres from the spring discharge area and these must be delineated during the EIA prior to setting site-specific setback distances. Springs with associated seismic activity may be associated with active geological structures where drilling and well stimulation may trigger earthquakes, and would need a larger setback than normal.

Concern	Sensitivity / Setback aspect		Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
	Geological features (based on 1:1,000,000 scale CGS data)	Dykes	None	Join co-linear dyke segments to estimate the 'actual' length of the dyke. Calculate Buffer setback zone (Assume mapped dyke is linear in outcrop, likely dip variation thus between 85º and 89º). $EZ_{85°} = \left(0.186 \times D_L^{0.65}\right) + \frac{D_W}{2}$ (Eq. 1) $EZ_{89°} = \left(0.046 \times D_L^{0.65}\right) + \frac{D_W}{2}$ (Eq. 2) Where *EZ:* width of Buffer (metres) D_L: Length of Dyke (metres) D_W: Dyke Width Dyke width can be measured in the field, estimated from high-resolution aerial photography or aeromagnetic imagery, or by using of the following equation: $D_W = 0.1 \times D_L^{0.54}$ (Eq. 3) If the estimated width of the calculated dyke buffer *EZ* is <250 m, set buffer to 250 m. Note that in practice mapped dykes must be differentiated as separate polygons and not intersecting lines, in order to calculate length.	The thicker the dyke, the wider the buffer zone must be. Dolerite dykes must be buffered because they represent one of the main targets for water supply borehole siting in the Karoo and also represent areas of possible groundwater recharge and preferential flow.

Concern	Sensitivity / Setback aspect		Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
		Kimberlites and diatremes	None	500 m radius from centre point of structure	Kimberlites have complex associated emplacement models (Field and Scott-Smith, 1999; Skinner, 2009) and the surface and underground morphology of these structures may be quite large and varied (Field and Scott-Smith, 1999; Woodford and Chevallier, 2002; Pacome, 2010), with surface outcrop morphology varying from 1 ha to >15 ha (Skinner, 2009). A 500 m buffer zone is recommended based on expert input (Esterhuyse et al., 2014).
		Faults, shear zones and fold axis	None	1 000 m from centre line of structure	250 m buffer was suggested by Rosewarne et al. (2013); however one expert stated that unless these features are mapped in detail, a buffer of 250 m is too narrow. Fold axes must be treated separately as their fold axis limb angles should be considered which may push the distance to several kilometres. A buffer of 1 000 m is thus recommended (Esterhuyse et al., 2014).
		Dolerite sills	None	250 m from rim of surface outcrops	Morphology of sill surface outcrops may not be representative of underground morphology (Rosewarne et al., 2013). The researcher suggested the applying the precautionary principle with a buffer zone of 250 m from the rim of these structures. One expert stated that a differentiated approach should be used here, since transgressing sills are complex and a dislodged contact may reach all along the contact zones, which might stretch for kilometres. Bedding plane sills may offer a high security to percolating fluids/gasses from the shale gas source. A buffer of 250 m is used here in lieu of more detailed data and to adhere to the precautionary principle (Esterhuyse et al., 2014)

Concern	Sensitivity / Setback aspect		Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
		Undifferentiated geophysical anomalies	None	1 000 m from centre line of feature	Depending on the structure geometry, SGD should be limited near these features. Unless detailed geophysical investigations have been conducted, the buffer should be 1 000 m, based on expert input (Esterhuyse et al., 2014).
Exploration, production and ancillary SGD activities (including wellpad establishment, drilling, waste water management, cleared vegetation, access roads, infrastructure, sanitation)	Artesian boreholes, artesian aquifer zones and artesian SOEKOR wells (KL 1/65, SA 1/66, VR 1/66, CR 1/65)		None	Calculate setback distance based on thermal spring methodology. **Setback distance = 1 000 m from centre point where no temperatures are available.** Also recommend that these features be investigated in detail during EIA to delineate any previously unidentified flowpaths and buffer such zones.	Artesian aquifer zones represent areas of possible deep/shallow groundwater connectivity.
	Deep recharge zones		None	Protect the source area and investigate these zones in detail during the EIA to delineate any flowpaths to shallow aquifers and then buffer accordingly.	Van Wyk (2010) postulates an 'L-shaped' recharge flow path from vertical source areas, laterally into aquifers. Such source areas are likely to be topographic highs such as the Great Escarpment and large dolerite/sandstone capped ridges/escarpments

Concern	Sensitivity / Setback aspect	Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
	Water resources (water courses including mapped dry river courses, wetlands, pans, shallow aquifers, cold and thermal springs) and water supply infrastructure (water supply boreholes, wellfields, water storage dams)	No mining, prospecting or any other operation under or within the 1:50 year floodline or within 100 m from any watercourse or estuary, whichever is the greatest[2]. No residue or substance which may cause pollution in underground workings, pit or excavation[2]. No sanitary convenience, fuel depot, reservoir or other depot for any substance which may cause pollution within the 1:50 year floodline or within 100 m from any watercourse or estuary, whichever is the greatest[2]. No structure on water-logged ground or on ground likely to become waterlogged[2]. No water use in terms of Section 21 c and 21 i of the NWA allowed within a 500m radius from the boundary of a wetland[3]. No alteration the bed, banks, course or characteristics of a watercourse within the 1:100 floodline or within the riparian habitat, whichever is the greatest[3].	Exclude areas where the wet season groundwater lies at 10 m or closer to the surface. No closer than 1 000 m from water supply sources infrastructure (domestic, stock watering or irrigation supply borehole or downslope storage dam or water supply wellfields). Where town wellfield is not known, identify town water source, if groundwater or a combination of groundwater and surface water, then use built-up area of town and buffer by 1 km, in accordance with precautionary principle. No closer than 500 m from any thermal spring or cold spring No closer than 500 m from any identified watercourse or other wetland type without a detailed ecological, hydrological and geohydrological investigation. Setback distance = 5 000 m from cold or hot springs within region of known seismic activity. Example: Middelburg cold springs area. Leeu-Gamka hot spring area. Springs with associated seismic activity may be associated with active geological structures where drilling may trigger earthquakes, and would need a larger setback than normal. As a general guideline, structures and infrastructure should be located at least 100 m from the delineated edge of any watercourse or other wetland and such that they do not impact on their condition, characteristics or function.	Shallow groundwater resources are at higher risk of contamination from exploration, appraisal and fracking activities. Ancillary activities including storage and transport of fracking fluids, chemicals or waste water are all considered potential contamination activities in terms of spills and leaks, representing a risk to water resources. Areas of cleared vegetation for seismic surveys or wellpads, roads, storage areas for equipment, water, chemicals and waste should not be closer than 500 m from thermal springs and cold springs in order to protect them from impacts related to these ancillary activities. This is a conservative width but takes cognisance of the possible high concentration of impacts/disturbance associated with the activity and risks associated with surface spills of contaminated flowback water or stored waste.

Concern	Sensitivity / Setback aspect	Setback distances in existing regulations GN R466[1] / GN 704[2] / GN 1199[3]	Potential setback distances and exclusion areas	Rationale
	Artificial recharge areas (current and future)	None	5 km around these areas, based on the setback distance in regulations GN R466 for water supply wellfields. Should such areas be managed in terms of inducing maximum drawdowns, then site-specific studies must be carried out to determine the required setback (pers. comm., R. Murray, 2016)	Artificial recharge zones are important to protect for future storage of drinking water and would become more important in water scarce South Africa. It is a more effective water storage method than surface water dams (less evaporation and no sedimentation).
	Geological features	None	No fracking chemicals storage, waste or waste water management infrastructure, fuel depots or sanitation infrastructure within 250 m of geological features listed in this table without a detailed geohydrological investigation.	Geological features may represent areas of possible groundwater recharge and preferential flow, thus potential groundwater pollution sources should not be established near these features. GN R466 makes provision for waste and fluids management, however apply precautionary principle in cases where detailed geohydrological investigations have not been performed for these features and use setback of 250 m.
	Groundwater source zones	None	Not within 5 km of groundwater source zones, based on setback distance for wellfields in GN R466. Source zones in process of being identified in WRC project (pers. comm., A. Maherry, 2016).	Source zones supply the most important aquifers in South Africa.

5.8 Monitoring framework and requirements

Monitoring of water resources is important for minimising, controlling and mitigating against the effects of SGD. Monitoring is key to assessing the condition of surface water ecosystems, which react to changes in flow volume, impacts of land use, and climate. Furthermore, some SGD-generated spatial and temporal changes in surface water ecosystems can be detected only with long-term monitoring. In addition, a comprehensive understanding of groundwater conditions is required prior to the commencement of exploration to ensure proper interpretation of changes in groundwater over time. It is therefore imperative that detailed monitoring plans are developed for the different phases of SGD. Monitoring data would also be used for calibration and verification of prediction and assessment models, for evaluating and auditing the success of management plans, and for assessing the extent of compliance with prescribed standards and regulations.

Monitoring must be linked to a management plan to ensure that water resources are protected and that action is taken when certain set thresholds are exceeded. Ideally, the monitoring plan should address the following:

- design of the initial monitoring programme;
- methods of sampling, collecting and capturing the data;
- methods for analysing the data;
- format for reporting the findings to the relevant authorities;
- mechanisms for auditing, and for recommending and implementing changes to the monitoring programme.

There is little point in monitoring if it cannot lead to changes in SGD practices, so all licences granted to the developers would need to take principles of adaptive management into account. In short, a mechanism would be needed to enforce modifications of SGD activities based on results of the monitoring programme.

Furthermore, it would be difficult, if not impossible, to identify the effects of SGD on surface and groundwater systems without baseline monitoring (Government Accountability Office (GAO), 2012a; 2012b). Long-term data would therefore need to be collected, preferably over at least five years, to identify trends in the biophysical conditions and functioning of these systems in the absence of SGD. Hildenbrand et al. (2016) indicate that groundwater contamination pathways are complex, and that various toxic compounds may be detected in groundwater, seemingly at random times, in areas of high SGD activity. These authors monitored groundwater in an area of increasing SGD over a period of 13 months. They reported ephemeral detections of various organic molecules with minimal co-variation, which suggests that contamination events may be variable and sporadic (as opposed to systematic). Additionally, the accumulation of bromide and various alcohol species indicates that residual changes in groundwater chemistry may persist in regions engaged in SGD. Brantley et al. (2014) note that high-confidence identification of contaminants in water resources as a result of shale gas exploration, appraisal and production activities are often hampered by:

- the lack of information about location and timing of incidents;
- the tendency to not release water quality data related to specific incidents due to liability or confidentiality agreements;

- the sparseness of sample and sensor data for the determinands of interest; the presence of pre-existing pollutants that make it difficult to determine potential impacts from shale-gas activity; and
- the fact that monitoring sensors can malfunction or drift.

Their study showed, too, that in areas where shale gas is developed quickly, baseline data against which future impacts can be assessed are often inadequate. The authors thus highlight the importance of:

- performing baseline water quality monitoring of water resources in areas considered most likely to be targeted, well before exploration drilling commences and according to predefined standardised procedures and flexible reporting templates;
- adequate siting of surface and groundwater monitoring sites so as to allow conclusive assessment of data and identification of possible sources of contamination.

In terms of who must perform the monitoring, the following aspects are important to note:

- Oil and gas companies, government or its appointees, and perhaps independent monitoring institutions, should be involved in monitoring. Monitoring of their operations by oil and gas companies should be required as part of the licensing agreement. Strict reporting requirements, to government and/or other independent institutions, should be in place and results should be independently verified. Government should play an oversight role, which might include verification sampling. It may be necessary to establish an independent laboratory for monitoring aspects such as natural isotopes, constituents of fracking fluids, and uncommon organic substances emanating from fracked wells and local groundwater.

- Government needs to acknowledge the regional and cumulative scale of SGD impacts, and implications for monitoring. Government must align legislation with regard to monitoring, as well as mandates, roles and responsibilities between relevant government departments. If this is not achieved, it will be necessary to institute an independent central entity to perform monitoring functions.

- It is crucial that the monitoring entity be independent, and be perceived as being independent, of the mining companies.

- Monitoring must be carried out in such a manner that the results will have legal standing

Esterhuyse et al. (2014) discuss monitoring of surface water and groundwater in detail, differentiating between monitoring requirements during the pre-development, exploration, development (during extraction) and post-development (after extraction) periods (see Digital Addenda 5F(i) - surface water and 5F(ii) – groundwater). The monitoring frameworks for groundwater and surface water bodies are summarised below.

5.8.1 Monitoring frameworks

Groundwater

In order to perform appropriate baseline monitoring, an understanding of the aquifer systems in an area, as well as migration pathways for contaminants, is necessary. Baseline groundwater quality and quantity also need to be quantified. With regard to water chemistry, the concentrations of constituents naturally found in the water must be known, and monitored, for both shallow and deep aquifers, as well as in additives in fracking fluids. GN R466 requires that SGD companies report their fracking water additives and some of these should be monitored as part of an early warning monitoring system for picking up contamination incidents. The list of constituents to be measured before initiation of fracking should be extensive enough that regulators can identify which are suitable for detecting fracking-related changes (Table 5.11).

During exploration and development, operators should be required to monitor the quantity of water used and other technical aspects such as drilling rate, volumes of drilling and fracking fluids and their constituents, and micro-seismicity at exploration and production sites. Regulators would have to ensure that data dissemination from the operators occurs as required by per license conditions. After SGD has ceased in an area, integrity of wells will need to be monitored. All decommissioned wells need to be monitored annually for well integrity going into the future, taking into account that well failure typically occurs over the long-term (>50 years). The detailed monitoring framework describing the "Why?", "What?", "How?", "Where?" and "Who?" in regard to quantity, quality and technical aspects for groundwater as described by Esterhuyse et al. (2014) can be seen in Digital Addendum 5F(ii).

Surface water

The spatial and temporal monitoring design is crucial to the reliability and usability of surface water monitoring data, as well as identifying the current condition of water bodies in the study area. Water quality, water quantity and habitat integrity should all be measured, together with weather data such as daily precipitation and evaporation. Site selection, sampling and interpretation of results should be done by trained, unbiased, independent, experienced professionals that are familiar with the type of water body (rivers, wetlands), geographical area and sampling techniques to be used. Baseline monitoring should cover all four seasons, preferably for a number of years, including at least a wet and a dry year, at representative sites. Frequency of sampling will need to be increased during wet periods. Long-term monitoring is needed for an understanding of hydrologically variable systems, as occur in the study area. Our limited knowledge of the functioning of these systems renders them particularly vulnerable to inadequately managed perturbations.

Techniques for analysing water chemistry of non-perennial systems should be appropriate, reliable and well tested, and carried out at reputable, accredited laboratories. Water quantity data need to be collected at least weekly, although real-time data collected automatically through gauging stations or water-level recorders is preferable. Baseline water quality data need be collected less frequently - perhaps every three months - except after rain, when daily or weekly sampling may be necessary.

For rivers that flow seasonally or perennially, habitat integrity, geomorphology (using the Geomorphology Assessment Index - GAI), fish (using the Fish Response Assessment Index - FRAI) and vegetation (using the Vegetation Response Assessment Index - VEGRAI) (Kleynhans et al., 2007) might be monitored yearly or after floods or drought. Macro-invertebrate indices are not very reliable for dryland rivers. They should initially be monitored every six to eight weeks *while the water is flowing* but an assessment will need to be made as to their usefulness for monitoring purposes. Current invertebrate indices such as SASS should *not* be used for non-flowing systems. Wetlands, and rivers that have been reduced to standing pools, should be monitored using one or more of a variety of existing methods for assessing *wetlands* (see Ollis et al., 2014). If the Rapid Habitat Assessment

Method (RHAM) is used for rivers then it needs to be monitored at least monthly and if possible weekly, together with the water quality and quantity measurements. The Why?", "What?", "How?", "Where?" and "Who?" is described in more detail in Digital Addendum 5F(i) for surface water.

5.8.2 Water quality analyses

It is important that, as far as possible, the same techniques are used for analysing ground and surface water quality and that the techniques to be used are well recognised and can be measured to a relevant level of accuracy. For instance, while major ions such as Cl^- and Ca^{2+} usually occur in the parts-per-million range of concentrations (mg/L), nutrients such as the PO_4^{3-} ion normally occur in parts per billion (µg/L), and many metals, metalloids and organic contaminants in parts per trillion (ng/L).

In addition,

- Procedures for collection of all water samples need to be specified in detail.
- Exact constituents to be analysed need to be specified.
- Exact methods, and detection limits, need to be specified for all constituents.
- For many of the less common constituents of fracking and drilling fluids, it is necessary to examine chromatograms to see what classes of compounds are present, and then identify those that appear in substantial quantities, because constituents of these fluids are not always divulged by the drilling company (G.T. Llewellyn, *pers. comm.*).
- Isotopic analysis of natural gas is extremely useful for investigating alleged gas drilling impacts and understanding gas source areas. Both methane and ethane should be examined (G.T. Llewellyn, *pers. comm).*

Table 5.11 summarises the list of recommended monitoring parameters. Broadly speaking, electrical conductivity (EC - equivalent to salinity or saltiness) is the most useful measure of background water quality, and is often helpful in identifying the groundwater source (deep or shallow) of the water being tested. The geochemical signature of the deep groundwater is as yet largely unknown, so as much data as possible is needed from these areas to provide background information. The EC of produced water after fracking will often provide information of the depth and strata from which the water emanated.

Analysis of two water samples obtained from SOEKOR well SA 1/66 (Murray et al., 2015) indicates that Br, Ba, F and Sr may be characteristic indicators of deep groundwater in South Africa. This requires further investigation as the level of ingress and mixing of this water is unknown and the sampling methodology was rudimentary.

The isotopic composition of water is a valuable tracer for evaluating water sources and mixing processes in aquifers (e.g. Baldassare et al., 2014). Mayer et al. (2015), for instance, have demonstrated that a multi-isotope approach ($\delta^{13}C_{CH4}$, $\delta^{2}H_{CH4}$, $\delta^{2}H_{H2O}$, $\delta^{18}O_{H2O}$, $\delta^{13}C_{C2H6}$), in concert with chemical analyses, is capable of identifying potential contamination of shallow aquifers with stray gases or saline fluids from intermediate or production zones, provided that sufficient baseline data have been collected. $\delta^{13}C_{DIC,}$ $\delta^{11}B$, ^{14}C and $^{87}Sr/^{86}Sr$ ratios would be valuable for identifying deep groundwater in the Karoo (Miller et al., 2015).

In groundwater, noble gas analyses can assist in distinguishing among different sources of hydrocarbons. Analyses of noble gases (e.g. He, Ne and Ar) and their isotopes in groundwater, when paired with hydrocarbon composition (e.g. methane $\delta^{13}C$, CH_4 and C_2H_6) and inorganic water chemistry (e.g. Cl, Ba), can therefore help differentiate between natural geological migration of hydrocarbon gases and anthropogenic contamination (Darrah et al., 2014) and may also help to determine the mechanisms whereby anthropogenic gas contamination occurs.

Radioactivity (gross alpha radioactivity, gross beta radioactivity) and radioactive isotopes also need to be monitored, particularly given the high level of uranium in parts of the Karoo (Subsection 5.2.2).

Table 5.11 provides an initial list of important parameters for monitoring surface and groundwater likely to be affected by SGD. It is not comprehensive and would need to be adjusted in consultation with baseline monitoring results. Cations and anions should be analysed in both surface and groundwater samples, while organics, radioactivity and isotopes will mainly be analysed in groundwater samples with analysis of these parameters only in very specific surface water samples.

Table 5.11: Important water chemistry constituents to be measured in SGD monitoring programmes. Note: analytes indicated in **bold** (Murray et al., 2015, Miller et al., 2015) have been identified in South African shales; analytes indicated in italics have been identified in produced water from gas shales internationally (Orem et al., 2014).

Field	Major ions	Secondary	Minor or trace	Organics	Isotopes	Radioactivity
pH Temperature Electrical conductivity Dissolved oxygen Oxidation reduction potential	Na Cl Mg Ca HCO_3 SO_4	K **F** **Sr** CO_3 NO_3-N B	Al, Pb, *Cd*, CH_4, *Co*, *Cr*, Cn, Mn, **Br**, Si, Phosphate tot, *As*, S, Se, *B*, ***Ba***, Cu, *Fe*, *Hg*, *Zn*, *Ni*, Mo, Hg, U, *V*, Sb, M-Alk. P-Alk. NO_3+NO_2, ORP, pH, TDS, Total hardness, NH_3 (ammonia nitrogen)	*TOC*, *PAHs*, VOC's, SVOC's, BTEX (Specific organic constituents to be specified for monitoring based on fracking water additives reported by O&G companies)	**Stable:** $\delta^{13}C_{CH4}$, $\delta^{2}H_{CH4}$ in groundwater $\delta^{13}C_{H2O}$, $\delta^{2}H_{H2O}$, $\delta^{18}O_{H2O}$, $\delta^{13}C_{DIC}$, $\delta^{13}C_{C2H6}$, $\delta^{2}H_{C2H6}$, $\delta^{34}S_{SO4}$, $\delta^{11}B$, ^{14}C **Radioactive:** *$^{235\ 238}U$, ^{232}Th, $^{226\ 228}Ra$, ^{222}Rn, ^{40}K, ^{210}Pb, $^{87}Sr/^{86}Sr$ ratio*	Gross alpha radioactivity Gross beta radioactivity

5.8.3 Quality assurance and quality control during water quality sampling

To ensure the collection of good quality data during water resource monitoring, standardised monitoring guidelines, sampling quality assurance and quality control (QA/QC), and laboratory and analytical criteria are necessary.

Sampling

- Field sampling procedures should be robust, reproducible and reliable.
- Taking duplicate samples for analyses at the same laboratory and at a quality control laboratory and employing trip blanks/field blanks is advised.
- The sampling should be undertaken by an accredited institution and accredited and appropriately trained individuals.
- The appointed institution needs to be unbiased and independent and should not be connected to any of the interested parties.
- Sampling and handling methods used need to be clearly documented.
- Copies of the chain of custody (COC) forms must be kept. Sample results must be traceable back through their collection, storage, handling, shipment and analyses; and information on persons handling the sample should be completed on a COC form.
- Data must be analysed and interpreted by individuals experienced in the particular field (e.g. water quality, fish), geographic locality and the type of system (wetland, non-perennial river, groundwater) sampled.

Laboratory and analytical criteria

- It is recommended that the selection of the preferred laboratories be based on quality, detection limits, and number of parameters which can be analysed.
- The quantification limits for all parameters used in assessing water for human consumption must, if available, be based on the SANS (2015a; 2015b) drinking water standards; South African Water Quality Guidelines for Agricultural Use (Livestock watering) are useful guides for suitability of water for livestock to drink. Where no guideline values have been published, international standards should be used to assess the water quality results.

5.8.4 Data management

The efficient management and safe storage of data are essential prerequisites for a successful monitoring programme and proper data management is therefore important. If the DWS does not have the capacity, an independent entity would need to manage, archive and disseminate the information collected during the monitoring programme.

The DWS keeps records of water quality, hydrology, and river health under the Directorate: Resource Quality Services. Surface water data, including streamflow, rainfall, evaporation and reservoirs, are available in the HYDSTRA, an integrated water resources management software database. Fitness-for-use data are housed in the National Microbial Water Quality Monitoring Programme, National Eutrophication Monitoring Programme, National Toxicity Monitoring Programme, Rivers database, Water Management System (WMS), HYDSTRA and GIS. Current records are too few to be used as baseline data for all proposed unconventional oil and gas mining areas.

For groundwater, the DWS keeps a National groundwater archive (NGA). The NGA can be viewed as the most up-to-date data archive on groundwater in South Africa, and options would have to be investigated to determine if this system can be efficiently adapted to manage oil and gas wellsite-specific information. Options would have to be investigated to streamline the WMS and NGA systems.

Important aspects to be kept in mind in connection with monitoring data are:

- A central database for all data should be curated by a reliable, institution and be accessible to all stakeholders, including the public.
- Monitoring records kept by oil and gas companies should also be accessible to all.
- Good record keeping is an essential part of quality assurance. Original datasheets should be kept for as long as possible. It is also vital that the transcription of data from data sheets to electronic format is accurate and validated, and that this is done by a competent person who understands the data and who is capable of data interpretation (DWAF, 2008).
- Data needs to be examined for irregularities immediately after collection and any identified impacts should be communicated to the relevant government department and to the company causing the impact as soon as possible.

Data requirements differ for each of the life cycle phases of SGD and this should be taken into consideration when prescribing monitoring requirements. Adequate data capture of development operations is a crucial part of proper monitoring and management of this activity internationally (Atlantic Council, 2011). Developing a database system similar to Fracfocus (Fracfocus, 2016) and a linked online mapping system such as Fracktracker (Fracktracker Alliance, 2016) would be ideal.

5.9 Gaps in knowledge

The assessment has necessarily identified a number of aspects for which available information is inadequate for scientifically sound decision-making purposes. This is as much a function of the complexity of the deep sub-surface hydro-environment such as is currently being revealed in a very few localities, as it is by the erratic and variable nature of event-driven surface flow. Factoring in the uncertainties associated with climate change adds another level of intricacy to an already complex environment. The following list identifies, in no specific order of significance, those aspects that are considered limiting factors in this assessment.

- The paucity of reliable information regarding groundwater use (both for municipal/town water supply and agricultural purposes) in the study area is identified as a critical shortcoming. As generally authorised and Schedule 1 water use (RSA, 1998a) is not licensable, yet collectively can constitute large volumes, verification of groundwater use in the study area is very difficult. For this and other reasons (see Section 5.3), a reconciliation of current groundwater use with availability of supply within the framework of future demand also from SGD, is problematic. Further, the distributed spatial extent of groundwater sources makes their enumeration an arduous task that is best addressed in an EIA.

- A number of aspects related to the geology and hydrogeology interaction at depth in the study area are constrained by limited knowledge. These include (a) the occurrence, hydraulic properties of 'aquifer' formations and quality of deep groundwater (>1 000 m), (b) the presence of potable groundwater at depth, (c) the measure of interconnectivity with the shallow aquifer, and (d) the occurrence and geometry of dolerite at depth. Specialised deep drilling is required to elucidate these aspects in order to carry out appropriate risk/impact assessments.

- There is a poor understanding of the nature of basinal groundwater flow and its properties, geometries and controlling factors in the Karoo Basin (Tóth, 1999). Groundwater flow systems serve to transport and distribute the products of water and soil/rock interaction within the basinal domain. Gravity-driven (unconfined and typically shallow) flow systems are relatively 'simple' compared to pressure-driven (confined) flow systems such as most probably characterise the deeper portions of the Karoo Basin. Whereas numerical modelling has been applied successfully in local shallow aquifer environments to resolve and inform groundwater resource behaviour and response, this has not been attempted at a regional or basinal scale. It is therefore presently not possible to comprehend the basinal flow dynamics within the Karoo Basin, and specifically in the study area, beyond a qualitative conceptual model.

- An understanding of the response of the Whitehill Formation and overlying strata to fracking remains poorly understood. For example, to what extent will overlying dolerite sills mitigate against the upward progression of fractures? For example, CIMERA-KARIN borehole KWV-01 intersected a ~18 m thick dolerite sill immediately overlying the Whitehill Formation, and an even thicker ~150 m dolerite sill in the 110 m shallower depth interval 2 037 to 2 186 m below surface.

- In common with most SGD projects globally, knowledge of the background (baseline or reference) groundwater quality is extremely sparse. This is true for the shallow, intermediate and deep environments. As the shallow environment supports a primary water supply function that is particularly vulnerable and at risk, a concerted effort is needed to 'fingerprint' shallow groundwater quality across the study area as completely as possible prior to up-scaled SGD at the latest.

- Improved understanding of the hydrodynamics that describe the interaction of surface water and groundwater is required in order to inform recommendations as to reasonable and responsible setbacks of wells and other activities from surface and groundwater resources, to reduce risks to these critically important resources. This understanding can be gleaned from numerical simulations that would need to be applied at a local scale. The veracity of the outputs would be constrained by the relevance of the conceptual model formulation and input data which, in most instances, are inadequate.

- The inter-dependence that exists between hydrology and the ecology of temporary surface water systems is similarly poorly understood. This interface is not yet served by suitable and appropriate hydrological models to simulate the hydrodynamics of temporary rivers. Even if such models did exist, their application would be constrained by the lack of detailed information and data associated with the often very short-term (hours and days) occurrence of these events, and the equally short-term response of the interconnected hydrosystem. It is therefore difficult to fully comprehend and predict the impact that SGD could have on these systems.

- The effect that additional groundwater extraction for SGD might have on the sustainability of temporary to ephemeral rivers and wetlands in the area is unknown and of great concern. It is possible that over-abstraction could damage these GDE's beyond repair. An added uncertainty is that recharge data area only available for localised areas, but is lacking on a regional scale. Recharge is influenced by land use changes and it is expected that the study area, because of its arid nature, will be very sensitive to a change in land use. A change in land use from natural to agriculture/industrial could result in more pronounced erosion, sedimentation, floods, less infiltration from precipitation and higher rates of evapotranspiration. This uncertainty is aggravated by the limited rainfall and poor/limited distribution of gauging stations in the study area.

- The technological advancement in drilling techniques and well construction practices in the field of SGD, and in particular the field of fracking, is unparalleled in the drilling industry. This extends to the monitoring of the integrity of production wells (see for example Addendum D of EPA, 2015). The closest that the local groundwater fraternity can manage, is the supervision of the drilling and construction of water production boreholes in highly leached and cavernous dolomitic strata (e.g. of the Malmani Subgroup) and highly fractured quartzitic sandstones (e.g. of the Table Mountain Group), often at depths >200 m below surface. Even in these instances, there are few groundwater scientists and technicians who can claim experience and competence in this field. The extent to which this competence will need to be grown depends on the scale of SGD activities. A failure to achieve this will seriously compromise any efforts to exercise regulatory oversight and control over the upstream developmental components of a shale gas industry.

- The volume of waste water (flowback and produced water) that will be generated during full-scale SGD is similarly subject to substantial uncertainty. This also applies to the quality of the waste water produced. These factors limit an appraisal of proper waste water management planning required to protect water resources from contamination.

- One of the greater uncertainties relates to the long-term impacts of SGD on the water resources of the Karoo. These impacts will form part of the legacy of impacts left behind by a defunct shale gas industry in the form of 'abandoned' gas exploration/production wells, and will likely be manifested for decades (or longer) beyond the cessation of SGD. The magnitude and extent of possible long-term contamination of freshwater resources can therefore not be predicted at this stage, as this would require a much better understanding of the complex hydrosystems that characterise the Karoo environment.

- The risk posed by SGD activities to downstream dependent systems including urban and agricultural users as well as environmental resources such as important estuaries is poorly understood and inadequately quantified.

- Finally, it is necessary that the DWS develops its own regulations to govern the exploration and development of petroleum resources as soon as possible. This authority is also best placed to initiate the much needed water resources baseline studies required prior to SGD. Care needs to be taken to ensure that the regulatory process is harmonised between the different authorities that have jurisdiction over the numerous and varied aspects involved.

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5.11 Digital Addenda 5A – 5F

SEPARATE DIGITAL DOCUMENT

Addendum 5A	Presentation of supplementary hydrological data used for the Karoo Shale Gas scientific assessment
Addendum 5B	Sections 88 and 122 of the Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)
Addendum 5C	Substances that have been detected in flowback water but not in drilling or fracking fluids, and therefore assumed to be derived from underlying substrates
Addendum 5D	Definition Of Buffer/Setback Zones for Dykes and Thermal Springs
Addendum 5E	Figures showing application of setbacks to protect surface- and groundwater resources
Addendum 5F	Monitoring frameworks

DIGITAL ADDENDA 5A – 5F

Contents

ADDENDUM 5A PRESENTATION OF SUPPLEMENTARY HYDROLOGICAL DATA USED FOR THE KAROO SHALE GAS SCIENTIFIC ASSESSMENT

Input by:

Prof. Roland Schulze and Stefanie Schütte

Centre for Water Resources Research

School of Agricultural, Earth and Environmental Sciences

University of KwaZulu-Natal, Pietermaritzburg Campus

CATCHMENT BACKGROUND

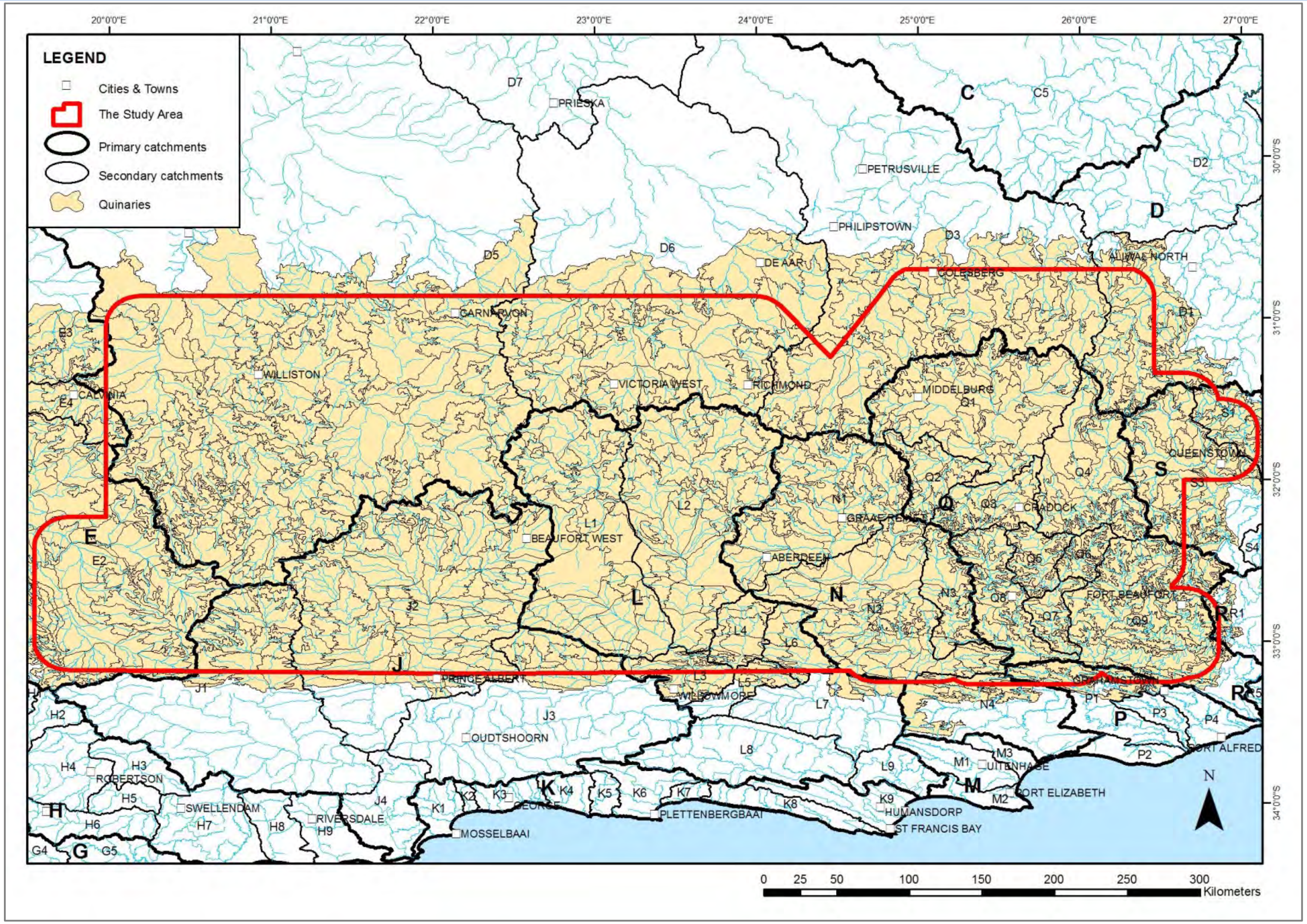


Figure 5A1.1: Map showing the distribution of Quinary catchments in the study area. Since the emphasis in these maps is on water resources / hydrology, the jagged outer boundaries designate the boundaries of all Quinary Catchments which are at least partially within the study area.

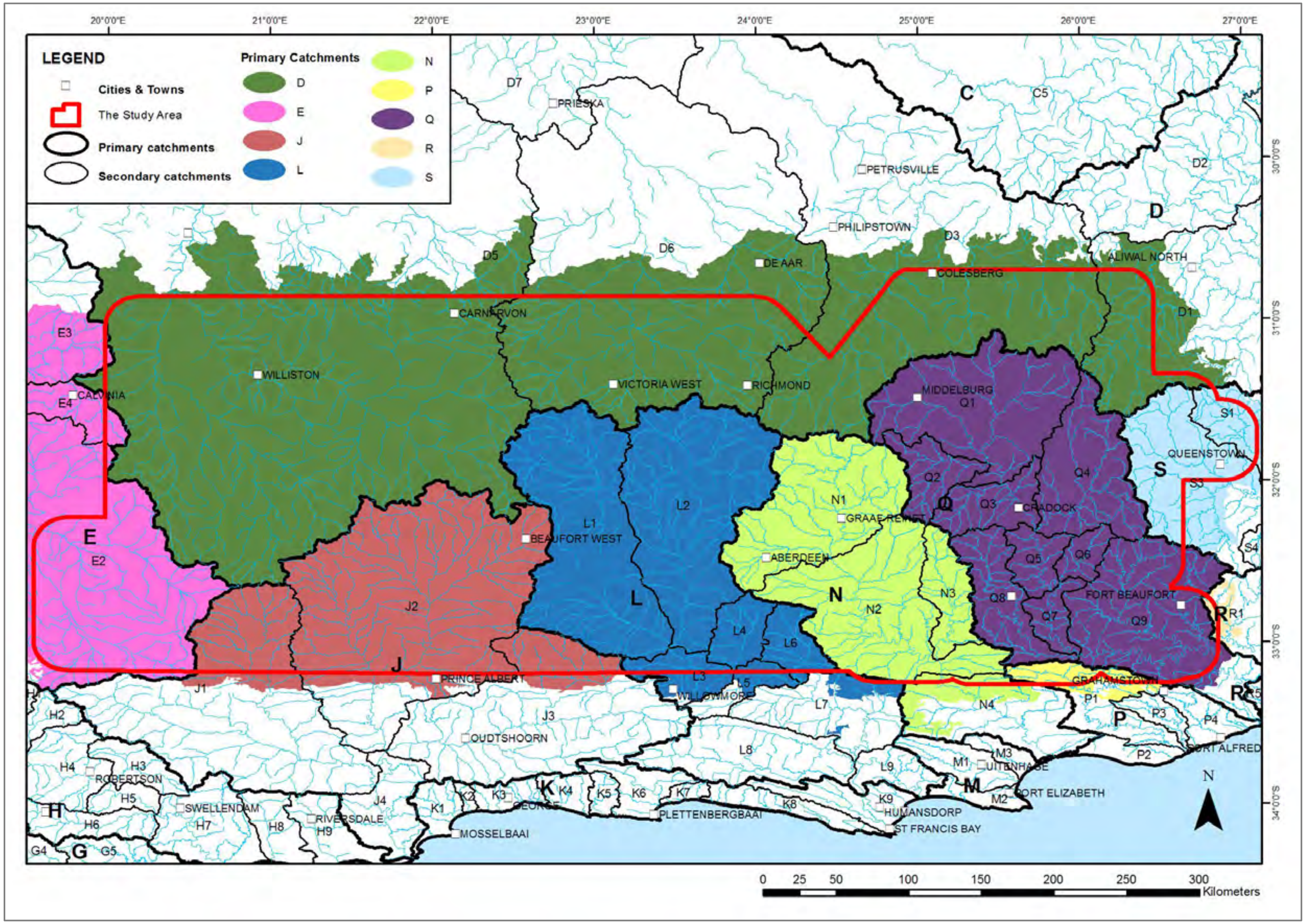


Figure 5A1.2: Map showing the study area in the context of Primary, Secondary and Quaternary Catchments.

BASIC RAINFALL AND EVAPORATION FIGURES

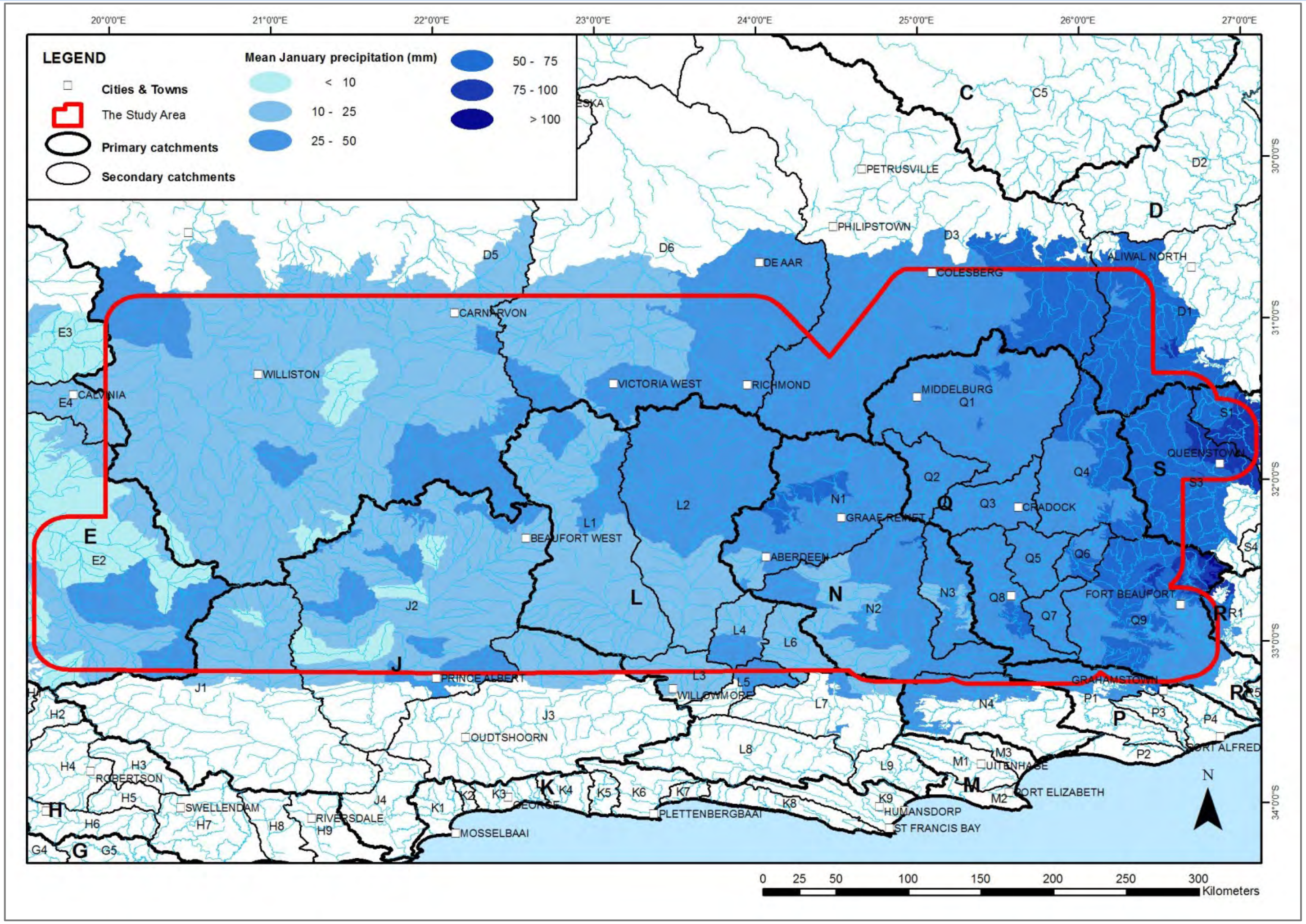
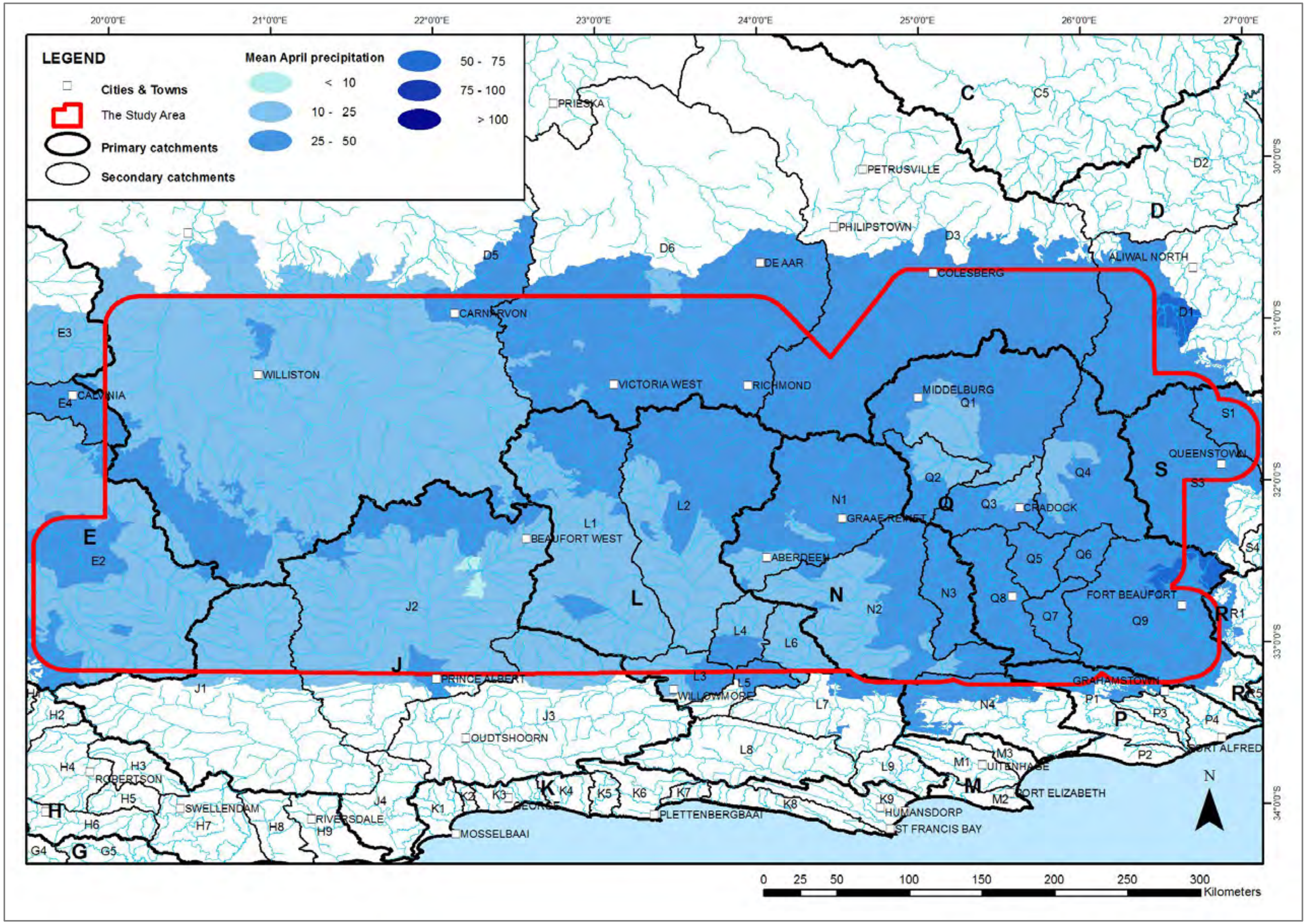


Figure 5A1.3:

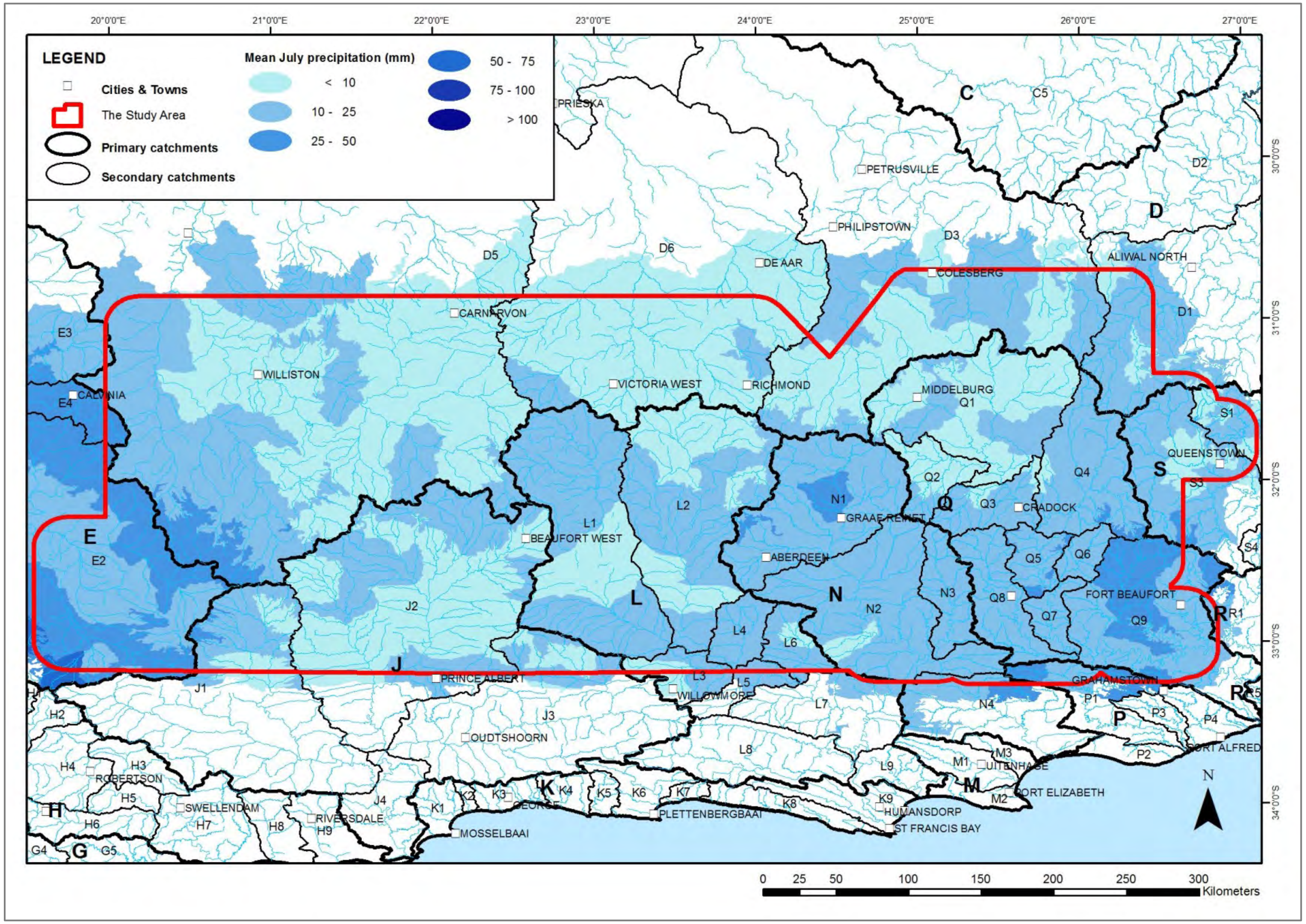
A. Mean January Precipitation (Summer)

Precipitation in the Cardinal Months of January (Representing Summer), April (Autumn), July (Winter) and October (Representing Spring)

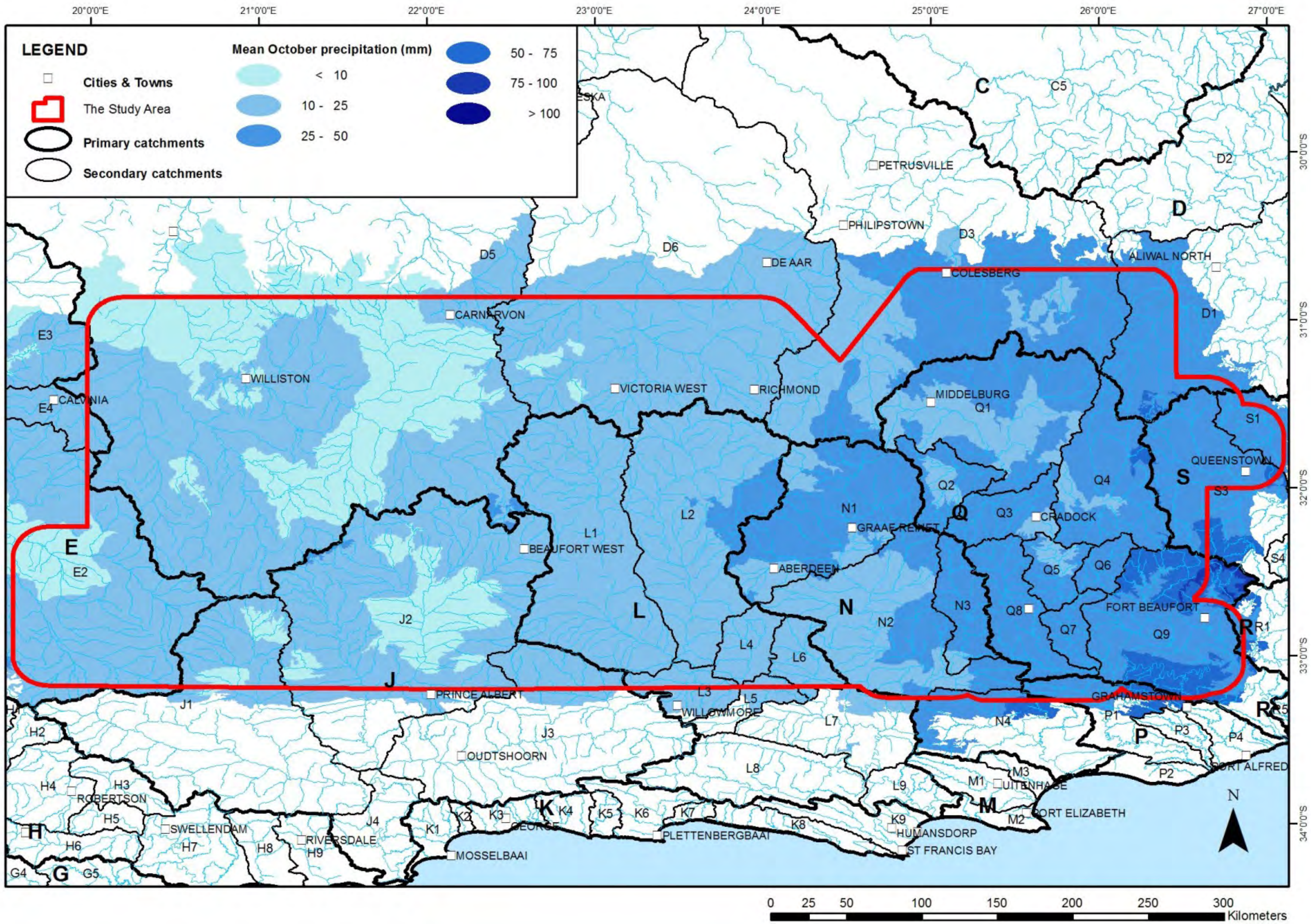
Noticeable in these maps is the west to east gradient of increasing monthly rainfall, and that in April a band of higher rainfall exists where the escarpment is located.



B. Mean April Precipitation (Autumn)



C. Mean July Precipitation (Winter)



D. Mean October Precipitation (Spring)
Figure 5A1.3 (A-D):
Precipitation in the Cardinal Months of January (Representing Summer), April (Autumn), July (Winter) and October (Representing Spring)
Noticeable in these maps is the west to east gradient of increasing monthly rainfall, that in April a band of higher rainfall exists where the escarpment is located and that in winter the west displays the highest rainfall. Original Data Source: Schulze (2012).

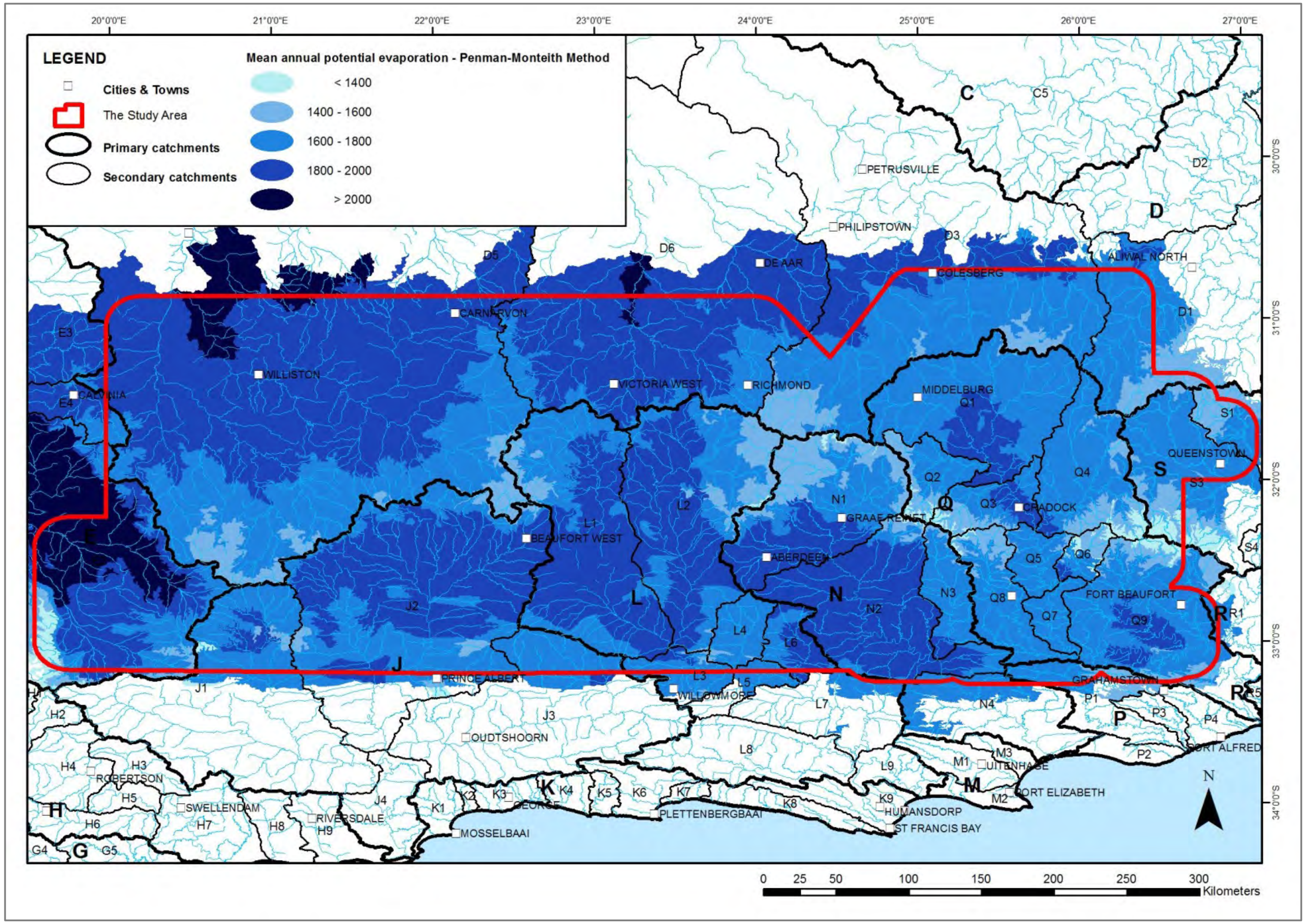


Figure 5A1.4:
Mean Annual Potential Evaporation (PE)
PE is an index of the atmospheric demand of water from a vegetated surface that contains sufficient soil water. PE is directly related to solar radiation and wind, and inversely related to relative humidity, Annual values are high, at generally over 1 600 mm and in parts of the arid west even > 2 000 mm. The band of relatively lower PE running through the centre occurs over the cooler higher lying east-west mountain range. Original Data Source: Schulze (2012).

HYDROLOGY – MAPS SHOWING STREAMFLOW DATA

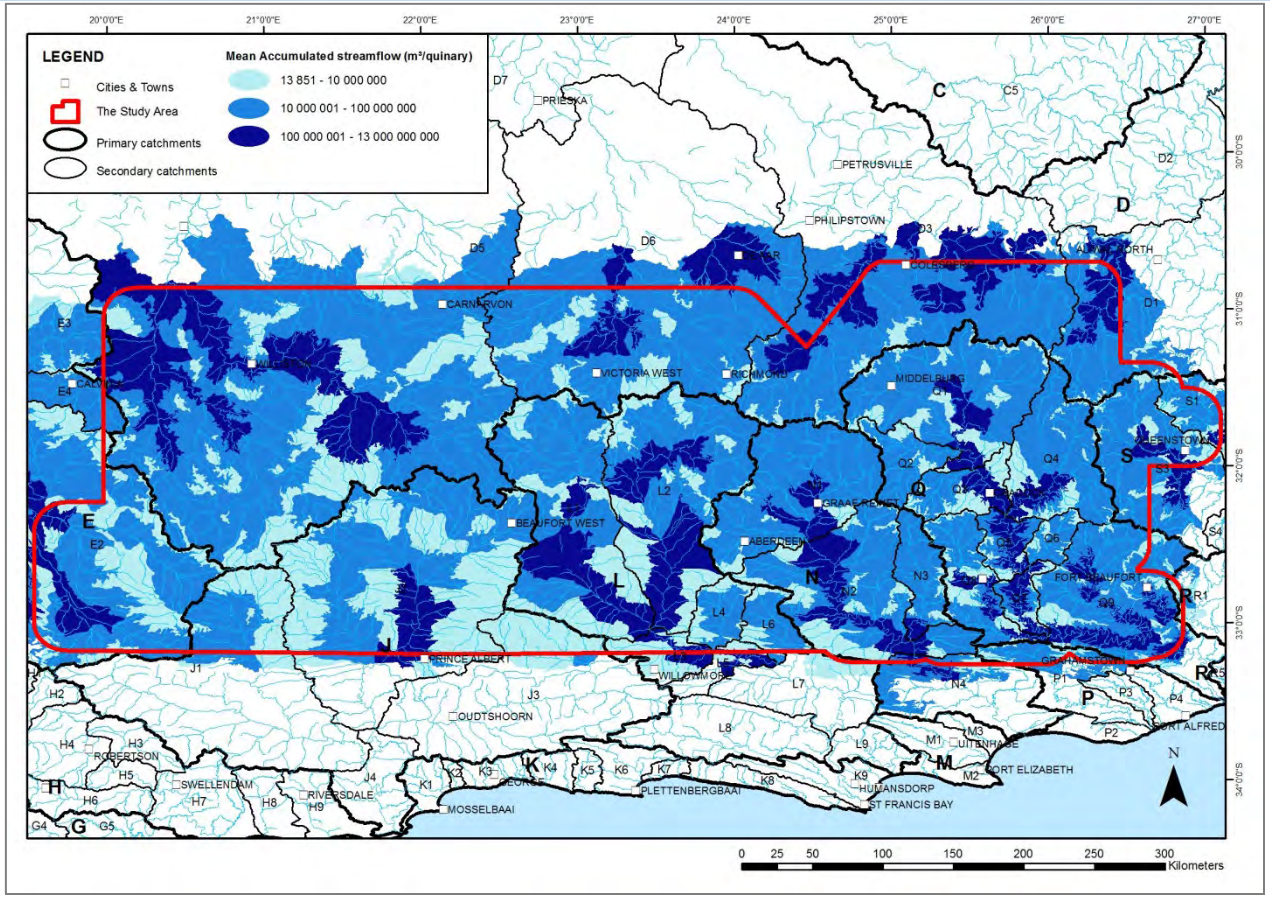


Figure 5A1.5:

Mean Annual Accumulated Streamflow (m^3/Quinary)

For each Quinary catchment, daily values of runoff were generated with the ACRU daily time-step physical-conceptual, multi-soil level and multi-purpose hydrological model (Schulze, 1995 and updates) using as inputs daily rainfall and daily potential evaporation and the catchment's actual soil properties of soil water at saturation, field capacity and wilting point plus saturated drainage rates for both the topsoil and the subsoil, and where runoff is the sum of daily stormflow (when it occur) and baseflow. The streamflow at the exit of a Quinary is then the runoff generated within that specific Quinary plus the accumulation of runoffs from all upstream Quinaries. Note that from the darker coloration one can clearly see how, for the bigger rivers, the streamflow gets larger and larger as one cascades downstream. Original Data Source: Schulze (2012).

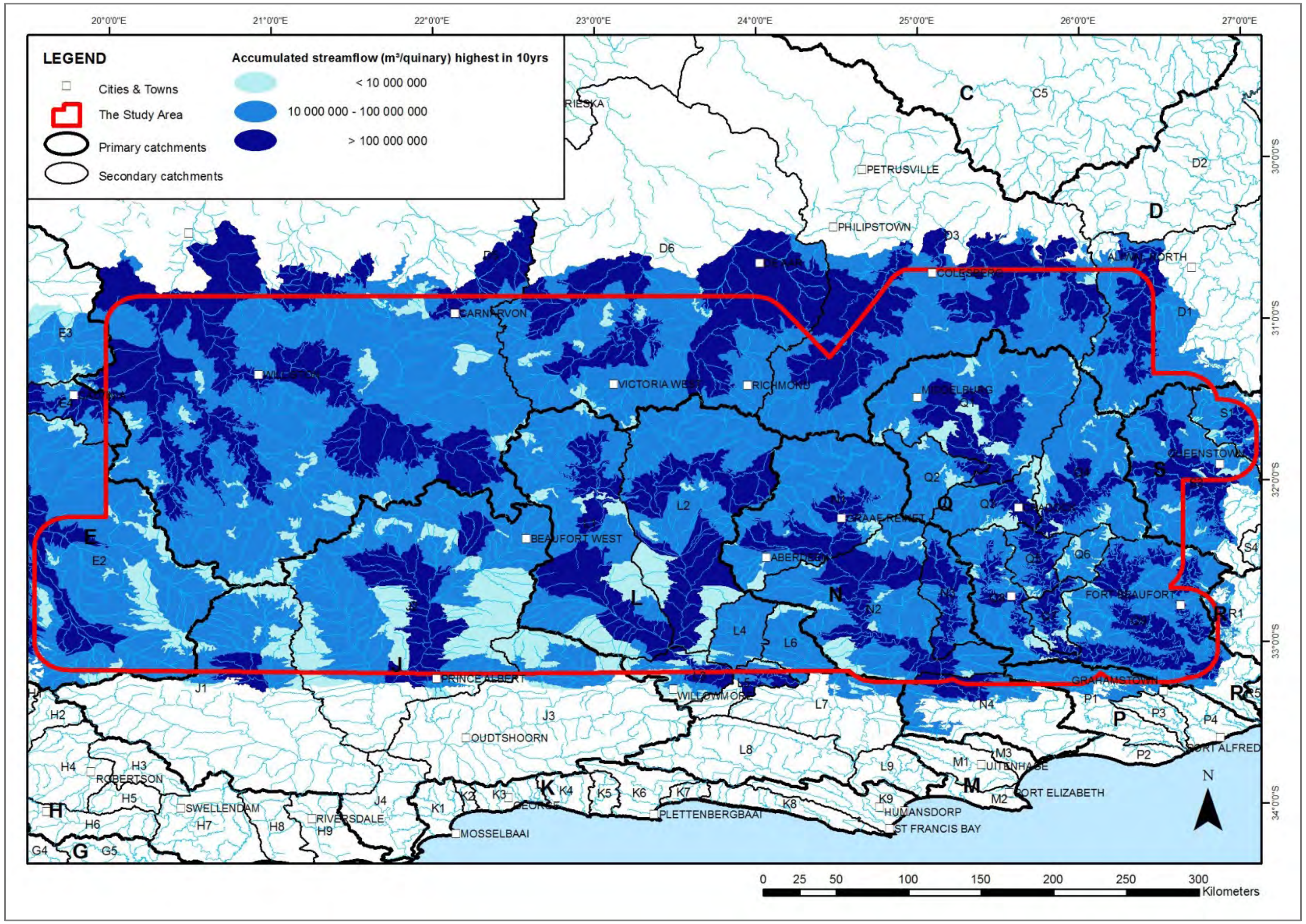


Figure 5A1.6:
Accumulated Streamflow (m³/Quinary) – Highest in 10 Years
In wet years the streamflows are considerably higher than in years with average streamflows, illustrated here for the year with the highest flows in 10 years. Original Data Source: Schulze (2012).

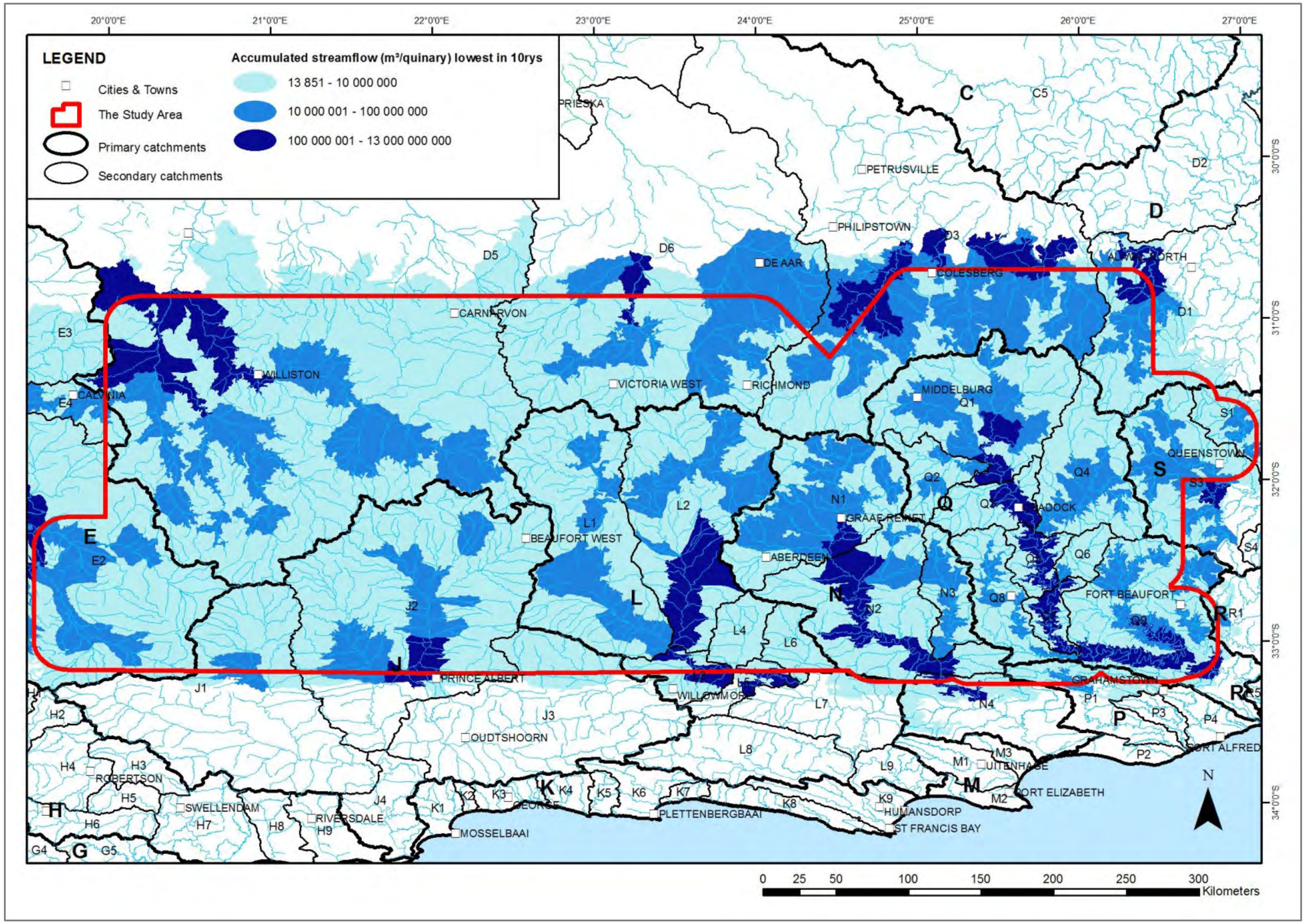


Figure 5A1.7:
Accumulated Streamflow (m^3/Quinary) – Lowest in 10 Years
Similarly, in dry years the streamflows are considerably lower than in years with average streamflows, illustrated here for the year with the lowest flows in 10 years. Note that in the study area the differences in flows between wet and dry years is vast, indicative of the high variability of streamflows and thus high uncertainty of assured supplies of water from local sources. Original Data Source: Schulze (2012).

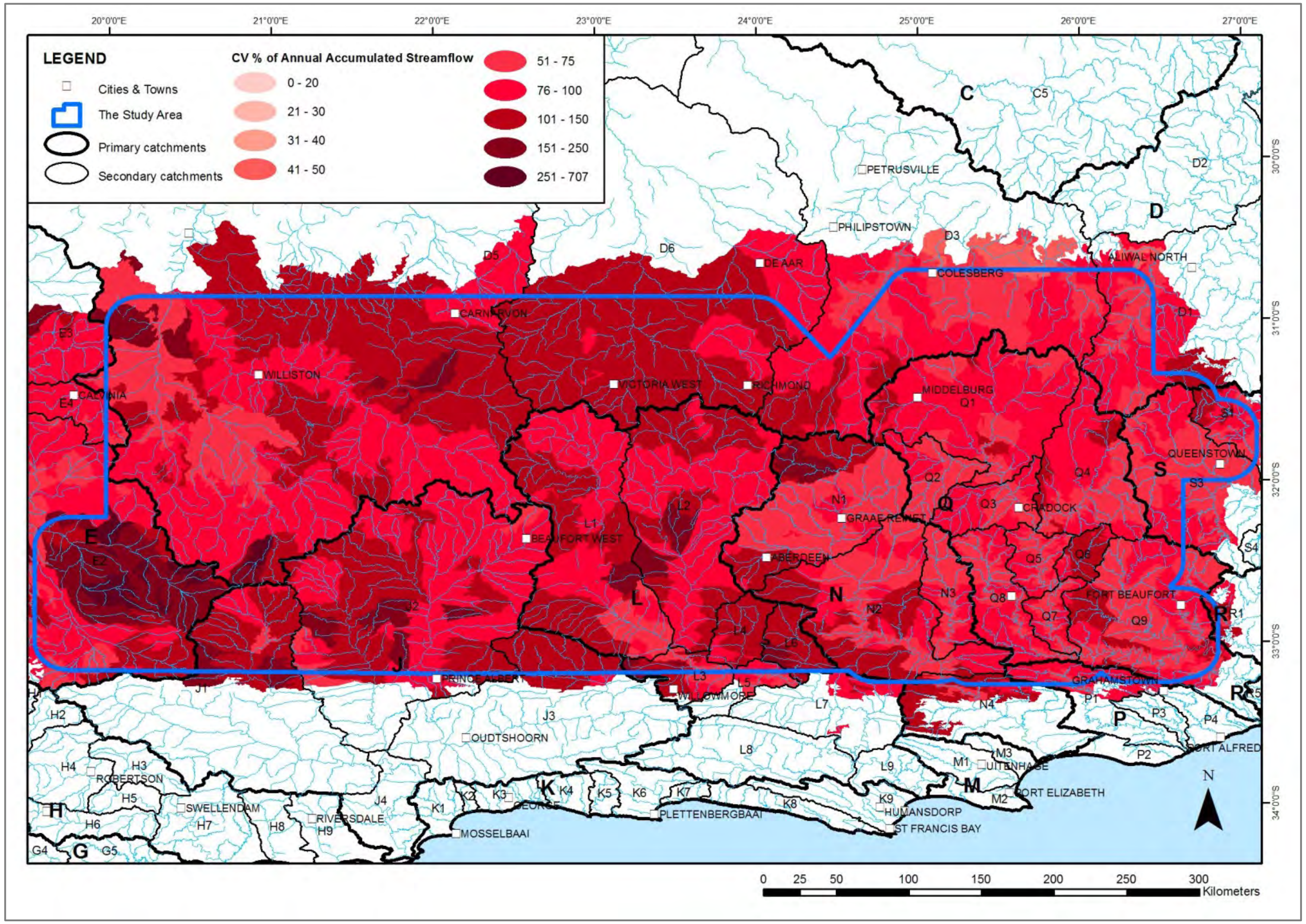


Figure 5A1.8:*Coefficient of Variation (%) of Annual Accumulated Streamflows*

As indicated above, there is a very high inter-annual variability in streamflows, shown by CVs in the range of 50-250%. Note that the CV of annual streamflow is considerably higher than that of annual rainfall, indicative of the non-linear response of runoff to rainfall, leading to an amplification of variability of the hydrological cycle, which is particularly prevalent in semi-arid regions. Original Data Source: Schulze (2012).

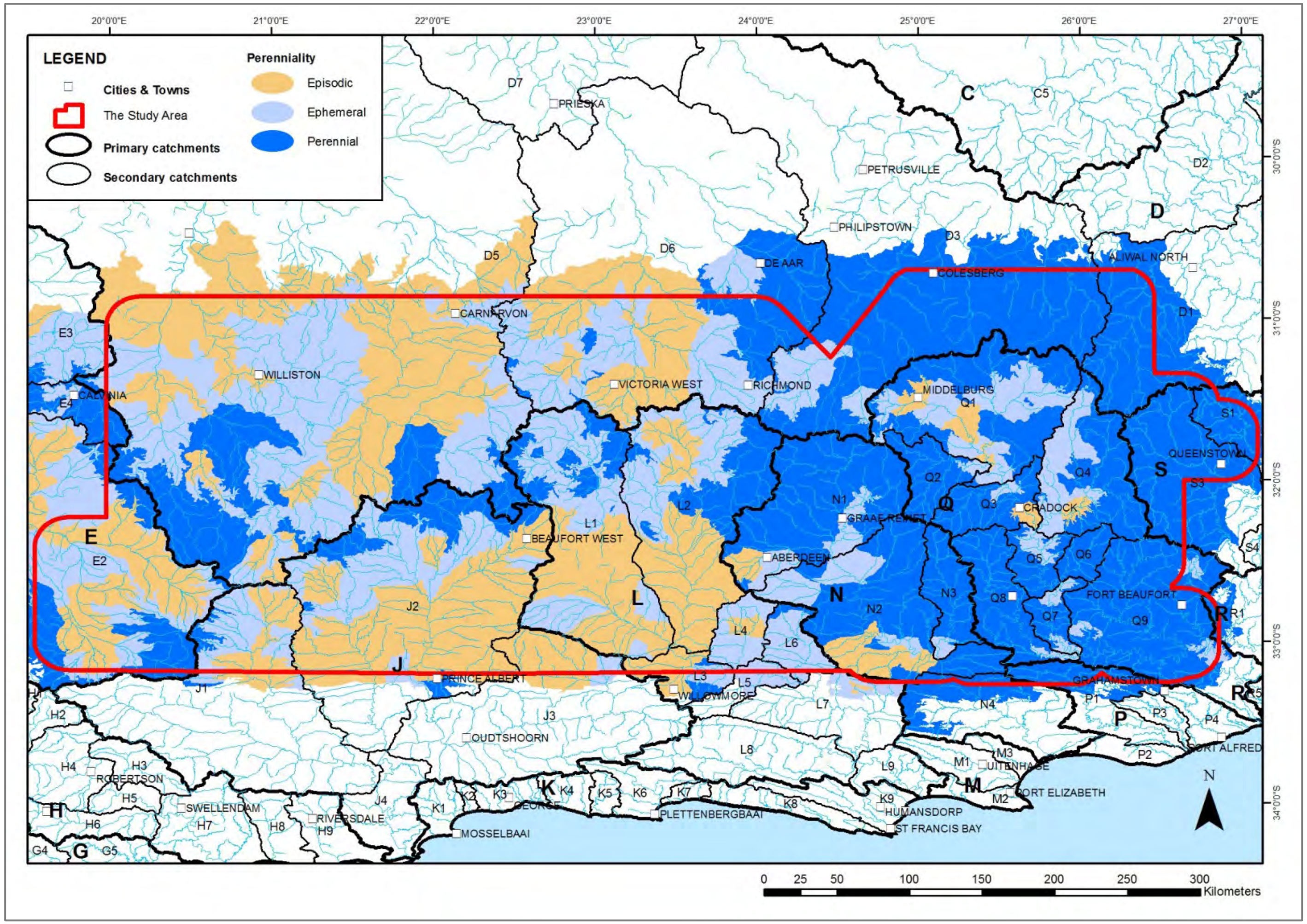


Figure 5A1.9:*Areas of Perennial, Ephemeral and Episodic Flows*
Perennial flows are defined here as effective runoff (i.e. runoff generated minus channel flow losses to evaporation) from individual Quinaries for at least 11 months in a year with average flows, while ephemeral streams are defined as exhibiting flows in at least 3 months and episodic streams have, in an average year, anything from zero flows to flows in two months only. The study area exhibits perennial flows in the east and along the high mountain Quinaries, with both areas of both ephemeral and episodic streams clearly evident. The latter two place great uncertainty on surface water availability in many parts of the study area.
Information Source: New unpublished research by Schulze and Schütte (2016).

HYDROLOGY: RECHARGE INTO THE SOIL PROFILE

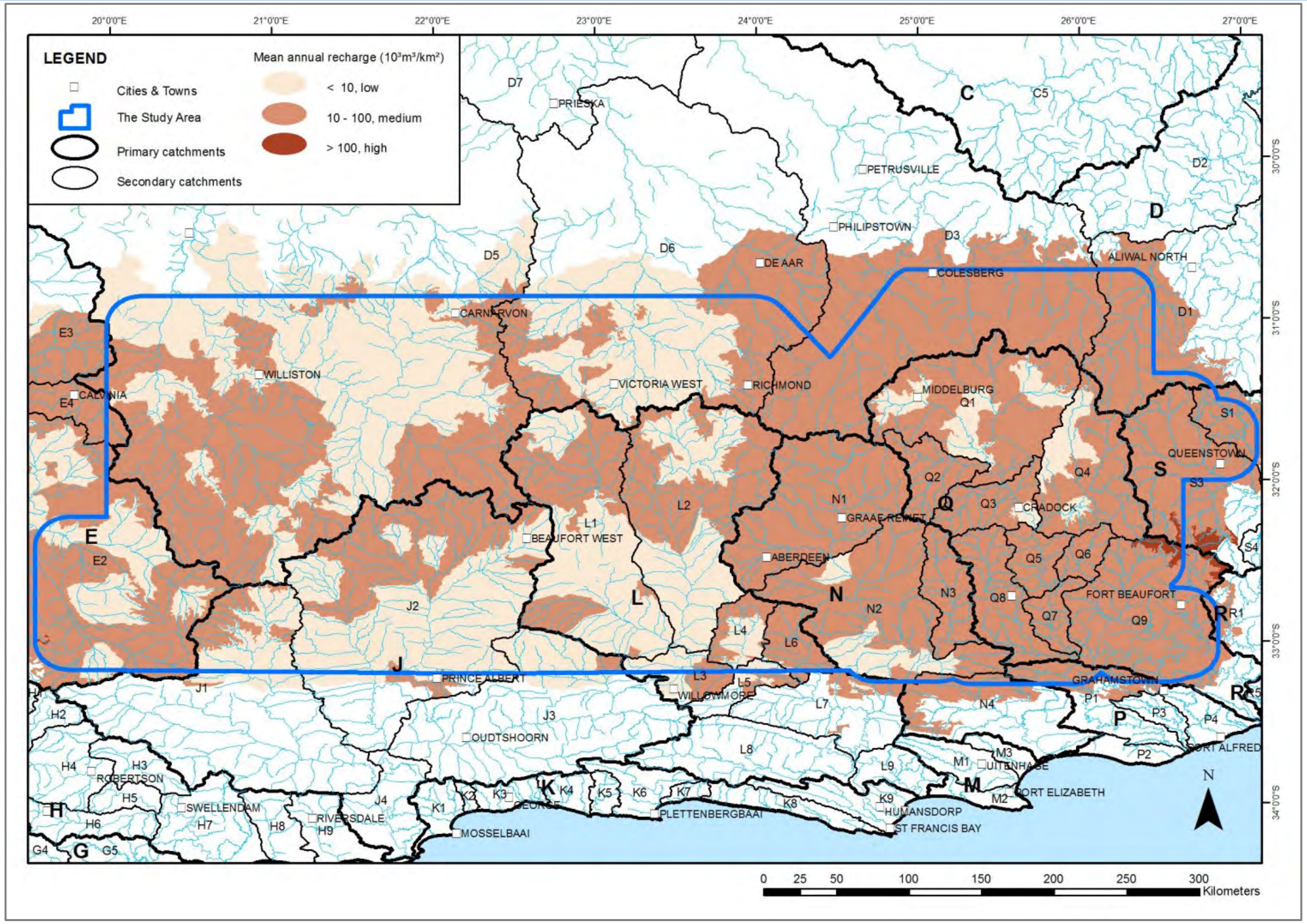


Figure 5A1.10:*Mean Annual Recharge ($10^3 m^3/km^2$) Through the Soil Profile*

Recharge generated by the ACRU model takes place once both the topsoil and the subsoil are saturated with soil water and drainage then takes place out of the subsoil (with the rate dependent on soil properties) into an intermediate groundwater store where it is no longer available to plants. Since ACRU is a daily time-step model, this recharge is physically based and takes place as discrete events highly dependent on days with high rainfalls, or consecutive days with sustained rainfalls, or rain falling on an already wet soil. Recharge here is expressed volumetrically as m^3/km^2 and the map shows clearly areas of low and medium mean annual recharge. Original Data Source: Schulze (2012).

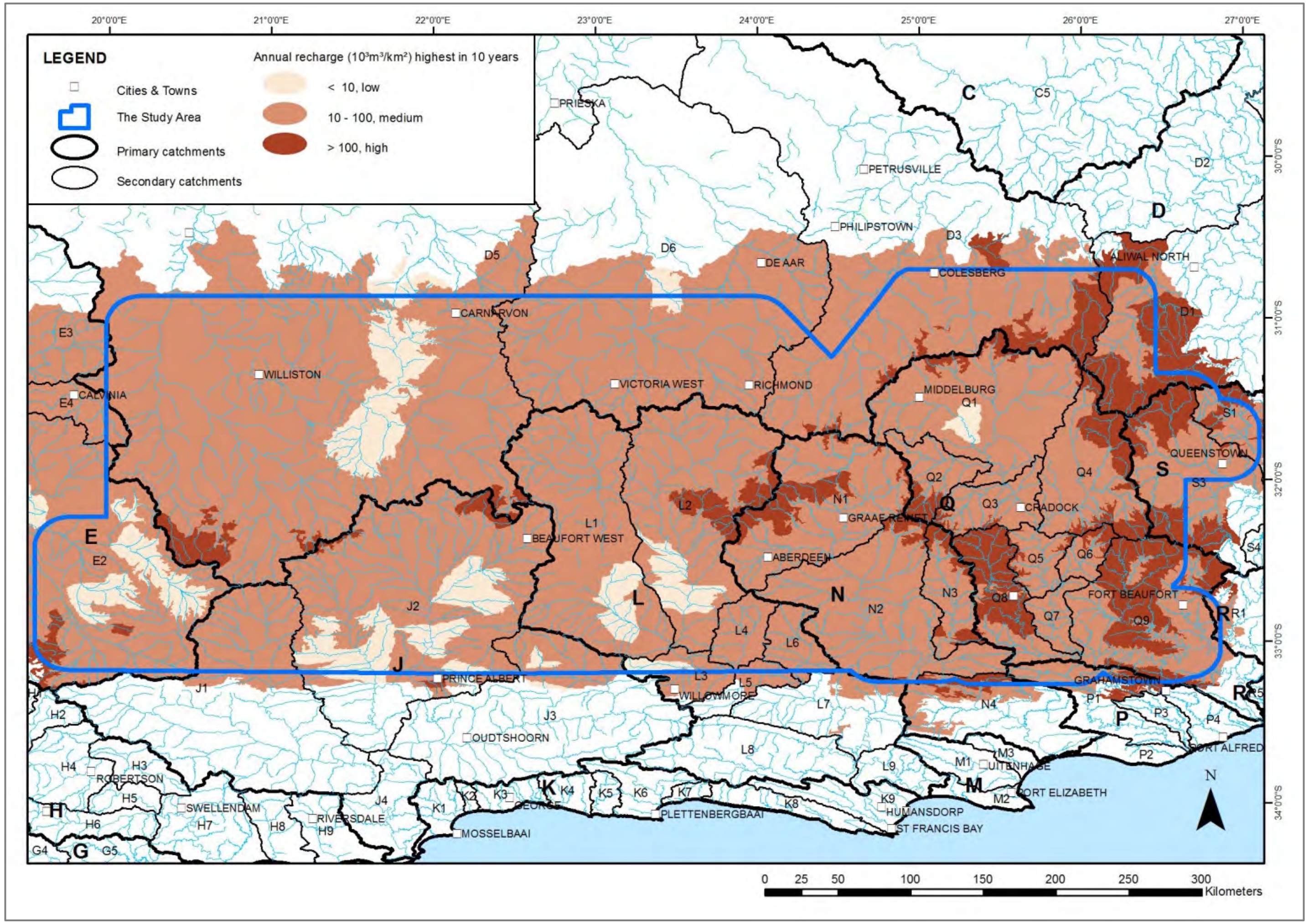


Figure 5A1.11:*Highest Annual Recharge ($10^3 m^3/km^2$) through the Soil Profile – highest in 10 Years*
In wet years recharge is non-linearly and exponentially higher than under average conditions as the thresholds for recharge to occur are exceeded more frequently and with higher magnitudes. Original Data Source: Schulze (2012).

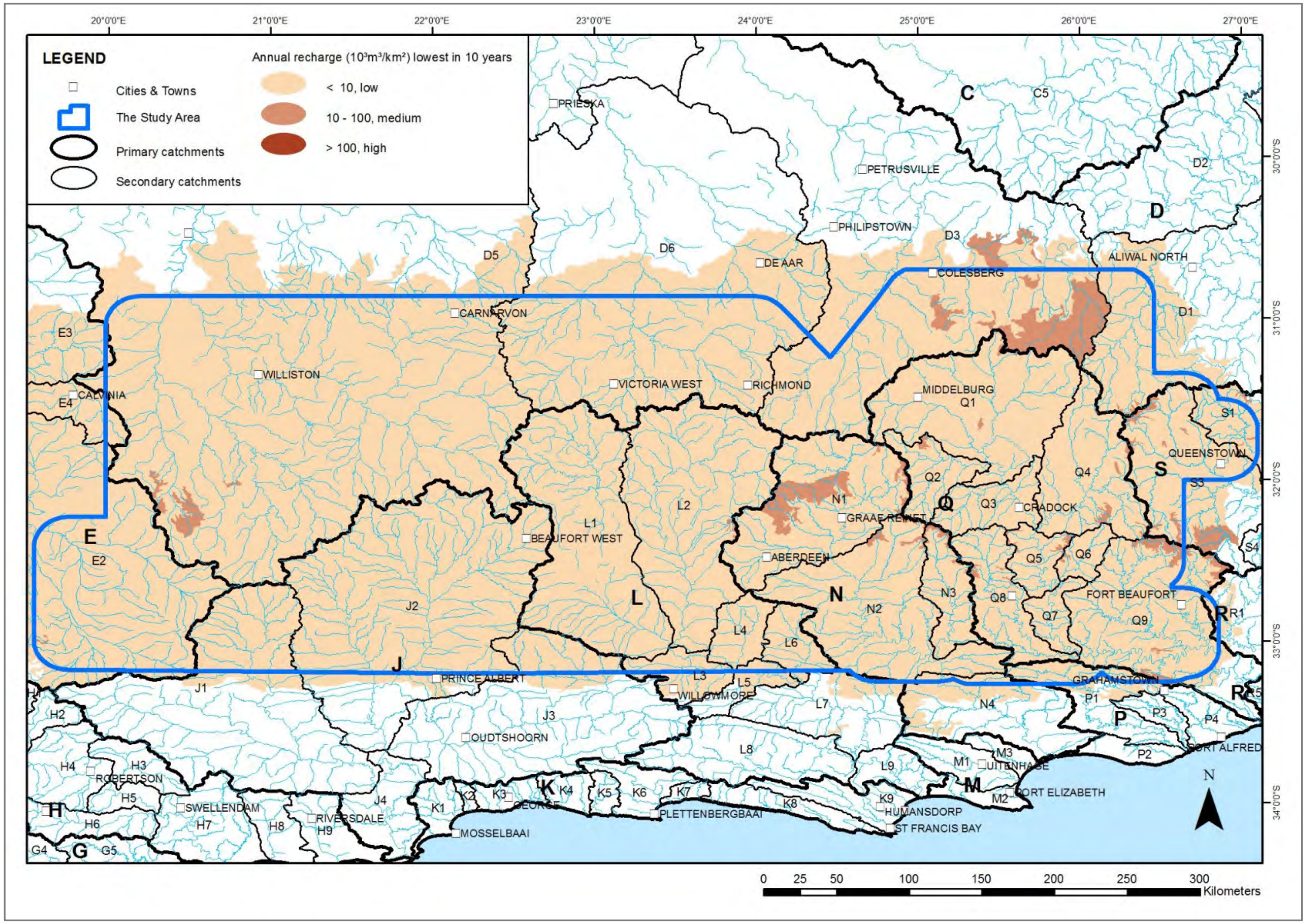


Figure 5A1.12:*Lowest Annual Recharge ($10^3m^3/km^2$) Through the Soil Profile in 10 Years*

By the same token as in Figure 5A1.11, in dry years recharge is non-linearly and exponentially lower than under average conditions as the thresholds for recharge to occur are exceeded less frequently and with lower magnitudes. Most of the study area now experiences recharge on average 10 times lower than in wet years, indicative of very high inter-annual variability of recharge. Original Data Source: Schulze (2012).

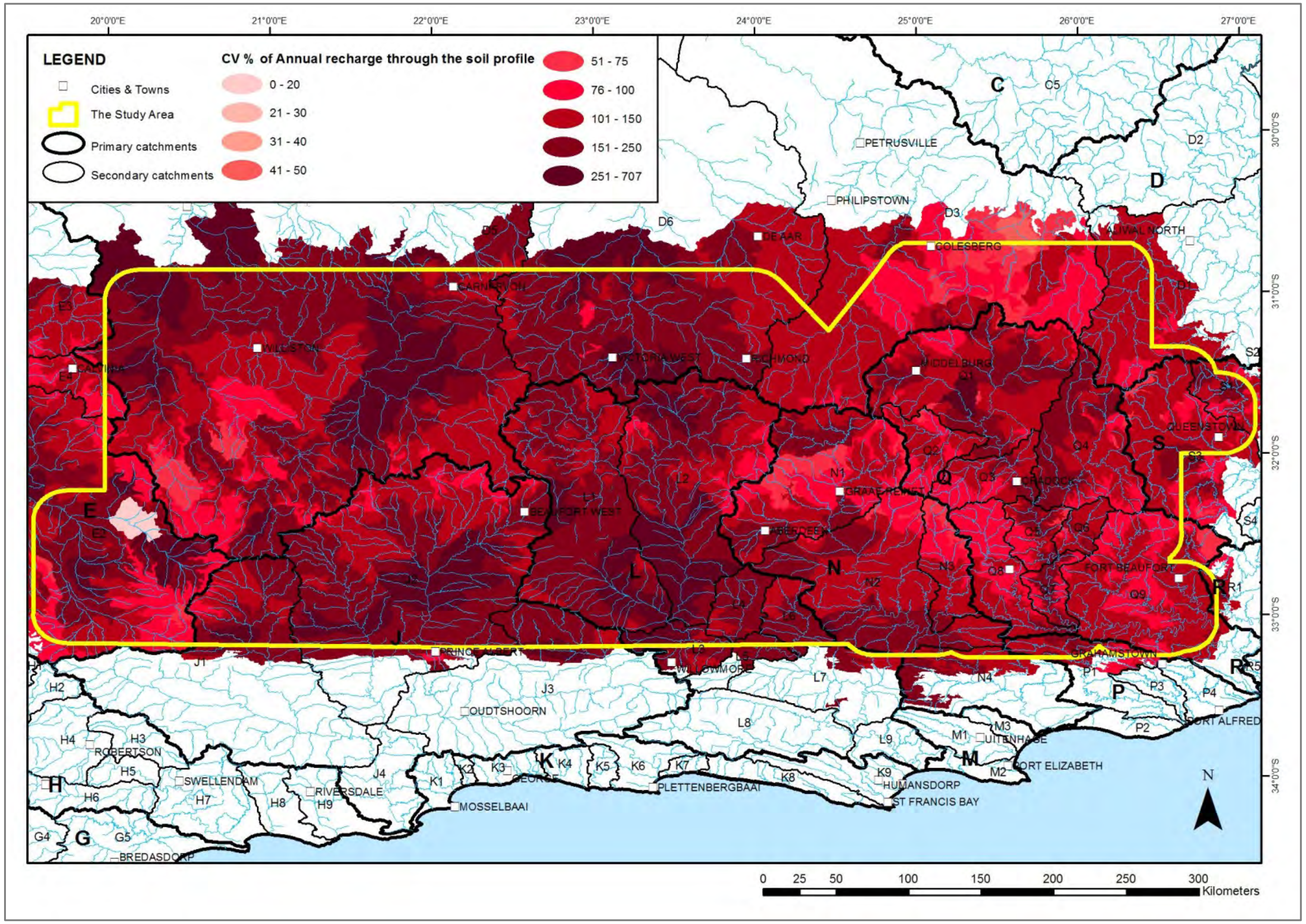


Figure 5A1.13:*Coefficient of Variation (%) of Annual Recharge through the Soil Profile*

As already indicated from the information above, the CV of recharge through the soil profile is exceptionally high in the study area, mostly in the range of 100-250%, rendering this area highly vulnerable to the over-exploitation of shallow groundwater reserves. Note that the CV of annual recharge is considerably higher than that of annual streamflow which, in turn, is considerably higher than that of annual rainfall, reinforcing again the notion of the non-linearity of the hydrological system. Original Data Source: Schulze (2012).

DROUGHT

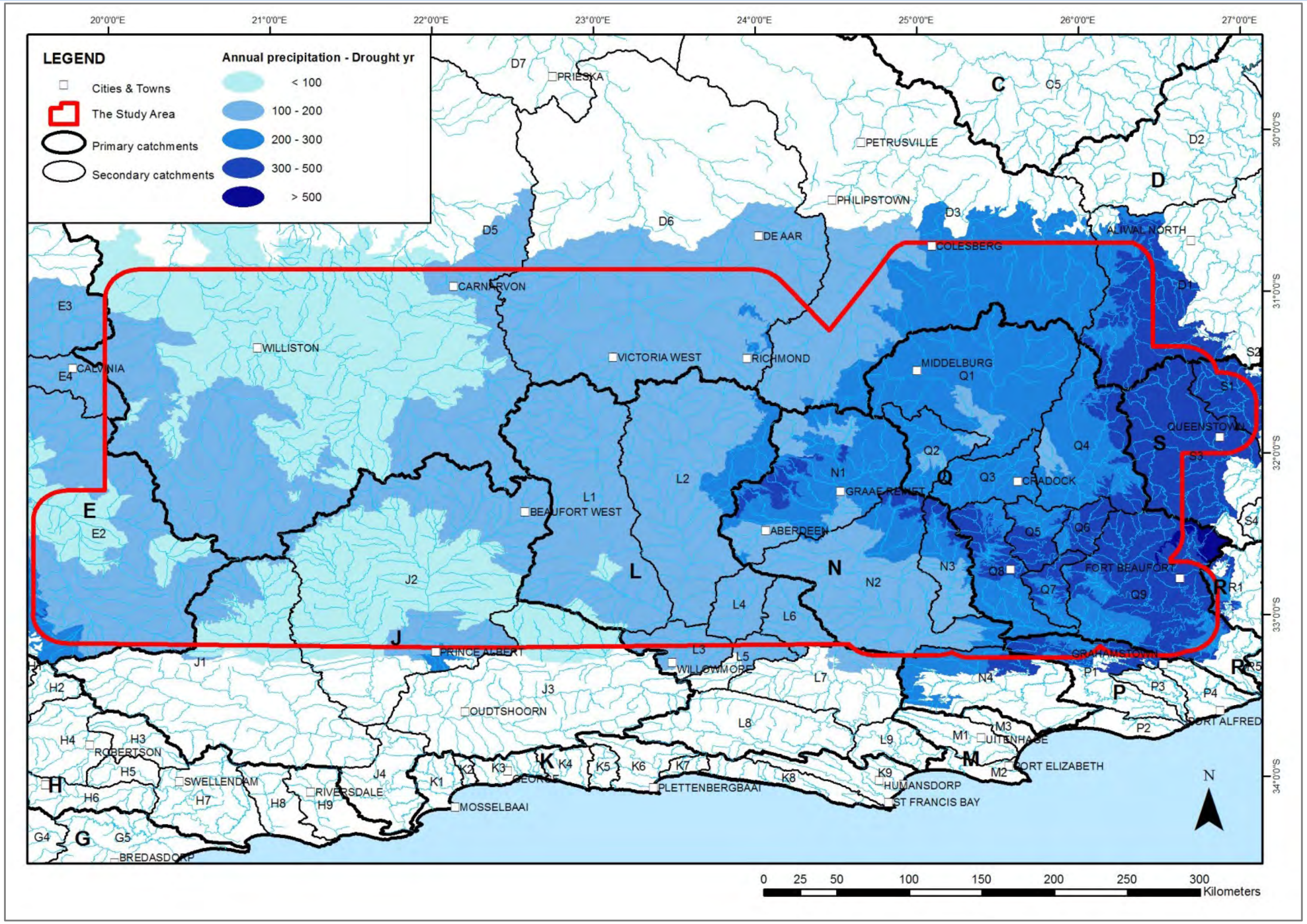


Figure 5A1.14:*Annual Precipitation in a Year with Drought*
A year with drought is defined here as rainfall one standard deviation below the mean annual precipitation. The map shows a decreasing rainfall gradient from east to west from around 500 mm to below 100 mm per year. Source: Newly derived, based on Original Data Generated for Schulze (2012).

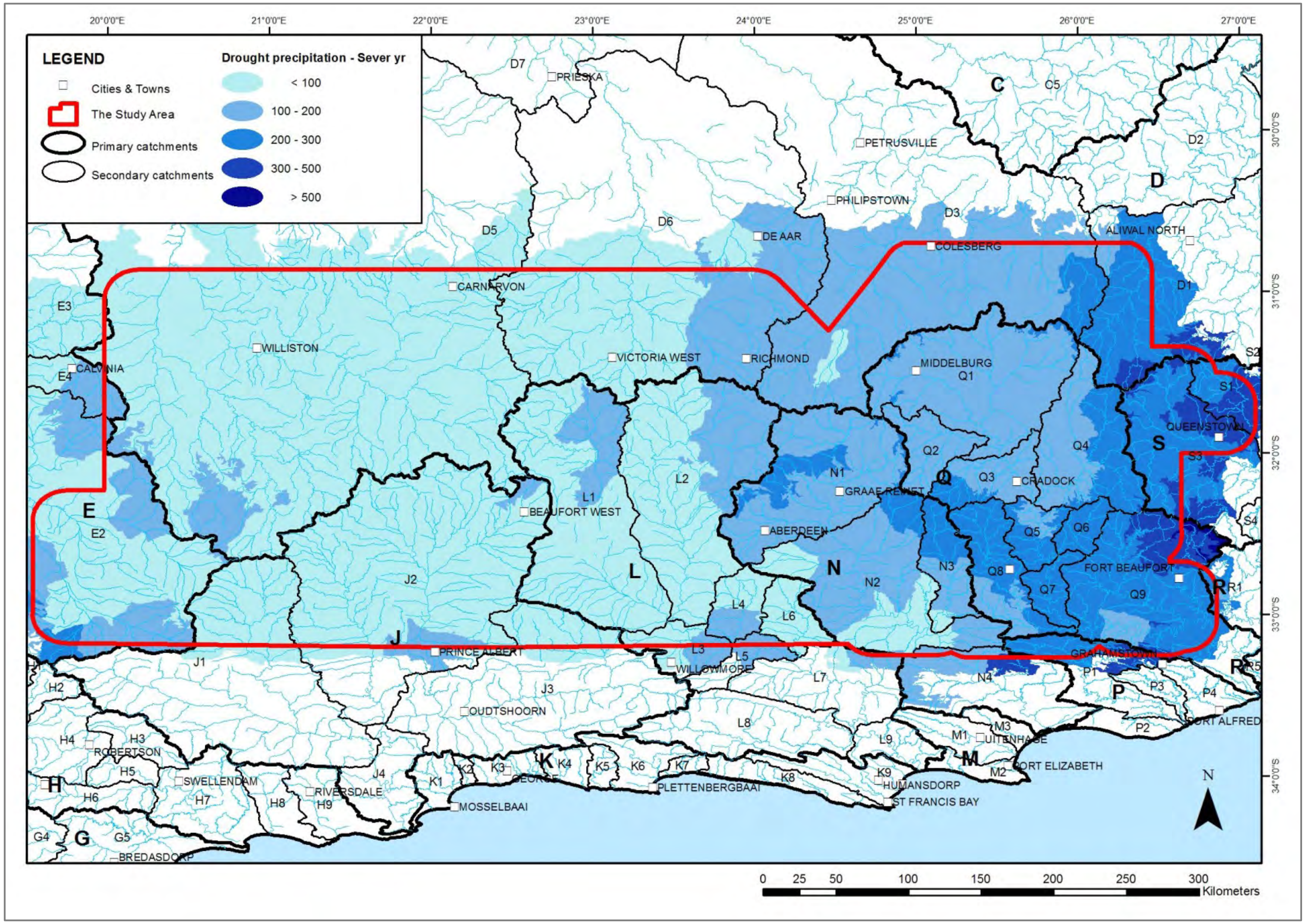


Figure 5A1.15:*Annual Precipitation in a Year with Severe Drought*
A severe meteorological drought is defined here as rainfall 1.5 standard deviations below the mean annual rainfall, and the map shows around 60% of the study area receiving less than 100 mm in such a year – indicative of the harsh climatic conditions existing in this region.
Source: Newly derived, based on Original Data Generated for Schulze (2012).

Figures showing extreme rainfall and streamflow

Extreme rainfall and streamflow events are those that occur, statistically, for example, once every 10 years or once every 50 years, and such extreme events can, for example, be of one days' duration or of a number of consecutive days' duration such as a three day event, resulting in damaging floods.

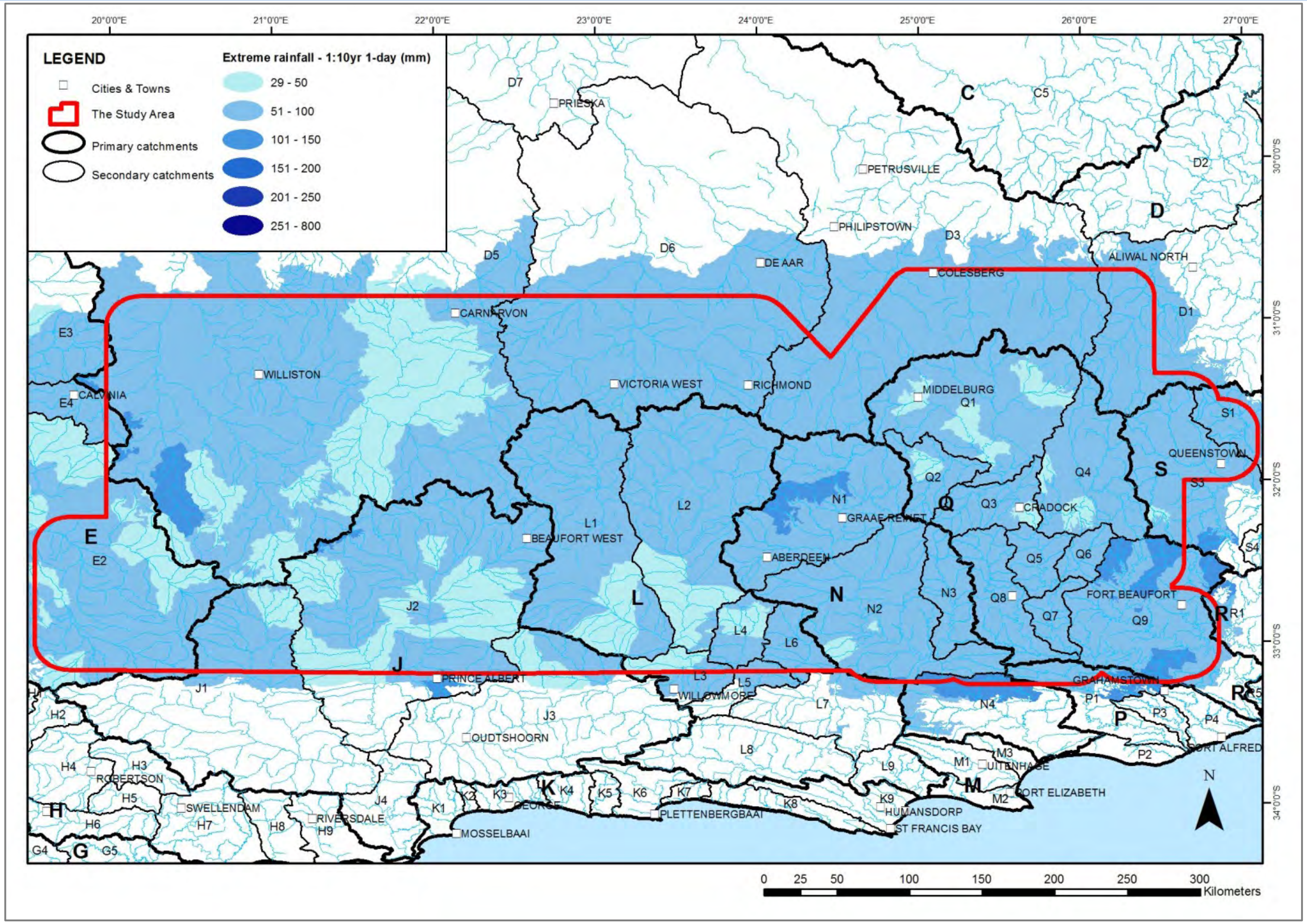


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Figure 5A1.16:*1 in 10 Year 1-Day Rainfall (mm)*

Values are generally in the range of 50-100 mm on a given day. Original Data Source: Schulze (2012).

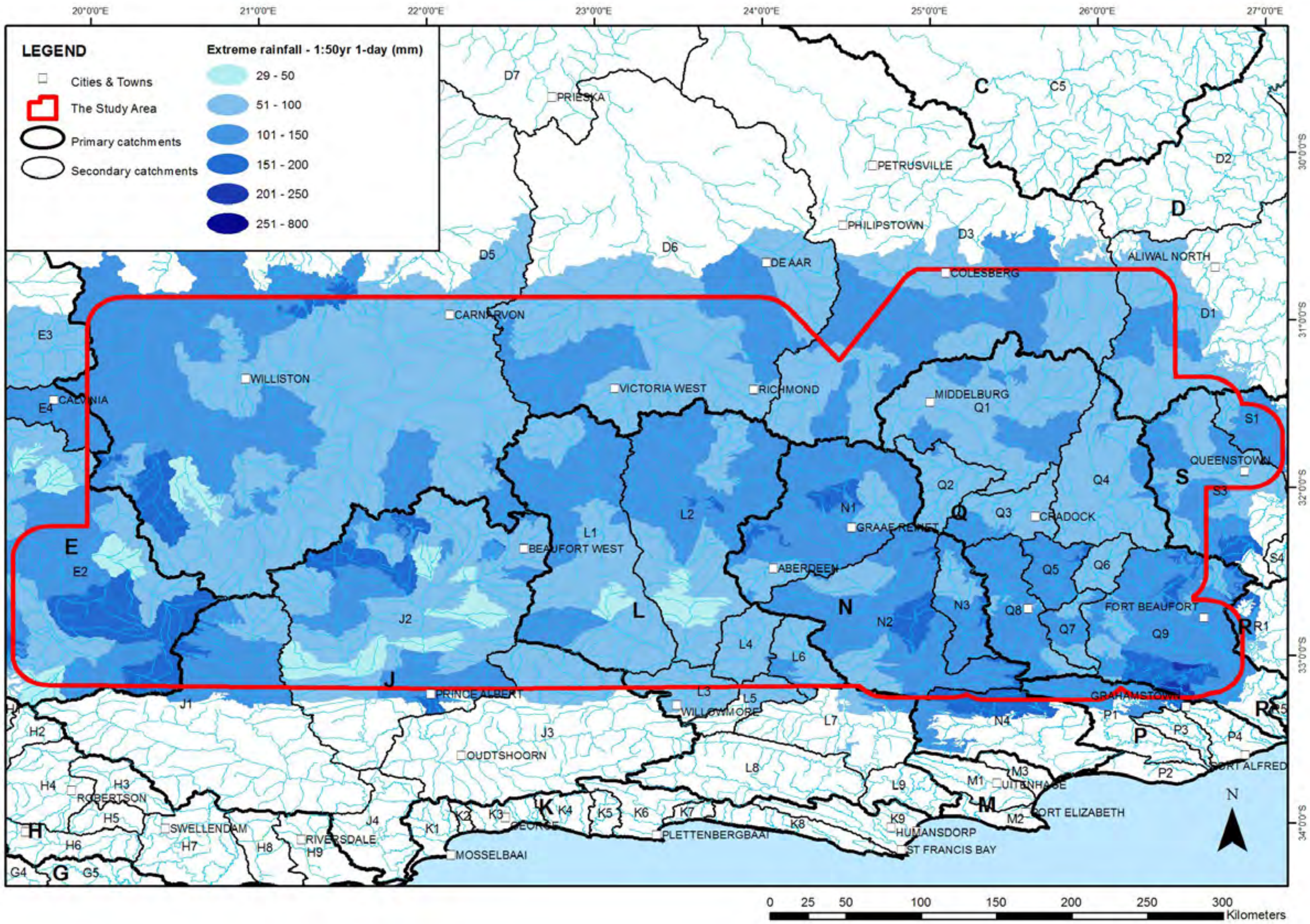

Figure 5A1.17:*1 in 50 Year 1-Day Rainfall (mm)*
Statistically, twice per century this region can expect a daily rainfall between 50 and 150 mm. Original Data Source: Schulze (2012).

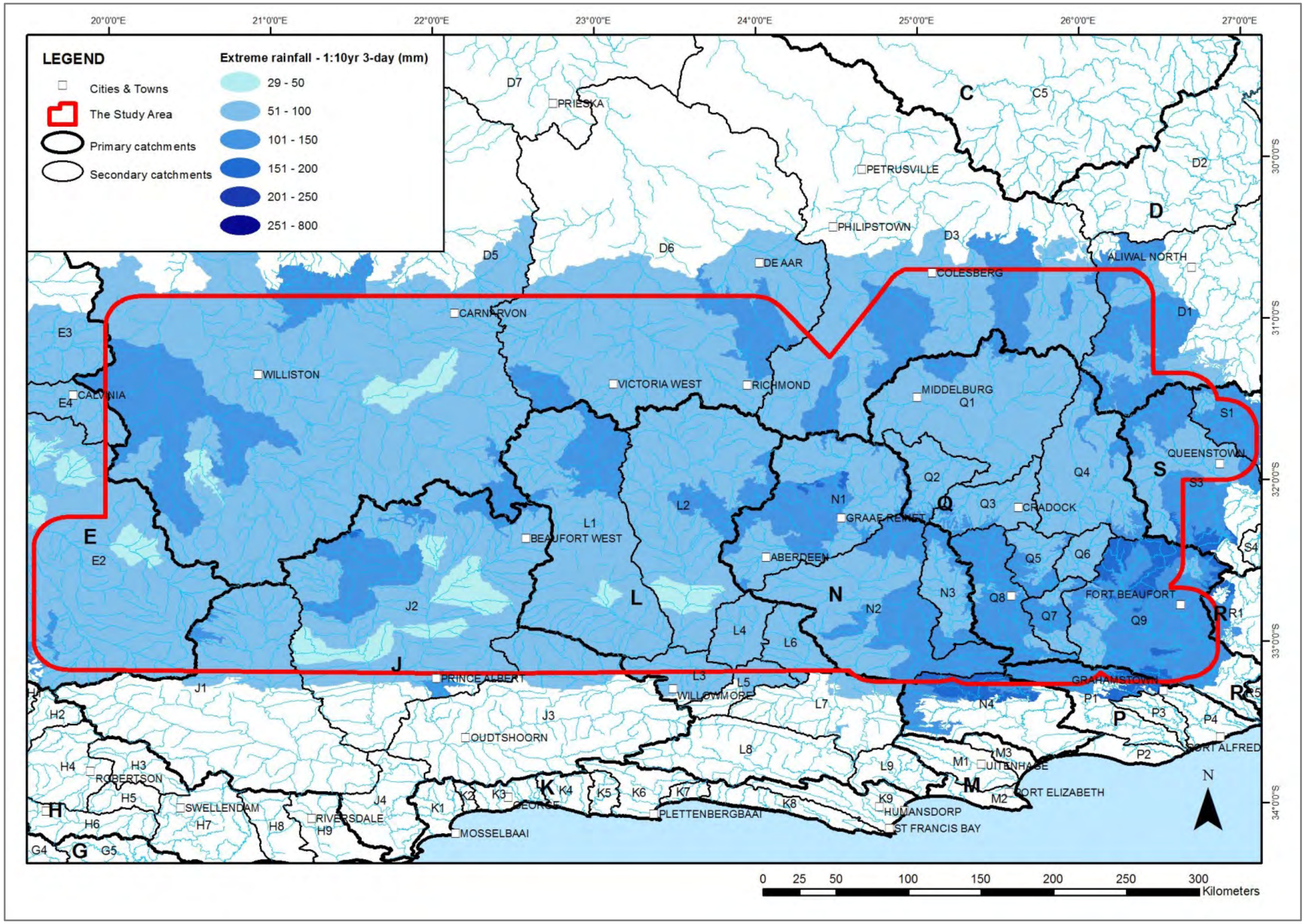

Figure 5A1.18:*1 in 10 Year 3-Day Rainfall (mm)*
For three consecutive days, rainfall values once in 10 years are generally in the range of 50-150 mm. Original Data Source: Schulze (2012).

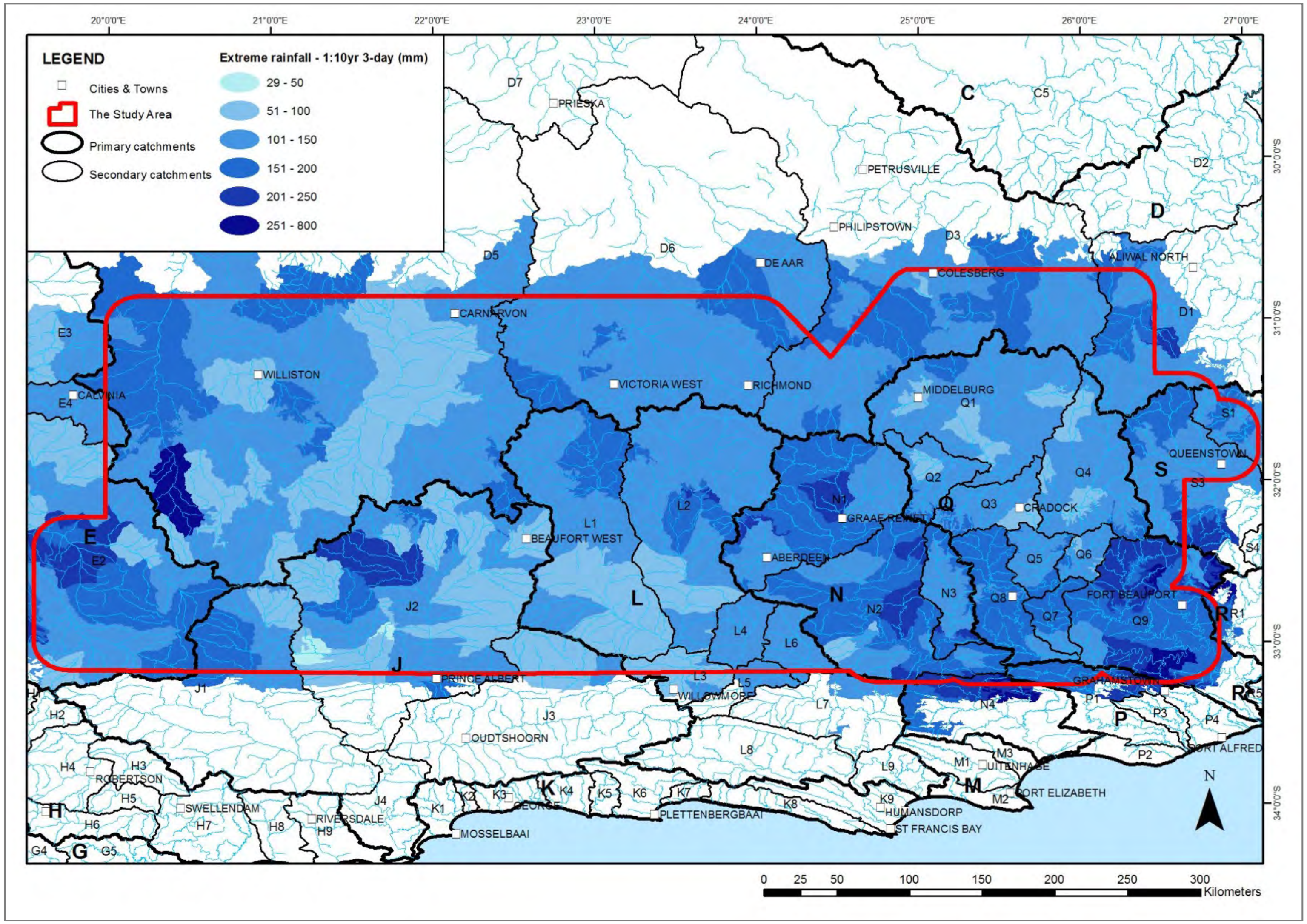

Figure 5A1.19:*1 in 50 Year 3-Day Rainfall (mm)*
For three consecutive days, rainfall values once in 50 years are generally much higher and in the range of 100-200 mm, with the potential to create major disruptions and damage. Original Data Source: Schulze (2012).

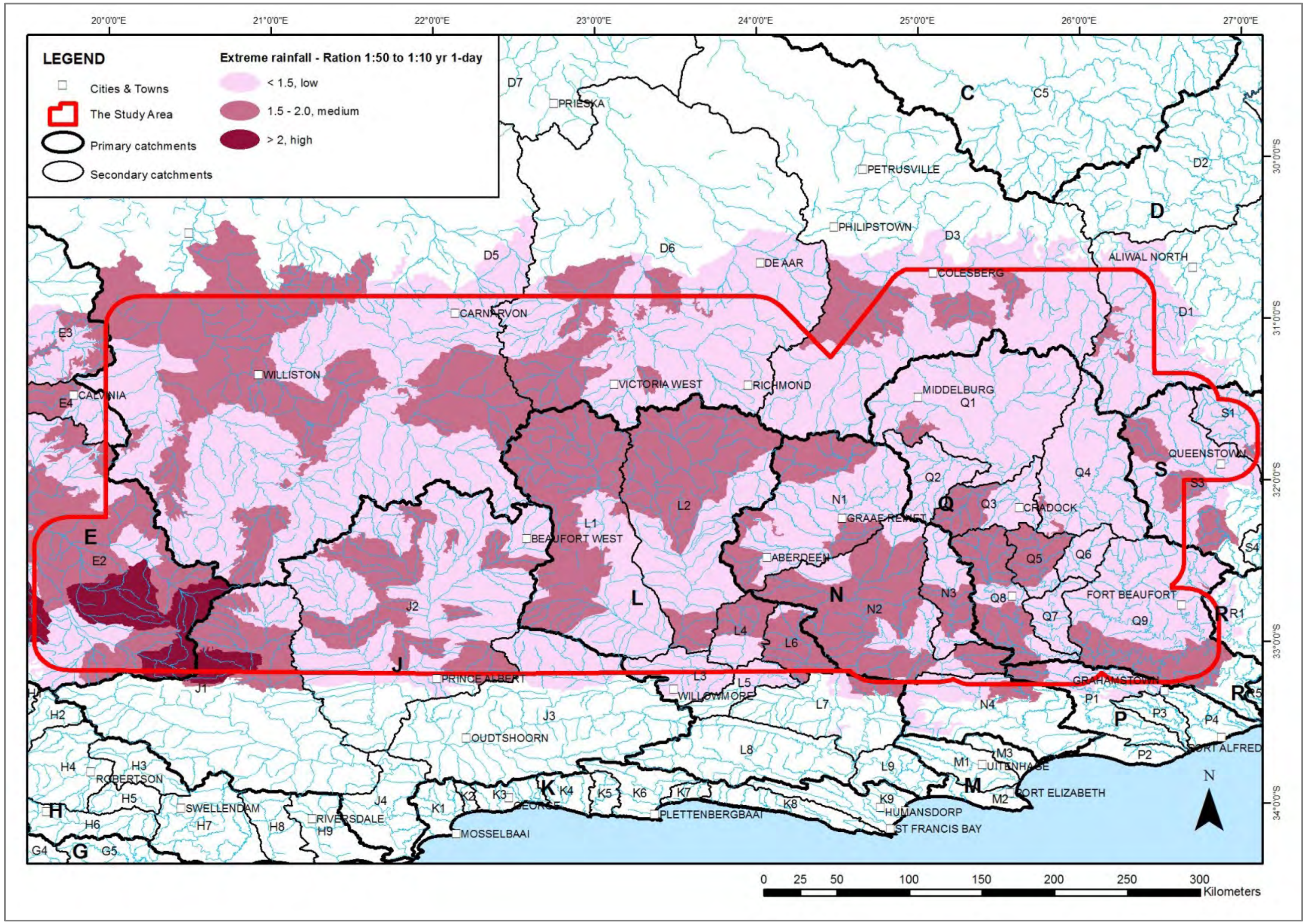

Figure 5A1.20:*Ratio of the 1:50 to 1:10 Year Extreme 1 Day Rainfall*

This ratio identifies particularly vulnerable areas, with a high ratio of the very rare event (1:50 year) to the less rare (1:10 year) event indicating very rare events being "shock" events. The highest ratios are in the south-west. Original Data Source: Schulze (2012).

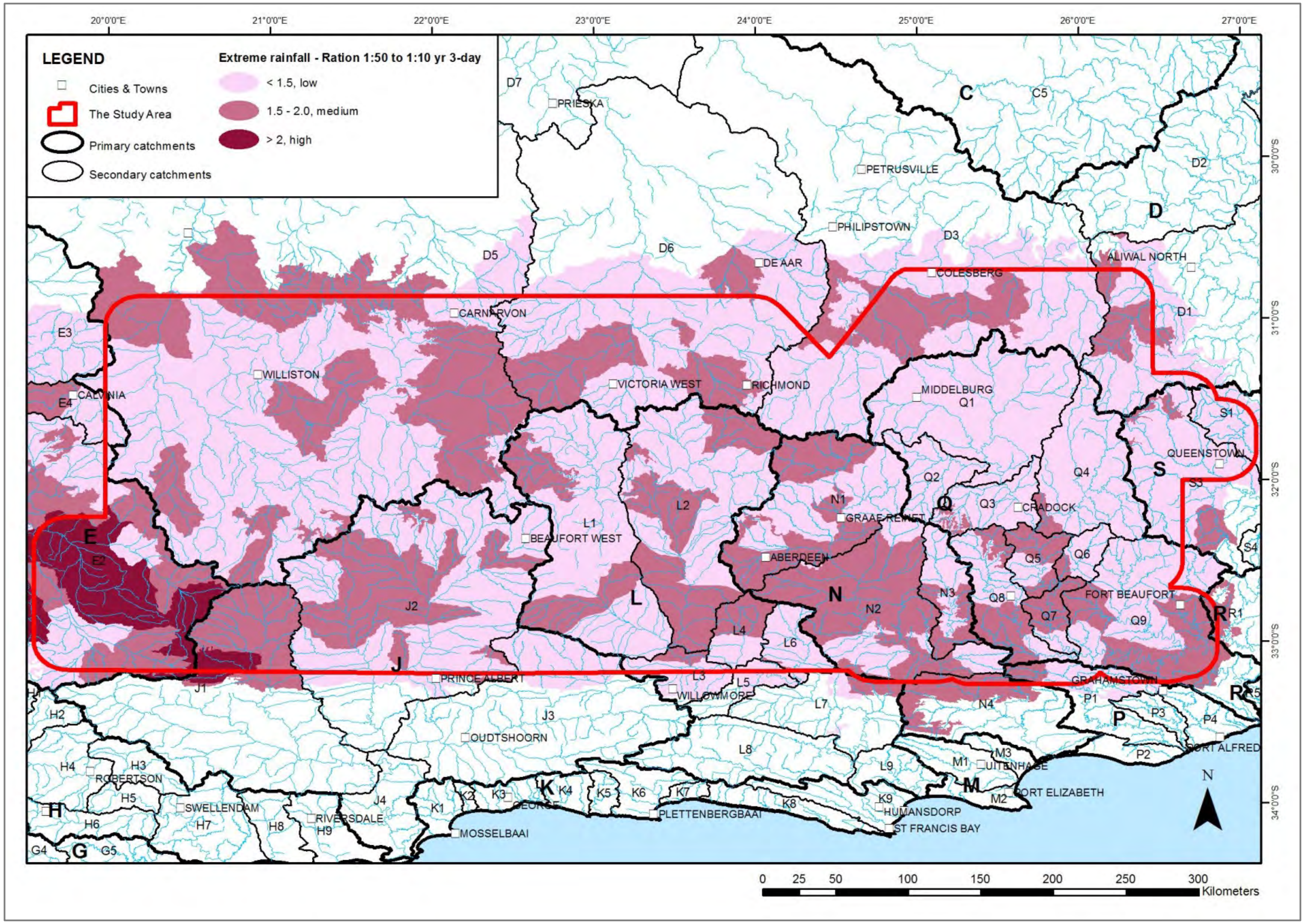

Figure 5A1.21:*Ratio of the 1:50 to 1:10 Year Extreme 3 Day Rainfall*

For longer duration rainfalls the spatial distributions of these ratios are similar to those of the one day events. Original Data Source: Schulze (2012).

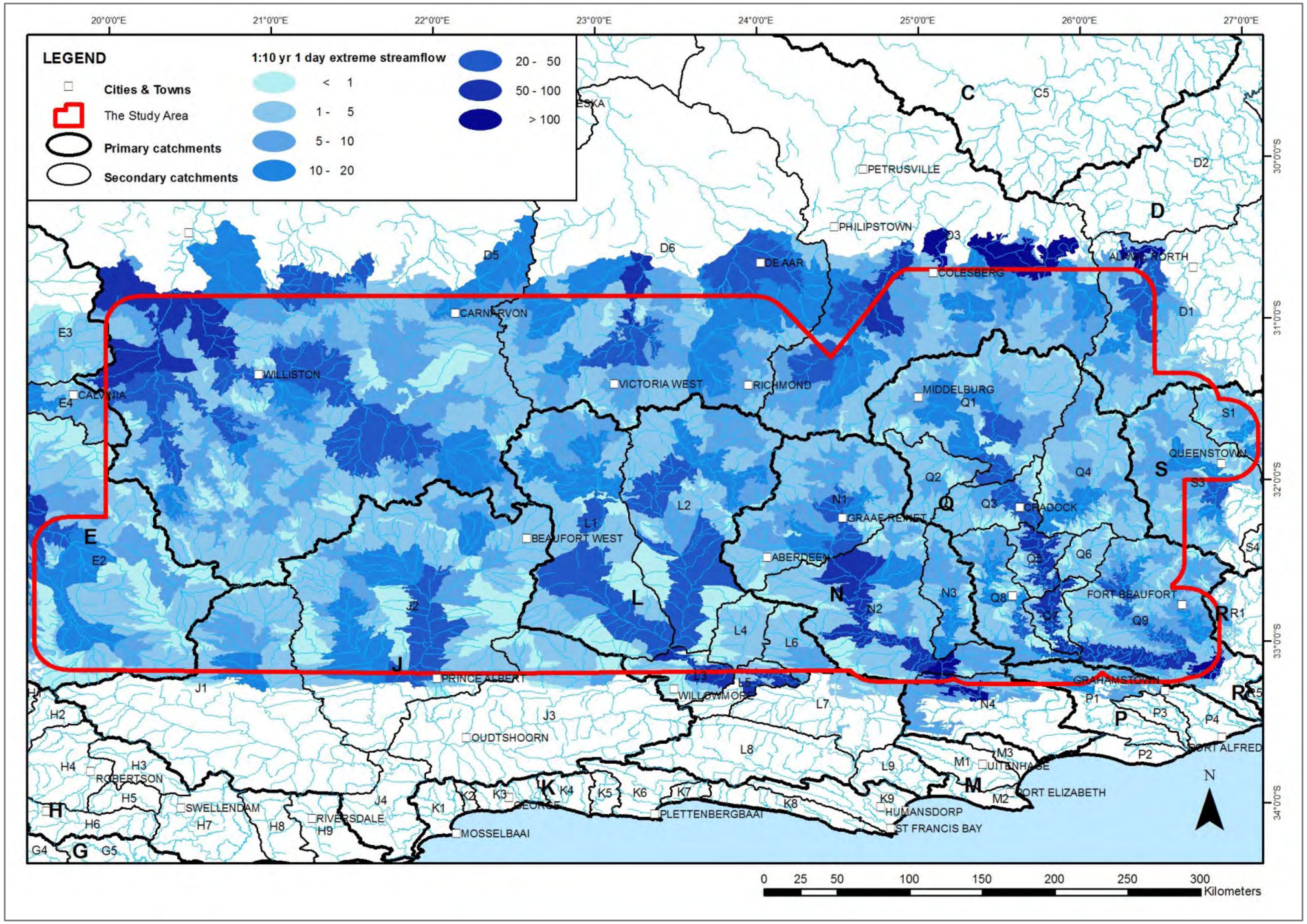

Figure 5A1.22:*1 in 10 Year 1-Day Streamflow* ($10^6 m^3$)

Values range very widely as streamflows are accumulated and presented in cubic metres of water. Clearly visible are the larger rivers with their higher accumulated values of extreme events as one moves downstream and flood waters from tributaries are added. Original Data Source: Schulze (2012).

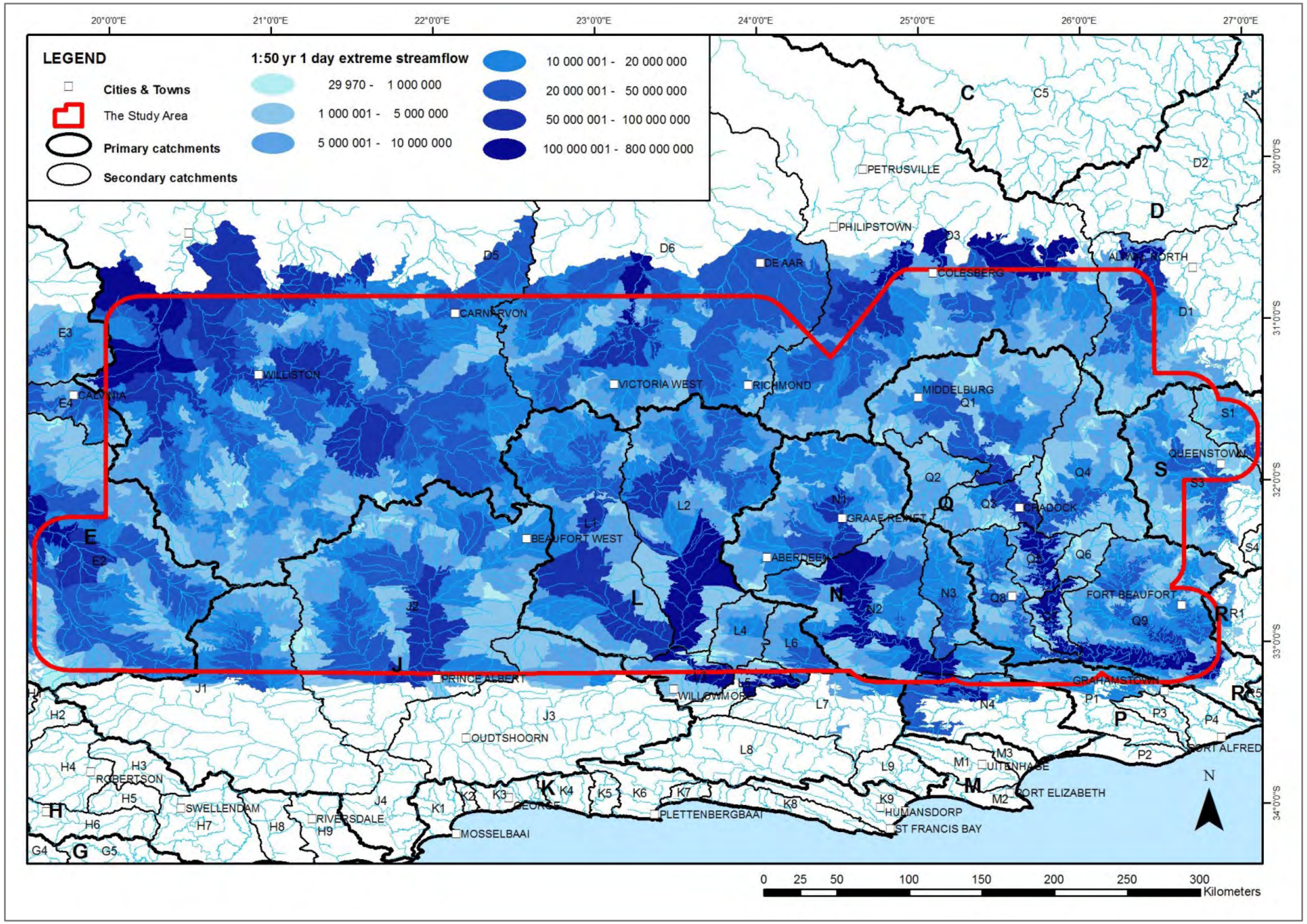

Figure 5A1.23:*1 in 50 Year 1-Day Streamflow ($10^6 m^3$)*
These very rare events display considerably higher flooding than the 1: 10 year equivalents, illustrating again the non-linearity of the hydrological system. Original Data Source: Schulze (2012).

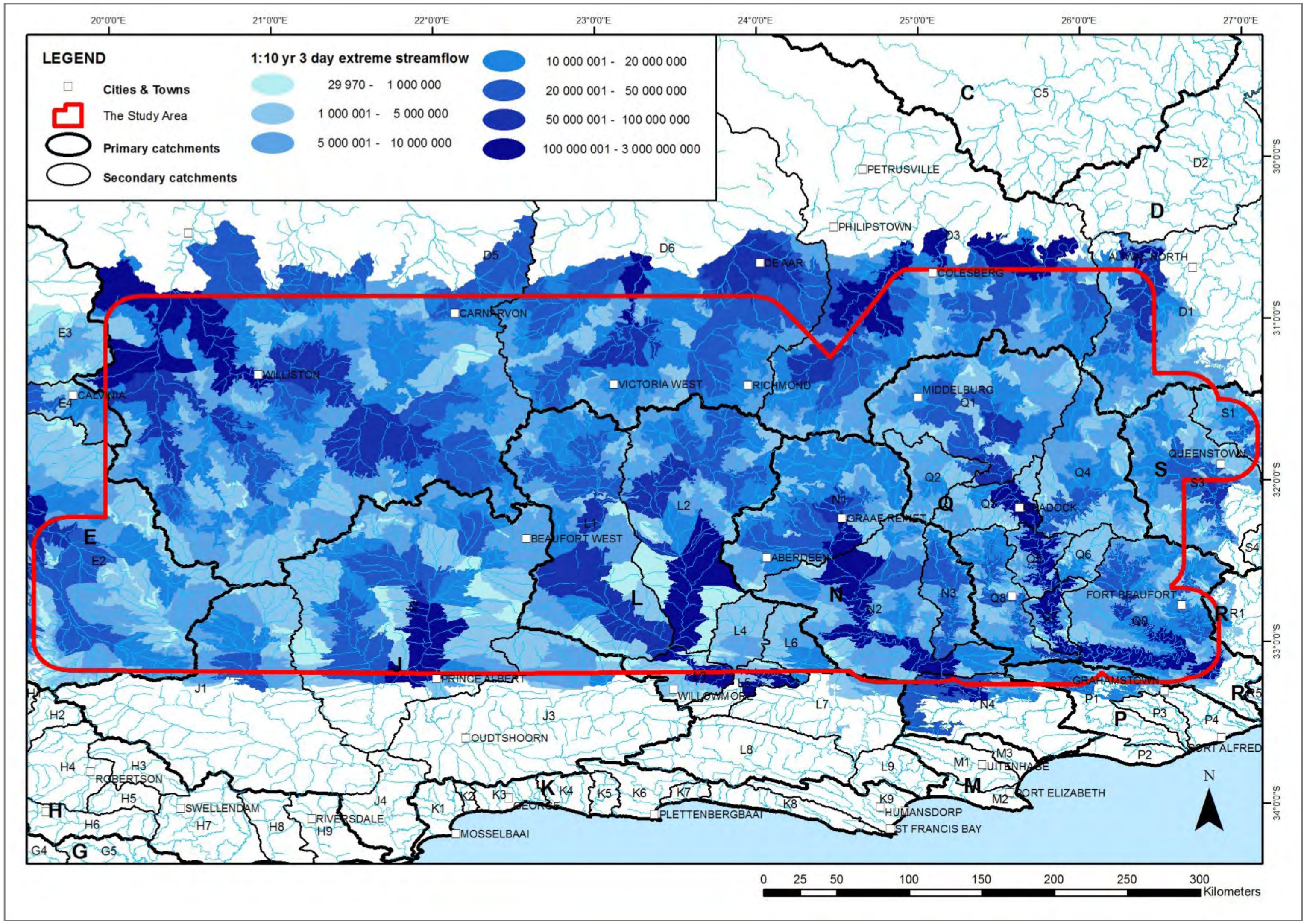

Figure 5A1.24:*1 in 10 Year 3-Day Streamflow ($10^6 m^3$)*
In terms of high flows, the 1:10 year three day flood is more or less equivalent to the 1: 50 year one day flood. Original Data Source: Schulze (2012).

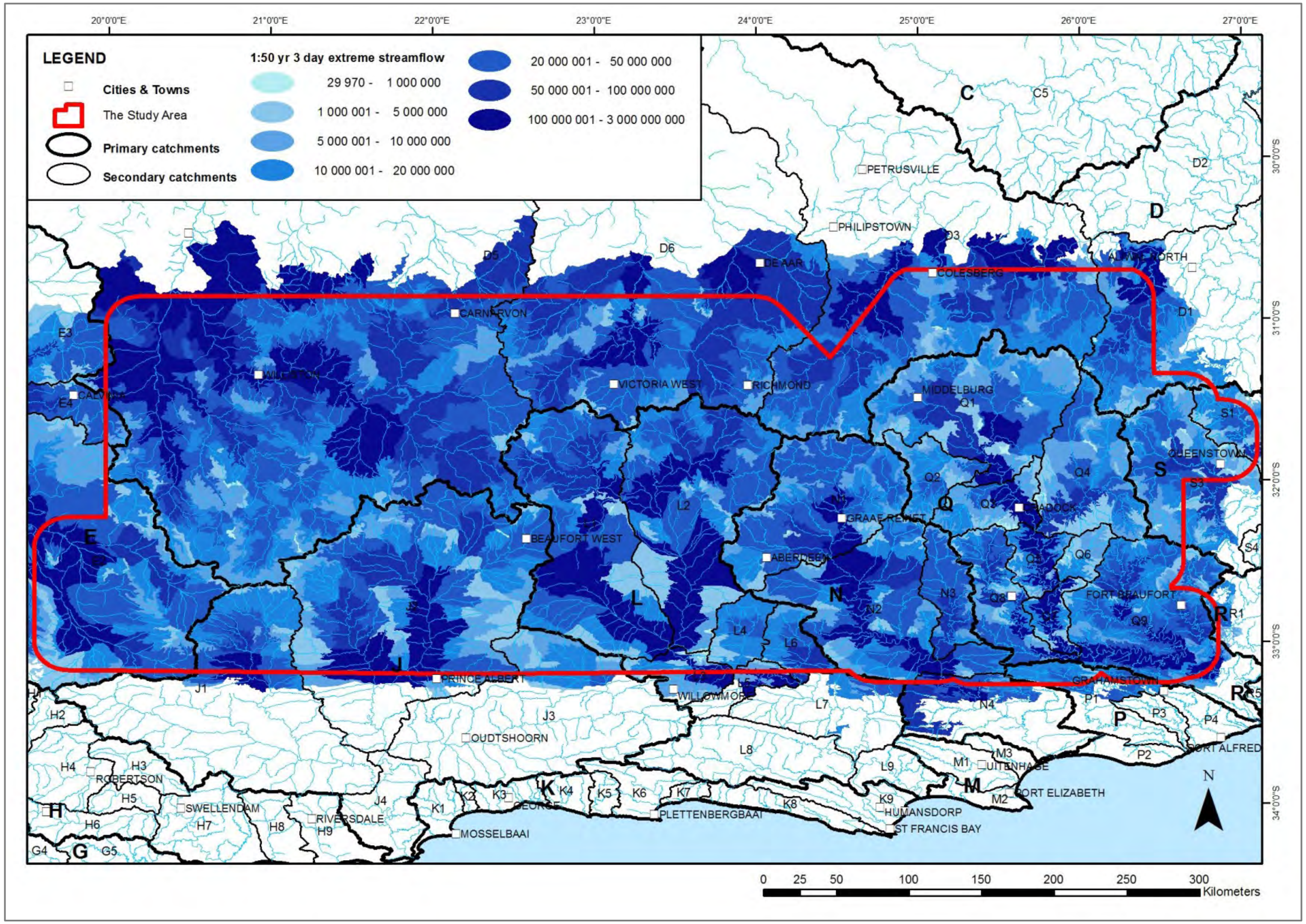

Figure 5A1.25:*1 in 50 Year 3-Day Streamflow ($10^6 m^3$)*

The three day very rare 1: 50 flood is considerably higher and more damaging than the 3 consecutive day less rare 1 : 10 year flood, showing again the amplification of the hydrological system. Original Data Source: Schulze (2012).

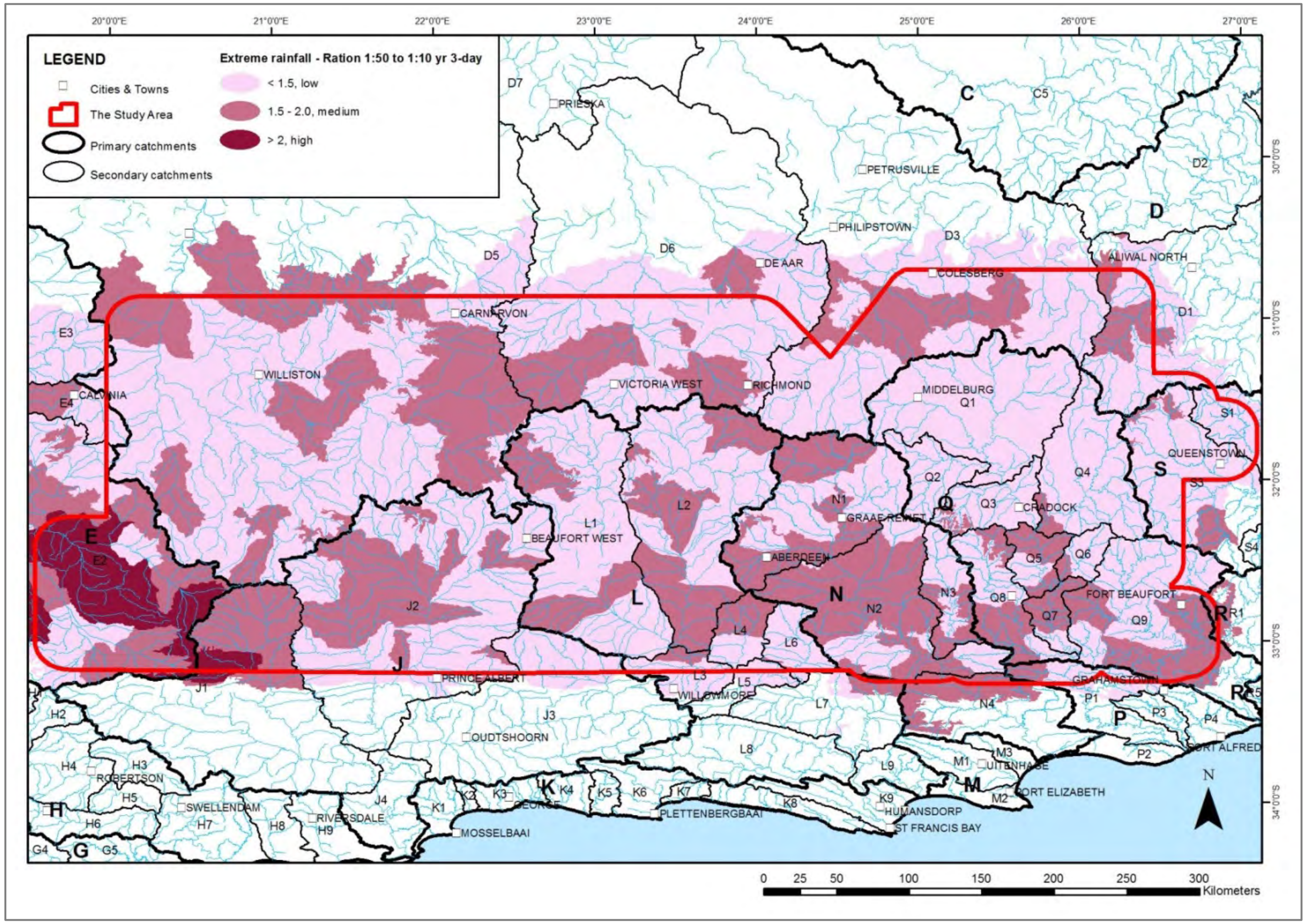

Figure 5A1.26:*Ratio of the 1:50 to 1:10 Year Extreme 3 Day Streamflow*

When this streamflow ratio is compared to its equivalent for rainfall, the high ratios, indicating highly vulnerable areas, cover considerably more of the study area than in the case of rainfall. Once again, this illustrates the rainfall to streamflow amplification that exists in the hydrological system, particularly for higher order statistics such as variability and extremes. Original Data Source: Schulze (2012).

Landuse: Sediment Yield

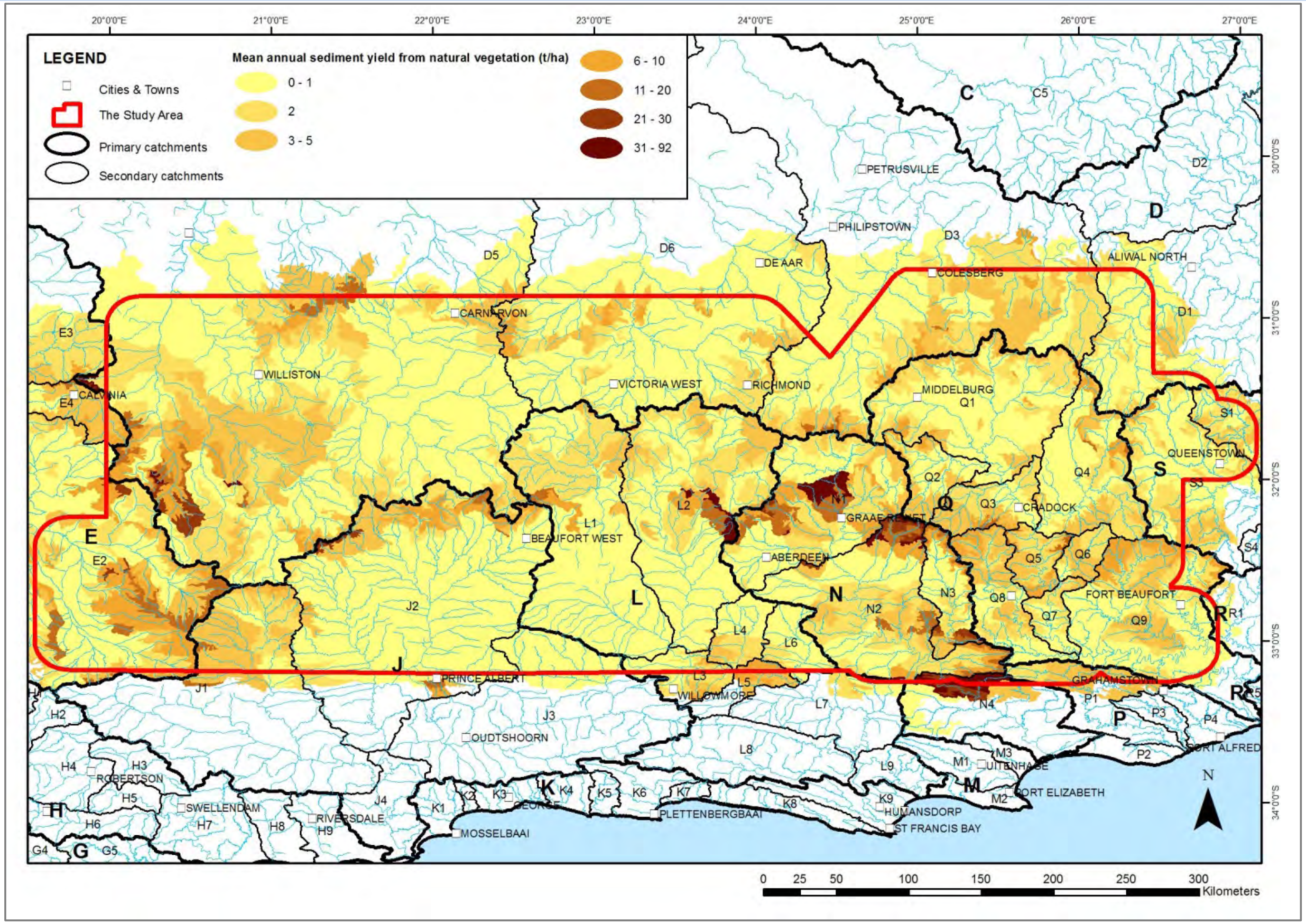

Figure 5A1.27:*Mean Annual Sediment Yield (t/ha)*
Sediment yield has been computed for a natural vegetation land cover with the Modified Universal Soil Loss Equation(MUSLE) on a daily event-by-event basis considering, inter alia, daily stormflow(when it occurs; as a variable to capture the transport of sediment), daily peak discharge on a day with stormflow (as a variable to capture the dislodging of soil), the intrinsic erodibility of the local soil, slope gradient and slope length, as well as intra-annual above-ground and ground level land cover information for natural vegetation.

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Schulze, R.E. and Maharaj, M. 2004. Development of a Database of Gridded Daily Temperatures for Southern Africa. Water Research Commission, Pretoria, RSA, WRC Report 1156/2/04. pp 83.

ADDENDUM 5B SECTIONS 88 AND 122 OF THE MINERAL AND PETROLEUM RESOURCES DEVELOPMENT ACT, 2002 (ACT NO. 28 OF 2002)

88. Water resource monitoring

(1) An applicant or holder must appoint an independent specialist to conduct a hydrocensus fulfilling the standard requirements of the department responsible for water affairs which indicates potentially affected water resources, on at least, a 3 kilometres radius from the furthest point of potential horizontal drilling, as well as identify priority water source areas and domestic groundwater supplies indicated on relevant geohydrological maps.

(2) An applicant or holder must prepare and submit, together with the water use licence application, to the department responsible for water affairs, a proposed water resource monitoring plan, for approval. The plan must at least identify-

(a) the sampling methodology;
(b) the monitoring points;
(c) the monitoring parameters;
(d) the monitoring frequency; and
(e) the reporting frequency.

(3) The monitoring plan contemplated in sub-regulation (2) must be submitted to the competent authority for consideration, as part of the application for Environmental Authorisation.

(4) Water samples collected as part of the monitoring plan contemplated in sub-regulation (2) must be analysed by an accredited laboratory and the holder must submit the results and their interpretation to the designated agency and the department responsible for water affairs within 7 days after receipt thereof.

(5) The results must at least include a detailed description of the sampling and testing conducted, including duplicate samples, the chain of custody of the samples and quality control of the testing.

(6) A full water monitoring report must be included in the EMPr required in terms of the Environmental Impact Assessment Regulations, 2014.

(7) A holder must, after conducting a baseline water quality assessment, continue with monitoring in accordance with the approved plan and must-

(a) have the water resources subjected to sampling, analysis and interpretation of water quality and changes in water levels by an independent specialist approved by the designated agency in accordance with the approved plan contemplated in sub-regulation (2);
(b) submit the results of the analysis and interpretation to the designated agency and the department responsible for water affairs within 7 days of receipt of the analysis and interpretation; and
(c) submit the monitoring assessment reports in accordance with the approved monitoring plan contemplated in sub-regulation (2).

(8) (a) The designated agency, Council for Geoscience, Council for Scientific and Industrial Research, designated local authorities or the department responsible for water affairs, may collect samples of fluids encountered in the exploration or production area (water or hydrocarbons, at depth or at the surface) for their own analysis and interpretation.

(b) The holder must allow site access to the authorities mentioned in paragraph (a) for the purpose of collecting the samples.

(9) Data collected as contemplated in this regulation must be published except where it may be shown to directly relate to the availability of petroleum and commercial value of the holder's acreage.

(10) Groundwater aspects must be recorded and reported according to the department responsible for water affairs' Standard Descriptors for Geosites.

(11) The holder must capture the water resource data generated into the relevant department responsible for water affairs' databases.

122. Protection of water resources

(1) A holder must, prior to and during all the phases of drilling and hydraulic fracturing operations, ensure that the operation does not pollute a water resource or reduce such a resource and where such an incident occurs, a holder must implement the necessary remedial measures;

(a) the operation does not cause adverse impact to water quality in the catchment area; and

(b) the rights of existing water users are protected.

(2) A well site where hydraulic fracturing operations are proposed or planned, must not be located-

(a) within 5 kilometres, measured horizontally, from the surface location of an existing municipal water well field and identified future well fields and sources and directional drilling may not be within 2.5 kilometres of municipals well field;

(b) within 500 metres, measured horizontally, from the surface location of an existing water borehole and directional drilling may not be within 500 metres of the borehole; and

(c) within 500 metres, measured horizontally, from the edge of a riparian area or within 1:100 year flood -line of a watercourse.

(3) A well may not be drilled within 1 kilometre of a wetland.

(4) A holder must undertake regular water quality testing as determined by the department responsible for water affairs.

ADDENDUM 5C SUBSTANCES THAT HAVE BEEN DETECTED IN FLOWBACK WATER BUT NOT IN DRILLING OR FRACKING FLUIDS, AND THEREFORE ASSUMED TO BE DERIVED FROM UNDERLYING SUBSTRATES

Compound	Source	Toxicity	Comments
Brines	Deep formations	Renders water undrinkable; Hazardous to surface and groundwater ecosystems	Potentially a problem in parts of the Karoo
Metals (e.g. barium, strontium)	Desorbed from deep clays	Barium itself extremely toxic; some salts (e.g. barium sulfate, used in "barium meals" not toxic but some (e.g. barium carbonate) extremely toxic when swallowed because stomach acid releases barium ions)	Barium is also sometimes used in the fracking process
Volatile organic compounds (e.g. toluene, benzene, xylene)	Found in surface waters near some fracking operations but said not to be used in the process	Extremely toxic: effects particularly on the central nervous system	Not clear if these substances used in fracking and not declared, or they are displaced from underground by the fracking process
Radioactivity	Deep rocks	Dose-dependent	Needs to be monitored in all flowback fluids

ADDENDUM 5D DEFINITION OF BUFFER/SETBACK ZONES FOR DYKES AND THERMAL SPRINGS (ADAPTED FROM WOODFORD (2012))

Definition of buffer/setback zones

The objective of this assessment is to provide a preliminary guideline for establishment of Buffer/Setback Zones around dolerite dykes and thermal springs in the Karoo Basin. The current understanding is that these exploration holes will be drilled vertical and that hydraulic fracturing tests will be conducted in the vertical holes (i.e. that no horizontal holes will be drilled). It is likely that some of the exploration holes will be realigned at the targets depths (1 500 to 4 500 m) to develop single, horizontal holes extending up to 1 500 m from the drill pad for assessment of the 'fracking' conditions and gas flows.

Dolerite dykes

Dolerite dykes are vertical to sub-vertical discontinuities that, in general, represent thin, linear zones of relatively higher hydraulic conductivity which act as conduits for groundwater flow within Karoo fractured-rock aquifers. However, they may also act as semi- to impermeable barriers to the movement of groundwater.

The common characteristics of Karoo dolerite dykes in the Main Karoo Basin (Woodford and Chevallier, 2002b) are:

- The majority of the dolerite dykes are stratabound and concentrated in the Upper Ecca and Beaufort stratigraphic units, which means that certain dykes may have propagated laterally along strike.
- Dolerite dykes typically range in width from 3 to 15 m. Enslin (1951) noted that dolerite dykes are seldom wider than 20 m. Dykes with widths of less than 3 m usually represent short, shallow-seated intrusions, whilst the more extensive, regional dykes are typically significantly thicker (i.e. an E-W 'shear' dyke north of Victoria West is c.65 m wide, the width of the 'Gap' dykes in the Eastern Karoo Basin often exceed 100 m) and can extend over lengths in excess of 300 km.
- Kruger and Kok (1976) evaluated the drilling results for 177 boreholes drilled on dykes in the north-eastern Free State and found a relationship between the dyke width (assessed range 4.5 to 14m) and borehole airlift yield (assess range 2 – 5 L/s), and concluded that the highest yields were obtained on dykes ranging in width between 7 and 11 m. Vandoolaeghe (1980) found that in the Queenstown area (Eastern Karoo) higher yields are generally obtained alongside dykes that are wider than 5 m.
- The dip of dykes generally range from 80º to vertical. Shallower dipping intrusions correspond more to inclined sheets and ring-feeder dykes.
- Extensive, regional dykes often exhibit en-échelon segmentation, where the segments are co-planar to the main strike of the intrusions (with angles of less than 10º).
- Typically, groundwater is intersected in a relatively narrow fracture zone developed along the dyke contacts. The width of this zone of jointing, thermal metamorphism ('baking') and weathering alongside dykes remains fairly constant, averaging ~5 m, and is largely independent of dyke width.
- Sub-horizontal 'open' fractures do occasionally transgress some dykes and they may extend up to tens of metres away from the dyke contact into the country rock. These transgressive fractures are thought to be related to thermal cooling, hydrothermal activity and/or erosional

unloading following intrusion. They are therefore expected to be confined to the near surface (i.e. upper 200 m).

- Thermal joints or cooling cracks develop perpendicular to the cooling surface of the dyke and their strike is therefore sub-horizontal. They affect the sediments in the host rock over relative short distances of only a few metres.
- Many dykes show signs of later tectonic reactivation (possibly associated with hydrothermal events). Such dykes are typically well fractured and display a brittle and brecciated aspect. The sediment is also affected over a distance of 5 to 10 m from the contact. In the western and central Karoo, tectonic reactivation seems to be a common feature of NNW trending dykes.
- On a regional scale there is a close correlation between the extensive NNW trending dykes and ‘corridors’ of fracturing, these are thought to be associated with the prolongation of mega-joints in the Cape Fold Belt. Systematic NNW (N150º to N170º) joints are very conspicuous in the western and central Karoo Basin.
- The regional E-W orientated dykes of the western and central Karoo Basin, as well as the associated N110º, N150º and N70º fracture systems, display a pattern in accordance with a typical right lateral shear zone. During emplacement of these dykes the maximum compressive stress was vertical, and therefore all fracture orientations could potentially be ‘open’.
- Dyke contact aquifers are typically semi-confined and immediate borehole yields in the order of 2 to 5 L/s are relatively common.
- There is considerable debate concerning to what distance away from a dyke the host rock is metamorphosed and jointed - thereby affecting the yield of boreholes drilled into this zone. Campbell (1975) referred to a ‘rule-of-thumb’ width of less than 3 m. Enslin (1951) found that the highest borehole yields are obtained within 1 m of the dyke contact. It must be noted that because in the field the distance from the dyke is measured at the surface, the dip of the dyke must also be considered.

GIS methodology for defining buffer/setback zones

The following GIS-based methodology is proposed for defining Buffer/Setback Zones around dolerite dykes and is based on the general assumption that the length of the dyke is related to its vertical extent with depth (i.e. the longer the dyke, the greater its depth of origin):

- It is assumed that the mapped 1:250 000 scale dolerite dyke dataset will initially be used to establish the Buffer/Setback Zones. Unfortunately, the dykes are often not mapped as continuous features as they are often ‘masked’ by overburden, exhibit small scale offsets etc. Therefore, it is necessary to review each dyke passing through an area of interest and, if necessary, to manually ‘join’ all co-linear dyke segments to form a single contiguous dyke feature (i.e. a single poly-line) and thereby obtain an estimate of the ‘actual’ length of the dyke (or dyke ‘corridor’ in the case an en-échelon dyke systems). Satellite and/or aerial photograph (Google Earth) imagery, or geophysical data (i.e. the CGS aeromagnetic ‘fabric’ map) could be used to assist with this process. Importantly, in order to obtain the best estimate of dyke length, it will be necessary to ‘trace’ the dyke beyond the boundary of the AoI. The GIS is then used to assign a length (D_L, m) to each ‘re-mapped’ dyke (it is recommended that ArcGIS’s COGO routine be used to estimate dyke length, as it will also calculates other useful parameters such a dyke ‘curvature’ and orientation). It should be noted that the 1:250 000 dyke dataset includes some complex, curvi-linear features that are not dykes but rather inclined sheets or narrow, sub-horizontal sill outcrops mapped in steep sided valleys (particularly in the Ecca Group) that should be excluded from the dataset.
- It is assumed that the mapped dyke is linear in outcrop and therefore the its dip is only likely to vary between 85º and 89º, and then the following power functions are then applied to each dyke

to estimate the width of its Buffer/Setback Zone (i.e. width by which to buffer the dyke):

- $EZ_{85^\circ} = \left(0.186 \times D_L^{0.65}\right) + \frac{D_W}{2}$ .... Equation 1
- $EZ_{89^\circ} = \left(0.046 \times D_L^{0.65}\right) + \frac{D_W}{2}$ .... Equation 2

Where EZ - width of Buffer (metres)
D_L - Length of Dyke (metres)
D_W- Dyke Width

The dyke width can either be measured directly in the field, estimated from high-resolution aerial photography or aeromagnetic imagery, or by using of the following equation:

$D_W = 0.1 \times D_L^{0.54}$ .... Equation 3

- If the estimated width of the calculated dyke EZ is <50 m, then it should be set to 50 m (i.e. the minimum EZ is 50 m). This minimum EZ value is prescribed to account for spatial accuracies in location of the dyke (i.e. 1:250 000 scale dyke GIS dataset) and uncertainties related to the subsurface geometry and fracturing of the dyke.

- It must be note that the relationship between dyke length and dyke vertical extent used in developing Equations 1 and 2 is based on the assumption that such a relationship exists in reality and using 'values' based purely on the authors experience ("gut feel"). It is recommended that following GIS assessment be conducted to provide a 'reality check' before they are implemented:
  - The process described above for defining 'true' dyke (corridor) lengths (D_L) be applied to various length and orientation dykes within the western and central Karoo Basin, especially selecting those that trangress topographic features and lithostratigraphic units (i.e. the E-W 'shear' dyke just south of Calvina extends through the Karoo sequence, down the Van Rhynsdorp Pass, and into to underlying Nama Group, the NNW Middelburg ('Dublane') dyke etc.).
  - These dykes (polylines) should be buffered (by c.50 m) and converted to ArcGIS GRIDS, which are then intersected with the SRTM90 Digital Terrain Model (DTM) and lithological units. This will produce an output GRIDs (or 'Fishnet' polygons) wherein each dyke has a unique ID and can be interrogated for length, minimum and maximum elevation and lithostratigraphic units intersected.
  - The relationship between dyke length and 'minimum' vertical thickness (maximum – minimum elevation along dyke length) can be assessed, as well as the relative density of dykes within the various lithostratigraphic units (particularly the 'target' Ecca Units).
- Similarly, Equation 3 was developed based purely on the authors experience and the values used to define the relationship between dyke length and dyke width have not been verified using actual values from mapped dykes.

At this stage two 'EZ' functions are provided with the idea that some testing of the method needs to be conducted within selected AoIs' and that the ArcGIS COGO 'curvature' value (as a rough guide to dyke dip) will be assessed and used to define which function to apply (i.e. low 'curvature' use Equation 2 and moderate 'curvature' use Equation 1). Based on the results of the proposed test work, it may be possible to incorporate the actual COGO 'curvature' value directly into a single equation that accounts for variations in dip.

The two power functions (Equations 1 and 2) defining a Buffer Zone' width envelope for various lengths of dyke are presented in **Figure 1**.

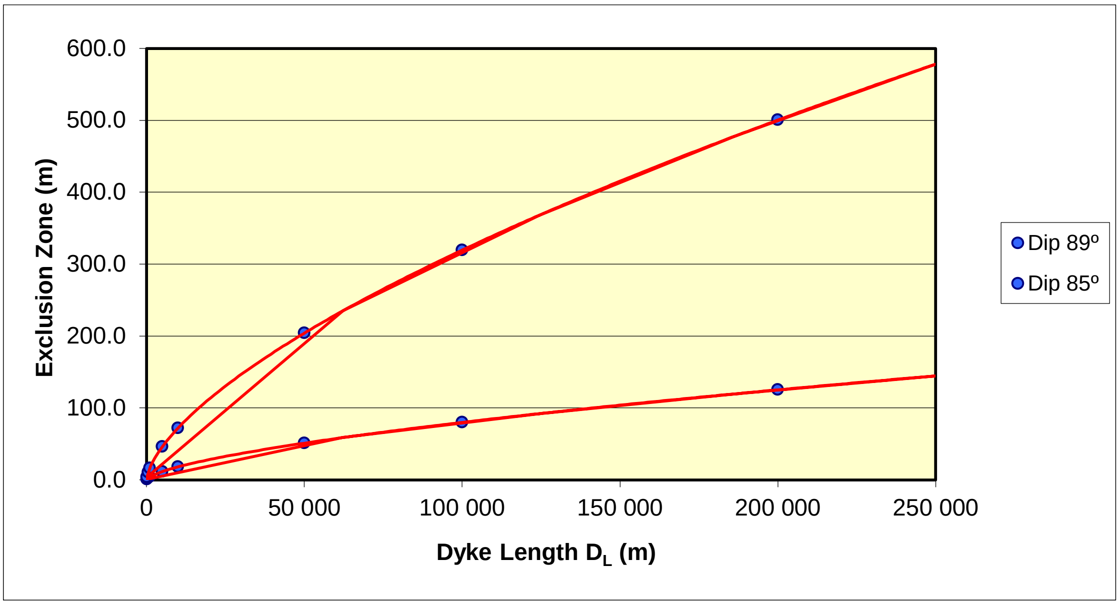
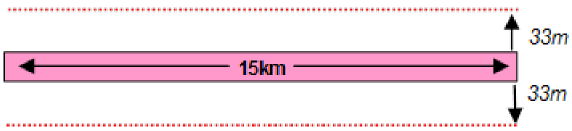


Figure 1: Width of Buffer Zone versus Length of Dyke

Example: if a near linear (in outcrop) dyke is 15 km long, then it is assumed that it is almost vertical and Equation 2 is used to estimate a Buffer Zone width of 33 m (See schematic below). If however, the dyke is curvi-linear in outcrop (less steeply dipping), then Equation 1 is used and the estimated EZ is then 105m. Note, in the case of Equation 2 being applicable, the *EZ* would be adjusted from 24 m to the recommended minimum of 50 m.



Thermal spring

Groundwater temperatures may be used as an indicator of the depth of groundwater circulation and therefore the relative scale of flow within the aquifer system. In reality, the depth may be greater because cooling typically takes places during upward flow along fractures to the surface.

Jones (1992) found that the geothermal gradients in South Africa vary from as low as 8°C/km to as much as 40°C/km, whilst a value of 30°C/km is more typical for Karoo rocks.

In order to define a Buffer Zone about the 'eye' of a thermal spring (EZ_{SP}), it is proposed that the minimum source depth of the spring be used to calculate a circular zone (i.e. assumes not significant regional hydraulic gradient) about the 'spring, as follows:

$$EZ_{SP} = \frac{T_{GW} - T_{MA}}{G_T} \times \arctan(\phi) \quad \text{....... Equation 4}$$

Where

EZ_{SP} - Radius of the circular Buffer Zone at the surface.

T_{GW} - Temperature (ºC) of thermal spring.

T_{MA} - Mean Annual Air (ºC) (possibly use Schulze's climatological dataset).

Possibly use the average temperature of the shallow (5-10 m below water table) groundwater.

G_T - Geothermal Gradient (ºC/m) for Karoo Basin (assumed 0.03ºC/m)

Ø - Angle (See **Figure 2**), currently assumed to be 30º, to take account potential dip / width of fracture system (tortuous preferential flow path) from source to surface.

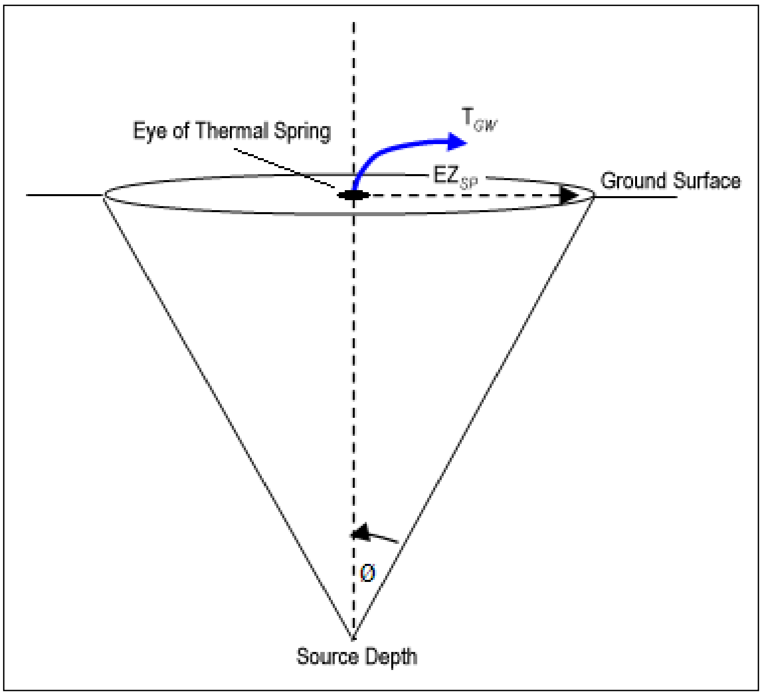


Figure 2: Circular 'Exclusion Zone' around Hydrothermal Spring

Example: Thermal spring with water temperature of 36ºC and mean annual air temperature of 24ºC. The radius of the Buffer Zone (EZ_{SP}) is estimated at c.230 m.

Geothermal Gradient =	25	ºC/km
Mean Annual Temperature =	24	ºC
Groundwater Temperatures =	36	ºC
Minimum Source Depth =	480	m
Angle Theta =	30	º
Radius Exclusion Zone	232	m

References

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Xu, Y. & van Tonder, G.J. 2002. Capture Zone simulation for boreholes located in Fractured Dykes using the Linesink Concept, *Water SA*, *28*(2), 5p.

ADDENDUM 5E FIGURES SHOWING APPLICATION OF SETBACKS TO PROTECT SURFACE- AND GROUNDWATER RESOURCES

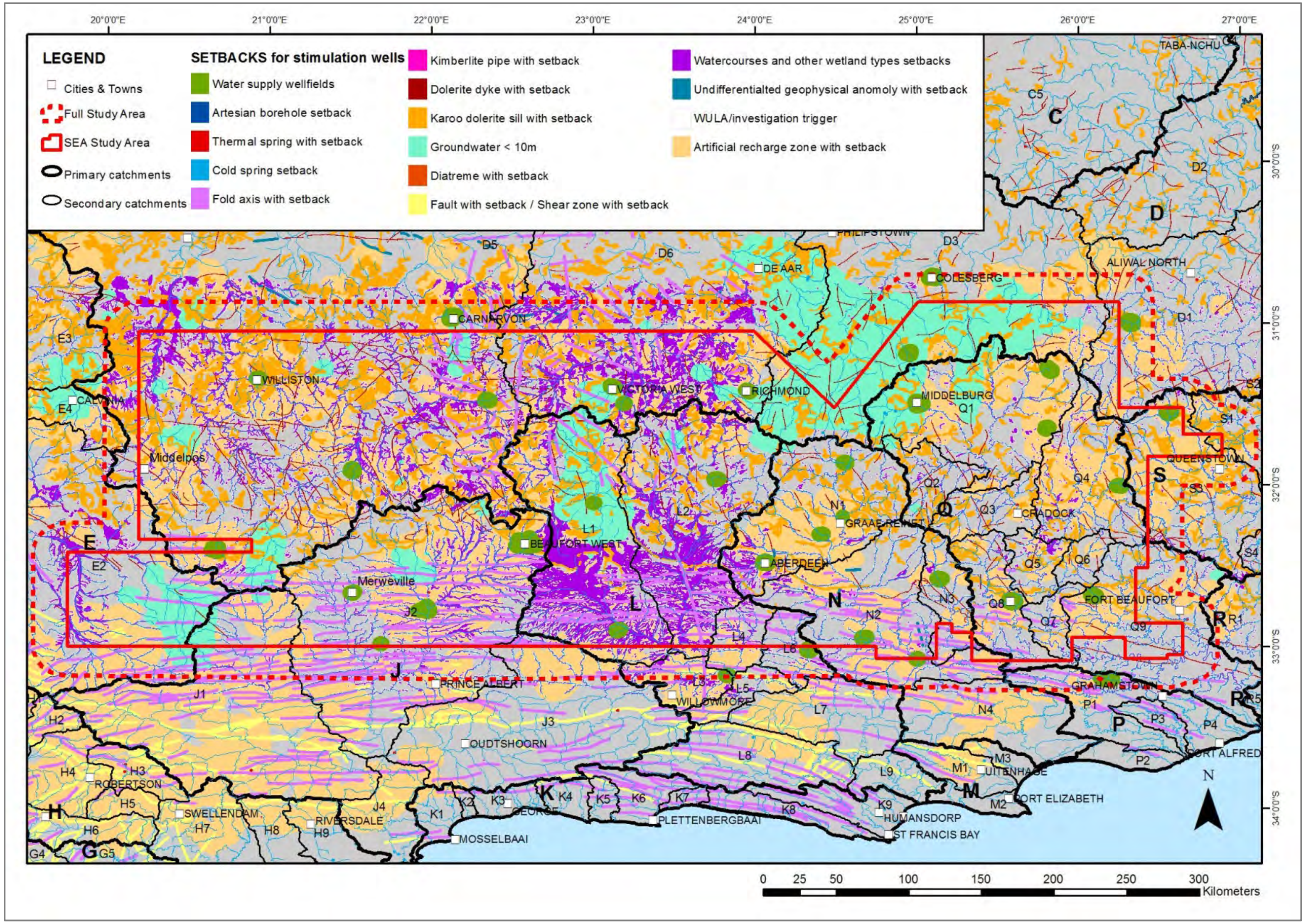

Figure 5A5.1: Recommended setbacks for stimulation well activities – differentiating between different setback or exclusion zones /areas.

Map showing remaining areas (grey) in which well stimulation (fracking) activities might take place without impacting significantly on known surface and/or groundwater resources. Shaded (non grey) areas variously comprise those areas in which some risk to water resources is potentially possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). In addition, dolerite dykes have been accorded a minimum setback of 250 m which might not always apply – these features must be mapped and buffered with better levels of resolution in any SGD planning. Setbacks shown here illustrate the setback distances recommended in Table 5.8. Note: Not all features in this table are represented in this figure, only features for which spatial data was available at the time of compilation of this chapter, are shown.

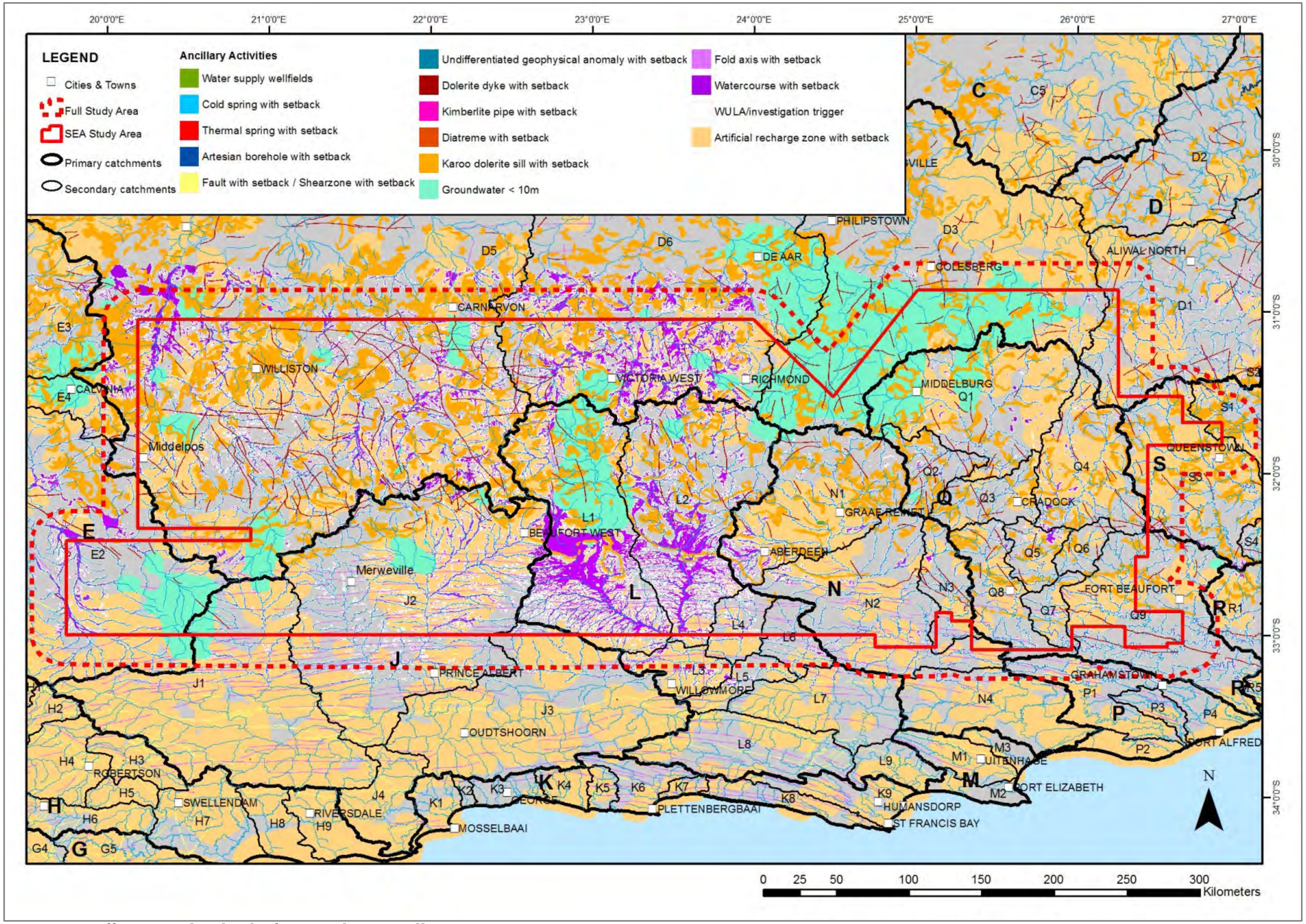

Figure 5A5.2: Differentiated setbacks for stimulation well activities.

Map showing remaining areas (grey) in which well stimulation (fracking) activities might take place without impacting significantly on known surface and/or groundwater resources. Other highlighted areas comprise those areas in which some risk to water resources is potentially possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). Setbacks shown here illustrate the setback distances recommended in Table 5.10. Note: Not all features in this table are represented in this figure, only features for which spatial data were available at the time of compilation of this chapter, are shown.

ADDENDUM 5F MONITORING FRAMEWORKS

5F(i) Monitoring Framework for Surface Water (from Esterhuyse et al., 2014)

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?)	• No possible impacts were identified during the pre-exploration phase. • It is, however, important to gather appropriate baseline information during this phase.	**Quality** • Increased runoff of contaminants such as diesel or constituents from fracking fluid. [1] • Water abstraction could lead to deterioration of water quality[2] in isolated pools. • Water quality deterioration due to sewage effluent from human settlements at exploration sites entering streams. **Quantity** • Removal of sand/sediment from rivers for proppant use would influence alluvial aquifers. • Water abstraction in conflict with current users. • Reduction of stream flow in perennial rivers.	**Quality** • Various sources of pollutants may contaminate surface water or have an impact on aquatic biota[3-7]. • Flowback water can contain high levels of TDS, waste water treatment works do not have the capacity to remove high levels of TDS, which could impact on receiving waterbodies. • Sewage effluent from drill pads could contaminate surface water systems. • Toxic or carcinogenic chemicals in fracturing fluid cocktail could contaminate surface water. • Increase in sediment could lead to high turbidity and associated impact on biota and water quality. **Quantity** • Water needed for hydraulic fracturing may impact on the natural hydrology of the resources. • Possible sand removal would impact on available surface water, especially during drought periods, in small tributaries and in non-perennial rivers.	**Quality** • Long term impacts of chemical pollutants on surface water uncertain, it may impact negatively on aquatic biota and fish. • Reduced fitness and health of fishes[9]. • Fish kills[9, 10]. • Reduction in the availability of food sources for fish, e.g. invertebrates. • Bioaccumulation of toxic substances in fish tissue[8, 11, 12], could also have an effect on food web.

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?) continued.	• No possible impacts have been identified during the pre-exploration phase. • It is, however, important to gather appropriate baseline information during this phase.	**Habitat** • Vibrations from seismic surveys may have an impact on invertebrate and fish abundance. • Increased sediment delivery to rivers would alter available habitat for biota. • Flash floods due to increased overland flow to rivers would increase disturbance to aquatic biota. • Fragmentation of aquatic habitat due to road crossings may disrupt fish migrations for feeding and breeding. • Loss of critical refuge habitat for biota during dry periods[8]. • Loss of biota diversity due to the combined effect of increased sedimentation, turbidity and fragmentation[8]. • Reduction in the fitness and health of aquatic biota due to increased predation, intra- and interspecific competition and crowdedness in isolated pools.	**Habitat** • Destruction of pans results in genetic isolation of invertebrates. • Improper construction of pipelines could cause erosion, increasing sediment transport to surface water bodies and impacts on habitat available for biota. • Change in land use could isolate rivers and pans, resulting in genetic isolation, a reduction in number of refugia, and a disruption of migrating routes of birds, amphibians, invertebrates and other biota [11]. • Flash floods due to increased overland flow to rivers would increase disturbance to aquatic biota [8]. • Loss of critical refuge habitat during dry periods [8]. • Loss of critical passage habitat, e.g. riffles and runs that connect pools. Lead to, e.g. loss of mobility, reduced availability of food, fragmentation and isolation of fish assemblages.	**Habitat** • Reduced habitat quality due to exposure to toxic substances.
Aspects that need to be monitored (WHAT?)	**Quality** • Baseline data for water quality (T, conductivity, TDS, oxygen, turbidity, barium, strontium, chloride). Include chemicals present in fracking fluids to be used in exploration and extraction process. • Baseline Present Ecological State (PES) of relevant indices in rivers, wetlands and pans as prescribed by the DWS. • Baseline data on *E. coli* and total coliform levels in surface water systems need to be determined.	**Quality** • Parameters to be monitored include T, conductivity, pH, Dissolved oxygen, turbidity, TDS and possibly chloride, strontium and barium (if elevated TDS is found). Barium (Ba) and Strontium (Sr) may point to oil and gas extraction activities, as these metals could be mobilized by the fracking operation. If conductivity/TDS are high, test for Ba and Sr. If those are also very high it can be assumed that the source is flowback water [17]. • Specific chemicals used in fracking fluid need to be monitored if contamination is suspected. • If sewage effluent from human settlements at exploration site enters a stream/wetland or pan then *E. coli* and total coliforms concentrations need to be monitored.	**Quality** • Parameters to be monitored are T, conductivity, pH, dissolved oxygen (DO), and turbidity, which would indicate a spill especially of saline waste water, in particular. • Need to monitor for TDS, strontium and barium levels in flowback water to be released into surface water. Receiving water also needs to be tested regularly to detect any increase from natural trends. • Ecostatus using HAI, PAI, MIRAI, FRAI, GAI, VEGRAI methods where possible or else an adjusted PES method as prescribed by the DWS especially in episodic rivers. • If sewage effluent from human settlements at exploration site enters a stream/wetland or pan then *E. coli* and total coliforms concentrations need to be monitored.	**Quality** • Parameters to be measured include T, conductivity, pH, DO, turbidity, TDS, and if needed strontium and barium. • Specific chemicals from fracking fluid need to be monitored if contamination of surface water is suspected.

Phases	Before exploration	During exploration	During extraction	After extraction
Aspects that need to be monitored (WHAT?) continued.	**Quantity** • Baseline for water quantity in rivers, pans and wetlands (parameters: stream flow, discharge, depth and stream width).The collection of daily rainfall and evaporation data is crucial. **Habitat** • Baseline Habitat Integrity study or RHAM to establish a baseline for habitat. **Present ecological state (PES)** • Riparian vegetation, aquatic macroinvertebrates, fish. • Terrestrial insects, mammals associated with water bodies (episodic rivers). • Hydrology, geomorphology, water chemistry. **Regulatory** • Address water availability requirements for oil and gas extraction, before exploration and extraction. • Basic water quality testing before drilling or exploration commences. Analyses at an accredited laboratory, data should be made available to all interested parties.	**Quantity** • Monitor surface flow, water depth and volume in rivers, pans and wetlands. **Habitat** • The IHI or RHAM method can be used as a surrogate for habitat quality and invertebrate and fish health. **Present ecological state (PES)** • Riparian vegetation, aquatic macroinvertebrates, fish. • Terrestrial insects and mammals associated with water bodies (episodic rivers). • Hydrology, geomorphology, water chemistry. **Technical** • Rate and amount of water withdrawal if surface water is used as water source. **Regulatory** • Application for water use licence – unconventional oil and gas extraction has been proposed as a controlled activity and compliance with licence obligations needs to be monitored.	**Quantity**: • Water level to indicate any artificial increase or decrease in flow or depth in streams, pans or wetlands. **Habitat** • RHAM method can be used as surrogate for habitat and biota integrity assessments. **Technical** • Rate and amount of water withdrawal should be monitored if surface water is used as water source. **Regulatory** • Require permission/ licence to withdraw any water for unconventional oil and gas extraction. • Domestic and ecosystem water use must be prioritised especially during drought periods (Water use for oil and gas extraction should not interfere with current local use especially for food production). • Reuse of waste water to be encouraged and prescribed where possible. • The assessment (and enforcement) of compliance with set water quality standards is important[(18)].	**Habitat** • The RHAM method can be used as a surrogate for habitat, invertebrates and fish. **Regulatory** • Compliance with mine closure specifications need to be monitored.

<table>
<tr><th>Phases</th><th>Before exploration</th><th>During exploration</th><th>During extraction</th><th>After extraction</th></tr>
<tr><td>How should these aspects be monitored?</td>
<td>Water quality
A baseline/reference needs to be determined for each site and for each parameter. This can only be done using long term data or collecting data seasonally and during different hydrological phases (wet/dry).
Water quantity
Baseline flow, depth and width measurements in rivers, pans and wetlands. Need to establish long term records to identify patterns especially in rivers in arid and semi-arid regions. Rainfall and evaporation data should also be collected.
Habitat
Use IHI method (13, 14) or HAM method (15, 16) to determine baseline.
Stream biota
PES of biota and drivers for rivers, wetlands and pans should be monitored using the standard methods prescribed by the DWS.
Fish (FRAI); macroinvertebrates (MIRAI); riparian vegetation (VEGRAI).
Observational and visual monitoring
Use checklists and fixed point photography to determine a control or baseline.</td>
<td>Water quality
TDS must be monitored and if elevated levels are found then barium, strontium and chloride need to be monitored. If elevated levels of Strontium, etc. are found other fracking fluid chemicals also need to be monitored.
Quantity
Flow, depth and width measurements in rivers, pans and wetlands. Daily rainfall and evaporation data should also be collected.
Habitat
Use IHI method (13, 14) or RHAM method (15, 16) to determine change in habitat from baseline.
Present ecological state (PES)
EcoStatus methods where appropriate, otherwise adjusted methods for rivers, wetlands and pans:
Fish (FRAI), macroinvertebrates (MIRAI), riparian vegetation (VEGRAI);
Hydrology (HAI), geomorphology (GAI), water chemistry (PAI).
Observational and visual monitoring
Use checklists and point photography to determine change from baseline.</td>
<td>Water quality
TDS must be monitored and if elevated levels are found then barium, strontium and chloride need to be monitored. If elevated levels of strontium, etc. are found other fracking fluid chemicals also need to be monitored.
PES of biota and drivers for rivers, wetlands and pans should be monitored using the standard methods prescribed by the DWA.
Quantity
Flow, depth and width measurements in rivers, pans and wetlands. Daily rainfall and evaporation data should also be collected.
Habitat
IHI method (13, 14) or RHAM method (15, 16) to determine change in habitat from baseline.
Observational and visual monitoring
Use checklists and point photography to determine change from baseline.</td>
<td>Water quality
If any groundwater pollution is suspected then the surface water quality needs to be monitored using firstly the TDS and then if needed levels of strontium, barium and chloride.
The RHAM method can be used as a surrogate for habitat, invertebrates and fish as habitat could be affected if surface water is polluted. .
Observational and visual monitoring
Use checklists and fixed point photography to determine change from baseline.
Regulatory
Compliance with mine closure specifications need to be monitored for as long as specified in mine closure regulations.</td></tr>
</table>

Phases	Before exploration	During exploration	During extraction	After extraction
Where do these aspects need to be monitored? (on site, regional?)	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites. Flowback and production water should be monitored at source and at point of discharge.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites Flowback and production water should be monitored at source and at point of discharge as well as downstream of discharge.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites. • Sites in at least a 1km radius from closed production site should be monitored if contamination is suspected.
Who must do the monitoring?	• DWS, oil and gas company and/or independent organisation appointed by DWA.	• DWS, oil and gas and/or independent organisation appointed by DWA.	• DWS, oil and gas company and/or independent organisation appointed by DWS.	• DWS, oil and gas company and/or independent organisation appointed by DWA.
Reference s		1: Lechtenböhmer et al., 2011; 2: Zorn et al., 2008; 8: Davis et al., 2006; 13: Kleynhans, 1996; 14: Kleynhans et al., 2008; 15: DWA, 2009a; 16: DWA 2009b; 17: Chapman, 2012	3: Herridge et al., 2012; 4: Rahm and Riha, 2012; 5: Lyons, 2012; 6: Scott et al., 2011; 7: Jackson et al., 2011. 18: DWAF, 2006.	9: Bishop, 2011; 10: Bamberger and Oswald, 2012; 11: Davis, 2008; 12: Lloyd-Smith and Senjen, 2011

Please refer to Esterhuyse et al. (2014) for details of the references cited.

5F(ii) Monitoring Framework for Groundwater (from Esterhuyse et al., 2014)

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?)	None that could be identified.	**Quality** Possible migration of formation fluids to freshwater aquifers during exploration drilling under localised artesian conditions. [12,13,14] Poor management of saline water produced by coalbed methane extraction [4,14] and shale oil and gas extraction may impact on surface water and groundwater quality. Possible contamination of aquifers with fracturing fluids if hydraulic fracturing is allowed during this phase. [4,14,15] **Technical** Poor drilling practices and poor well construction may impact on aquifers. [4,27,28, 29] Shale instability may lead to borehole collapse, aquifer connectivity. [16,17,18,19]	**Quality** Fluid migration and aquifer connectivity due to geological structures. [4,14,15] Surface activities may contaminate aquifers via surface water-groundwater interaction. [25, 26] **Quantity** Sourcing large quantities of water may impact on aquifers [4,15, 23,24] and large scale groundwater extraction may affect aquifer connected streams. [14] **Technical** Poor drilling practices and poor well construction may impact on aquifers. [4,27,28, 29] Shales that pose drilling problems, may lead to contamination. [16,17,18,19] **Regulatory** Poor wastewater treatment and disposal of large volumes of water may put aquifers at risk. [14,15,30]	**Quality** Aquifer pollution from deep shale layers may only surface years after a pollution incident. The extent of possible long-term contamination in freshwater aquifers could not be predicted at this stage. **Technical** South Africa may not be able to rehabilitate contaminated aquifers in complex geology (physically and economically). [31] Oil and gas well casing failure and leakage may pose long term legacy issues and lead to inevitable groundwater contamination. [14,32,33] **Regulatory** Well abandonment and long term monitoring may be problematic. [14,15,34]
Aspects that need to be monitored (WHAT?)	**Quality** Determine regional groundwater quality: Drinking water quality[1], stockwater quality parameters[2], parameters possibly associated with deeper zones [3,4,5,6], radioactivity [7] isotopes [7,8], methane, ethane[7,9], noble gases[10,11] **Quantity** Determine more accurately groundwater quantities used and yields. Determine baseline on type of groundwater use. Get baseline groundwater levels. **Regulatory** Monitor regulatory compliance with baseline monitoring requirements.	**Quality** Drinking water quality[1], stockwater quality parameters [2], parameters possibly associated with deeper zones[3,4,5,6], radioactivity[7], isotopes [7,8], methane, ethane[7,9], noble gases [10,11] **Quantity** Volumes of groundwater and surface water use on a regional scale linked with type of groundwater and surface water use (e.g. transfer schemes), monitor groundwater levels. **Technical** Drilling rate, fluid usage (volumes and type), microseismicity. [20,21,22] **Regulatory** Monitor regulatory compliance with fluid storage, volumes of waste produced per well, reporting frequencies to authorities Monitor compliance with license conditions. Monitor waste treatment methods and efficiency.	**Quality** Drinking water quality[1], stockwater quality parameters [2], parameters possibly associated with deeper zones [3,4,5,6], radioactivity [7] isotopes [7,8] methane, ethane[7,9], noble gases [10,11] **Quantity** Volumes of groundwater and surface water use on a regional scale linked with type of groundwater and surface water use (e.g. transfer schemes); monitor groundwater levels. **Technical** Drilling rate, fluid usage (volumes and type), microseismicity, well integrity during fracking operations. [20,21,22] **Regulatory** Monitor regulatory compliance with fluid storage, volumes of waste produced per well, reporting frequencies to authorities. Monitor compliance with license conditions. Monitor waste treatment methods and efficiency.	**Quality** Long term monitoring of Drinking water quality [1], stockwater quality parameters [2], parameters possibly associated with deeper zones [3,4,5,6], Radioactivity [7] isotopes [7,8], methane, ethane[7,9], noble gases [10,11] at a lower frequency unless pollution suspected. **Quantity** Long term monitoring groundwater levels at lower frequency also recommended together with quality, monitor changes in water use in previous oil and gas extraction areas. **Technical** Monitor well integrity over the long term. [31] **Regulatory** Monitor compliance with long term monitoring requirements. Monitor long term acceptability of waste treatment methods and efficiency.

Phases	Before exploration	During exploration	During extraction	After extraction
How should these aspects be monitored?	**Quality** Monitor identified list of parameters for regional baseline. Do higher resolution sampling in vicinity of expected oil and gas extraction (e.g. one sample per farm) and lower resolution in other areas. **Quantity** Monitor volumes by assessing baseline groundwater use (registration and licensing volumes at DWA) linked with type of groundwater use – fast track registration and licensing verification. Monitor water levels in aquifers.	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Continue high resolution monitoring in vicinity of oil and gas exploration (e.g. one sample per farm and higher resolution at oil and gas exploration wells); lower resolution in other areas. **Quantity** Monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use (especially transfer schemes). Monitor water levels in aquifers. **Technical** Monitor drilling rate, fluid usage (volumes and type), microseismicity at exploration sites. [20,21,22]	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Continue high resolution monitoring in vicinity of oil and gas extraction (e.g. one sample per farm and higher resolution around oil and gas extraction wells); lower resolution in other areas. **Quantity** Continue to monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use (especially transfer schemes). Monitor water levels in aquifers. **Technical** Monitor drilling rate, fluid usage (volumes and type), microseismicity at oil and gas extraction sites. [20,21,22] **Regulatory** Ensure that data dissemination occurs as required per license conditions.	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Monitor in vicinity of oil and gas extraction (e.g. one sample per farm and selected sites around oil and gas extraction wells); lower resolution in other areas. **Quantity** Continue to monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use to identify any linked usage patterns with other changes. Monitor water levels in aquifers. **Technical** Monitor well stability and integrity if wells are not closed [31] **Regulatory** Ensure continuous data dissemination of post extraction monitoring to regulatory authorities.
Where do these aspects need to be monitored? (e.g. on site, regional)	**Quality and quantity** Need to be monitored on a regional scale to determine a baseline. Monitor on a higher resolution in exploration target site areas.	**Quality and quantity** need to be monitored on site (local scale) as well as on a regional scale **Technical** To be monitored at drilling sites.	**Quality and quantity** Need to be monitored on site (local scale) as well as on a regional scale **Technical** To be monitored at oil and gas extraction sites.	**Quality and quantity** Need to be monitored on site (local scale) as well as on a regional scale. Expected timeframes for on-going monitoring will have to be determined based on monitoring observations and analyses. **Technical** To be monitored at closed oil and gas well sites.

Phases	Before exploration	During exploration	During extraction	After extraction
Who must do the monitoring?	**Regional baseline:** DWS/independent entity (new or existing for example academia, consultants, etc.). **Target area baseline:** Oil and gas company with reporting to the DWS, and independent spot check verification by DWS/independent entity (new or existing for example academia, consultants, etc.).	**Regional quality and quantity monitoring:** DWS/independent entity (new or existing for example academia, consultants, etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWS, and independent verification by DWS/independent entity (new or existing for example academia, consultants, etc.) **Site specific technical monitoring:** Oil and gas companies with rigorous reporting structure to government and/or independent monitoring entity.	**Regional quality and quantity monitoring:** DWS/independent entity (new or existing for example academia, consultants, etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWS, and independent verification by DWS/independent entity (new or existing for example academia, consultants, etc.) **Site specific technical monitoring:** Oil and gas companies with rigorous reporting structure to government and/or independent monitoring entity.	**Regional quality and quantity monitoring:** DWS/independent entity (new or existing for example academia, consultants, etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWS, and independent verification by DWS/independent entity (new or existing for example academia, consultants, etc.) **Site specific technical monitoring:** Over short term after closure: Oil and gas companies with verification by independent body, handover to government or independent entity for long term monitoring.
References	1: SANS 241 2: DWA, 1996 3: USDOE, 2004 4: USEPA, 2011a 5: Vidic, 2010 6: Clark and Veil, 2009 7: O'Brien et al., 2013 8: Vengosh et al, 2014 9: Talma and Esterhuyse, 2013 10: Darrah et al., 2013	11: Darrah et al, 2014 12: Steyl et al., 2012 13: Woodford and Chevalier. 2002 14: Williams et al., 2012 15: Broomfield 2012 16:Manohar, 1999 17: Khan et al., 2011 18: Cabot, 2010 19: Khodja et al., 2010 20: UKHC, 2012 21: National Assembly of Wales, 2012	22: GAO, 2012a 23: Broderick et al., 2011 24: Galusky, 2007 25: Seaman et al., 2010 26: Parsons, 2004 27: Kargbo et al., 2010 28: IEA, 2012 29: USEPA, 2011b 30: Lechtenböhmer et al., 2011	31: GAO, 2010 32: Dusseault et al., 2000 33: Jinnai and Morita, 2009 34: Diller, 2011

Please refer to Esterhuyse et al. (2014) for details of the references cited.

CHAPTER 6

Impacts on Waste Planning and Management

CHAPTER 6:
IMPACTS ON WASTE PLANNING AND MANAGEMENT

Integrating Author:	Suzan Oelofse[1]
Contributing Authors:	Johan Schoonraad[2]
Corresponding Authors:	Dave Baldwin[3]

1 Natural Resources and the Environment (NRE), Council for Scientific and Industrial Research (CSIR), Pretoria, 0001

2 Enviroserv Waste Management, Johannesburg, 2008

3 Environmental and Chemical Consultants cc (En-Chem), George, 6530

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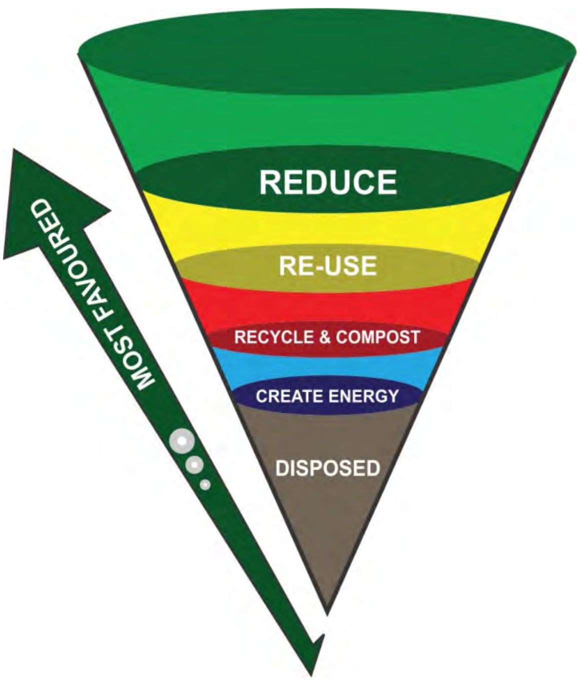
Executive Summary

It is reported that "***problems related to mining waste, may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk***" (European Environmental Bureau (EEB), 2000). The potential impacts of waste from shale gas development (SGD) is therefore of particular concern in the study area where supporting infrastructure is limited.

Municipal solid waste landfill sites in the study area do not meet the design requirements as outlined in the national norm and standards for disposal of waste to landfill. It is unlikely that the municipalities in the study area will be able to afford the required upgrades in the near future. There is also lack of available capacity, in terms of infrastructure, access control and skills to deal with different types and additional volumes of waste in the study area including hazardous waste disposal facilities licensed to accept Type 1, 2 or 3 hazardous waste.

An imminent amendment to the Waste Act, 2008 may result in SGD waste being classified as general waste in which case municipal waste disposal sites are at risk of receiving waste from SGD in future. Municipal landfills in the study are not designed or equipped to receive waste of this nature and staff do not have the skills or experience to manage this waste responsibly.

Available waste water infrastructure in the study area is under pressure and requires urgent intervention. The technologies and capacity at these already stressed facilities are not sufficient or appropriate to treat waste water from SGD.



Waste must be managed in an integrated way in-line with the waste management hierarchy and the principles for integrated waste management in South Africa. The emphasis here is to minimise waste arisings, promote the use of non-hazardous chemicals, re-use and recycling and minimise the impact of waste on water, the environment and communities.

CHAPTER 6: IMPACTS ON WASTE PLANNING AND MANAGEMENT

6.1 Introduction and scope

The European Environmental Bureau (EEB) stated that "*problems related to mining waste, may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk*" (EEB, 2000). The release to the environment of mining waste can therefore result in profound, generally irreversible destruction of ecosystems. The management of waste is an integral part of responsible shale gas development (SGD) but can be especially challenging in areas where supporting infrastructure or regulatory frameworks are not well developed (International Association of Oil and Gas Producers (OGP), 2009). The potential impacts of waste from SGD is therefore of particular concern in the study area where supporting infrastructure is limited.

Principles for Integrated Waste Management in South Africa (Department of Environmental Affairs and Tourism (DEAT), 2000)

- Sustainable Development
- Access to Information
- Precautionary
- Duty of Care
- Preventative
- Polluter Pays
- Best Practicable Environmental Option (BPEO)
- Cooperative Governance
- Integrated Environmental Management
- Environmental Justice
- Participatory
- Equitable access to environmental resources

Waste is defined in South African law in both the National Water Act (NWA), 1998 and in the National Environmental Management: Waste Act, (NEMWA) 2008. The two definitions differ in that the NWA defines waste based on its potential to pollute the water resource (Republic of South Africa (RSA), 1998) while the NEMWA defines waste as any substance, material or object that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be disposed of, irrespective of whether or not such substance material or object can be re-used, recycled or recovered (RSA, 2008 as amended). When considering waste in the context of this study, both definitions will apply.

Waste must be managed in accordance with the waste management hierarchy and the principles for integrated waste management in South Africa. The emphasis here is to minimise waste arisings, promote re-use and recycling, and minimise the impact of waste on water, the environment and communities. All waste must be separated at source in line with the requirements of the NEMWA to maximise opportunities for re-use and recycling, and treatment efficiencies.

The onshore production of gas includes various phases in which hazardous, non-hazardous waste and waste water can be generated. Typical waste streams would include construction and demolition waste, drill cuttings and drilling muds, and flowback (Amec, 2013). Much of the waste generated by hydraulic fracturing ("fracking") will be Type 1 hazardous waste in terms of Section 7(3) of the National Norms and Standards for the Assessment of Waste for Landfill Disposal, 2013 (RSA, 2013a):

> *"If a particular chemical substance in a waste is not listed with corresponding LCT and TCT limits in Section 6 of these Norms and Standards, and the waste has been classified as hazardous in terms of regulation 4(2) of the Regulations based on the health or environmental hazard characteristics of the particular element or chemical substance, the following applies*
> *(a) the waste is considered to be Type 1 Waste;"*

Inappropriate treatment and management of these wastes and spills of fracking fluids has the potential to threaten human health and safety and impact negatively on water resources and the environment (Kiboub, 2011; OGP, 2009). Fracking uses a large number of chemicals including some known hazardous substances (e.g. the foaming agent 2-butoxyethanol) (see Table A.1 in Burns et al., 2016 Digital Addenda), and brings many potentially dangerous compounds to the surface, such as hydrocarbons, brine, and other naturally occurring geological components (e.g. arsenic, radionuclides) (Council of Canadian Academies, 2014; Zhang et al., 2016). This scientific assessment will therefore assess all waste and waste water streams generated as a result of SGD, and the potential risks associated with the various waste and waste water management options. It will also propose mitigation measures to protect human health and the environment against the effects caused by spills and the collection, transport, treatment, storage and disposal of waste and waste water.

6.1.1 What is meant by this topic?

Fracking and the production of natural gas from wells yield wastes that must be managed responsibly to avoid potential harm to the environment and human health. The waste waters generated are known as "flowback" and "produced water" and both may contain potentially harmful pollutants including salts, organic hydrocarbons (oils and grease), inorganic and organic additives and naturally occurring radioactive materials (NORM) (also see Hobbs et al. (2016) for a description of the groundwater quality). Contaminated

Key definitions and abbreviations

"*Flowback*" refers to fracking fluid injected into a gas well that returns to the surface when drilling pressure is released.

"*Produced water*" refers to all waste water emerging from the well after production begins, much of which is salty water contained within the shale formation.

Source: Hammer and Van Briesen, 2012

run-off also needs to be contained and treated as waste water. The solid wastes produced are mostly drill cuttings (mud) or sludges from waste water treatment. Impacts of spills during off-site transport of waste water or waste may result from accidents, inadequate management or training, and illicit dumping. Domestic solid waste associated with worker deployment to the area and opportunistic migrants looking for employment and other economic opportunities are also considered.

Issues not covered in this chapter are non-water related impacts of waste water management (with limited exceptions). Such impacts include air emissions from trucks used to haul waste water and waste (refer to Winkler et al., 2016), noise (Wade et al., 2016) and traffic impacts from those trucks (Van Huyssteen et al., 2016), soil contamination and land disturbance impact from the construction of waste water management facilities (refer to Hobbs et al., 2016 and Holness et al., 2016).

Assumptions: Operators/prospectors must fully disclose the composition of the fracking fluid additives, consistent with the provisions of the Regulations for Petroleum Exploration and Production, 2015, as this will determine the treatment options required to ensure correct treatment and proper management of this waste stream. The waste stream has been predefined as hazardous waste in Schedule 3 of the Waste Amendment Act, 2014 (RSA, 2014).

6.1.2 Overview of international experience

Disposal of drilling and fracking wastes, as well as spills of fracking fluids and waste, poses a number of potential environmental and health risks. Surface spills of fracking fluid may pose a greater contamination risk than fracking itself (see also Section 6.5) (Grout and Grimshaw, 2012). Released materials include fuels, drilling mud and cuttings, and chemicals (particularly for fracking). Fracking chemicals in concentrated form (before mixing) at the surface present a more significant risk above ground than as a result of injection in the deep subsurface (Grout and Grimshaw, 2012). Leaks and spills associated with SGD may occur at the drill pad or during transport of chemicals and waste materials. Sources at the wellsite include the drill rig and other operating equipment, storage tanks, impoundments or pits, and leaks or blowouts at the wellhead. The primary risk of uncontrolled releases is generally to surface water and groundwater resources (Grout and Grimshaw, 2012).

Many of the waste streams generated by fracking are the same as or similar to those of conventional oil and gas production (Grout and Grimshaw, 2012). The flowback and produced water generated by SGD may pose a serious risk to the surrounding environment and public health because this waste water usually contains many toxic chemicals and high levels of total dissolved solids (TDS) (Zhang et al., 2016). The composition of waste waters changes over the lifetime of the well with produced water increasing in salinity in the latter stages of SGD (Koppelman et al., 2012). The management of these wastes may be the greatest challenge of shale gas regulation by the responsible authorities (Grout and Grimshaw, 2012). The United States Environmental Protection Agency (US EPA) reported groundwater contamination in Pavillion, Wyoming as a direct result of improper operational practices associated with fracking waste management (DiGiulio et al., 2011). "*Detection of high concentrations of benzene, xylenes, gasoline range organics, diesel range organics, and total purgeable hydrocarbons in groundwater samples from shallow monitoring wells near pits indicates that pits are a source of shallow groundwater contamination in the area of investigation. Pits were used for disposal of drilling cuttings, flowback, and produced water*" (DiGiulio et al., 2011:33).

According to Grout and Grimshaw (2012) US regulations for waste storage primarily address temporary pits and tanks for drilling fluid and cuttings and flowback and produced water. These regulations typically include requirements for pit liners, freeboard (excess volumetric capacity), and closure, all of which have the objective of preventing soil and water contamination. Some states in the US are adopting provisions which require that drilling and fracking waste must be stored in tanks rather than pits before disposal to reduce the potential impacts on the environment (Grout and Grimshaw, 2012). Open storage ponds are not allowed in the UK (Koppelman et al., 2012) or in South Africa (RSA, 2015a).

According to Hammer and Van Briesen (2012) there are five basic management options for contaminated waste water from SGD as illustrated in Figure 6.1. These are:

1) Minimisation of produced water generation;
2) Recycling and re-use within operations;
3) Treatment;
4) Disposal; and
5) Beneficial re-use outside the operations.

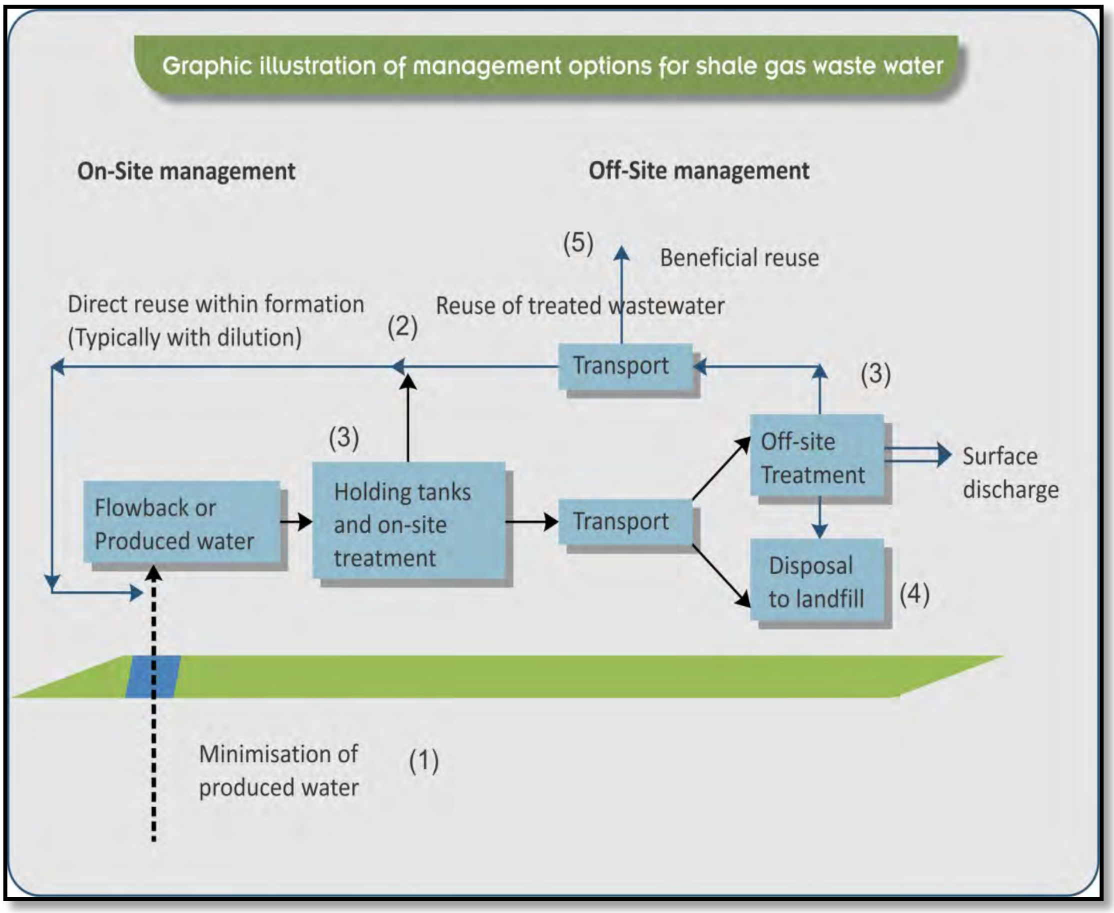


Figure 6.1: Management options for shale gas waste water.

6.1.2.1 Minimisation, re-use and recycling of flowback and produced water

Minimising the volume of produced water that is generated to the surface is a way to simplify water management options and costs. To achieve produced water minimisation, processes are modified, technologies adapted or products are substituted so that less water is generated (Veil, 2015).

Challenges to re-use may include removing constituents that could affect well performance (salts, suspended solids, microorganisms and scale forming chemicals) and adjusting the stimulation chemistry with chemical additives that work in saltier waters (Hammer and Van Briesen, 2012).

Produced water minimisation technologies are summarised in Table 6.1 below (Veil, 2015).

Table 6.1: Produced water minimisation technologies (Veil, 2015).

Approach	Technology	Pros	Cons
Reduce the volume of water entering the wells.	Mechanical blocking devices (e.g. packers, plugs, good cement jobs).	These should be used in new construction. They can be added later on to fix some problems.	May not be easy to fix pre-existing problems.
	Water shut-off chemicals (e.g. polymer gels).	Can be very effective in selected instances, primarily in sandstone and limestone formations.	Need the right type of formation in order to achieve cost-effective results.
Reduce the volume of water managed at the surface by remote separation.	Dual completion wells (downhole water sink).	Can be very effective in selected instances.	Limited prior use. Makes wells more complex.
	Downhole oil/water separation.	May be a good future technology.	Earlier trials were inconsistent and the technology went out of favour. New designs and good candidate wells are needed to bring back this technology.

The opportunity for re-use and recycling is greater during the flowback period than during the production phase. Produced water generated during the lifetime of the well can be collected and repurposed for operations at other wells, but this requires transport to new wellpads which may be costlier than transport to disposal or treatment locations. Logistics and economics therefore control the re-use opportunity (Hammer and Van Briesen, 2012). Reinjection for enhanced recovery is a fairly common practice in the US and elsewhere (Veil, 2015). In general, increased emphasis is being placed on requirements for waste water reduction through re-use and recycling of fracking fluids (Grout and Grimshaw, 2012). Desalination technologies are being developed to control salinity and support re-use of waste waters (Koppelman et al., 2012). Examples of water re-use and recycle management options and some of the specific uses are shown in Table 6.2 below (Veil, 2015).

Table 6.2: Examples of water re-use and recycle management options and some of the specific uses (Veil, 2015).

Management Option	Specific Use	Pros	Cons
Reinjection for enhanced recovery	Water flood; stream flood	Common use of produced water for onshore conventional formations. Usually has low cost	Need to ensure chemical compatibility with receiving formation.
Injection for future water use	Aquifer storage and recovery	Can augment public water supplies	Need to ensure that water meets drinking water standards before injecting it into a shallow aquifer. May encounter public opposition. Oil and gas companies may not choose this option due to fear of future liability.

Management Option	Specific Use	Pros	Cons
Injection for hydrological purposes	Subsidence control	Can help solve a local problem (e.g. Wilmington Oil Field, Long Beach, CA)	Need to ensure chemical compatibility with receiving formation.
Agricultural use	Irrigation; subsurface drip irrigation	Can be a great benefit to arid areas	May need to treat the water before applying it to the soil or add soil supplements. May need to choose salt-tolerant plant species.
	Livestock and wildlife watering	Can provide a source of water for animals	Need to ensure that water is clean enough to avoid illness or other impacts to animals.
	Managed/ constructed wetlands	Provides a “natural” form of treatment. Creates a good habitat for wildlife.	Large space requirements. Needs extensive oversight and management. Typically limited to water with low to moderate salinity.
Industrial use	Oil and gas industry applications (e.g. drilling fluids, fracking fluids)	Can substitute for fresh water supplies in making new drilling or stimulation fluids	May need treatment in order to meet operational specifications
	Power plants (cooling water)	May be able to supplement cooling water sources	Will require treatment. The large volumes needed result in collection and transportation costs.
	Other (e.g. vehicle wash, fire-fighting, dust control on gravel roads; road de-icing)	Can be a good supplemental water supply in arid areas	Will need storage facilities and possibly treatment. Concerns about water quality impacts from runoff after application or inappropriate application.
Treat to drinking water quality	Use for drinking water and other domestic uses	Can help supply water to communities in arid areas	Cost to treat may be high. Need good quality control. May encounter public opposition and face concern over liability. It may be more cost-effective and energy-conserving to treat other water sources like saline groundwater rather than treating produced water.

Pre-treatment could take place onsite, but this is currently very expensive (Koppelman et al., 2012). Off-site re-use of untreated produced water is rare due to the high concentration of salts and the scaling potential (Hammer and Van Briesen, 2012).

6.1.2.2 Treatment

Prior to disposing of or re-using water from fracking operations, different treatment processes and technologies may be required (Veil, 2015). The quality requirement for the final disposition of the water will determine the type and extent of treatment required. For example, if water is discharged, the parameter of greatest concern can be related to either the organic content or the salt content to meet the resource quality objectives. Treatment technologies designed to remove salts and other inorganic compounds from produced water are listed in Table 6.3 below (Veil, 2015).

Table 6.3: Treatment technologies designed to remove salts and other inorganic compounds from produced water (after Veil, 2015).

Technology	Subcategory	Pros	Cons
pH adjustment, flocculation, and clarification	N/A	This is a common pre-treatment step to remove metals. The cost is modest.	This process removes metals but does not treat chlorides or TDS. The process generates sludge that requires disposal.
Membrane processes	Microfiltration, ultrafiltration, and nanofiltration	They are good pre-treatment steps for more advanced processes like Reverse osmosis (RO). They operate at lower pressure and lower cost than RO. Ultrafiltration followed by RO can process high chemical oxygen demand (COD).	These levels of filtration cannot remove most salinity. Potential for membrane fouling. Sensitivity to fluctuating water quality.
	Reverse osmosis (RO)	RO can remove salinity (up to about 40,000 mg/L TDS).	Requires pre-treatment and regular membrane cleaning. Not suitable for high-salinity water. Potential for membrane fouling. Sensitivity to fluctuating water quality. Generates concentrated brine stream that requires separate disposal. Moderate to high energy usage and cost.
	Other (e.g. electrodialysis, forward osmosis)	May offer future treatment opportunities.	Have not been used extensively in full-scale oil field treatment systems yet. Potential for membrane fouling. Sensitivity to fluctuating water quality.
Thermal Treatment	Distillation	Can process high-salinity waters like flowback. Generate very clean water (can be re-used).	High energy usage and cost. Generates concentrated brine stream that requires separate disposal. Potential for scaling. May require remineralisation before release or beneficial re-use.
	Evaporation/ Crystallisation	Can treat to a zero liquid discharge standard. Solar evaporation in ponds could be relatively cheap.	High energy usage and cost if not solar evaporation. Limited usage in oil field applications. Potential for scaling. Challenges in disposing of salt residue.

Technology	Subcategory	Pros	Cons
Ion exchange	N/A	Successfully treats low to medium salinity water (e.g. Powder River Basin).	Large acid usage. Resins can foul. Challenges in disposing of rinse water and spent media (resin). Also ineffective on high salinity produced waters.
Capacitive deionisation	N/A	Low energy cost.	Limited to treating low salinity waters. Limited usage in oil field applications.

Treatment technologies designed to remove oil and grease and other organics from produced water are listed in Table 6.4 below (Veil, 2015).

Table 6.4: Treatment technologies designed to remove oil and grease and other organics from produced water (Veil, 2015).

Technology	Subcategory	Pros	Cons
Physical separation	Advanced separators (e.g. inclined plate, corrugated plate)	Provide enhanced oil capture compared to basic oil/water separators.	Work well for free oil, but not as effective on dispersed and soluble oil. Performance can be improved by adding flocculants.
	Hydrocyclone	No moving parts results in good reliability. Separates free oil very well.	Does not work well on dispersed and soluble oil.
	Filtration	Different types of filter media and filter operations provide a good range of oil and grease removal.	Requires regular back-flushing. Does not treat most soluble oil.
	Centrifuge	Provides good separation of free and dispersed oil.	More expensive than other technologies in this group.
Coalescence	N/A	Collects small oil droplets and forms larger droplets that can be more easily removed by the other technologies.	Limited value for dispersed or soluble oil.
Flotation	Dissolved air flotation, induced gas flotation	Removes free and dispersed oil.	Does not remove soluble oil.
Combined physical and extraction processes	Compact separators and other units	Can treat to very low oil and grease levels.	Not used currently in US because its low level of oil and grease is not needed to meet US regulatory standards.
Solvent extraction	Macro-porous polymer extraction	Can treat to very low oil and grease levels.	Not used currently in US because its low level of oil and grease is not needed to meet US regulatory standards. Probably is very costly.
Adsorption	Organoclay, activated carbon, zeolites, specialised polymers, swelling glass	Does a good job at removing oil and grease. Used primarily for	Most types of media cannot be re-used or regenerated – results in large volume of

Technology	Subcategory	Pros	Cons
		polishing.	solid waste.
Oxidation	Advanced processes using combinations of ozonation, cavitation, and electrochemical decomposition	Creates nearly sterile brine	Has high energy input. Limited use to date.

Veil (2015) reports that new produced water technologies and products are being introduced to the marketplace each month; the technologies listed in the above tables are major technology categories that were in use in 2014.

Treatment is the most complex management option and can be done on- or off-site and in conjunction with recycling, re-use, discharge and disposal. On-site treatment is designed for re-use only and will incorporate the minimum treatment technology required for re-use without compromising the chemistry of the fracking water makeup (Hammer and Van Briesen, 2012). Desalination is possible, but is rarely necessary to produce water suitable for re-use in fracking operations (Hammer and Van Briesen, 2012).

Biofouling of membranes by organic material has historically been responsible for the largest number of failures in reverse osmosis desalination processes. Thus, effective pre-treatment of oilfield-produced brines is necessary to prevent biofouling and scaling of reverse osmosis membranes (Lee et al., 2002). Treatment is predominantly done off-site and therefore requires transport of the waste water (Hammer and Van Briesen, 2012). Off-site options and decisions are more complex and will require initial analysis of the water to determine its fate. Regardless of its ultimate fate, preliminary treatment is likely to be required (Hammer and Van Briesen, 2012).

The main contaminants to be removed during treatment are: 1) salts, including metals; 2) organic hydrocarbons (sometimes referred to as oil and grease); 3) inorganic and organic additives; and 4) naturally occurring radio-active materials (NORM). The treatment technology to employ can only be determined through complete chemical analysis of the water. Significant concern has been raised regarding the nature of the additives, with 29 identified as of particular concern for human health and 13 identified as probable or known human carcinogens (Hammer and Van Briesen, 2012).

Among the most notable are naphthalene, benzene and polyacrylamide. Polyacrylamide itself is not carcinogenic, but the acrylamide monomer is. There is some concern that during manufacture the polyacrylamide retains small amounts of the monomer. A list of the chemicals of concern present in fracking fluids is provided in Table 1 in the Digital Addendum 6A. In the US, there are calls for operators to disclose fully the composition of the fracking fluid additives and it is already a requirement in the United Kingdom (UK) (DiGiulio et al, 2011; Koppelman et al., 2012) and included in South African regulations (RSA, 2015a).

Shale gas operators in the US are known to have sent waste water to publicly owned treatment works for treatment (Hammer and Van Briesen, 2012), but this practice has become controversial and has been banned in some states, while other states require pre-treatment before discharge into publicly owned treatment works (Grout and Grimshaw, 2012). In July 2011, 15 US treatment facilities were exempted from compliance with the regulations, meaning that they were allowed to discharge treated waste water with concentrations exceeding the TDS and chlorides limits. Nine of these facilities were publicly owned waste water treatment plants. An alternative is treatment of produced water at dedicated brine or industrial waste water facilities (Hammer and Van Briesen, 2012). The US EPA has indicated that waste water treatment standards will be developed for shale gas waste water (Grout and Grimshaw, 2012).

Treated water may be discharged, shipped back to the well site for re-use or diverted for beneficial re-use or resource extraction, depending on the final quality (Hammer and Van Briesen, 2012).

6.1.2.3 Disposal

Direct disposal above ground or to soils in the near surface environment, on- or off-site was routine in the early part of the 20th century, and the use of on-site unlined ponds and nearby off-site land applications were common disposal practices (Hammer and van Briesel, 2012). These practices are no longer used due to salt contamination in soils and aquifers. Produced water in the US is often disposed via underground injection into disposal wells (Hammer and Van Briesen, 2012; Shaffer et al., 2013). A small fraction of produced water is reportedly discharged to surface water, managed by evaporation ponds, or beneficially re-used outside the industry (Shaffer et al., 2013). Some states are re-evaluating the practice of on-site land disposal of waste (Grout and Grimshaw, 2012). Field evaluations on a subset of impoundments and pits used for waste and waste water storage in the Marcellus Shale development, found several construction and maintenance deficiencies related to the containment systems and transport pipelines (Ziemkiewicz et al., 2014).

In some shale gas areas, operators manage waste at a centralised waste disposal facility that accepts waste from multiple well sites (Koppelman et al., 2012; Grout and Grimshaw, 2012). These facilities may be subject to general state requirements such as best management practices to protect human health and the environment or to specific requirements such as an operating plan, water well monitoring and stormwater diversion (Grout and Grimshaw, 2012). Water disposal methods (Veil, 2015) are listed in Table 6.5 below.

Table 6.5: Water disposal methods (Veil, 2015).

Technology	Pros	Cons
Discharge*	Very common for offshore facilities. Offers moderate cost and acceptable environmental impact, where permitted.	Not approved for most onshore wells. Where allowed, requires treatment unless the water is high quality, such as some coalbed methane (CBM) effluent. Different treatment requirements for discharges into different types of water bodies.
Underground injection** (other than for enhanced recovery)	Very common onshore practice. Tends to have low cost. EPA and state agencies recognise this as a safe, widely used, proven, and effective method for disposing of produced water.	Requires presence of an underground formation with suitable porosity, permeability, and storage capacity. May require treatment to ensure that injectate does not plug formation. A small subset of disposal wells has been linked to felt earthquake activity – this is an active area of research. Transportation costs can be significant.
Evaporation***	In arid climates, takes advantage of natural conditions of humidity, sun, and wind.	Not practicable in humid climates. May create air quality and salt deposition problems.
Offsite Commercial disposal	Companies providing services to oil and gas community by accepting and disposing water for a fee. Removes water treatment burden from the operator.	Requires infrastructure (disposal facilities and transportation network to move water to disposal site). Can be costly.

Note:
* Discharge of untreated waste water is prohibited in South Africa in terms of Section 124 (5) of Regulation 466 (RSA, 2015a).
** Disposal to underground is prohibited in South Africa in terms of Section 124 (4) of Regulation 466 (RSA, 2015a).
*** Disposal of liquid waste to land is being phased out in South Africa and will be prohibited from 23 August 2019 (RSA, 2013b).

6.1.2.4 Beneficial re-use

The beneficial re-use of oil and gas brines has a long history in the US. For low-TDS water beneficial re-use options include livestock watering, aquaculture and hydroponic vegetable culture, irrigation of crops, washing of equipment and fire control. None of these opportunities exist for waste water from highly saline formations like the Marcellus Shale. The unique mixture of chemicals in treated fracking waste water has not yet been studied with respect to its uptake into crops (Shariq, 2013). However, according to Shariq (2013) arsenic, one of the known toxic inorganic constituents in the waste water, has been shown to bio-accumulate throughout rice plants, and organic hydrocarbons have also been identified in wheat plants grown in contaminated soil.

6.2 Special features of the Karoo in relation to waste

There are currently no specialised hazardous waste disposal or treatment facilities in the Karoo. The spatial distribution of waste water treatment and solid waste disposal facilities in the study area is illustrated in the map (Figure 6.2) below. Eden District Municipality is in the process of building a Class B regional waste disposal site with a hazardous waste cell that will be able to accept Type 2 hazardous waste from 2017. The hazardous waste generated by fracking is likely to be Type 1 hazardous waste (Section 7(3) of Regulation 635) which will not be allowed at the new Eden regional waste disposal facility. All Type 1 hazardous waste generated in the study area will therefore have to be transported to a suitably designed and authorised hazardous waste disposal site in Gauteng, Port Elizabeth or Cape Town. Although the PetroSA landfill in Mossel Bay is also licensed to accept Type 1 hazardous waste, it is not a commercial facility and therefore would require the consent of the permit holder and the relevant authorities (possibly including an Environmental Impact Assessment (EIA) as this would be a change in scope of the original licence issued) to be used for disposal of waste from fracking activities. Construction of a new on-site or centralised disposal facility could be considered for large scale development and production (Scenario 3 (Big Gas)) subject to a full EIA and approval of a disposal site licence under the Waste Act (Act 56 of 2008).

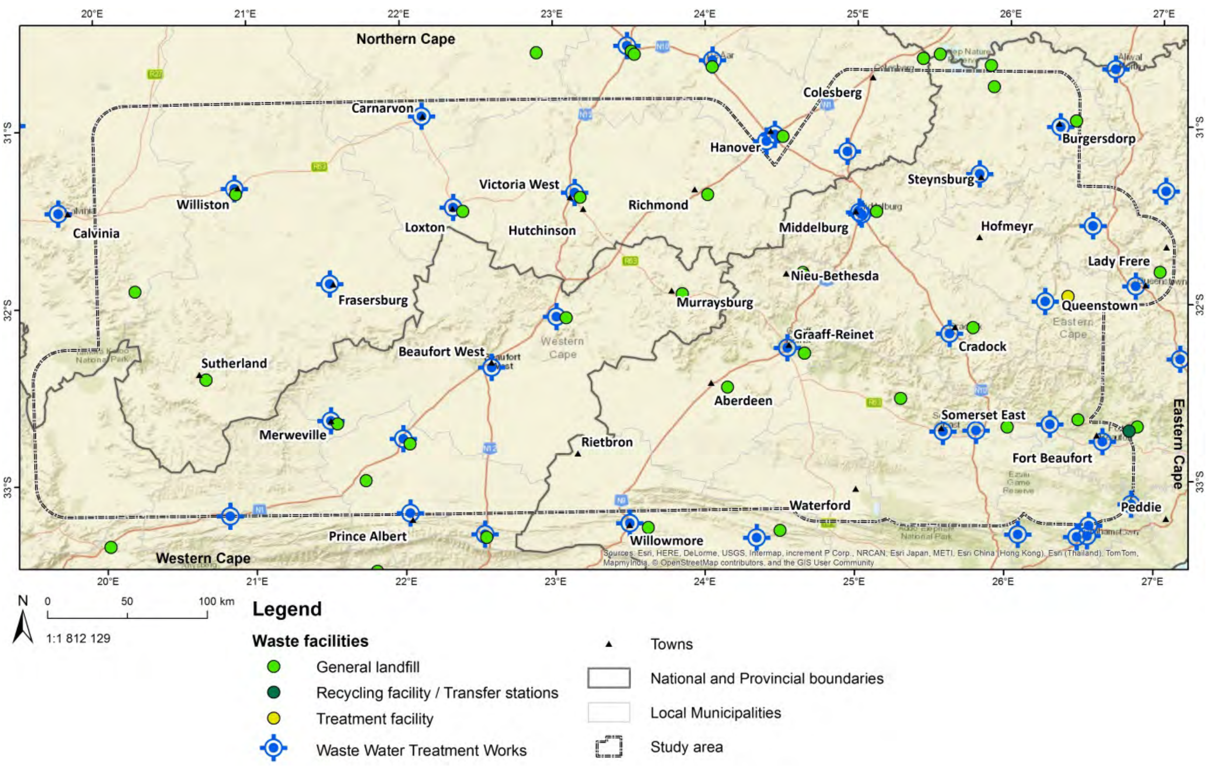


Figure 6.2: Map of the study area showing waste facilities for general landfills and Waste Water Treatment Works.

Facilities for the disposal of domestic solid waste, generated by workers deployed to the study area and opportunistic migrants, are limited to small and communal disposal sites (Table 2 in Digital Addendum 6A). As at 2007, only twelve sites were estimated to have 15 years or more airspace remaining (DEAT, 2007), the other sites are likely to be filled up by now. Additional waste generated for all SGD scenarios will put pressure on these already constrained waste disposal facilities. All landfills in the study area require upgrades to meet the requirements of the National Norms and Standards for Disposal of Waste to Landfill. Recycling initiatives in the Karoo are limited due to relative low volumes and large transport distances to markets for recyclables.

Waste water infrastructure in the study area is limited to municipal owned treatment works (see Table 3 in Digital Addendum 6A). The majority of these facilities are placed under regulatory surveillance or require immediate interventions (Department of Water and Sanitation (DWS), 2014). The 'risk' associated with municipal waste water treatment facilities relates to design capacity (including the hydraulic loading into the receiving water body), operational flow (exceeding, on or below capacity), and number of non-compliance trends in terms of effluent quality (discharged into the receiving environment) and compliance or non-compliance in terms of technical skills (DWS, 2014). Waste water generated by SGD (Scenario 1(Exploration Only) and 2 (Small Gas)) will therefore have to be treated on-site or transported (trucked or piped) to suitable facilities further afield. The volumes during the Exploration Only scenario will likely be best addressed though on-site (possibly mobile or packaged) treatment facilities as it will be too small to justify pipelines. Transportation by road to off-site facilities further afield will be the other alternative. During the Small and Big Gas scenarios the ideal would be to have local modular waste water treatment facilities to minimise fluid transport movement and distances in line with Section 117(a) of the Petroleum Exploration and Production Regulations (RSA, 2015a). Refer to Digital Addendum 6B for examples of packaged, mobile and modular on-site treatment technologies for flowback and produced water from SGD[1].

There are currently no licensed NORM waste facilities in the study area; therefore NORM waste will have to be transported to suitably licensed off site facilities outside of the study area. The proposed uranium mining in the study area will also produce NORM waste and is likely to establish slimes dams for disposal of NORM waste. The establishment of such facilities will be subject to regulatory control by the National Nuclear Regulator.

[1] The authors do not promote this specific technology but merely refer to it as examples of what is commercially available internationally.

6.3 Relevant legislation, regulation and practice

Applicable legislation to SGD in South Africa has been promulgated by the Department of Mineral Resources (DMR), Department of Water and Sanitation and the Department of Environmental Affairs (DEA). The DMR is responsible for the sustainable development of South Africa's mineral and petroleum resources within the framework of national environmental policy, norms and standards while promoting economic and social development (RSA, 2002). The DEA is the lead agent for the protection of the environment (RSA, 1998a) and waste management (RSA, 2008) while the DWS is the public trustee of the nation's water sources (RSA, 1998).

6.3.1 Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002)

The objective of the Mineral Resources and Petroleum Development Act, 2002 (MRPDA) (Act 28 of 2002) is amongst other to "*give effect to Section 24 of the Constitution by ensuring that the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner while promoting justifiable social and economic development*" (RSA, 2002).

Section 41 of the MPRDA states that applicants for prospecting rights, mining rights or mining permits must make financial provisions for the rehabilitation or management of negative environmental impacts.

Regulation 466 for Petroleum Exploration and Production (RSA, 2015a) requires, amongst other, the following measures to prevent environmental contamination from SGD:

Section 91 Suitably designed impermeable site underlay systems and site drainage arrangements.

Section 109 Drilling fluids must be declared through material safety data sheets.

Section 112(8) (g) Proppants must be tagged with radioactive isotopes so that proppant can be analysed to locate where different stages of the proppant went and to locate fractures at depth.

Section 112(8) (h) Chemical tracers must be added to improve the understanding of fracture fluid loss and flowback.

Section 113 Fracking fluid disclosure including prohibition of substances listed in schedule 1 (refer to Table A1, Burns et al., 2016 Digital Addenda).

Section 115 Fracturing fluids management through a risk management plan.

Section 116 Management of flowback and produced fluids through an approved waste management plan.

Section 117 An approved fluid transportation plan, planning to minimise fluid transport movements and distances.

Section 118 Fluid storage: at the well site and centralised storage for potential re-use prior to disposal, fracking additives, fracking fluids, flowback and produced water must be stored in above-ground tanks with lined bund walls.

Section 123(3) Re-use of fracking fluids and produced water from operation on site or from neighbouring operations must be considered to reduce competition with freshwater uses.

Section 124(1) Waste must be disposed of in accordance with applicable legislation.

Section 124(2) Waste containing radioactive materials must be managed in accordance with National Radioactive Waste Disposal Institute Act, 2008 (Act 53 of 2008).

Section 124(3) Liquid waste must be disposed of at an approved waste treatment facility in accordance with relevant legislation and disposal of liquid waste at domestic waste water treatment facilities must only take place after prior consultation with the department responsible for water affairs.

Section 124(4) Disposal to underground, including the use of re-injection disposal wells, is prohibited.

Section 124(5) Discharge of fracking fluids, fracking flowback, and produced water into surface water course is prohibited.

Section 124(6) Annular disposal of drill cuttings or fluids is prohibited.

Section 124(7) Drill cuttings and waste mud must be temporarily stored in above-ground tanks.

Section 124(8) Solid waste generated during operations must be categorised and disposed of accordingly at a licensed landfill site or treatment facility.

Section 125 A waste management plan must be prepared and approved as part of the application for Environmental Authorisation.

6.3.2 National Environmental Management Act, 1998 (Act 107 of 1998)

This act sets out the fundamental principles that apply to environmental decision making. The core environmental principle is the promotion of ecologically sustainable development. Principles referring to waste and pollution include:

- That pollution and degradation of the environment are avoided or where they cannot be altogether avoided, are minimised and remedied.
- That waste is avoided, or where it cannot be altogether avoided, minimised and re-used or recycled where possible and otherwise disposed of in a responsible manner.
- Decisions must be taken in an open and transparent manner, and access to information must be provided in accordance with the law.

- The cost of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment.

NEMA Section 30 and 30A establish the framework for dealing with emergency situations and will apply directly to such occurrences in the SGD context.

Waste management activities that have, or are likely to have, a detrimental effect on the environment as listed in Regulation 921 of 29 November 2013 (RSA, 2013c) are subject to the EIA Regulations made under Section 24(5) of NEMA as part of a waste management licence application under the NEMWA.

Relevant regulations under NEMA:

- Environmental Impact Assessment Regulations (Regulation 982 of 4 December 2014);
- Regulations pertaining to the financial provisions for prospecting, exploration, mining or production operations (Regulation 1147 of 29 November 2015).

6.3.3 National Environmental Management: Waste Act, 2008 (Act 56 of 2008)

South Africa has an integrated pollution and waste management policy that is driven by a vision of environmentally sustainable economic development by amongst other, preventing and minimising, controlling and remediating pollution and waste to protect the environment from degradation (DEAT, 2000). Waste management in South Africa is informed by the waste management hierarchy which outlines waste management options covering the lifecycle of waste, in descending order of priority: waste avoidance (prevention and minimisation), re-use and recycling, recovery, waste treatment and disposal as last resort (DEA, 2012).

Waste legislation in South Africa is emerging and constantly changing. The NEMWA is the first law in South Africa dedicated to waste and a number of new strategies and regulations under this act are currently under development.

Waste management activities that may require a licence in terms of NEMWA are listed in Regulation 921 of 29 November 2013 (RSA, 2013c) and Regulation 633 of 24 July 2015 (RSA, 2015b). These activities include:

- Storage of general waste in lagoons and storage of hazardous waste in lagoons excluding storage of effluent, waste water or sewage;
- Recycling or recovery of waste;

- Treatment of waste;
- Disposal of waste;
- Construction, expansion or decommissioning of facilities and associated structures and infrastructure; and
- Establishment or reclamation of a residue stockpile or residue deposit resulting from activities which require a prospecting right or mining permit in terms of the MPRDA.

Depending on the size, handling capacity and the type of waste to be managed at the facility, a basic assessment or full EIA set out in the EIA regulations under Section 24(5) of NEMA will be required as part of the licence application process. All hazardous waste management facilities will require a full EIA.

Applicable regulations under NEMWA include:

- Waste Information Regulations (Regulation 625 of 13 Aug 2012) – every person generating more than 20 kg of hazardous waste per day or disposing of any amount of hazardous waste to landfill must register on the South African Waste Information System (SAWIS) and submit actual quantities of waste into the SAWIS.
- Waste Classification and Management Regulations (Regulation 634 of 23 Aug 2013) - All waste generators must ensure that the waste they generate is classified in accordance with South African National Standards (SANS) 10234 and a safety data sheet prepared for each waste stream as prescribed.
- National Norms and Standards for the Assessment of Waste for Landfill Disposal (Regulation 635 of 23 Aug 2013).
- National Norms and Standards for Disposal of Waste to Landfill (Regulation 636 of 23 Aug 2013).
- List of Waste Management Activities that have or are likely to have a detrimental impact on the Environment (GN 921 of 29 Nov 2013).
- National Norms and Standards for Storage of Waste (GN 926 of 29 Nov 2013).
- National Norms and Standards for Remediation of Contaminated Land and Soil (GN 331 of 2 May 2014).
- Regulations regarding the planning and management of residue stockpiles and residue deposits from a prospecting, mining, exploration or production operation (Regulation 632 of 24 July 2015).
- Amendments to the list of waste management activities that have or are likely to have a detrimental effect on the environment (Regulation 633 of 24 July 2015).

SGD is considered a high risk activity that is likely to result in land contamination in all scenarios. The Minister or MEC may identify investigation areas, direct site assessments to be done and issue remediation orders for the remediation of contaminated land (NEMWA, Chapter 4, Part 8) (RSA, 2008 as amended). All costs associated with the assessments and remediation will be for the account of the owner of the land or company responsible for SGD (RSA, 2008) in line with the "polluter-pays-principle". Financial provision for the costs associated with the undertaking of management, rehabilitation and remediation of environmental impacts from prospecting, exploration, mining or production operations through the lifespan of such operations and latent or residual environmental impacts that may become known in the future is regulated under Regulation 1147 in terms of NEMA.

NEMWA and its regulations will not be able to adequately deal with the waste from SGD. Financial provisions as outlined in Regulation 1147 may not be sufficient to cover the costs for remediation of contaminated land from spills during SGD. The regulations focus on financial provisions to implement the rehabilitation and closure plan as well as latent or residual impacts in the future but not for accidental spills. Although norms and standards for waste classification and containment barrier system designs is prescribed, the law is silent on landfill management, operational and groundwater monitoring requirements at facilities receiving waste from SGD. Possible contact between the waste and humans is also not regulated. Site specific waste management licences are required for each waste activity requiring a licence. Multiple storage and treatment facilities will potentially attract the need for multiple licence applications each with a requirement for an EIA at scoping or full assessment level which will add cost and time delays in obtaining authorisations. There is currently not enough capacity at national and provincial government level to evaluate and process the potential flood of waste licence applications that may be experienced from the Small and Big Gas scenarios. Waste classification regulation stipulate that waste must be kept separate for purposes of classification, and must be "*re-classified within 30 days of modification to the process or activity that generated the waste, changes in raw materials or other inputs, or any other variation of relevant factors*" (RSA, 2013). This implies that every change in the composition of the fracking fluid will require a reclassification of the waste before disposal for all three scenarios.

The DEA have indicated their intention to amend schedule 3 of NEMWA which currently pre-classify wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals as hazardous waste. If this pre-classification of waste from SGD changes, then it is possible that the waste may be classified as Type 1, 2 or 3. Most municipal landfill sites in the study area would at best be Class C or D sites and will not be able to receive Type 1, 2, or 3 wastes.

6.3.4 National Water Act, 1998 (Act 36 of 1998)

The National Water Act, 1998 (NWA), provides regulatory and market based instruments to manage the impacts on water quality. These instruments include licensing of water uses (NWA, Section 21), including disposal of waste, which may impact on water resources and waste discharge charges in line with the "polluter pays" principle (DWA, 2009).

Water used in excess of the limits specified in Schedule 1 and General Authorisation notices will require a water use licence. The Minister may however dispense with the requirement for a licence under the NWA (Section 22(3)) by issuing a Record of Decision which is then incorporated in the waste licence issued under NEMWA.

Several water uses can be covered by one integrated water use licence. The integrated water use licence will prescribe conditions for the management, monitoring and reporting relating to the water use. An integrated water and waste management plan is a typical requirement of a water use licence.

National Water Act, 1998,

Section 21 Waste Discharge related water use

- Engaging in a controlled activity (where the controlled activity relates to waste discharge activities).
- Discharging waste or water containing waste into a water resource.
- Disposing of waste in a manner which may detrimentally impact on a water resource.
- Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process.
- Altering the bed, banks, course or characteristics of a water course (where such activities have impacts on the water quality of the water course).
- Removing, discharging or disposing of water found underground if it is necessary

The Pricing Strategy, as amended (RSA, 2015), provides for six water use categories including fracking (as illustrated in Figure 6.3) to represent the user groups and to allow for clearly targeted charges. Charges will be calculated based on the volume of the waste water discharged from a point source, and on the degree of management activity required for non-point source registered users. Cost allocations will be based on:

- Point source discharge – management effort for point discharges, attracting all waste discharge related costs.
- Waste disposal to facilities/land – management effort for waste disposal to land, attracting all waste discharge related activity costs.
- Irrigation of land with water containing waste – Management effort for irrigated effluent, attracting all waste discharge related activity costs.

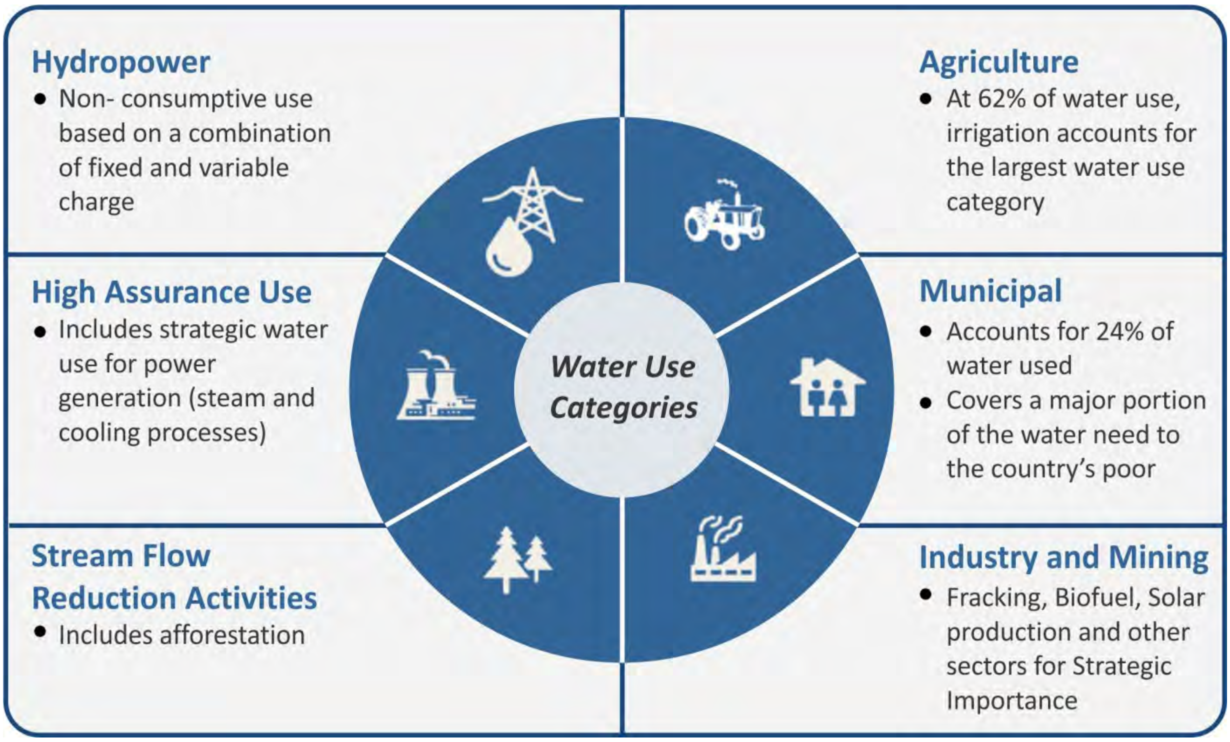


Figure 6.3: Water use categories as defined by the Pricing Strategy (RSA, 2015).

Relevant regulations under NWA:

- Regulations on the use of water for mining and related activities aimed at the protection of water resources (Regulation 77 of 12 February 2010).

6.3.5 National Nuclear Regulator Act, 1999 (Act 47 of 1999)

NORM waste will be regulated under this act. The National Nuclear Regulator (NNR) document RD-004 'Requirements Document on the Management of Radioactive waste associated with waste products from facilities handling NORM (2007)' describes how NORM waste must be managed.

6.3.6 National Road Traffic Act, 1996 (Act 93 of 1996)

Vehicles transporting dangerous goods (including hazardous waste) must adhere to SANS 10228 in terms of identification and classification of goods and display the relevant signage.

In terms of Section 76 of the National Road Traffic Act, 1996 the following standards are deemed to be regulations:

SANS 10228: Identifies and classifies each of the listed dangerous goods and substances and set out information including the United Nations Number, the correct shipping name, hazard class assigned and other information pertinent to the substance.

SANS 10229: Contains information on acceptable packaging for dangerous goods and substances and also include requirements for the testing of packaging and the correct marking and labelling of packages.

SANS 10230: Includes statutory vehicle inspection requirements for all vehicles conveying dangerous goods. This code stipulates the safety aspects of both the vehicle and the goods containment. Minimum inspection requirements by both in-house and outside agencies are listed.

SANS 10231: This code of practice prescribes the operation rules and procedures for transporting Dangerous Goods and Hazardous Materials. It also includes the prescribed responsibilities of the owner/operator of the dangerous goods vehicle. It outlines the information required and who will have to supply information for the safe conveyance of dangerous goods. The requirements for the drafting and formulating of an operational agreement are also specified. This code also requires the owner/operator or vehicle to be registered as dangerous goods carrier. It is also prescribed that the owner operator has available adequate insurance cover for civil liability as well as pollution and environmental rehabilitation cover in the event of an incident.

SANS 10232-1: 2007: This code includes details of new placarding requirements for vehicles transporting dangerous goods and the individual or substance exempt quantities and the compatibility requirements of mixed loads. Part 3 of this code contains information on the Emergency Response Guides to be used in case of an incident or accident.

6.3.7 Disaster Management Act, 2002 (Act 57 of 2002)

This act provides for an integrated and coordinated disaster management policy that focuses on preventing or reducing the risk of disasters (natural or human induced) mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery.

6.4 Key potential impacts and their mitigation

Waste-generating pathways and handling options, include, *inter alia*, drilling fluids, drilling muds, fracking fluids, lubricating oils and greases, contaminated land (spills on-site), domestic waste, sewage, construction waste etc. The expected volumes of waste generated during the different scenarios for SGD in the Karoo is summarised in Burns et al. (2016). Composition of the waste is important in terms of classification and management of the waste - it is likely that most of the waste will be Type 1 hazardous waste. Disclosure of the fracking fluids in terms of chemical and concentration by mass, as provided for in Section 113 of Regulation 466 (RSA, 2015a) will assist in the accurate classification of the waste. Prohibition of certain chemicals, as listed in Schedule 1 of Regulation 466 (RSA, 2015a) (see Burns et al., 2016, Table A.2 in Digital Addenda), will limit the toxicity of the waste and thereby also the potential risk to the environment and human health.

The NNR regulates the management of low-level radio-active waste. The volume and concentration of NORM waste generation will be dependent on the underlying geology of the SGD area. Options for viable and safe re-use or recycling of NORM waste should be sought before designating NORM residues as waste (NNR, 2015). Treatment processes are often used in combination for effective decontamination of liquid waste streams but result in secondary radioactive waste streams i.e. contaminated filters, spent resins and sludges). Conditioning of NORM residues include immobilisation, stabilisation and packaging to render them suitable for handling, transportation, storage and long-term management. Immobilisation methods include solidification of liquid residues, for example in cement. Stabilisation methods include dewatering and chemical adjustment (NNR, 2015). On-site storage of NORM waste is permissible and final disposal is determined by a safety assessment in the selection of the site and the environmental impacts thereof (NNR, 2015). NORM waste may only be disposed of at a facility authorised by the NNR.

Municipalities will not be able to cope with additional waste loads as a result of SGD (municipal solid waste and waste water) at their facilities (landfill and sewage plants) (refer to Table 2 and 3 of the Digital Addendum 6A) due to limited capacity and technical expertise in municipalities (Municipal Demarcation Board (MDB), 2011, Department of Science and Technology (DST), 2013). Inappropriate academic qualifications and inadequate relevant work experience of municipal staff are issues of concern (Van Baalen, 2014). Similarly, technical knowledge on the specialised waste streams from SGD will need to be developed at national and provincial government level to ensure informed decision making and enforcement of legislation.

The available literature findings suggests that surface spills and leakages from holding ponds, tank battery systems and transport of chemicals and waste materials are important routes of potential ground and surface water contamination from fracking activities (Grout and Grimshaw, 2012; Gross et al., 2013; Ziemkiewicz et al., 2014). Sources of spills at the wellsite include the drill rig and other operating equipment, storage tanks, impoundments or pits, and leaks or blowouts at the wellhead

(Grout and Grimshaw, 2012). Leaks or spills may also occur during transportation (by truck or pipeline) of materials and wastes to and from the wellpad in all three SGD scenarios. The primary risk of uncontrolled releases is generally to surface and groundwater resources (Grout and Grimshaw, 2012). Mitigation measures to prevent pollution from spills include impermeable site underlay (Section 91 Regulation 466) and lined bund walls around storage tanks (Section 118(3) Regulation 466) (RSA, 2015a). Constituents of particular concern include benzene, toluene, ethylbenzene and xylene which, at sufficient doses, have been associated with adverse human health effects (Osborn et al., 2011) and arsenic (Grout and Grimshaw, 2012). These constituents of concerns have all been prohibited from being used as additives in fracking fluids in SGD in South Africa (Schedule 1, Regulation 466) (RSA, 2015a). The prohibition of these chemicals reduces the risk to human health and the environment should SGD proceed in the study area.

Three important characteristics of an incident will determine the severity of its consequences – volume, degree of containment and characteristics of the material (waste water or waste) (Grout and Grimshaw, 2012). It is therefore important to provide secondary containment for areas of fuel and fracking fluid chemicals storage, loading and unloading areas, and other key operational areas (Grout and Grimshaw, 2012) including waste and waste water storage, treatment and disposal sites. Such containment areas are already prescribed in Section 118(3) of Regulation 466 (RSA, 2015a).

6.4.1 On-site storage

Maximising recycling and re-use of flowback and produced water will reduce the amount of chemicals and need for clean water, but may increase the volume of waste and waste water to be stored on-site and may increase the potential impacts. The mitigation measures to implement will include barrier and containment systems such as impermeable site linings, bunding and using non-hazardous chemicals where possible (Koppelman et al., 2012). All these measures are already prescribed in Regulation 466 (RSA, 2015a). Minimising design, construction and maintenance problems associated with: out-slope berm stability, uncontrolled groundwater seepage, geomembrane liner puncture, and tear potential from improper site preparation and maintenance (Ziemkiewicz et al., 2014). In this regard, Regulation 466 already prescribes above-ground storage tanks for all liquids, liquid waste, drill cuttings and waste mud (RSA, 2015a). Secondary containment is a best management practice where the tank sits within a tray-like structure with raised sides or berms such that materials released during a tank rupture would be contained (Hammer and Van Briesen, 2012). Section 118 of Regulation 466 stipulate a containment capacity to hold the volume of the largest container stored on-site plus 10% to allow for precipitation, unless the container is equipped with individual secondary containment (RSA, 2015a).

6.4.2 Liquid Waste Treatment

Liquid waste must be treated at an approved waste treatment facility in accordance with relevant legislation (RSA, 2015a). The designated treatment works must have capacity to accept the load and volume of waste water to be treated and must be duly authorised to receive the waste water from fracking operations. Technologies must be appropriate for the quality of the waste water received and it must be able to produce the required quality after treatment to support re-use, recycling or discharge. Waste water treatment technology choice must be based on the degree and surety of removal of constituents required. Pre-treatment may also be required depending on the treatment technology selected and the objectives to be met (DWAF, 2007).

It is expected that treatment of liquid waste from Exploration Only to Small Gas could potentially be dealt with by modular, on-site treatment facilities which are commercially available (refer to Digital Addendum 6B). Disposal of liquid waste at domestic waste water treatment facilities is not an option given the current status of these facilities (Section 6.2) but in terms of law could be considered after prior consultation with and approval by the department responsible for water affairs (RSA, 2015a). The cost of establishing or upgrading of treatment facilities for treatment of liquid waste from SGD should be for the account of the developer and not that of the municipality.

6.4.3 Off-site management and disposal

The current off-site disposal options for Type 1 hazardous wastes are limited to licensed commercial hazardous waste treatment and disposal facilities in Gauteng, Port Elizabeth and Cape Town and possibly the private PetroSA hazardous waste landfill in Mossel Bay, provided that the relevant authorities and landfill owner approve. Municipal waste water treatment works (WWTW) in the study area do not have the capacity or required technologies to treat the waste water from SGD. It is therefore likely that for the Small and Big Gas scenarios, if on-site treatment is not an option, the waste water will have to be trucked to a suitable off-site facility for treatment. Key potential impacts from off-site management and disposal relates to the transport of the waste and waste water by road or pipelines. Construction and maintenance deficiencies related to transport pipelines, or road accidents if the waste or waste water is transported off site by road need to be mitigated (Ziemkiewicz et al., 2014). Mitigation measures relating to pipelines will include proper design, construction and placement of liquid transfer piping (Ziemkiewicz et al., 2014). It is also imperative that inadequate capacity, treatment technologies and human resources at municipal treatment and disposal facilities be addressed to ensure that additional loads of municipal solid waste and sewage can be handled appropriately.

Whether to have central processing facilities or have those in conjunction with wellpads in the Small and Big Gas scenarios, is a decision that needs to be taken for each specific development, based on minimising the overall negative impact from the development (Det Norske Veritas AS (DNV), 2013). A centralised waste disposal facility for Type 1 hazardous waste may be considered for the Big Gas scenario. Site selection for establishing a disposal facility will involve elimination of areas with associated fatal flaws, identification of candidate sites, based on site selection criteria, ranking of candidate sites and carrying out a feasibility study on the best option (DWAF, 1998a). Site selection criteria include:

- Economic criteria
- Environmental criteria
- Public acceptance criteria

Establishment and authorisation of such a facility will require a full EIA, and meeting the design requirements as outlined in the Norms and Standards for disposal of waste to landfill (Regulation 636 of 23 August 2013).

Processing facilities for solid waste and waste water must be designed and constructed to meet the following criteria (DNV, 2013):

- Design and construction will be in compliance with applicable standards;
- Design and construction will be to achieve effective utility according to anticipated lifetime and future development prospects;
- Processing facilities should as far as reasonably practicable be placed in the terrain in such a way that any impact on vulnerable areas is minimised;
- Shall have area space and load bearing capacity to cater for processing systems and equipment;
- Shall have appropriate spill control measured in place.

6.4.4 Deep well injection

Deep well injection is a common disposal option in the US, but due to the South African geology and legal framework, it is not an option in South Africa. Regulation 466 for Petroleum Exploration and Production (Section 124(4)) prohibits disposal to underground, including the use of re-injection disposal wells (RSA, 2015a).

6.4.5 Surface water discharge

Discharge of fracking fluids, fracking flowback, and produced water into a water source is prohibited in terms of Section 124(5) of Regulation 466 (RSA, 2015a). Treated surplus water not recycled back into the operations (all three SGD scenarios) may be discharged into surface water resources provided that it meets quantity and quality limits stated in the applicable water use licence. There is a risk of pollution of surface and groundwater sources if the water quality does not meet the required discharge standards. Mitigation measures to ensure meeting water quality requirements will include alternative use options for the waste water, treatment to prescribed standards, as specified in General Authorisations or applicable licence, before discharge (this may require some form of pre-treatment as well) and regular maintenance of treatment works. Regular water quality testing of effluent before discharge and regular downstream water quality monitoring will also be required. Development of norms and standards specific for discharge of treated shale gas flowback and produced water in the Karoo may be required to ensure equal and adequate protection of all the water resources and associated ecosystems in the study area.

6.4.6 Land application

Application of produced water to roads for dust control in all scenarios has several potential negative impacts including: surface and groundwater deterioration, soil contamination, toxicity to soil and water biota, toxicity to humans during and after application, air pollution from volatile dust suppressant components, accumulation in soils, changes in hydrologic characteristics of soil, and impacts on native flora and fauna populations (Hammer and Van Briesen, 2012). Areas with shallow groundwater resources may also be at risk of pollution if the quality of the water used in land application does not meet the standards. Mitigation of these negative impacts will be to treat the water to acceptable standards before land application and continued monitoring. Norms and standards for land application of waste water from SGD may be required to ensure adequate protection of the water resource and ecosystems from potential impacts associated with land application of waste water.

6.4.7 Spills

There is a risk of spillages occurring in all three scenarios. The impact of spills of fracking fluids (or waste water) onsite can be mitigated using established best practices such as installing impermeable site linings, bunding and using non-hazardous chemicals where possible (Koppelman et al., 2012). These requirements are already included in Regulation 466 of 3 June 2015. The impacts of spills resulting from transport incidents can be mitigated by prescribing transport routes, limiting the transport distance as far as possible as envisaged by Regulation 466 of 3 June 2015 and having spill response units on stand-by in the study area.

6.4.8 Residuals management

Regardless of the treatment options selected, residuals – the concentrated brines and solids containing the chemicals removed from the produced water, and sludge – will be treated as a waste in all three scenarios. Since chemicals present in the residual wastes are present at higher concentrations than in the original produced waters in all three scenarios, careful management is essential. Solids and sludges generated in treatment plants for produced water should be disposed of in landfills with adequate protection against the formation of subsequent brines in the leachate. The only mitigation measure for this waste will be to dispose of the waste at a duly authorised landfill site, designed and constructed in line with the National Norms and Standards for disposal of waste to landfill and operated in line with the Minimum Requirements for waste disposal by landfill.

6.5 Risk assessment

The risks associated with the impacts discussed in the previous section relates to:

- Exposure of humans and the environment to hazardous waste from SGD including sludge, mud, drill cutting, flowback and produced water and NORM.
- Exposure of humans and the environment to domestic waste i.e. municipal solid waste. Volumes of domestic waste are likely to increase as a result of influx of people into the area if SGD progress to the Small and Big Gas scenarios.
- Additional waste water load at already stressed municipal waste water treatment works as a result of influx of people into the study area.

Assessment of the risks that waste from SGD and associated activities pose to human health and the environment has been based on the methodology and assumptions outlined in Burns et al. (2016). The spatial zone of impact for the identified risks in the study area is based on expert opinion, and delineated as a 1000 m radius around both waste water treatment and waste disposal facilities. It is however acknowledged that impacts from waste water could also extend downstream from the discharge point. It is however assumed that the risk will be decreasing with increasing distance and therefore a 1000 m radius should be sufficient following a conservative, risk-averse approach.

6.5.1 How risk is measured

Assessment of risk associated with waste and potential impacts on human health and the environment must take into account all properties that are related to exposure within the environment (DWAF, 1998), such as:

- Biodegradability

- Persistence
- Bioaccumulation
- Chronic toxicity
- Concentration
- Production volume
- High dispersion
- Leakage to the environment

Risks associated with disposal of waste water sludge relate to sludge stability, disposal site design and location, the constituents in the sludge and their hazardousness, possible groundwater pollution, pollution of surface run-off as well as valuable land surface area taken up by surface disposal (DWAF, 2007).

This risk assessment is at the strategic environmental assessment (SEA) level, and SGD has not commenced in South Africa, therefore no site specific data was available to inform the assessment. Consequently, this assessment based on the expert opinion of the authors. The consequence terms Table 6.6 used in the risk matrix (Table 6.7, Section 6.5.2) are defined as follows:

Table 6.6: Consequence terms for the risk matrix.

Impact	**Slight but noticeable**	**Moderate**	**Substantial**	**Severe**	**Extreme**
Exposure to hazardous waste	Low toxicity, short term exposure	Low toxicity, long term exposure	Medium toxicity, short term exposure	Medium toxicity, long term exposure	High toxicity
Exposure to domestic waste	Increase in waste volumes at well managed landfills	Increase in volumes at poorly managed landfills	Increase in volumes at poorly managed landfills and noticeable increase in illegal dumping	Exceeding landfill capacity with substantial amounts of illegal dumping	Indiscriminate dumping, failing waste services, health impacts
Additional waste water load at WWTW	Increased load with spare treatment capacity	Increased load with limited to low capacity	Occasional exceedance of treatment capacity.	Frequent exceedance of treatment capacity	Constant exceedance of treatment capacity

6.5.2 Risk Matrix

Table 6.7: Risk Matrix.

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	Likelihood	Risk	Consequence	Likelihood	Risk
Exposure to hazardous waste (Sludge, mud, drill cuttings, flowback and produced water)	Reference Case	Near disposal or spillage site	Moderate	Not likely	Low	Slight but noticeable	Not likely	Very low
	Exploration Only		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Small Gas		Severe	Very likely	High	Moderate	Very likely	Low
	Big Gas		Severe	Very likely	High	Moderate	Very likely	Low
Exposure to domestic waste	Reference Case	Municipal landfill	Moderate	Likely	Low	Slight but noticeable	Likely	Very low
	Exploration Only		Moderate	Likely	Low	Slight but noticeable	Likely	Very low
	Small Gas		Moderate	Very likely	Low	Slight but noticeable	Very likely	Very low
	Big Gas		Severe	Very likely	High	Moderate	Very likely	Low
Additional sewage load at already stressed WWTW	Reference Case	Municipal WWTW	Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Exploration Only		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Small Gas		Severe	Very likely	High	Moderate	Very likely	Low
	Big Gas		Severe	Very likely	High	Moderate	Very likely	Low

Risk associated with the transport of the waste and waste water is assessed in Chapter 18 by Van Huyssteen et al. (2016).

6.5.3 Best practice guidelines and monitoring requirements

According to the Council of Canadian Academies (2014) appropriate environmental monitoring approaches for the anticipated level of SGD have not yet been identified. Monitoring programs will have to be adapted to advances in technologies and to the location, scale, and pace of the SGD.

Best practice guidelines of relevance to this study, which are discussed in more detail below, include:

- Best practice guideline No H4: Water Treatment (DWAF, 2007);
- Guidelines for the utilisation and disposal of waste water sludge;
- National Norms and Standards for the Assessment of Waste for Landfill Disposal (Regulation 635 of 23 Aug 2013);
- National Norms and Standards for Disposal of Waste to Landfill (Regulation 636 of 23 Aug 2013);
- National Norms and Standards for Storage of Waste (GN926 of 29 Nov 2013);

- Minimum Requirements for the Monitoring of Water Quality at Waste Management Facilities (DWAF, 1998b).

6.5.3.1 Best Practice Guideline No H4: Water Treatment

These guidelines (DWAF, 2007) outline a water treatment plant evaluation and selection process to assist decision-makers in selecting an appropriate technology for their specific requirements. It describes, in a fair amount of detail, the differences between different treatment technologies including benefits and constraints of each technology option. The guidelines also touch on the characteristics of residue streams and provide some guidance on possible disposal options for the residue streams. Costs associated with the disposal of residues/sludges include disposal costs (based on volume and nature) and transportation cost (transportation distance to disposal site).

6.5.3.2 Guidelines for the Utilisation and Disposal of Waste water Sludge

The development of the sludge guidelines (Herselman and Snyman, 2007) was commissioned by the Water Research Commission (WRC) to encourage the beneficial use of waste water sludge. It is however recognised that beneficial use of waste water sludge is not always feasible. A separate Guideline Volume dealing with each of the management options were therefore developed as follows:

Volume 1: Selection of management options
Volume 2: Requirements for the agricultural use of sludge
Volume 3: Requirements for the on-site and off-site disposal of sludge
Volume 4: Requirements for the beneficial use of sludge
Volume 5: Requirements for thermal sludge management practices and for commercial products containing sludge

The quality and classification of the sludge is the determining factor in selecting the best management option.

6.5.3.3 National Norms and Standards for Assessment of Waste for Landfill Disposal

The assessment of waste for the purpose of disposal to landfill requires a full chemical analysis of the waste and laboratory analysis to determine the total concentrations (TC) and leachable concentrations (LC) of the elements and chemical substances contained in the waste (RSA, 2013a). The TC and LC limits must then be compared to the threshold limits specified in the norms and standards to determine the type of waste. All analyses must be done at accredited laboratories.

6.5.3.4 Norms and Standards for Disposal of Waste to Landfill

The norms and standards for disposal of waste provides for four different classes of landfills based on their containment barrier designs parameters. Waste acceptance criteria for landfill is based on the Type of waste and the class of landfill as outlined in Section 4 of Regulation 636 (RSA, 2013b).

6.5.3.5 National Norms and Standards for Storage of Waste

These standards apply to any person who stores general or hazardous waste in a waste storage facility irrespective of whether a waste management licence is required or not. Waste storage facilities must be registered with the competent authority. Location of hazardous waste storage facilities must be within an industrial demarcated zone or must have a buffer zone of at least 100 m unless there is a prescribed buffer zone by the relevant municipality and must be located in areas accessible to emergency response personnel and equipment (RSA, 2013d).

Liquid waste storage areas must have firm, impermeable, chemical resistant floors and a roof. Liquid waste containers that are not stored under a roof must be coated to prevent direct sunlight and rain from getting into contact with the waste. There are also requirements for liquid storage areas to be surrounded by an interception trench with a sump and a secondary containment system (i.e. bund, drip tray) (RSA, 2013d).

Hazardous waste storage facilities must have impermeable and chemical resistant floors (RSA, 2013d).

These norms and standards also prescribe access control and notices as well as operational requirements. There are also prescribed minimum requirements for above ground waste storage tanks (Section 11) (RSA, 2013d).

6.5.3.6 Minimum Requirements for Monitoring of Water Quality at Waste Management Facilities

Acknowledging the uniqueness of the South African groundwater systems, the Minimum Requirements were developed to ensure coordinated and meaningful water quality monitoring by applying the principle of best available technology, not entailing excessive cost (DWAF, 1998b). It is a minimum requirement that a risk assessment, to determine the risk of water becoming polluted, be performed at all waste sites before the installation of a monitoring system. This serves to ensure that the design of the monitoring system is adequate and the risk assessment methodology to follow is prescribed in the report (DWAF, 1998b).

According to DWAF (1998b) the main purpose of a monitoring system is to:

- Provide reliable data on the quality and chemical composition of the groundwater;
- Detect and quantify the presence and seriousness of any polluting substances in the groundwater at the earliest stage possible;
- Detect possible release or impending release of contaminants from the waste facility;
- Provide a rationale comparison between the predicted and actual flow and solute transport rates; and
- Provide and ongoing and reliable performance record for the design and control systems for effectively controlling pollution.

To achieve the above objectives it may necessary to employ two separate monitoring systems in cases where the generation of hazardous leachate may be a problem. The two monitoring systems are:

- Early warning monitoring systems
- Regional monitoring systems.

A schematic presentation (DWAF, 1998b) of these monitoring systems is shown in Figure 6.4 below.

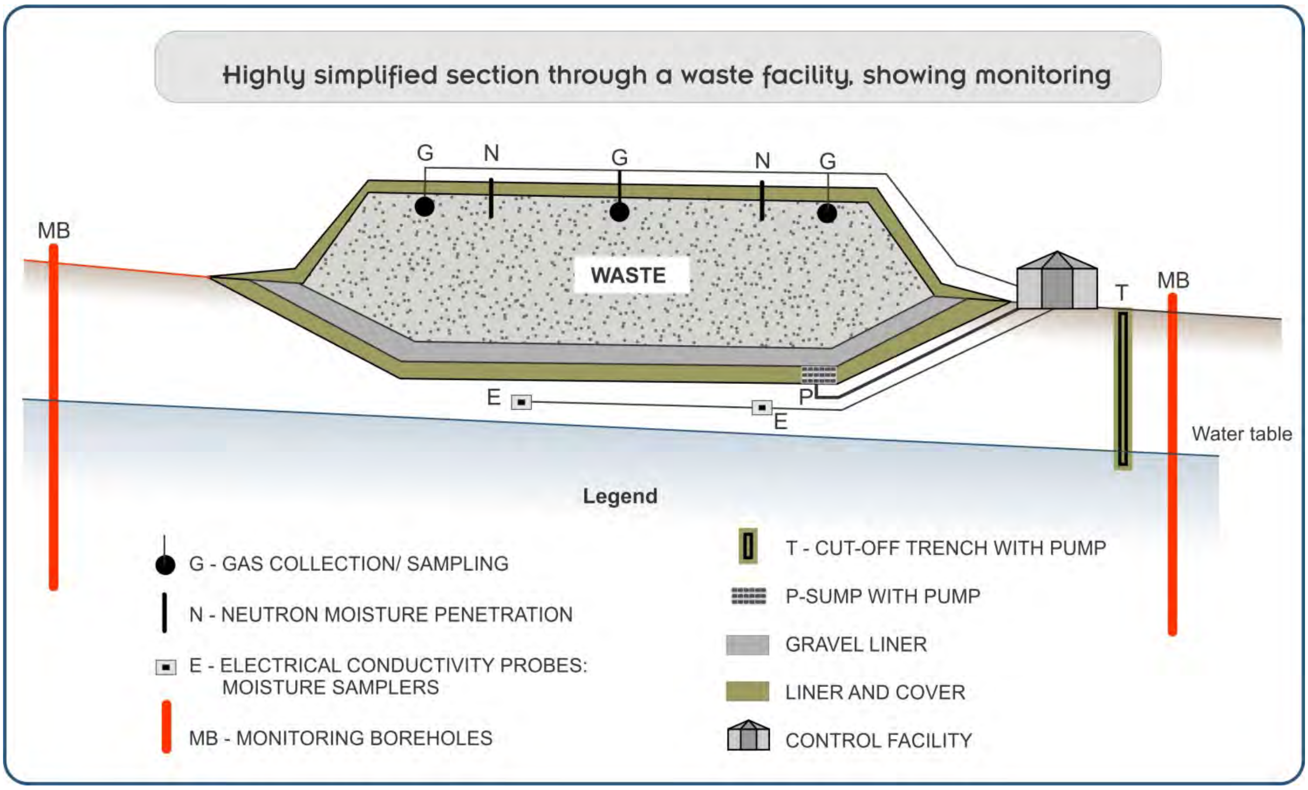


Figure 6.4: A schematic presentation of these monitoring systems (DWAF, 1998b).

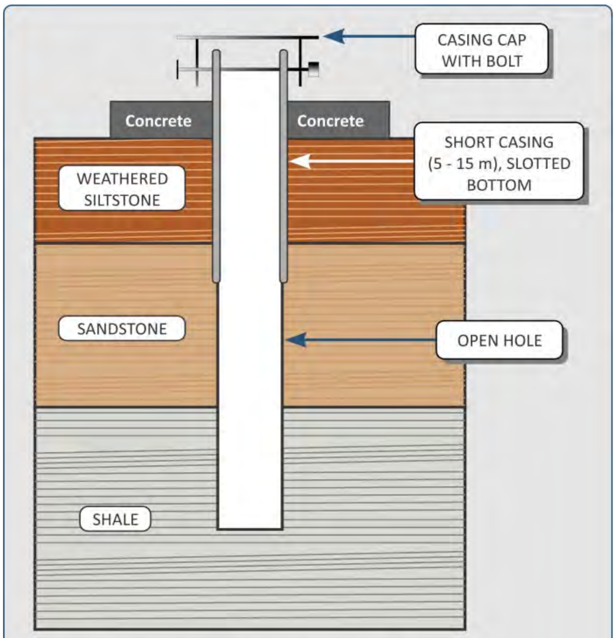
Minimum monitoring requirements at various types of waste management facilities provided does not include above-ground storage facilities as are required for SGD. It does however include monitoring requirements for general and hazardous waste disposal facilities and sewage sludge as indicated in Table 6.8 below.

Table 6.8: Monitoring requirements for general and hazardous waste disposal facilities and sewage sludge.

	At or near surface monitoring								Within waste or unsat. zone						Groundwater monitoring							
Monitoring Requirements → / ↓ Waste environment	Rainfall	Evaporation	Run-off (volume, quality)	Water infiltration on waste	Toe seepage from waste	Soil cover on waste	Vegetation on waste or soil	Bioassaying	Pressure vacuum lysimeters	Gas samplers	Electrical conductivity probes	Leachate collectors	Temperature within waste	Special detectors	Special monitoring holes	Other existing holes	Groundwater levels	Groundwater chemistry	Borehole yield	Groundwater usage	Fountain seepage	Water balance
Mines – Reactive environment	d		d																			m
Slimes (Slurry)				m	m	y	y					m			yes	yes	m	6m	yes	y	m	m
Ore discards			d	m	m	y	y					m			yes	yes	m	6m	yes	y	m	m
Rock Discards (opencast)				m	m	y	y								yes	yes	m	6m	yes	y	m	m
Rock discards (other)					m	y	y								yes	yes	y	y	yes	y	y	y
Mine water (impoundment)				m	m										yes	yes	3m	6m	yes	y	m	m
Mine water (discharged)			d					y														w
Mines – Inert environment	d		d												no	yes	y	y	yes	y	y	m
Slimes (slurry)					m										no	yes	y	y	yes	y	y	m
Rock discards					m										no	yes	y	y	yes	y	y	y
Ore discards					m										no	yes	y	y	yes	y	y	y
Mine water (discharged)			d																			d
Coal fired power stations	d		d												yes	yes	3m	6m	yes	y	m	m
Coal stockpiling					m							m			yes	yes	3m	6m	yes	y	m	m
Ash disposal (slurry)					m										yes	yes	3m	6m	yes	y	m	m
Ash disposal (dry)				m			y								yes	yes	3m	6m	yes	y	m	m
Dirty water systems					m										yes	yes	3m	6m	yes	y	m	m
Water discharged			d					y														
General waste																						
Large (>500 t/d)	d		d		m	y	y	y		m		m			yes	yes	3m	6m	yes	y	m	m
Medium (26 – 500 t/d)	d		d		m	y	y			m					yes	yes	y	6m	yes	y	m	m
Small (1 – 25 t/d)					m										yes	yes	y	6m	yes	y	m	
Communal (<1 t/d)					m										no	yes	y	6m	yes	y	m	
Sewage																						
Unlined maturation ponds			d												yes	yes	y	6m	yes	y	m	
Sludge			d																			
Hazardous waste	d	d	d	m	m	m	m	y	m	m		m		m	yes	yes	m	6m	yes	y	m	y
Waste irrigation	d		d	m	m	m	m	y							yes	yes	m	6m	yes	y	m	m
Agriculture (feed lots)	d		d												yes	yes	m	6m	yes	y	y	
Agriculture (diffuse sources)															no	yes	y	y	yes	y		
Septic tanks and pit latrines															no	yes	y	y	yes	y		
Underground storage tanks														m	yes	yes	m	6m	yes	y	m	
Urban development	d		m												no	yes	y	y	yes	y		
Industries	Refer to specific waste above, such as general, hazardous, irrigation, impoundment																					
Radioactive waste	As specified by the CNS in collaboration with the DWA&F																					

Explanation of codes: d = daily monitoring; w = weekly monitoring; m = monthly monitoring; 3/6m = 3/6-monthly monitoring; y = yearly monitoring

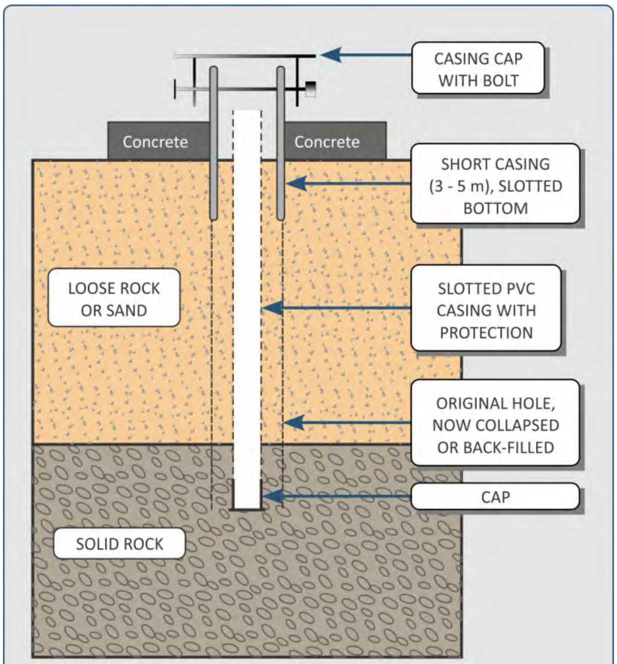
The Minimum Requirements (DWAF, 1998b) also provide guidance on borehole design for groundwater monitoring at landfills as illustrated in Figure 6.5 below.



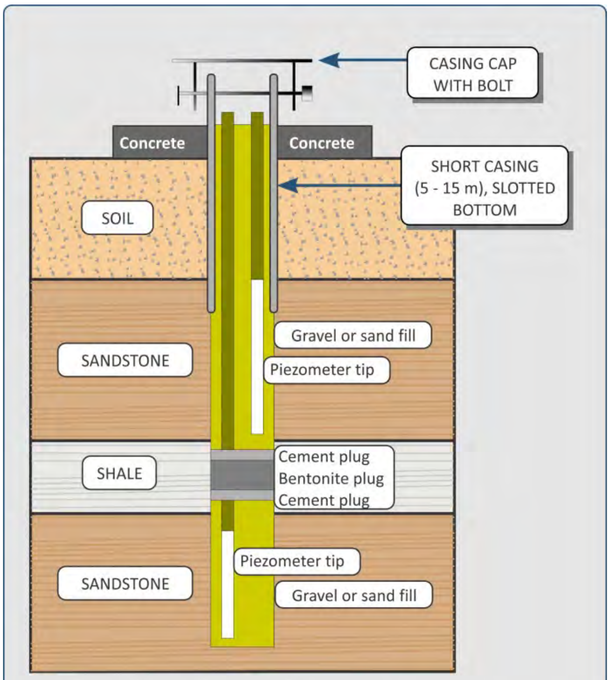
Typical installation required for monitoring boreholes into solid rock, average depth 40 metres.

Data required from monitoring boreholes (DWAF, 1998b):

- Geological log.
- Water intersections (depth and quantity.
- Construction information (depth of hole and casing, borehole diameter, method drilled, date drilled).
- Use of water, if not solely for monitoring: Frequency of abstraction; abstraction rate; and whether other water sources are readily available.
- Water quality.



Typical installation for monitoring boreholes into the loose material such as sand, gravel, discards or rock spoil at th opencast mines



Typical installation of piezometer tubes in a monitoring borehole

Figure 6.5: Minimum Requirements (DWAF, 1998b) also provide guidance on borehole design.

6.6 Gaps in knowledge

Suitable sites for waste water treatment and on-site disposal of waste must be identified should SGD go ahead. Detail on the composition of the wastes will be required to inform site selection, design requirements of these facilities as well as the technology choices to consider.

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6.8 Digital Addenda 6A – 6B

SEPARATE DIGITAL DOCUMENT

Addendum 6A: Tabulated detailed information

Addendum 6B: Examples of Commercially available Modular Water Treatment Technologies

DIGITAL ADDENDA 6A – 6B

Addendum 6A: Tabulated detailed information

Table 1: Chemical components of concern present in Produced water (Hammer and Van Briesen, 2012)

Chemical component used 2005-2009	Chemical category	Detected in at least one produced water sample (MSC report)
Methanol	HAP	Not tested
Ethylene glycol (1,2-ethanediol)	HAP	Yes
Diesel	Carcinogen, SDWA, HAP	Not tested
Naphthalene	Carcinogen, HAP, PC	Yes
Xylene	SDWA, HAP	Yes (total xylene)
Hydrochloric acid	HAP	Not tested
Toluene	SDWA, HAP	Yes
Ethylbenzene	SDWA, HAP	Yes
Diethanolamine	HAP	Not tested
Formaldehyde	Carcinogen, HAP	Not tested
Sulfuric Acid	Carcinogen	Not tested
Thiourea	Carcinogen	Not tested
Benzyl chloride	Carcinogen, HAP	Not tested
Cumene	HAP	Not tested
Nitrilotriacetic acid (NTA)	Carcinogen	Not tested
Dimethyl formamide	HAP	Not tested
Phenol	HAP	Yes
Benzene	Carcinogen, SDWA, HAP	Yes
Di (2-ethylhexyl) Phthalate	Carcinogen, SDWA, HAP	Not tested
Acrylamide	Carcinogen, SDWA, HAP	Not tested
Hydrofluoric acid	HAP	Not tested
Phthalic anhydride	HAP	Not tested
Acetaldehyde	Carcinogen, HAP	Not tested
Acetophenone	HAP	Yes
Copper	SDWA	Yes
Ethylene oxide	Carcinogen, HAP	Not tested
Lead	Carcinogen, SDWA, HAP, PC	Yes
Propylene oxide	Carcinogen, HAP	Not tested
p-xylene	HAP	Yes (total xylene)

Table 2: List of operational municipal waste disposal sites in the study area (DEAT, 2007)

Province	Municipality	Landfill site	Class	Airspace estimate 2007 (years)
Eastern Cape	Lukhanji	Queenstown	GCB-	25
	Baviaans	Willowmore	GSB+	10
	Blue Crane Route	Cookhouse	GSB-	3
		Pearston	GCB-	6
		Somerset East	GMB-	
	Camdeboo	Nieu-Bethesda (Jakkalshoek)	GCB-	10
		Aberdeen	GCB-	30
	Gariep	Burgersdorp	GCB-	15-20
	Tsolwana	Tarkastad	GSB-	4
		Britstown	GCB-	10
		Hanover	GCB-	20
	Emalahleni	Dordrecht	GCB+	5-10
		Indwe	GCB+	5
Northern Cape	Hantam	Nieuwoudtville	GCB-	20
		Middelpos	GCB-	10
	Kareeberg	Vosburg	GCB-	20
		Vanwyksvlei	GCB-	20
	Karoo Hoogland	Williston	GCB-	10
		Sutherland	GCB-	8
	Ubuntu	Loxton	GCB-	15
		Richmond	GCB-	15
	Umsobomvu	Norvalspont	GCB-	20
Western Cape	Beaufort West	Merweville	GCB-	10
		Nelspoort	GCB-	30
	Laingsburg	Laingsburg	GSB^-	
	Prince Albert	Klaarstroom	GCB-	20
		Prince Albert Road	GCB-	6
		Leeu Gamka	GCB-	8

Table 3: The number of waste water treatment plants per municipality in the study area and technologies employed

Province	Municipality	No of WWTW	Technologies in use	Cumulative Risk Rating (DWS, 2014)
Eastern Cape	Lukhanji	2	Activated sludge Drying beds Oxidation ponds Anaerobic digestion Biological filters Maturation ponds Sedimentation Chlorination	High
	Baviaans	3	Drying beds Oxidation ponds Chlorination	High
	Blue Crane Route	3	Oxidation ponds	High
	Camdeboo	3	Activated sludge Drying beds Oxidation ponds Chlorination	Medium
	Gariep	4	Activated sludge Drying beds Oxidation ponds Maturation ponds Sedimentation Chlorination	Medium
	Maletswai	2	Activated sludge Drying beds Maturation ponds Chlorination	Medium
	Sundays River Valley	4	Activated sludge Drying beds Oxidation ponds Chlorination	High
	Tsolwana	2	Oxidation ponds Maturation ponds Chlorination	High
	Ngqushwa	2	Activated sludge Drying beds Belt press dewatering Sedimentation Chlorination Filtration	Medium

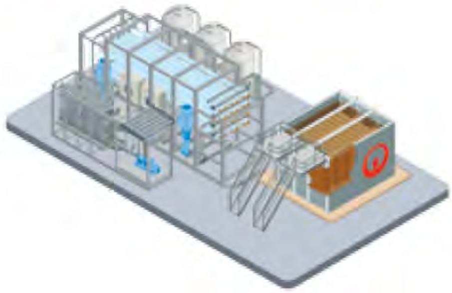
Province	Municipality	No of WWTW	Technologies in use	Cumulative Risk Rating (DWS, 2014)
	Nkonkobe	3	Activated sludge Drying beds Maturation ponds Sedimentation Chlorination	Medium
	Emalahleni	2	Oxidation ponds Maturation ponds	High
	Inkwanca	2	Activated sludge Oxidation ponds Maturation ponds Chlorination	High
	Inxuba Yethemba	2	Activated sludge Drying beds Oxidation ponds Anaerobic digestion Biological filters Chlorination	High
	Nxuba	2	Activated sludge Drying beds Oxidation Maturation ponds Chlorination	Medium
	Ikwezi	2	Oxidation ponds Maturation ponds	High
	Makana	3	Activated sludge Oxidation ponds Anaerobic digestion Biological filters Sedimentation Chlorination	High
Northern Cape	Hantam	5	Oxidation ponds Anaerobic ponds Maturation ponds	Low
	Kareeberg	3	Drying beds Oxidation ponds	Medium
	Karoo Hoogland	3	Oxidation ponds Chlorination	High
	Emthanjeni	3	Activated sludge Drying beds Oxidation ponds Maturation ponds	Low

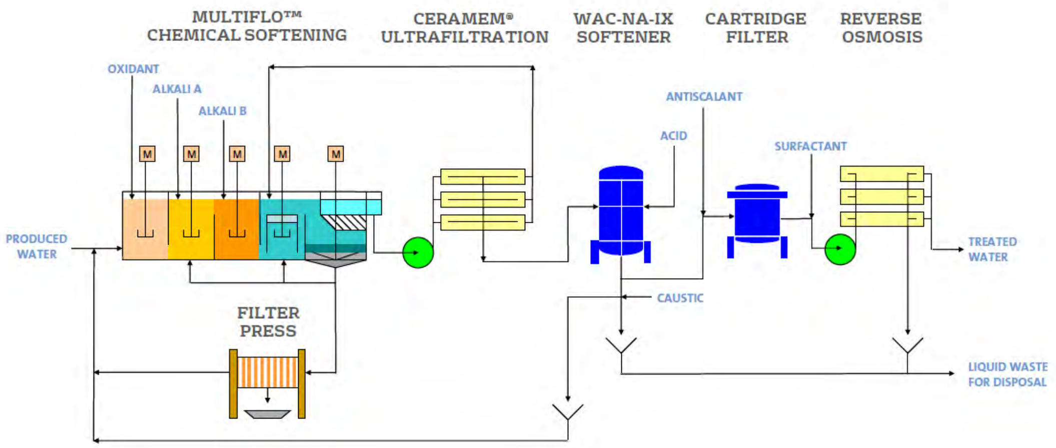
Province	Municipality	No of WWTW	Technologies in use	Cumulative Risk Rating (DWS, 2014)
	Ubuntu	3	Activated sludge Drying beds Oxidation ponds Chlorination	Medium
	Umsobomvu	3	Activated sludge Oxidation ponds Anaerobic digestion Maturation ponds	High
Western Cape	Beaufort West	4	Activated sludge Drying beds Oxidation ponds Biological filters	Low
	Witzenberg	4	Activated sludge Oxidation ponds	Low
	Laingsburg	1	Oxidation ponds	High
	Prince Albert	3	Aerated lagoons Oxidation ponds Anaerobic digestion	High
	Breede Valley	4	Activated sludge Drying beds Anaerobic digestion Biological nutrient removal Biological filters Maturation ponds Sedimentation	Medium

Addendum 6B: Examples of Commercially available Modular Water Treatment Technologies

OPUS® II technology is a proprietary Optimized Pretreatment Unique Separation technology developed to achieve high recovery of clean water for reuse or discharge. This new generation of OPUS technology is a compact design that results in lower installed costs than comparable systems.

Developed by Veolia Water Technologies, this unique technology utilizes our proprietary CeraMem® ceramic membranes with chemical and ion exchange softening as pretreatment to a reverse osmosis (RO) process operated at an elevated pH. The result is a compact treatment system that provides high quality water suitable for reuse in industrial processes or replenishment of raw water sources.



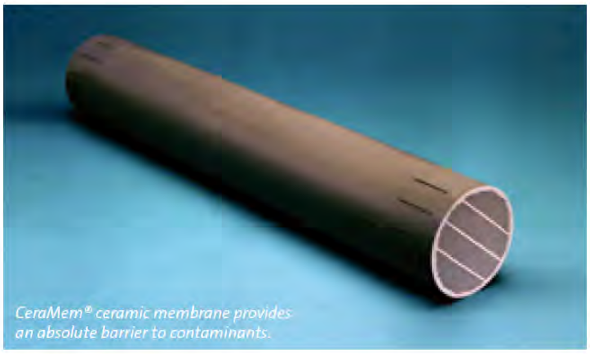


Technology Description

OPUS II technology consists of multiple treatment processes involving chemical softening, membrane filtration, ion exchange softening and reverse osmosis operated at an elevated pH. The pretreatment processes ahead of the RO are designed to reduce free oil, hardness, metals and suspended solids in the feed water. The RO process operates at an elevated pH, which effectively controls biological, organic and particulate fouling, eliminates scaling due to silica and increases the rejection of silica, organics and boron.

In the OPUS II technology, the feed water is subjected to chemical softening, free oil and solids removal in a pretreatment process that uses CeraMem ultrafiltration technology. This process consists of a series of reaction tanks followed by a crystallization tank fitted with our patented Turbomix® mixing technology, which facilitates precipitation of hardness and metals in the feed water and crystallization of the solids generated by precipitation. The softened water and crystalline solids are then processed through the ceramic membrane ultrafiltration system operated in cross-flow mode for removal of free oil, total hardness and suspended solids to lower concentrations. The solids waste from the CeraMem process is continuously recycled to the crystallization tank and purged intermittently for dewatering and subsequent hauling to landfill for disposal.

The filtrate from the CeraMem process is further treated with ion exchange softening utilizing Weak Acid Cation (WAC) resin in sodium form for further removal of hardness and metals to lower concentrations, without pH correction. Any remaining particulates are removed by cartridge filtration. The pretreated water is then pressurized through the RO, operated at an elevated pH in single or double pass mode, to reduce the TDS, boron and organics.



CeraMem® ceramic membrane provides an absolute barrier to contaminants.

Our mobile pilot systems are available for deployment.

Technology Benefits

- >90% recovery rate up to 7,500 ppm influent TDS
- Compact, modular systems with low field installation costs
- Prevents scaling caused by silica, calcium and metal salts
- Controls fouling due to organics and particulates
- Achieves salt rejection removal rates of >99.4% boron, >99.7% silica and >99% TOC
- Continuous Clean-In-Place (CIP) process minimizes RO cleaning frequency
- 3-year, pro-rated membrane life warranty
- Robust treatment approach with minimal system downtime
- Effectively handles variations in feed water quality

Applications

- Oil and Gas Field Produced Water
- Power Plant Cooling Tower Blowdown
- Reuse of Industrial Wastewater to Achieve Zero Liquid Discharge

Guaranteed Performance

Veolia Water Technologies offers a performance guarantee after testing OPUS II technology using our mobile pilot system. Our pilot units, capable of treating 20 gallons per minute (685 barrels per day), are deployed to your site to demonstrate the process for your water characteristics before the full-scale system is designed, enabling us to optimize performance and minimize cost. Long-term operation and maintenance contracts are also available to ensure continued optimization of your system and extend the performance guarantee for the life of the contract.

Flexible Project Delivery Options

Our project delivery can be tailored to your purchasing preferences:

- Engineer / Procure
- Design / Build
- Design / Build / Operate / Maintain
- Design / Build / Operate / Guarantee*

Typical Performance Data

Constituent	Feed Water	CeraMem® Ultrafilter Filtrate	Double Pass RO Permeate	Removal Efficiency
Free Oil (>20µ), ppm	100	<0.2	Non-Detect	>99.9%
Total Suspended Solids, ppm	100	<0.2	Non-Detect	>99.9%
Total Hardness, ppm as $CaCO_3$	236	<10	Non-Detect	>99.9%
Calcium, ppm	65	<3.2	Non-Detect	>99.9%
Magnesium, ppm	18	<0.5	Non-Detect	>99.9%
TDS, ppm	2,200	2,500	<15	>99.3%
Boron, ppm	8.6	8.6	<0.03	>99.7%
Silica, ppm	220	<50	<0.03	>99.9%
Organics, ppm	210	210	<0.99	>99.5%

* Veolia is the only water treatment company that offers DBOG project delivery. Long-term operation contracts include facility maintenance, treatment chemicals and guaranteed system performance for the life of the contract. DBOG contracts eliminate risks associated with rising costs, performance and availability.

VEOLIA

The CoLD® Process

Treatment of Flowback/Produced Water

Benefits of the CoLD Process

- Achieves complete desalination of high TDS produced waters
- Lowest CAPEX and OPEX as compared to conventional methods
- No chemical softening or sludge production
- Produces clean water and stable solids for disposal or reuse
- Simple, robust process with high reliability and availability

Innovative Process Solutions

Veolia Water Technologies is the global leader for innovative process solutions that use HPD® Evaporation and Crystallization as core technologies. With more than 800 installations in more than 30 countries, Veolia has decades of process design experience in the oil & gas, power, chemical, mining, salt, and fertilizer industries, providing wastewater treatment, volume reduction, and Zero Liquid Discharge (ZLD) systems.

The **CoLD® Process** is a proprietary crystallization process developed by Veolia as a simpler and more economical approach to desalination of produced water than conventional thermal processes. The CoLD Process eliminates the need for expensive pretreatment of the produced water, thereby reducing capital and operating costs. The CoLD Process is an ideal solution to address stricter water reuse standards, ZLD, and increasing regulation of discharge limits of total dissolved solids (TDS) facing the shale oil & gas industry.

Process Background

In the North American onshore oil & gas industry, on average nearly eight barrels of water are brought to the surface for every barrel of oil. This produced water is often highly saline and contaminated by hydrocarbons and even radioactive elements: it is a hazardous waste that requires treatment, disposal, and increasingly, recycling.

Increased reuse of produced water is driving the implementation of physical, chemical, biological, and thermal treatment methods. Physical, chemical, and biological treatment methods can reduce the concentrations of certain pollutants, but the volume and salinity of the produced water is unchanged. Thermal desalination of produced water is a proven method to completely separate the salts from the water, so both can potentially be beneficially reused.

Veolia has applied proven process designs based on HPD® Evaporation and Crystallization technologies used in the salt, fertilizer, and chemical industries to develop a simple and robust process to separate the flowback and produced water from hydraulic fracturing into clean water and a stable, non-hazardous solid for disposal and/or reuse.

WATER TECHNOLOGIES

The CoLD® Process

Produced Water Chemistry

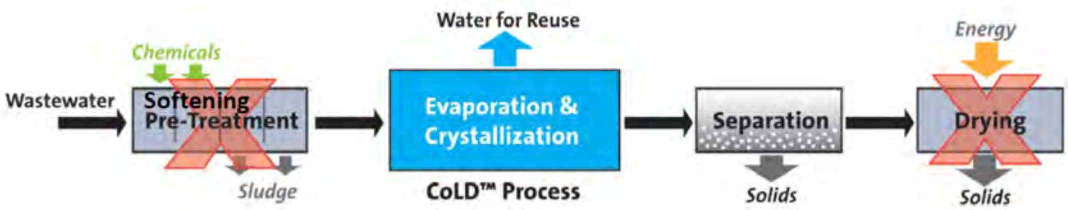
Some portion of the frac fluid injected into a well will return to the surface during the first few days to weeks. This is referred to as flowback water. Over a much longer period of time, additional water that is naturally present in the shale formation (produced water) continues to flow from the well. Both flowback and produced water can contain very high levels of TDS, composed mainly of dissolved chloride salts of sodium, calcium and magnesium. Significant quantities of barium and strontium salts may also be present as well as some heavy metals and naturally occurring radioactive material (NORM). The produced water is also contaminated with a range of hydrocarbons.

Limitations of Conventional Methods

Conventional thermal processes for desalination of produced water require complete softening of the produced water using lime, soda ash, caustic, and other chemicals to replace the calcium and magnesium ions in the produced water with sodium ions in order to produce a crystalline solid.

In some cases, a final drying step is necessary to produce a stable solid suitable for disposal. Softening pretreatment equipment includes chemical feed/storage facilities, solids settling or filtration equipment, and sludge dewatering equipment. Drying equipment is capital and energy intensive. These additional facilities increase the footprint of the ZLD system as well as the capital costs and overall maintenance. The logistics of unloading, storing, and preparing chemicals, and dewatering and transporting sludge for disposal substantially increase the OPEX.

The **CoLD® Process** operates under vacuum at low temperature. The chemistry of many produced waters favor the formation of hydrates and double salts which precipitate at low concentrations as the temperature of the solution is lowered. When concentrating the waste stream at low temperature, dissolved solids will crystallize at relatively low concentration, without the need for chemical softening pretreatment and the resulting sludge production.



Advantages of CoLD Crystallization

The CoLD Process will completely desalinate high TDS produced water containing significant quantities of chloride salts. Substantial savings in CAPEX and OPEX are achieved by eliminating the chemical softening step and discharging the final solid product as a wet cake, which does not require any further drying in order to transport it to a disposal site. This results in a simpler flow scheme, less equipment to operate, and a smaller footprint. It also eliminates the cost of buying, shipping, storing, and handling of bulk chemical softening reagents and the dewatering, storage, transport, and disposal of softener sludge. The CoLD Process recovers all the water contained in the feed at a quality suitable for discharge under an NPDES permit or reuse.

Veolia Water Technologies
Plainfield, IL USA
tel +1 815 609-2000
www.veoliawaterstna.com • hpd.info@veolia.com

CHAPTER 7

Biodiversity and Ecological Impacts: Landscape Processes, Ecosystems and Species

CHAPTER 7: BIODIVERSITY AND ECOLOGICAL IMPACTS: LANDSCAPE PROCESSES, ECOSYSTEMS AND SPECIES

Integrating Author:	Stephen Holness[1], Amanda Driver[2]
Contributing Authors:	Simon Todd[3], Kate Snaddon[4], Michelle Hamer[2], Domitilla Raimondo[2], Fahiema Daniels[2]
Corresponding Authors:	Graham Alexander[5], Corinna Bazelet[6] , Roger Bills[7], Christy Bragg[8], Bill Branch[9], Peter Bruyns[10], Albert Chakona[7], Matthew Child[8], Ralph Vincent Clarke[11], Andre Coetzer[12], Willem Coetzer[7], Jonathan Colville[2], Werner Conradie[9], Richard Dean[13], Connal Eardley[14], Ismail Ebrahim[2], Dave Edge[12], Dave Gaynor[15], Simon Gear[16], Dai Herbert[17], Mahlatse Kgatla[2], Kedibone Lamula[2], Given Leballo[2], Robin Lyle[14], Norma Malatji[2], Mervyn Mansell[18], Silvia Mecenero[12], John Midgley[19], Musa Mlambo[19], Hlengiwe Mtshali[20], John Simaika[6], Andrew Skowno[2], Herman Staude[12], Krystal Tolley[2], Les Underhill[21], Dewidine van der Colff [2], Simon van Noort[22], Lize von Staden[2].

[1] Nelson Mandela Metropolitan University (NMMU), Port Elizabeth, 6031

[2] South African National Biodiversity Institute (SANBI), Pretoria, 0184

[3] South African Environmental Observation Network (SAEON) Arid Lands Node, Kimberly, 8306

[4] Freshwater Consulting Group, Cape Town, 7800

[5] University of the Witwatersrand, Johannesburg, 2000

[6] University of Stellenbosch, Stellenbosch, 7600

[7] The South African Institute for Aquatic Biodiversity (SAIAB), Grahamstown, 6139

[8] Endangered Wildlife Trust, Johannesburg, 1609

[9] Bayworld/ Port Elizabeth Museum, Port Elizabeth, 6013

[10] University of Cape Town (UCT), Rondebosch, 7701

[11] Rhodes University, Grahamstown

[12] The Lepidopterists' Society of Africa (LepSoc)

[13] Renu-Karoo Veld Restoration cc, Prince Albert, 6930

[14] Agricultural Research Council (ARC), Pretoria, 0001

[15] University of Pretoria, Hatfield, 0028

[16] BirdLife South Africa, Johannesburg, 2196

[17] KwaZulu-Natal Museum, Pietermaritzburg, 3021

[18] Independent Consultant, Pretoria, 0001

[19] Albany Museum, Grahamstown, 6139

[20] Botanical Society of South Africa, Mayville, 4058

[21] Animal Demography Unit, University of Cape Town, Rondebosch, 7701

[22] Iziko Museums of South Africa, Cape Town, 8000

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Executive Summary

Nature of the study area and shale gas development (SGD) impacts

1. **The study area includes relatively high levels of biodiversity, including highly sensitive and unique ecosystems and -species**. Seven different biomes and 58 vegetation types, 119 range-restricted plant species, and 12 globally threatened animal species have been recorded from the study area. See Section 7.1.3: Special features of Karoo ecology and biodiversity.

2. **The Karoo is an arid ecosystem characterised by ecological processes that operate over extensive areas.** In addition, the Karoo is sensitive to disturbance, and disturbance has long-term impacts; recovery in disturbed areas is generally not spontaneous and rehabilitation is often met with poor success. See Section 7.1.3: Special features of Karoo ecology and biodiversity.

3. **A major concern is that the extensive linear infrastructure associated with SGD will result in fragmentation of the landscape.** Loss of connectivity, edge effects and disruption of ecological processes associated with a network of linear structures (such as roads, powerlines and pipelines) are likely to undermine the biodiversity integrity of the study area. This supports the requirement for landscape-level mitigation, discussed below. This issue is examined in Section 7.2.3: Cumulative impacts.

4. **Impacts on species, ecosystems and ecological processes extend well beyond the actual activity or physical footprint.** For many species the impacts of noise, pollution, erosion and other disturbance can extend for hundreds of metres or kilometres from the source, and fragmentation of the landscape can disrupt ecological processes over large areas. Potential impacts across the landscape are examined in Section 7.2: Key potential impacts and their mitigation.

5. **Impacts on species and ecological processes can have cascading effects.** Although the dynamics of a specific impact are difficult to predict, cascading ecological impacts are likely to occur. Again, this supports landscape-level mitigation whereby a representative sample of the biodiversity of the study area, as well as key ecological processes, are secured. Impacts are examined in Section 7.2: Key potential impacts and their mitigation.

Strategic landscape-level approach to mitigation of impacts

6. **Mitigation of ecological and biodiversity impacts must take place not only at the site scale but also at the landscape scale.** The scientific assessment has identified areas of Ecological and Biodiversity Importance and Sensitivity (EBIS), from EBIS-1 (highest) to EBIS-4 (lowest). **The primary mitigation for SGD is avoiding and securing the EBIS-1 and EBIS-2 areas, which effectively makes EBIS-3 and EBIS-4 areas available for SGD**. Strategic mitigation at the

landscape level is essential, as the impacts of SGD cannot be effectively mitigated on site or at the operational level. The explanation for this approach is given in Section 7.3: Risk Assessment.

7. **EBIS-1 and EBIS-2 areas make up 50% of the study area.** Loss or degradation of habitat in these areas must be avoided and they should be secured through legal mechanisms. This may involve formal protected area declaration (including through biodiversity stewardship agreements), but can include other types of stewardship, protection under Section 49 of the MPRDA, appropriate designation in land use schemes, or protection through other legal means. Securing these areas may lend itself to a fast-tracked, integrated protected area expansion strategy, similar to Operation Phakisa in the marine environment. This issue is examined in Section 7.3: Risk Assessment.

8. **EBIS-1 areas contain extremely sensitive features and are irreplaceable.** Activities related to SGD in these areas are assessed as very high risk. **It is not possible to minimise or offset impacts of SGD in EBIS-1 areas**, and impacts of SGD in these areas would undermine the ecological integrity of the study area (and more broadly, the Karoo). See Section 7.3: Risk assessment.

9. EBIS-2 areas contain highly sensitive features and features that are important for meeting biodiversity targets and/or maintaining ecological processes in the study area. **Where SGD activities in EBIS-2 areas are unavoidable, the impacts must be minimised <u>and</u> residual impacts must be offset by securing ecologically equivalent sites in EBIS-1 or EBIS-2 areas** for the representation of biodiversity and maintenance of ecological processes**.** In the case of such offsets, appropriate national and provincial offset guidelines and methodologies should be applied to ensure no net loss. This issue is examined in Section 7.3: Risk Assessment.

10. **Environmental compliance in EBIS-3 and EBIS-4 areas is still required**. This includes specialist-led assessment of local sensitivities and identification of appropriate mitigation. It is necessary to ground-truth desktop assessments and avoid unnecessary impacts. Specific impacts are discussed in Section 7.2.2: Activities, impacts and mitigation measures and monitoring requirements are discussed in Section 7.4: Best practice guidelines and monitoring requirements.

11. **The cumulative and unforeseen impacts of SGD, as well as effectiveness of mitigation, must be monitored.** The outcomes of the monitoring programme need to dynamically inform ongoing strategic and regional-level decisions on SGD. Monitoring requirements are discussed in Section 7.4: Best practice guidelines and monitoring requirements.

CHAPTER 7: BIODIVERSITY AND ECOLOGICAL IMPACTS

7.1 Introduction and scope

7.1.1 What is meant by this topic?

Biodiversity[1] is commonly considered to include three components or levels: ecosystem diversity, species diversity and genetic diversity. This topic deals with biodiversity at the ecosystem and species level, as well as with the ecological processes at the landscape scale which support this biodiversity. As discussed in several places in the scientific assessment, the ecological impacts of shale gas development (SGD) in the arid Karoo environment, in which many ecological processes operate over extensive spatial areas, are likely to be felt especially at the landscape scale. A focus on landscape processes and connectivity in the landscape is often difficult to achieve in individual Environmental Impact Assessments (EIAs), because the spatial scale at which these processes operate is generally larger than the individual projects for which EIAs will be conducted, so it is particularly important to address these aspects in the scientific assessment, with its broad spatial scope.

In addition to the strong emphasis on ecosystems and landscape-scale ecological processes, this topic also covers plant and animal species, focusing on species of special concern, which include threatened species and species endemic or near-endemic to the study area. An additional focus is on ecological infrastructure[2] and ecosystem services. In particular, aquatic ecosystems, such as rivers and wetlands, play a key role in underpinning ecological infrastructure, which is important for delivering a range of services and benefits to people. In the arid Karoo context, ecological infrastructure that is linked to water-related ecosystem services is especially vital.

The topic covers terrestrial and aquatic biodiversity. The topic of biodiversity and ecological impacts has links with several other topics, including:

- Water resources (Hobbs et al., 2016);
- Tourism (Toerien et al., 2016);
- Visual impacts (Oberholzer, et al., 2016);
- Noise (Wade et al., 2016);
- Sense of place (Seeliger et al., 2016); and

[1] Biodiversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. It includes diversity within species, between species and of ecosystems. (Convention on Biological Diversity, Article 2).
[2] Ecological infrastructure means naturally functioning ecosystems that generate or deliver valuable services to people. It is the nature-based equivalent of built or hard infrastructure, and is just as important for providing services and underpinning socio-economic development (SANBI, 2013).

- Agriculture (Oettle et al., 2016).

Impacts on these other elements are dealt with in these separate topics. A particularly important split is the one in aquatic systems: this scientific assessment deals with aquatic ecosystems and species, while issues related to water as a resource (such as water use) are dealt with in Hobbs et al. (2016).

The approach taken in this scientific assessment is based on of the following key assumptions:

- Avoiding impacts on sufficient area that represents all known aspects of biodiversity (i.e. sufficient suitable habitat of each distinct type) in a spatial configuration that allows for ecological processes to be maintained (i.e. that maintains landscape connectivity, that avoids fragmentation across the entire landscape, and that secures sufficient internal habitat that is not impacted by edge effects) will result in the long-term persistence of biodiversity.
- Biodiversity issues related to genetic diversity are sufficiently dealt with through the broader level assessments of ecosystems, species and ecological processes.
- Enough is known about biodiversity and ecological processes in the Karoo to understand the potential impact of SGD on these components, but it is clear that there are major knowledge gaps. For example, almost nothing is known of the impact of fragmentation (a key focus of this scientific assessment) on ecological processes in the Karoo. Further, the understanding of Karoo invertebrate diversity is very poor. Therefore, the assumption is that by avoiding impacts on sufficient habitat that is representative of all known biodiversity, in a spatial configuration that maintains known ecological processes, the needs of unknown and poorly known aspects of biodiversity will also be met and poorly understood ecological processes will be allowed to be maintained.

7.1.2 Overview of international experience

SGD has outpaced both research and legislation (Souther et al., 2014; Robbins, 2013), with the result that many of the negative ecological impacts of SGD are only starting to emerge now as long-term studies begin to provide results. Brittingham et al. (2014) reviewed the potential impacts of SGD on ecosystems and species, but acknowledged that actual studies on impacts are currently rare. As a result, the existing literature contains a lot of speculative conclusions and anecdotal evidence, and many presumed impacts are inferred based on similar extractive industries such as oil and conventional gas. Clearly there is no directly relevant information in South Africa as an active onshore oil and gas industry or any significant industrial activity does not exist in the Karoo. Comparisons with existing research are useful, but the limitations should be kept in mind, as these studies have been conducted in different, usually much wetter, ecosystems and the affected ecosystems and fauna do not always have direct analogues here. To date, the only published study on the ecological impacts of SGD in South Africa is that of Todd et al. (2016) who provide a review of the international literature on SGD and interpret the findings in terms of Karoo ecosystems and risks posed by the different activities associated with SGD.

Assessing the direct impact of SGD in the form of loss of intact habitat is relatively simple, as this can easily be determined from the footprint of the development as assessed on the ground or through satellite imagery. Jones et al. (2014) found that impacts on vegetation disappeared within 25 m of the development footprint, and that the direct footprint of SGD in their study site in Uzbekistan was less than 1% of the landscape, which is likely to be similar to the extent of direct habitat loss under the SGD scenarios considered in this scientific assessment. However, SGD is also likely to generate significant indirect impacts that extend beyond the direct footprint. Much of this impact is associated with seismic exploration activities and the development of roads and pipelines that fragment the landscape (Brittingham et al., 2014). Disturbed areas around wellpads and along roads will increase the vulnerability of these areas to invasion by alien plants (Gelbard & Belknap, 2003), which may then spread to intact areas and impinge on ecosystem services, biodiversity and agricultural production (Jones et al., 2015). The introduction of invasive and non-native plants on vehicles (for example in seed mixes) is a particular problem and is difficult to avoid. Disturbance generated by road and pipeline construction and maintenance increases the ability of invasive plants to spread (Brooks & Berry, 2006; Mortensen et al., 2009). Once present, these invasive species can out-compete native species and severely reduce habitat quality and ecosystem service delivery (Brooks 2000, Pimentel et al., 2001; Jones et al., 2015). The impacts of access roads in the Karoo may be higher than most overseas situations due to the arid conditions and increased propensity for dust to be generated by vehicles, which may affect vegetation and fauna over broader areas (Trombulak & Frissell, 2000).

Impacts on fauna are more difficult to quantify as behavioural and demographic responses to disturbance by sometimes elusive species have to be monitored. A range of studies have documented faunal impact resulting from spills from waste water ponds when blowouts or failure of ponds occur. A number of instances resulting in mortality of in-stream fish or mammals that drank the water from affected streams have been documented (Robbins, 2013). Furthermore, animals tend to drown in or be poisoned by the waste water storage ponds (Wall et al., 2013) as they are often attracted to them (Hein, 2012; Ramirez, 2009). Under such circumstances storage ponds act as ecological traps for a wide range of species (Kiviat, 2013). This is likely to be problematic in the Karoo as many animals are attracted to standing water under the prevailing arid conditions. The best mitigation for this is to ensure that waste water is kept in closed containers or in suitably sealed ponds covered with shade cloth. Lights around wells can also cause avian entrapment which occurs particularly during foggy or cloudy conditions when birds are attracted to lights and fly around them till exhausted (e.g. Gauthreaux & Belser, 2006).

Apart from the direct impacts on fauna, there are also indirect impacts on sensitive fauna, usually through disturbance and noise (see Andrews et al., 2008; Barber et al., 2010; Blickley et al., 2012). International examples of shy species include Sage Grouse, which could be compared to the various Korhaan and Bustard species that occur across the Karoo, as well as Moose and Mule deer which could be seen to have similar responses to large ungulates such as Kudu here. Impacts on fauna require long-term detailed monitoring and such studies are only just starting to emerge. Many of these studies are highlighting the cumulative impact of development on sensitive species and the interactive role that disturbance-related stress plays in breeding success and susceptibility to disease (e.g. Barber et al., 2010; Gavin & Komers, 2006).

Although habitat loss is a leading cause of ecological impact in many parts of the world, most of the vegetation types within the Karoo are still largely intact and, while they may have been impacted by livestock overgrazing and consequent degradation, they retain a significant proportion of their biodiversity and ecological integrity. However, roads, pipelines and other associated infrastructure will generate a significant amount of habitat loss and landscape fragmentation within the affected areas (Jones et al., 2015), especially under Scenario 3 (the Big Gas scenario). The impacts of fragmentation will be variable, depending on both the habitats and species affected. In addition, habitat fragmentation is usually associated with increases in other disturbance factors such as noise and human presence (Brittingham et al., 2014), and while some species are likely to become habituated to these conditions, it is likely that some species will remain sensitive (Epps et al., 2005; Sawyer et al., 2006).

As mentioned, it is important to consider the manner in which roads and associated fragmentation will impact Karoo ecosystems. Large parts of the Karoo consist of low, relatively open shrublands or shrubby grasslands with regular, relatively open or bare areas. Consequently, most fauna present are adapted or accustomed to traversing open areas and the loss of cover resulting from smaller roads may have little effect in these areas. However, in areas of high vegetation cover such as the Thicket Biome areas in the south-east of the study area and the higher elevation grasslands of the east, the fauna present are more likely to be averse to traversing open ground or more vulnerable to predation and so the potential for disruption of dispersal and other processes is higher (e.g. Andrews & Gibbons, 2005; Epps et al., 2005). A significant increase in faunal impact due to roadkill as a result of increases in traffic volumes as well as the construction of many new access roads is potentially significant across the entire study area (Collinson et al., 2015). Impacts on slow reproducing (e.g. tortoises), slow moving species (e.g. snakes, tortoises) and species attracted to roads due to the presence of roadkill themselves (e.g. Bat-eared Foxes, polecats) is of potential concern (Andrews & Gibbons, 2005; Clarke et al., 2010).

7.1.3 Special features of Karoo ecology and biodiversity

The Karoo is an arid ecosystem characterised by low, unpredictable rainfall and episodic drought events (Hoffman & Cowling, 1990). This has important implications for the dynamics of vegetation within the region. Concepts such as succession and gradual, stepwise and predictable changes in vegetation composition do not apply well in arid ecosystems, and instead ecologists have recognised the event-driven, non-linear dynamics of arid systems such as the Karoo (Milton & Hoffman, 1994; Wiegand & Milton, 1996). Recognition is given under this concept to the unpredictable nature of such systems and their ability to switch quickly from one state to another in response to climatic or biotic events, without the need to pass gradually through intermediate stages. This has important implications for physical disturbance in the Karoo and the ability of humans to repair these impacts (Visser et al., 2004). Many of the shrub species present are long-lived (hundreds of years) and recruitment occurs infrequently in response to rare sequences of rainfall and climate conditions (Wiegand & Milton, 1996). As such, it can be very difficult to re-establish the dominant shrub species in disturbed areas as recovery does not occur spontaneously and active rehabilitation is often met with poor success (Carrick & Kruger, 2007; Visser et al., 2004). This has important implications for the manner that SGD should take place within this environment. Disturbance can persist for decades or even centuries, and many areas are also vulnerable to erosion once the vegetation has been disturbed (Boardman et al., 2003). Therefore, the primary avenue through which to minimise negative impacts in this environment is to ensure that the disturbance footprint is kept to a minimum.

Special features related to the following are discussed below:

- Terrestrial ecosystems;
- Plant species diversity and endemism;
- Terrestrial fauna (including mammals, birds, reptiles and invertebrates); and
- Aquatic ecosystems and species.

7.1.3.1 <u>Terrestrial Ecosystems</u>

The study area includes seven different biomes of which the Nama Karoo (Mucina et al., 2006), at 68% of the exploration application area, is by far the most important (Table 7.1). There are 58 vegetation types within the area (out of approximately 430 vegetation types nationally), of which ten have more than 75% of their extent within the study area, based on the national map of vegetation types of South Africa (Mucina & Rutherford, 2006). Nine of the 14 Nama Karoo vegetation types are represented, five of which have more than 75% of their extent within the study area. However, it is important to recognise that the 14 vegetation types of the Nama Karoo Biome as mapped in the national map of vegetation types do not adequately reflect the diversity of this area, as the national vegetation types have not been mapped at a homogenous scale across the country. The vegetation types within the Nama Karoo have been conceived very broadly relative to those in much of the rest of the country, and include levels of variation that were considered indicative of different vegetation types within the adjacent biomes. At a broad level, areas of potential concern would be Central Mountain Shale Renosterveld, Roggeveld Shale Renosterveld, Karoo Escarpment Grassland and Eastern Lower Karoo, all of which have the majority of their area within the exploration application area and have high levels of diversity or endemism. Ecosystem types in the SGD area are largely not listed as threatened ecosystems in terms of the National Environmental Management: Biodiversity Act (NEMBA) (Act No. 10 of 2004), though Ceres Shale Renosterveld, listed as Vulnerable, extends into the study area.

Table 7.1: Extent of the different biomes within the exploration application area, showing the preponderance of the Nama Karoo Biome within the study area with some Grassland and minor areas of the other biomes. All areas are in km^2.

Biome	**Study area extent (km^2)**	**Exploration application extent (km^2)**	**Proportion of study area (%)**	**Proportion of exploration application area (%)**
Albany Thicket Biome	12945	6854	7.5	5.5
Azonal Vegetation	7985	5819	4.6	4.6
Forests	85	38	0.05	0.03
Fynbos Biome	5774	3725	3.3	3.0
Grassland Biome	21917	14559	12.7	11.6
Nama-Karoo Biome	108229	85753	62.6	68.3
Savanna Biome	362	0	0.2	0.00
Succulent Karoo Biome	15517	8815	9.0	7.0
Total	**172815**	**125565**	**100**	**100**

Invasive Alien Plants in the Karoo

Invasive alien plants require management because they may impact biodiversity as well as the provision of ecosystem services which contribute to human livelihoods and well-being (Richardson & Van Wilgen, 2004; Van Wilgen et al., 2008).

In terms of legislation, the Alien and Invasive Species Regulations (2014), promulgated under the National Environmental Management: Biodiversity Act (Act No 10 of 2004) require that land users clear *Declared Weeds* from their properties and prevent the spread of *Declared Invader Plants* on their properties.

The Karoo has a long history of alien plant invasion, with the Boetebos (*Xanthium spinosum)* being the first species to be legislated as a declared invader in 1860. Prickly Pears (*Opuntia* spp.) were also once a widespread problem in the Karoo but were controlled in most areas by *Cactoblastis* and Cochineal biocontrol agents.

Disturbance is a major driver of alien plant invasion, and roads in particular have been identified as an avenue of alien plant invasion (Gelbard & Belnap, 2003; Von Der Lippe & Kowarik, 2007). This applies in the Karoo, where most common invasive species are already present at low density and are able to expand rapidly into disturbed areas, aided by the low cover of indigenous species in these areas as well as water subsidies received from adjacent roads and other disturbed or hardened surfaces. As discussed in Section 7.2, roads and other forms of disturbance are among the key potential impacts of SGD in the study area, including but not only because of risks related to invasion by alien species.

Invasive alien species of economic or ecological concern in the Karoo include the various *Prosopis* hybrids which together occupy more than 1.5 million hectares of the country and generate a significant negative hydrological impact through their use of groundwater and suppression of indigenous species (Dzikiti et al., 2013; Ndhlovu et al., 2011). There are also various *Opuntia*/*Cylindropuntia* species and other Cactaceae which reduce grazing capacity and may have thorns which injure animals; *Xanthium spinosum* which has burrs that affect the quality of wool and mohair; Satansbos (*Solanum elaeagnifolium)* which is a problem on cultivated lands and overgrazed veld; as well as a number of other significant invasive alien species which are a general problem in disturbed areas including *Salsola kali* and *Argemone ochroleuca*.

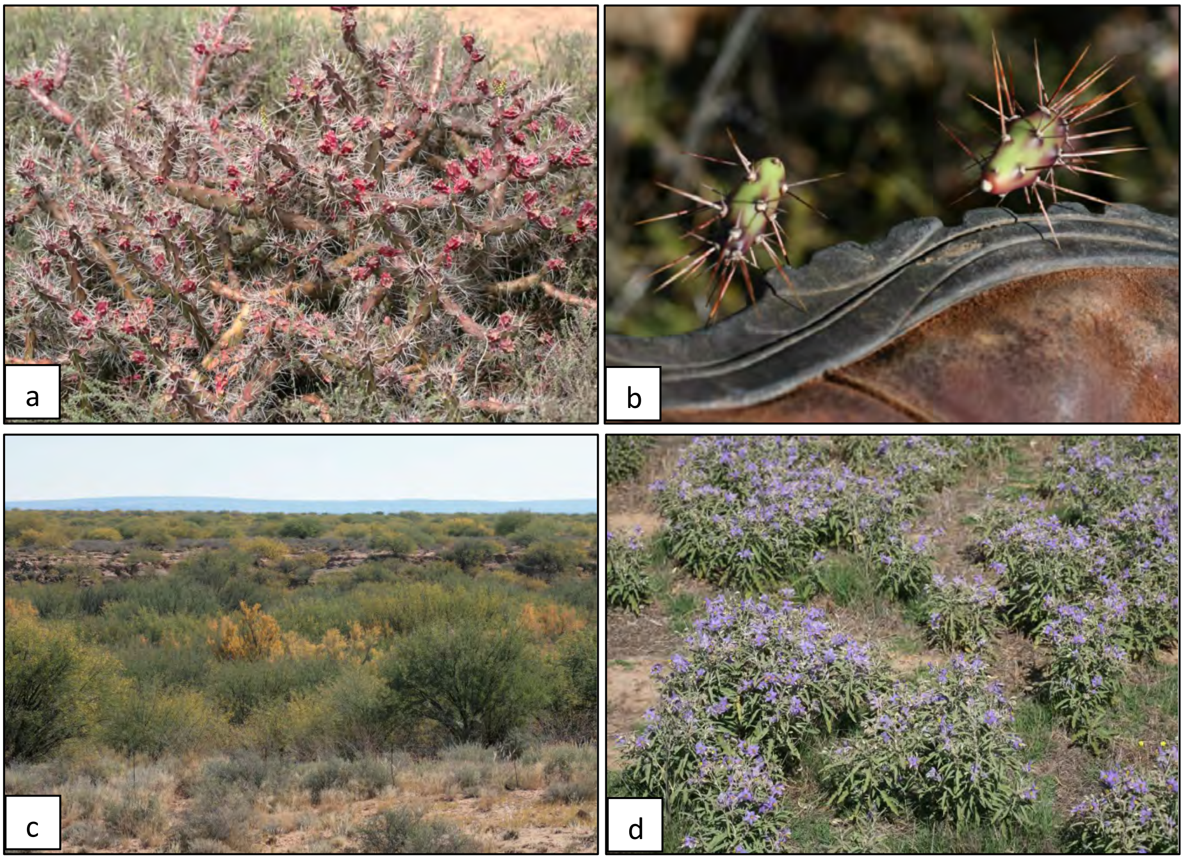

Figure 7.1: a) Jointed cactus (Opuntia aurantica) is an aggressive invasive plant with segmented stems that break off easily when their sharp barbed spines attach to passing animals or people. b) This species can render areas unusable for livestock grazing as the cladodes (leaves) stick to animals' hooves and mouths leaving them unable to walk or eat. c) Mesquite Prosopis spp. hybrids occupy large tracks of the upper Karoo especially along drainage lines and bottomlands. d) The aptly-named satansbos (Solanum elaeagnifolium) is notoriously difficult to eradicate as it is able to regenerate from small root fragments.

7.1.3.2 Plant species diversity and endemism

There are 193 endemic or near-endemic plant species out of a total of 2 158 indigenous species known to occur in the study area. Of the endemic or near endemic species, 119 (Digital Addendum 7A) can be considered to be of conservation concern because they have ranges and habitat requirements that are narrow and specific enough to make them vulnerable to development impacts. A large proportion of these range-restricted species (75 species, or 63%) occur in the mountains and are concentrated in the botanical centres of endemism, including the Roggeveld Escarpment around Sutherland (46 species), the Cape Midlands Escarpment that includes the Sneeuberg Massif that surrounds Graaff-Reinet (23 species) and the Nuweveldberge (12 species) just west of Beaufort West. This limits their vulnerability to impacts of SGD, as mountainous areas tend to be less suitable for SGD. However, there are 44 range-restricted species that are associated with the open plains of the Karoo. These are mainly succulent plants from the families Aizoaceae (Vygies especially small succulents within the genera *Aloinopsis*, *Cylindrophyllum*, *Peersia*, *Deilanthe*, *Stomatium* and *Pleiospilos*); Euphorbiaceae

(Euphorbias) and Apocynaceae (Stapeliads especially in the genera *Orbea*, *Piaranthus*, *Duvalia* and *Hoodia*). Although some of these occur on dolerite outcrops, where they are less likely to be impacted, 25 species are reportedly restricted to clay and gravel flats where they would be highly vulnerable to the impacts of SGD (see text box below). It is worth pointing out that information on many plant species is lacking due to the poor historical sampling of the area.

Where in the Karoo Landscape is Plant Diversity?

In order to understand the potential impact of SGD on the Karoo, it is useful to know the distribution of plant diversity among the different landforms of the Karoo as these will not be equally impacted by SGD. It can be anticipated that SGD will have a disproportionate impact on the plains and relatively low-slope hills and less impact on rocky outcrops and mountains, especially where these are dolerite in origin. A number of studies provide some insight in this regard. Burke et al. (2003) found that species richness of mesas was not significantly higher than the plains near Middelburg, but that the proportion of species shared between plains and mesas declined with increasing size of the mesas. Cowling et al. (1994) compared species richness at paired sites on plains and rocky hills across the Karoo and found that the rocky hills had significantly higher species richness than the adjacent plains. Todd (2003) conducted a detailed vegetation study near Beaufort West and compared species richness within five different habitats and found that calcrete and sandy plains had significantly lower species richness than dolerite hills, shale gravel hills and drainage lines (Figure 7.2). In terms of the proportion of species shared between the different habitats, approximately 25% of the species found on the rocky hills are unique and not found elsewhere, while less than 2% of the species on the calcrete plains are unique to this habitat. The overall implication of these different studies is that development on the open plains would have less impact on plant diversity than development within other habitats. Although there is little supporting data, it is also likely that turnover (β-diversity) across the rocky hills is greater than on the plains (Figure 7.3).

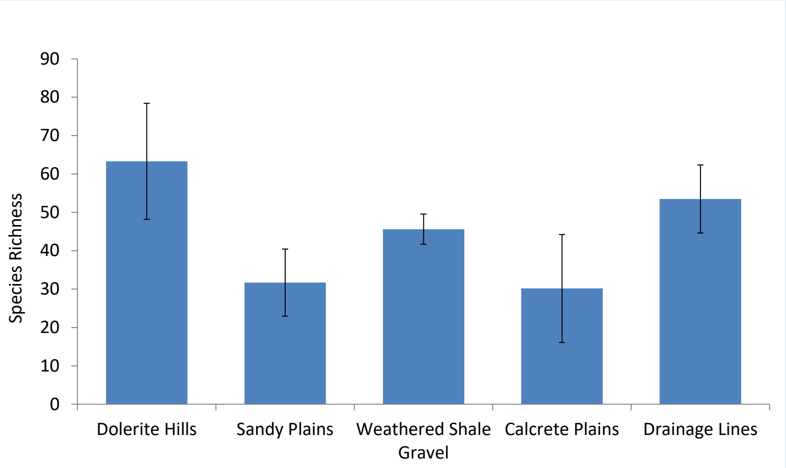

Figure 7.2: Mean species richness with standard deviation bars within five habitats within the Karoo near to Beaufort West (from Todd, 2003).

Figure 7.3: Although there are some plant species of conservation concern that are restricted to the plains, the majority of range-restricted endemic plant species are associated with mountains and rocky hills of the Karoo. This may limit the potential impact of SGD on plant species of conservation concern.

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7.1.3.3 Terrestrial fauna

The vertebrates of the Karoo are well adapted to the unpredictability of the system through a range of physiological and behavioural traits. Many larger mammal species have extensive home ranges and occur at a low density across broad areas. For such species, mobility and the ability to move about the landscape is a key adaptation allowing them to persist in an arid landscape.

The majority of mammals in the Karoo are species with a widespread distribution that originate in the Savanna and Grassland biomes. The MammalMap database[3] lists approximately 177 indigenous species for the study area of which at least 11 are confined to protected areas where they are conservation dependent and cannot be considered free-ranging. Widespread species which occur in the study area and which are of conservation concern include three species categorised as Vulnerable on the International Union for Conservation of Nature (IUCN) Red List; Leopard, *Panthera pardus*, Black-footed Cat, *Felis nigripes*, and White-tailed Mouse, *Mystromys albicaudatus*, and the Critically Endangered Riverine Rabbit, *Bunolagus monticularis.* Impacts are likely to be most serious for

[3] MammalMap database available at: http://vmus.adu.org.za/

species that are endemic or near endemic to the study area, which include Grant's Rock Mouse, *Micaelamys granti*, the Riverine Rabbit, a subspecies of Sclater's Golden Mole, *Chlorotalpa sclateri shortridgei*, and the recently described Karoo Rock Sengi, *Elephantulus pilicaudus*. Of these the most critical species is the Riverine Rabbit which is recognised as one of the most threatened terrestrial mammals in southern Africa and is strongly associated with riparian habitat adjacent to seasonally dry river systems. Two-thirds of its habitat has been fragmented or destroyed in the past 50 years by human activity. The alluvial soil terraces along seasonal rivers typically support halophytic shrublands that are essential for Riverine Rabbit forage and cover. The Riverine Rabbit functions as an indicator species of the condition of river ecosystems, specifically riparian habitat, in the Karoo and its local extinction in many areas is indicative of degradation, fragmentation and loss of the valuable riparian vegetation cover caused by over-utilisation and cultivation. Populations become isolated where riverbanks and floodplains have been transformed for cultivation of crops or other development. Such isolated populations are less able to persist over the long-term and more vulnerable to local extinction.

Some mammals such as aardvark and porcupine are considered especially important due to the ecological impact that they have, especially with regard to the diggings they create when foraging, which creates soil disturbances that are important for plant establishment and the maintenance of diversity (Bragg et al., 2005). In addition, the burrows they dig are important for other fauna as they are used by many other animals which do not usually dig their own burrows but use or modify aardvark or porcupine burrows. Both porcupine and aardvark are considered vulnerable to impact from SGD, due to poaching, traffic collisions and in the case of aardvark disturbance and noise as well. These are useful species for monitoring as they are widespread, have broad habitat requirements, are good indicators of ecological condition, and are vulnerable to impact.

In terms of reptiles, the Karoo is relatively diverse and 35 snake, 49 lizard (including 15 gecko and two chameleon) and five tortoise and terrapin species have been recorded from the study area. One tortoise species, the Karoo Padloper, *Homopus boulengeri*, and two subspecies of the Tent Tortoise, *Psammobates tentorius*, are largely restricted to the Karoo and the Karoo Padloper is listed as Near Threatened. The Plain Mountain Adder, *Bitis inornata*, which is restricted to the Nuweveldberge, is the only snake species that is endemic to the study area and it is categorised as Endangered. The degree of endemism is low for the lizards and most species derive from the Succulent Karoo or Savanna. Three lizard species, however, are largely restricted to the Nuweveldberg area of the Karoo; Braack's Pygmy Gecko, *Goggia braacki*, Cloete's Girdled Lizard, *Cordylus cloetei*, and the Crag Lizard, *Pseudocordylus microlepidotus namaquensis*. Three other lizard species, the Dwarf Karoo Girdled Lizard, *Cordylus aridus*, the Karoo Flat Gecko, *Afroedura karroica*, and Thin-skinned Gecko *Pachydactylus kladaroderma* have much of their distribution in the Karoo.

Several terrestrial invertebrate groups include species with narrow ranges, but there is insufficient data to be able to identify endemics with any certainty, and the threat status of most invertebrate groups has not been assessed according to the IUCN criteria. Butterflies are an exception, with good data and a recent conservation assessment (Mecenero et al., 2013). Nineteen species or subspecies recorded from the area have more than 60% of their distribution in the study area, and four of these are wholly endemic to the area (*Aloeides pringlei*, *Lepidochrysops victori, Thestor compassbergae, T. camdeboo* and *Cassionympha camdeboo*). *Lepidochrysops victori* is categorised as Vulnerable, and is only known from montane grassland in the foothills of the Great Winterberg. Eight terrestrial mollusc species are endemic to the study area and several of these species are restricted crevices in rocky areas where there is some moisture (Digital Addendum 7A). Three Orthoptera (grasshopper/katydid) species are only known from the study area (Digital Addendum 7A), and it is likely that there are many other endemic invertebrates as well.

Figure 7.4: Although the national vegetation map identifies relatively few vegetation types within the Nama Karoo, this belies the large amount of landscape variation that is present and that is important for the fauna. Many species use different parts of the landscape at different times of the year or even each day. As much of the landscape is very open, drainage lines and other areas of dense vegetation can be especially important for animals.

The Karoo lacks a distinctive avifauna (Winterbottom, 1968) but is rich in bird species around the edges, with a steady decrease in species richness towards the arid centre. This is, however, accompanied by a shift in the way that birds use the environment and a concomitant increase in the number of nomadic species, with a trend towards high temporal variability in the density of individuals of resident species (Dean, 1995). There are no families of birds endemic to the Karoo, but members of the Alaudidae, Cisticolidae, Sylviidae, Muscicapidae and Fringillidae are well represented. Very few species of birds in the Karoo are considered to be rare throughout most of their geographic ranges. Most species that are rare in the Succulent and Nama Karoo are common in substantial parts of their geographic ranges elsewhere. At least ten species that have been recorded in the study area were categorised as Threatened in the latest national assessment (Taylor et al., 2015) (Digital Addendum 7A).

There is very little hard data on the impacts of SGD on birds from anywhere in the world, apart from a recent study in the Appalachian forest (Farwell et al., 2016). Almost all written information on the impacts on birds lack publication in peer reviewed journals, and whatever has been posted on various internet sites refers almost entirely to the situation in relatively well-watered sites. However, based on responses of avifauna to disturbance in general, a number of conclusions regarding the likely impacts of SGD on avifauna can be reached.

The density of birds in the Karoo is unusually low compared with other biomes. There are no data available for most of the Nama Karoo, but an estimated density, calculated from counts along transects, suggests that there are 32 individual birds /km² in plains shrubland on the southern edge of the Nama Karoo (Dean & Milton, 2001). The following density data are available for 3 common and widespread Karoo species that make up most of the local community at Tierberg near Prince Albert: Karoo Long-billed Lark, *Certhilauda subcoronata (ca* 6 birds/km²), Karoo Chat, *Cercomela schlegelii* (*ca* 10 birds/km²) and Rufous-eared Warbler, *Malcorus pectoralis*, (*ca* 10 birds/km). All three of these species are territorial to some extent; all avoid settlements, even small settlements such as would be represented by shale gas wellpads. In addition, habitat loss for such species is not equivalent to the wellpad footprint, as birds may avoid areas as much as 200 m from settlements. Under the Big Gas scenario, this would result in habitat loss at the landscape scale of as much as 15%, from wellpads alone. Taking additional habitat loss and disturbance along roads into account, it is not unreasonable to expect declines of as much as 20% in the abundance of the above species.

A major impact on bird populations and local communities is likely to be through increased vehicular traffic. A large number of species of mammals, birds and reptiles are killed, both diurnally and nocturnally, on the roads in the Karoo (Siegfried, 1965), providing food for a number of scavenging birds, including raptors and crows (Collinson et al., 2015; Dean & Milton, 2003; Dean et al., 2006; Macdonald & Macdonald, 1985; Malan, 1992; Schmitt et al., 1987; Steyn, 1982; Winterbottom, 1975) and even small species such as the Fiscal Shrike, *Lanius collaris*, (pers. obs.). Birds (and other animals) eating road kills, and foraging on roads, are vulnerable to themselves becoming roadkill (Collinson et al., 2015); both raptors and crows have been recorded killed on roads (Dean & Milton, 2003).

Adaptable bird species such as crows may increase in response to human activity, which can have negative effects on other biota. Crows attracted to roads by the availability of road kills are likely to also forage in the surrounding shrublands, impacting smaller birds and reptiles. The lights at the wellpads that are on all night will attract insects, and therefore will attract nightjars, some of which may settle on roads near the wellpads and get killed on the road. Spotted Thick-knees (Dikkops), *Burhinus capensis*, are active in the evenings and sometimes into the night; this species is frequently killed on roads.

Another hazard to birds is likely to be posed by the water produced from shale gas drilling operations. In fact, for many birds, this may be the major hazard connected with well sites, and is the most documented aspect of the problems associated with gas and oil wells. Pits or sludge dams constructed near well sites to hold produced water may be lethal to birds. Open water is a limited resource in the Karoo, but a number of nomadic bird species utilise ephemeral ponds for foraging and breeding. While it is not likely that birds would use ponds immediately adjacent to active drilling activities on wellpads, there may be negative impacts from spills and there is also the possibility that ponds are left in place during the production phase when disturbance would be lower and at such time there would be a strong possibility that birds will land on the water, and species such as swifts and swallows (and bats), that drink on the wing by flying across ponds, will attempt to land or to drink. The use of mechanical birds (that look like raptors) perched on the fence surrounding the ponds may be effective deterrents. Recommendations for “reserve pits” to hold produced water include fencing to keep out walking animals and netting over the pits to keep out flying animals (Ramirez, 2009).

Flares to burn off excess gas may be another hazard for birds that has not been quantified. Many bird species migrate and fly through the night to reach their wintering or summering grounds. It is known that migrant birds flying at night are attracted to lights and may inadvertently stray into the flares. This hazard cannot be easily mitigated, but its prevalence would depend on the extent of flaring.

Of interest and potential conservation concern in the Karoo are relic species and habitats that are indicative of a wetter past. These are concentrated along the Great Escarpment and are best exemplified by the various freshwater molluscs that occur in these areas as well as the presence of Ice Rats, *Myotomys sloggetti*, on the highest peaks of the Nuweveldberge, and the presence of an isolated, potentially new species of ancient Velvet Worm (Onychophora) in the Graaff-Reinet area (Daniels et al., 2016).

7.1.3.4 Aquatic ecosystems and species

The Karoo landscape is heavily influenced by the occurrence of dolerite dykes, sills and rings (see Burns et al. (2016) for a description of these geological features), which control surface and subsurface drainage patterns and the occurrence of watercourses and wetlands (Woodford & Chevalier, 2001; Gibson, 2003) (see Hobbs et al. (2016) for definitions of aquatic ecosystems). The low rainfall across the study area means that evaporation is the dominant component of the water balance (Allan et al., 1995), and while rainfall drives the inundation periodicity of the aquatic ecosystems in the area, surface–groundwater interactions are thought to be important for sustaining them. Most of the surface water ecosystems in the study area are thus intermittent or ephemeral, being inundated only for brief periods each year, with periods of drought that are predictable in frequency but unpredictable in duration.

The less common but more perennial springs and seeps associated with Karoo dolerite dykes and sills occur on peaty soils typically at the base of dolerite cliffs or on dolerite slopes, in depressions along fractures or topographical breaks, and are fed by groundwater seeping from deep, fractured aquifers, or even from unconfined alluvial aquifers (Nhleko, 2003). These aquatic ecosystems are one of five types of aquifer-dependent ecosystems (ADEs) recognised in South Africa (Chevalier et al., 2004; Colvin et al., 2007).

The ephemeral rivers of the Karoo are highly dependent on groundwater discharge, which occurs at springs and when groundwater recharge (through precipitation at higher elevations) allows the water table to intersect with the river channel. The upper reaches of the Salt River (Beaufort West), the Kamdeboo, Sundays and Brak Rivers (De Aar) are all good examples of these groundwater-fed watercourses.

Ephemeral rivers are particularly vulnerable to changes in hydrology, as they are specifically adapted to brief periods of inundation and flow (Figure 7.5). Consequently, pollutants and sediments entering these watercourses are not regularly diluted or flushed out of the catchment, leading to a lack of resilience to pollution, erosion and sedimentation (Figure 7.6). The same can be said of ephemeral or seasonal wetlands, which make up the majority of the lentic systems located in the study area. Many of these wetlands – predominantly depressions or pans – are endorheic, i.e. isolated from other surface water ecosystems, usually with inflowing surface water but no outflow.

Figure 7.5: The same stream a few hours after a large rainfall event (left) and some days thereafter (right), showing how such aquatic ecosystems can come down in spate but dry up very quickly afterwards.

Figure 7.6: Although the Karoo is arid, it can experience occasional intense showers (left), and due to the low vegetation cover and susceptible soils, erosion can be high (right).

A dominant feature of the Karoo landscape is the alluvial floodplains, washes and fans. These systems are difficult to classify, as their hydrological characteristics (the way water flows into, through and out of these features) are difficult to determine. They are characterised by multiple channels that traverse a floodplain, valley floor or alluvial fan. Surface water may flow along a particular channel in one year, but owing to little topographic definition or gradient across the landscape, a parallel channel may be eroded the following year, leading to a network of channels. The ecological functioning and importance of these alluvial features are not known.

There are several Threatened faunal species that are associated with permanent rivers and wetlands in the Eastern Cape portion of the study area. This includes five Threatened freshwater fish species that occur in rivers in this area - the Eastern Cape Redfin, *Pseudobarbus afer*; the Cape Rocky, *Sandelia* *bainsii; Barbus trevelyani*; *Pseudobarbus asper*; and the Amatola Barb, *Barbus amatolicus*. Two Threatened damselfly species, the Kubusi stream-damsel, *Metacnemis valida*, and the Basking Malachite, *Chlorolestes apricans*, are restricted to rocky, fast-flowing streams in the more mountainous part of the Eastern Cape. Twenty-six frog species have been recorded from the study area out of a total of 123 species in South Africa. This is a relatively high diversity given the aridity of much of the area and paucity of perennial water. The only frog species which can be considered endemic to the Karoo is the Karoo Dainty Frog, *Cacosternum karooicum*.

The fauna of the more seasonal to ephemeral ecosystems is not well known, but they have been found to provide aquatic habitat to a diverse array of faunal species that depend on brief periods of inundation for hatching, mating, feeding and refuge (Anderson, 2000; Hamer & Rayner, 1996; Minter et al., 2004). For instance, many frogs of the Karoo region breed in temporary pools associated with watercourses and wetlands, this includes the Karoo Toad, *Vandijkophrynus gariepensis*, and Karoo Dainty Frog, *Cacosternum karooicum*. A great number of other organisms are not confined to these temporary systems, but derive crucial benefits from them, like migratory birds and many invertebrates that migrate from permanent to temporary habitats on a regular basis. Connectivity between aquatic ecosystems, and between aquatic ecosystems and the surrounding terrestrial landscape, is essential for supporting the fauna of the region, including their need to feed, breed and migrate.

Very little is known of the invertebrate fauna of the watercourses and wetlands of the Karoo region. Given the constant shift from aquatic to dry phases, ephemeral ecosystems support unique, well-adapted biotic communities with species that show rapid hatching, fast development, high fecundity, and short life spans. Organisms that inhabit these ecosystems rely on the production of desiccation-resistant or dormant propagules (such as eggs, cysts, seeds, spores) to survive the dry period, and then become active again when the wetland is inundated. The eggs of these organisms can survive in the sediments for many years, and rapidly hatch when sufficient rain falls. Many taxa will reproduce asexually several times during the wet season.

The ephemeral pans and rock pools in the Karoo are inhabited by branchiopod crustaceans, commonly known as fairy shrimps (Anostraca), tadpole shrimps (Notostraca), clam shrimps (Spinicaudata and Laevicaudata), and water fleas (Cladocera), and also the ostracods or seed shrimps (Lloyd & Le Roux, 1985; and Musa Mlambo, Albany Museum, pers. comm., January 2016). There are several taxa that are completely dependent on ephemeral wetlands to complete their life cycle. For example, the tadpole shrimp, *Triops granarius*, is reportedly common where mean inundation is less than one month; this invertebrate reaches sexual maturity within days (Figure 7.7). Two fairy shrimp species have only been recorded from the study area – *Branchipodopsis browni and B. hutchinsoni*; both have been recorded in temporarily inundated ditches along the road. There are also specially adapted copepod, ostracod and cladoceran crustaceans that inhabit these pools.

Figure 7.7: Tadpole shrimps (*Triops granarius*) are common in pans in the Karoo but spend most of their time as dormant eggs in the soil, sometimes with years between life cycles.

7.1.4 Relevant legislation and policy

National legislation central to the management and conservation of biodiversity in South Africa includes:

- The National Environmental Management Act (NEMA) (Act 107 of 1998, as amended) outlines measures that…. "prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development." Its associated EIA Regulations and Listing Notices identify activities deemed to have a potentially detrimental effect on natural ecosystems and outline the requirements and timeframe for approval of development applications.
- The National Environmental Management: Biodiversity Act (NEMBA) (Act 10 of 2004, as amended), provides for, *inter alia*, the management and conservation of South Africa's biodiversity, the protection of species and ecosystems that warrant national protection, and the sustainable use of indigenous biological resources.
- The National Environmental Management: Protected Areas Act (Act 57 of 2003, as amended) provides for; *inter alia*, the protection and conservation of ecologically viable areas representative of South Africa's biodiversity and its natural landscapes and seascapes. The Protected Areas Act provides for protected areas to be declared on private or communal land, with the landowner retaining title to the land. This has led to the development of biodiversity stewardship programmes, in which conservation authorities (such as provincial conservation agencies) enter into contractual agreements with landowners. Nature Reserves and Protected Environments declared through biodiversity stewardship programmes are considered formal

protected areas, and are collectively referred to as contract protected areas (distinguished from state-owned protected areas).

- The National Water Act (NWA) (Act 36 of 1998) addresses, *inter alia*, the "protection of the aquatic and associated ecosystems and their biological diversity". The Act regulates all water uses, some of which are non-consumptive but which may impact on the integrity, functioning and biodiversity of wetlands and watercourses. The process to be followed to obtain authorisation for these categories of water use relate to the risk associated with the water use, where authorisation of low risk activities is a simpler, faster process than for full Water Use Licence Application (WULA). Generally, non-consumptive water uses that impact directly on a wetland, or which occur within 500 m of a wetland or within the outer edge of the 1 in 100 year floodline or delineated riparian area of a watercourse are of medium to high risk, requiring a full WULA.
- The Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002) and its associated regulations provide for the protection of water resources, and stipulate required setbacks from wells, in order to protect the integrity of watercourses and wetlands. Section 49 of the MPRDA provides a mechanism for excluding mining from certain areas.

In addition to legislation, several national strategies and plans are central to the management and conservation of biodiversity in South Africa:

- As a contracting party to the Convention on Biological Diversity (CBD), South Africa is obliged to develop a National Biodiversity Strategy and Action Plan (NBSAP). Strategic objectives of the recently revised NBSAP for 2015 to 2025 (Department of Environmental Affairs (DEA), 2015a) include that the management of biodiversity assets and their contribution to the economy, rural development, job creation and social wellbeing is enhanced, and that investments in ecological infrastructure enhance resilience and ensure benefits to society.
- Spatial assessment and prioritisation of biodiversity based on the principles of systematic biodiversity planning is strongly embedded in the policy and practice of the biodiversity sector in South Africa, for example through the National Biodiversity Assessment (NBA) (Driver et al., 2012), the National Protected Area Expansion Strategy (NPAES) (Government of South Africa, 2010), the Atlas of Freshwater Ecosystem Priority Areas of South Africa (FEPA) (Nel et al., 2011), and provincial spatial biodiversity plans. These principles include the need to conserve a viable representative sample of all ecosystems and species, as well as the ecological and evolutionary processes that allow biodiversity to persist over time.

At the provincial level, provincial environmental affairs departments are often the authority for permitting or authorising for a range of activities, and they provide comments on mining-related authorisations. Provincial spatial biodiversity plans identify Critical Biodiversity Areas (CBAs) and Ecological Support Areas (ESAs) which guide such authorisations and comments.

7.2 Key potential impacts and their mitigation

This section identifies and describes potential impacts of SGD on the study area, and recommends mitigation measures based on the ecology and biodiversity of the area. The mitigation measures are structured according to the mitigation hierarchy that is widely applied in EIAs – avoid, minimise, rehabilitate, offset.

Because of the potential cumulative landscape-scale impacts of SGD, the mitigation hierarchy should be applied not only at the site level in EIAs, but also at a strategic landscape level. A framework for application of the mitigation hierarchy at the landscape level is set out in Section 7.2.1 (Table 7.2), followed by more detailed discussion of mitigation measures for specific activities related to SGD in Section 7.2.2 (Table 7.3). Cumulative impacts are discussed further in Section 7.2.3, and gaps in capacity for implementing mitigation measures at both the landscape level and site level are outlined briefly in Section 7.2.4.

As discussed in Section 7.1.3, rehabilitation efforts in the Karoo environment are often met with poor success, and disturbance can persist for decades or even centuries. This means that the preferred mitigation measures in this environment are to *avoid* or *minimise* impacts, whether at the landscape level or the site level. In cases where rehabilitation measures are recommended, they are generally aimed at restoring basic ecological functioning rather than at restoring species composition. In cases where residual impacts (after avoiding and minimising) need to be *offset*, ecologically equivalent sites must be identified and secured. An ecologically equivalent site means a site that contains equivalent ecological processes, ecosystems and species, and that compensates for the full ecological impact of the activity as identified through a detailed study.

7.2.1 Strategic approach to mitigation at the landscape level

The table below sets out a framework for mitigation at the landscape level. It is underpinned by the spatial analysis that identified areas of EBIS in the study area, from EBIS-1 (highest) to EBIS-4 (lowest), as described in Section 7.3.1. Protected areas, EBIS-1 areas and EBIS-2 areas collectively meet targets for representation of biodiversity and maintenance of ecological processes in the study area, in a spatial configuration designed to ensure connectivity in the landscape.

The primary mitigation for SGD in the Karoo as a whole is securing the EBIS-1 and EBIS-2 areas; which effectively make EBIS-3 and EBIS-4 areas available for SGD. EBIS-1 and EBIS-2 areas should be secured through legal mechanisms that limit loss and degradation of habitat, such as:

- Establishing or expanding a state-owned protected area;
- Establishing a contract protected area, for example through legally binding biodiversity stewardship agreements (this could be either a contract Nature Reserve or a contract Protected Environment, in which landowners enter into a long-term contractual agreement with a conservation authority);
- Establishing a lower tier biodiversity stewardship agreement (for example, a Biodiversity Management Agreement or Biodiversity Partnership Area);
- Zoning the land as an appropriate zone (e.g. conservation) in a municipal Land Use Scheme;
- Protection under Section 49 of the MPRDA.

Securing EBIS-1 and EBIS-2 areas may lend itself to a fast-tracked, integrated programme to expand the protected area network, which takes a strategic approach rather than an *ad hoc* piecemeal approach, similar to Operation Phakisa in the marine environment. Biodiversity offsets can also play an important role in securing EBIS-1 and EBIS-2 areas as protected areas; EBIS-1 and EBIS-2 areas are first-tier and second-tier receiving areas respectively for biodiversity offsets.

In addition to securing EBIS-1 and EBIS-2 areas, it is critical that an effective set of operating rules is established for all areas to ensure that overall impacts on the landscape in general, and impacts on EBIS-1 and EBIS-2 areas in particular, are kept within acceptable limits. Subject to reasonable on-site operating rules to reduce unnecessary impacts, and careful minimisation of any broader impacts on adjacent EBIS-1 and EBIS-2 areas, biodiversity loss within EBIS-3 areas could be absorbed without compromising the overall function and integrity of the Karoo ecosystem as a whole. Impacts restricted to EBIS-4 areas are unlikely to be of ecological significance.

Table 7.2: Strategic application of the mitigation hierarchy at the landscape level, based on the map of EBIS.

Ecological and Biodiversity Importance and Sensitivity (EBIS)	**Primary focus of mitigation, based on the mitigation hierarchy**
Protected areas	**AVOID** • These areas are legally protected in terms of the Protected Areas Act.
EBIS-1 (highest)	**AVOID** • EBIS-1 areas contain extremely sensitive features and are irreplaceable. Because they are irreplaceable, it is <u>not possible to minimise or offset</u> impacts of SGD activities in these areas. • SDG activities <u>must always be avoided</u> in these areas. • Ideally these areas should be <u>secured</u> through legal mechanisms that limit habitat loss and degradation. • These are *first-tier receiving areas for biodiversity offsets*.
EBIS-2	**Best option: AVOID** **Otherwise: MINIMISE <u>AND</u> OFFSET RESIDUAL IMPACTS** • EBIS-2 areas contain highly sensitive features and features that are important for representation of biodiversity and/or maintaining ecological processes. • Ideally they should be <u>secured</u> through legal mechanisms that limit habitat loss and degradation. • If they cannot be avoided, then ecologically equivalent sites must be secured through biodiversity offsets. • These are *second-tier receiving areas for biodiversity offsets*. **For shale gas *<u>exploration</u>*** in EBIS-2 areas, it may be possible to minimise impacts sufficiently at the site level to achieve no loss or degradation of habitat i.e. no residual impacts. In such cases, an offset will not be required. **For shale gas *<u>production</u>*** in EBIS-2 areas, impacts of production cannot be effectively mitigated on-site or at the operational level: There will <u>always be residual impacts</u> that must be offset.
EBIS-3	**MINIMISE** • EBIS-3 areas are natural areas that do not contain currently known sensitive or important features. • Environmental compliance is required. This includes specialist-led assessment of local sensitivities and identification of appropriate mitigation. • From a biodiversity and ecological perspective, SGD activities need not be avoided in these areas <u>IF</u> there is no loss or degradation of EBIS-1 and EBIS-2 areas. • These are *third-tier receiving areas for biodiversity offsets*.
EBIS-4 (lowest)	**MINIMISE** • EBIS-4 areas have no remaining natural habitat. • Environmental compliance is required. • From a biodiversity and ecological perspective, there is no need to avoid SGD in these areas; however, there may well be other reasons to avoid SGD in these areas.

7.2.2 Activities, impacts and mitigation measures

This section focuses in more detail on mitigation measures for those activities associated with SGD that are most relevant from a biodiversity and ecological point of view. In the Karoo environment, where transformation for cropping and other intensive agricultural activities is limited, habitat loss at a local scale is not usually of high significance (with EBIS-1 areas being a clear exception). As discussed, a major concern is the cumulative and interactive effect of the activities at the landscape scale, particularly through activities on the land surface that fragment the landscape, and the resulting impact on spatially extensive ecological processes. The actual drilling footprint is in general less significant than the ancillary infrastructure and activity, including roads and vehicular activity.

From a terrestrial ecology perspective, the activities of most concern or relevance are removal of indigenous vegetation and destruction of natural habitat; construction and maintenance of roads, wellpads and other physical infrastructure; off-road driving; vehicular traffic on roads; and activities linked to ongoing operation, including human activities such as collection of species of special interest, disturbance such as light and noise, and industrial accidents. From an aquatic ecological perspective, the activities of most concern or relevance are waste water management; water extraction and use; destruction of natural habitat in riparian areas and wetlands; construction and maintenance of roads that traverse watercourses or wetlands; and off-road driving through watercourses and wetlands.

Table 7.3 sets out activities and their associated impacts, as well as potential mitigation measures structured according to the mitigation hierarchy (avoid, minimise, rehabilitate, offset). Some impacts are closely tied to the location and layout of activities. In many cases, careful planning of the siting and layout of activities away from EBIS-1 and EBIS-2 areas can substantially avoid impacts. The map of EBIS (see Section 7.3.1) should be used to inform the siting of activities. Others impacts are linked to the carrying out of ongoing activities as part of operations.

Table 7.3: Activities, impacts and mitigation measures.

Activity	Description	Mitigation measures
Exploration	**Exploration will generate physical disturbance as well as above and below ground noise**. Although the noise will be short-lived and probably not of long-term consequence, off-road driving in unsuitable conditions can cause long-term impacts. • Driving of heavy vehicles even once over wet clay floodplain areas can have major impact as these areas are highly sensitive to change. The whole ecology of the system is dependent on water spreading out over vast flat areas during rainfall events. Tracks left by vehicles after driving over the soil surface when it is wet can cause significant changes in water run-off patterns and will remain in the landscape for decades. • Many different subterranean animals, including golden moles, use soil vibrations to find prey and the loud noises generated by seismic exploration may have a significant impact on such species, but this is not well known and the severity or extent of this problem should be investigated. • Although the footprint of exploration is likely to be relatively limited, it may cover a large area.	<u>Avoid</u> - No driving off-road for prospecting when there are wet soil conditions. - No exploration within sensitive habitats such as wetlands, quartz patches, and rack pavements. <u>Minimise</u> - Minimise disturbance footprints. <u>Rehabilitate</u> - Rehabilitation of disturbed areas on steep slopes and other sensitive areas required.
Vegetation clearing, destruction or other loss of intact vegetation	Vegetation clearing for roads, wellpads, pipeline routes and other infrastructure. This can lead, *inter alia,* to the following impacts: • **Fragmentation of natural habitat**, resulting in loss of connectivity in the landscape. This impact extends far beyond the footprint of the cleared areas themselves, and may impact on all ecological processes in the Karoo. It includes fragmentation of aquatic habitat within wetlands and watercourses. • **Altered surface water flow patterns**, e.g. changing sheet flow to concentrated flows, which leads to erosion, altered flow regimes and changes in water availability. Driving on wet clay forms ruts that later develop into dongas or holes too deep for vegetation establishment.	<u>Avoid</u> - Design and layout of infrastructure to avoid restricted habitats and high sensitivity areas. - No wellpads within EBIS-1 and EBIS-2 areas, unless an offset has been implemented. - No land application of waste fluids. - No injection/disposal wells. - No direct discharge of waste water to wetlands and watercourses. <u>Minimise</u> - All traffic off of public roads should adhere to 40 km/h speed limits or lower. - No off-road driving in wet conditions. In particular, no driving in veld should take place on clay or fine-textured soils following rain. - Preferably roads should not be fenced off as this increases fragmentation for

Activity	Description	Mitigation measures
	• **Erosion and sedimentation** are important ecological processes in the Karoo. Loss and fragmentation of habitat disrupt these processes. Erosion is a particularly high risk on steep slopes, and in drainage lines that lack channel features and are naturally adapted to lower energy runoff with dispersed surface flows (such as unchannelled valley-bottom wetlands), and naturally less turbid freshwater systems. • **Spread of invasive alien species**. Altered soil structure, moisture availability and light availability can lead to invasion by weeds and invasive alien plants and animals.	many fauna. - If roads or structures are fenced, use plain strands and not jackal proof fencing to ensure animals can still move through fences. - Design to use as much common/shared infrastructure as possible with development in nodes, rather than spread out. - Access routes should use existing roads and tracks before making new roads. - If unavoidable, surface discharge of waste water to the environment must be monitored to the highest possible water quality standards. - Waste water storage or treatment ponds must be fenced and covered with shade cloth. <u>Rehabilitate</u> - All cleared areas that are not being used must be rehabilitated with perennial shrubs from the local environment.
Construction activity and maintenance of roads, wellpads and other physical infrastructure	Construction phase earth moving, construction and the maintenance of roads and other infrastructure will affect runoff amount and quality as well as generate significant amounts of dust. • **Dust can have a direct negative impact** by covering the leaves of plants, which affects their growth and reproduction (and wears away the teeth of herbivores such as indigenous antelope and livestock); by degrading the habitat of animals and causing them to move away; and by causing accumulation of sedimentation in adjacent drainage lines which clogs the gills of fish and aquatic invertebrates. This impact can extend quite substantial distances from the construction activity and can last for a long time after the activity is completed. • **Stormwater runoff** from roads, buildings, borrow pits and excavation sites may cause erosion and channelling of flow, changes in flow patterns, head-cut and gully erosion, and sedimentation in wetlands and watercourses. • **The disruption of surface drainage patterns** where roads are raised above the base level of natural drainage channels or wetlands can cause fragmentation of aquatic ecosystems, and loss of connectivity, and can hamper the movement of aquatic	<u>Avoid</u> - No vehicles, machinery, personnel, construction material, cement, fuel, oil or waste outside of the demarcated working areas. - No fuel storage, refuelling, vehicle maintenance/washing or vehicle depots within 50 m of the edge of any wetlands or watercourses. <u>Minimise</u> - Refuelling and fuel storage areas, and areas used for the servicing, washing or parking of vehicles and machinery located on impervious bases and with bunds around them. Bunds sufficiently high to ensure that all the fuel kept in the area will be captured in the event of a major spillage. - Use existing bridges for watercourse or wetland crossings wherever possible. - Minimise new crossings over wetlands and watercourses. If wetlands or watercourses cannot be avoided, ensure that road crossings are constructed using riprap, gabion mattresses, and/or other permeable material to minimise the alteration of surface and sub-surface flow. Drift crossings are preferable to bridge crossings, where feasible. - Flow of water under roads must be allowed to occur without leading to concentration of surface flow. This can be achieved through designing bridges that span the entire width of aquatic ecosystems where possible, or laying down pipes or culverts to ensure connectivity and avoid fragmentation of surface aquatic ecosystems. Bank stabilisation measures (gabions, eco logs, geofabric,

Activity	Description	Mitigation measures
	or semi-aquatic fauna along riverine corridors or within and between wetlands. • **Construction results in substantial noise pollution**. This has general disruptive influences on mammals and birds causing shy and sensitive animals to avoid areas where noise pollution occurs. Mating systems for various animals including some insects are disrupted by noise which is likely to result in reduction in populations. • **Construction will result in disturbance of vertebrate species.** This is especially detrimental to ecological processes when species that are ecosystem engineers (Bat-eared Foxes, Porcupines) are affected. This can include the death of animals, especially of slow-moving and burrow-dwelling animals that are not able to move away. • **Construction can introduce invasive alien species**, and lead to the spread of those that are already present. Invasive species will negatively compete with indigenous species and disrupt ecological processes. • Construction and maintenance of roads and other infrastructure can be associated with spills of fuel and other chemicals.	sediment fences) required when wetland or watercourse banks steeper than 1:5 are denuded during construction. - Ensure erosion control along roads. Put in culverts at drainage lines. Build water diversion structures at 20 to 50 m intervals (depending on the steepness of the slope) along veld tracks. Soil should be dug out across veld tracks and used to create berms downslope of the ditch. Berms must be at least three times the width of the road, to prevent water running around the berm and back onto the tracks. Berm ends should be extended on the downslope side of the road with rocks to prevent diverted water eroding the soil. These will prevent veld roads acting as water channels, causing donga erosion. It will also facilitate vegetation recovery on closed roads. - If construction areas are to be pumped of water (e.g. after rains), this water must be pumped into an appropriate settlement area, and not allowed to flow straight into any watercourses or wetland areas. - Stormwater runoff from all roads must be spread as much as possible, to avoid concentration of flows off compacted or hardened surfaces. - Roads should not be raised above the natural base level, allowing surface runoff to flow uninterrupted. Crossings over watercourses and wetlands should be built as stabilised drifts rather than using culverts or pipes. - Any materials brought in to construction sites should be from sources free of invasive alien species. - There must be regular dust suppression during construction. Rehabilitate - Clearing of invasive alien species must take place during and after extraction work. - Impact of clearing and rate of recovery of vegetation must be monitored. - Clearing of invasive alien plants must take place coupled with the sowing of seeds of indigenous grass species to stabilise disturbed habitats. - Roads must be closed properly after use with the construction of multiple berms. Temporary roads must be closed on termination of the exploration or other activity for which they were used. - Compacted bare ground should be loosened and pitted, and covered with branches or stones. This will improve the ability of the surfaces to trap seeds and to absorb rainwater, thereby hastening vegetation recovery.

Activity	Description	Mitigation measures
		- Domestic livestock should be excluded from areas under rehabilitation until the vegetation has recovered sufficiently.
Vehicular traffic on roads	Construction and to a lesser extent operation will significantly increase traffic volumes within the affected areas and this may lead to significant increases in mortality of susceptible species. • **Increased vertebrate roadkill** is expected to occur. Some species such as Bat-eared Foxes appear particularly vulnerable to roadkill and may be disproportionately affected. • Shy animal species may avoid the proximity of busy roads and thus experience habitat loss.	Avoid - No driving off roads. - No driving at night. Minimise - Establish culverts for fauna crossings. - Establish and enforce strict speed limits.
Waste water management including treatment, storage and disposal of waste water (flowback and produced water and sewage)	• **Waste water ponds that are accessible to animals are likely to cause mortalities from consumption and drowning**. Leaks, spills, and spread of contaminants are the most significant concern for freshwater species and also others that depend on access to water. • **Water pollution/contamination from waste water treatment, flowback and produced water**, e.g. releases from waste water ponds, or from accidental releases associated with natural flood events; leaking infrastructure (e.g. ponds, closed water treatment units); and spills of waste water. Flowback and produced water is likely to contain drilling fluids, drilling mud, contaminated fossil water, radioactive nucleotides, biocides and other toxins (e.g. heavy metals), and is likely to have a high salinity.	Avoid - No land application of waste fluids. - No injection/disposal wells. - No direct discharge of waste water to wetlands and watercourses. Minimise - If unavoidable, surface discharge of waste water to the environment must be monitored, in order to ensure that the water quality guidelines for maintenance of aquatic ecosystems, as provided by Department of Water & Sanitation (DWS), are adhered to. In addition, the regulations regarding the use of water for mining and related activities in order to protect water resources (GN 704/1999 in Government Gazette of 4 June 1999) must be applied (see Hobbs et al., 2016). - Waste water storage or treatment ponds must be fenced and covered with shade cloth. - The mining companies must be responsible for dealing with the waste water generated by SGD activities on site.
Water abstraction and use including water used for fracking	Extensive abstraction of water (surface or groundwater) in the arid Karoo environment will result in impacts on inundation/saturation regimes in wetlands, and flow regimes in watercourses. Abstraction of groundwater will also result in localised drawdown of the water table. • **Large-scale abstraction of water** (surface or groundwater)	Avoid - No groundwater abstraction or drilling of boreholes within 500 m of existing springs, wellpads or boreholes. - No water abstraction from perched water tables.

Activity	Description	Mitigation measures
	in the Karoo environment is likely to have a catastrophic effect on the condition of aquatic ecosystems, other water-dependent ecosystems, and associated species. In extreme cases it may cause subsidence. • Ephemeral and seasonal pools lower down in catchments are more vulnerable as they are more dependent on groundwater. • Abstraction of water will cause a decline of species dependent on water availability, including amphibians and fish, and may impact availability of breeding habitats for aquatic species. • Riparian plant species and communities dependant on perched water tables (such as *Valchelia karroo*, *Searsia lancea*, *Phragmites australis*) will be impacted. • Deeper fossil water (if used for fracking) can contaminate shallower aquifers during fluid migration, and ecosystems dependent on these.	<u>Minimise</u> - Water use must be subject to the determination of a comprehensive Ecological Reserve, both for surface and groundwater resources. - Sound assessments of water quantity available must be conducted. - Water levels in source water holes must be monitored.
Activities linked to ongoing on-site operations and maintenance	Human presence/activity has impacts such as: increased firewood collection; increased poaching of species for human consumption (e.g. Kudu, Porcupine); killing of animals seen as dangerous (e.g. snakes and spiders); increased collection of species of special interest (e.g. medicinal plants and species popular for the pet trade such as scorpions, baboon spiders and reptiles; trampling of habitats; increased domestic and feral animals which kill indigenous animals, especially birds; and increased fishing in larger river systems (e.g. Sundays River, Fish River). • **Disturbance, such as light and noise**. This changes behaviour of species. Impacts can occur over long distances. Noise pollution frightens animals away. Persistent noise results in habitat degradation and impacts on predation and reproduction. Numerous invertebrates groups are negatively impacted by light pollution due to disorientation, and disruption to mating systems. Lights cause prey community change, which affects some bat species; it affects predation on rats by owls and small carnivores; and can disturb behaviour of invertebrates at night. • **Industrial accidents** e.g. chemical or fuel spills, lead to contamination of soils and water, and result in habitat	<u>Avoid</u> - Staff should not be permitted to walk into the veld but should remain only on the wellpads. - No collection of fire wood, medicinal plants, or animals with potential for the pet trade permitted. - Wells must be sited to avoid ecological buffers determined for the protection of biodiversity, and adhere to the buffers set by Hobbs et al. (2016) for protection of the water resource. - No fuel storage, refuelling, vehicle maintenance or vehicle depots within 50 m of the edge of any wetlands or watercourses. <u>Minimise</u> - Minimise the amount of lighting at all facilities and use downward-directed low-UV emitting LED lights at wellpads and direct these exclusively to the areas where night-time lighting is required. - Minimise noise from facilities and infrastructure. - An emergency protocol must be developed that deals with accidents and spills. This must include methods for absorbing chemicals/oils/fuel, and the transport and disposal of all contaminated material in a suitable hazardous waste site.

Activity	Description	Mitigation measures
	degradation and mortalities.	- Refuelling and fuel storage areas, and areas used for the servicing or parking of vehicles and machinery, should be located on impervious bases and should have bunds around them. Bunds should be sufficiently high to ensure that all the fuel kept in the area will be captured in the event of a major spillage. Water permits must be issued both for use or water as well as discharge. - Toilets must not be allowed to leak or drain into natural areas. - Ensure sufficient capacity for management of water contamination. Rehabilitate - Areas contaminated by accidents and spills must be rehabilitated.

7.2.3 Cumulative impacts

It is often cumulative impacts and related fragmentation of the landscape that are of major concern from an ecological point of view, rather than the impact of any particular activity at the level of an individual site. Given the extensive nature of the Karoo, the development of a few widely scattered wellpads is not likely to generate any impacts of broader significance. However, the cumulative impact of numerous wellpads and associated infrastructure across an extraction area is likely to generate significant impacts on ecological patterns and processes.

The different scenarios have the potential to generate different levels of cumulative impact. Under the Small Gas scenario, the total estimated footprint of development within a 30x30 km block would be approximately 110 ha of wellpads and up to 61 km of new access road equivalent to approximately 61 ha of transformation assuming that roads are 10 m wide. This represents less than 1% of the 30x30 km development block. However, this does not adequately indicate the potential for cumulative impact. Under the Small Gas scenario there is no point more than 5 km from a wellpad or access road and 25% of the area is within 500 m of a wellpad or access road and 48% is within 1 km. By comparison, under the Big Gas scenario, 54% of the block would be within 500 m of a well or access road and 86% is within 1 km. Clearly, within the Big Gas scenario it is impossible for fauna to avoid the SGD. The landscape fragmentation impacts of the Small and Big Gas scenarios are illustrated schematically in Figure 7.8. It is not the extent of direct habitat loss that is of concern, but rather impacts that extend beyond the footprint such as noise or increased impediments to faunal movement such as fences, as well as a combination of such factors.

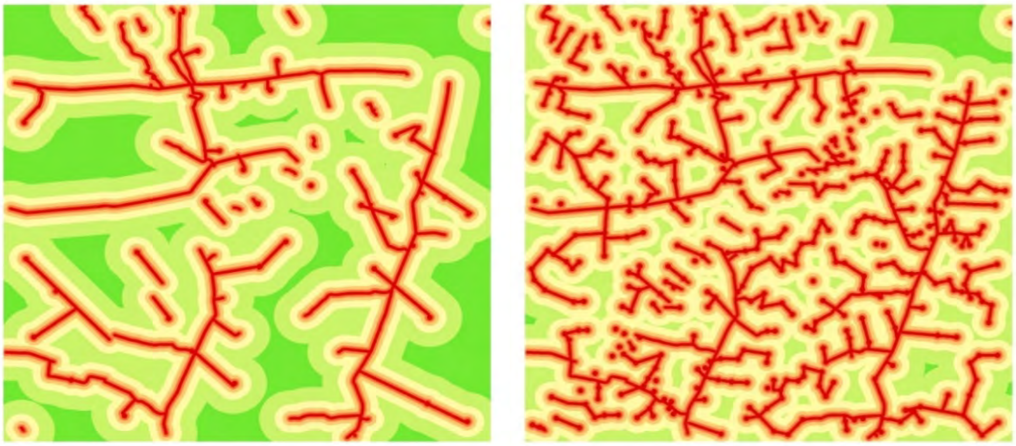

Figure 7.8: Distance surfaces from shale gas infrastructure, under the Small Gas scenario (left) and the Big Gas scenario (right), illustrating the fragmentation of the landscape by SGD, even where it occupies a small proportion of the landscape.

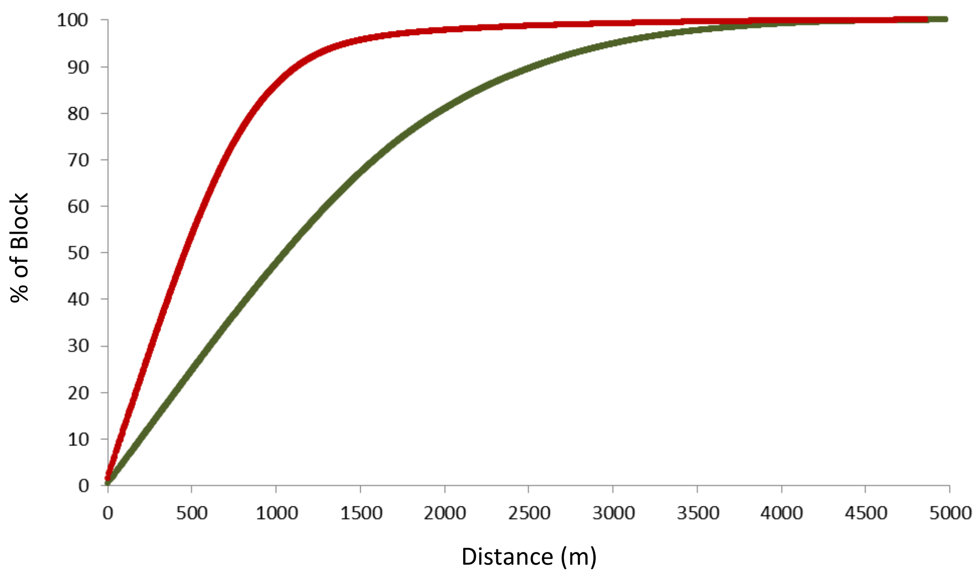

Figure 7.9: Cumulative distance curves illustrating the proportion of a 30x30 km block that would be within the x-axis distance from an access road or wellpad under the Small Gas scenario (green) and the Big Gas scenario (red).

For many small fauna which can complete their life cycle within a few hectares, the main impact of SGD would be habitat loss roughly equivalent to the development footprint. However, as the mobility or home range of fauna increases, they are increasingly likely to encounter shale gas infrastructure and hence potential negative impact. For larger mobile species, typical reported home ranges are in the order of 2 – 5 km^2 for Aardvark, *Orycteropus after*; 1 – 6 km^2 for Aardwolf, *Proteles cristatus*; 6 – 48 km^2 for Caracal, *Caracal caracal*; 5 – 15 km^2 for Black-footed Cat, *Felis nigripes*; up to 500 km^2 for Honey Badger, *Mellivora capensis;* and up to 21.9 km^2 for Kudu, *Tragelaphus strepsiceros* (Skinner & Chimimba, 2005). With a projected average well density of one wellpad every 2.25 km^2 under the Big Gas scenario; it is clear that resident individuals of these species would need to negotiate shale gas infrastructure or disturbance on a daily basis. Although many fauna become habituated to human activity, certain impacts such as roadkill are not conducive to habituation and cumulative long-term impact may compromise local populations of vulnerable species.

Cumulative impacts result both from the repeated nature of each impact across the landscape as well as the combined impact of each different impact source. For some species there may be a dominant source of impact, while for others there is likely to be a combination of contributing factors. In addition, many impacts are likely to be context specific and would not operate equally across different habitats or environments. For example, within the Gamka Karoo, there are extensive tracts of stony ground where vegetation cover rarely exceeds 10%. A 10 m wide gravel road in this area would hardly be noticed by most resident fauna as they are accustomed or adapted to conditions of low vegetation cover. In contrast, vegetation cover in the Sundays Noorsveld or adjacent Thicket communities may be in the order of 80-90%, and in these areas many species would avoid crossing such roads or would be vulnerable to predation when doing so (Figure 7.10). The impacts of noise on the other hand may operate in the other direction as vegetation would dampen noise in the thicket much more quickly than on the open plains and fauna may also be more tolerant of noise in the thicket due to the cover it provides.

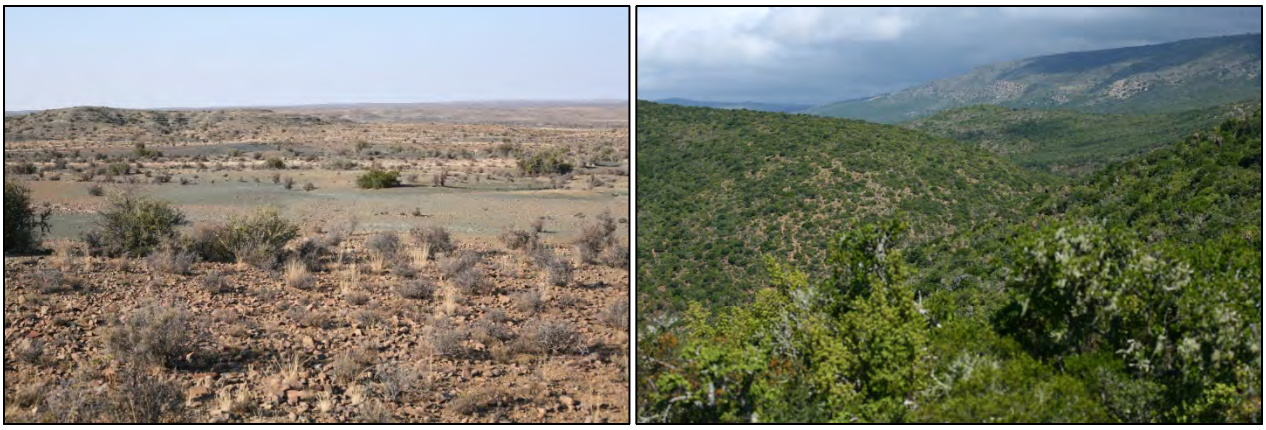

Figure 7.10: The impacts of SGD are likely to be very different in vegetation types with low vegetation cover such as this Gamka Karoo near Laingsburg (left), compared to Thicket vegetation types with a high standing biomass such as this Great Fish Thicket near Riebeeck East (right).

Although it is difficult to predict which species would be impacted and to what extent, where these are ecologically important species, ecosystem-level changes and cascade effects are likely to occur as a result. Although cumulative impacts are identified here as a likely key impact associated with SGD, these impacts are hard to quantify due to the large spatial scales over which they are likely to occur and the difficulty of identifying appropriate indicators for monitoring, compounded by the paucity of knowledge of the potential impacts of such large-scale disturbance in an environment which has not experienced anything like it before.

7.2.4 Capacity gaps for implementation of mitigation measures

The implementation of the strategic approach to mitigation set out in Table 7.2, as well as the specific mitigation measures set out in Table 7.3, assumes the existence of appropriate capacity in a range of organs of state including regulatory authorities. Capacity is currently weak with regard to some of the mitigation measures, and would need to be strengthened in order to support their successful implementation.

A major gap exists in capacity to expand the protected area network to secure EBIS-1 and EBIS-2 areas, either through state-owned and managed protected areas or through contract protected areas in partnership with landowners. This is essential for achieving the strategic landscape-level approach to mitigation set out in Table 7.2. Biodiversity stewardship programmes have a key role to play, as do mechanisms for private entities to purchase land and transfer it to the state along with an annuitised lump sum for management for an agreed period. Both of these provide avenues for the implementation of biodiversity offsets, for which EBIS-1 and EBIS-2 areas are the first-tier and second-tier receiving areas, respectively.

Biodiversity stewardship is an approach to securing land in biodiversity priority areas through entering into agreements with private or communal landowners, led by conservation authorities (SANBI, 2015). Biodiversity stewardship programmes in provincial conservation authorities in the Northern, Eastern and Western Cape currently lack capacity to enter into new agreements with landowners, and to support existing agreements with landowners. The Northern Cape Department of Environment and Nature Conservation (DENC) have recently initiated a biodiversity stewardship programme but this is largely restricted to the Succulent Karoo, and implementation of biodiversity stewardship in the province currently relies heavily on Non-Government Organisation (NGO) support. In CapeNature, the biodiversity stewardship programme is small and its capacity is already fully allocated to supporting existing agreements with landowners. CapeNature also depends on resources from the NGO sector to supplement the implementation of biodiversity stewardship. The Eastern Cape Parks and Tourism Agency (ECPTA) has a small biodiversity stewardship programme, which, despite limited staffing, has recently secured the declaration of a Protected Environment in the Compassberg area of the SGD study area. South African National Parks (SANParks) has active stewardship programmes in the buffer regions around the 5 National Parks in the study area, although the current focus is on the Mountain Zebra to Camdeboo corridor and contractual National Park declarations in the north portions of Addo Elephant National Park.

Recommendations in the recently approved Business Case for Biodiversity Stewardship (SANBI, 2015) provide an excellent starting point for addressing these capacity constraints. Implementation of these recommendations requires proactive support from the DEA and National Treasury to unlock resources for strengthening biodiversity stewardship programmes.

In addition to lack of capacity for expanding the protected area network in EBIS-1 and EBIS-2 areas in support of strategic landscape-level mitigation (Table 7.2), the following gaps exist for implementing the activity-specific mitigation measures proposed in Table 7.3:

At the national level:

- In the DWS:
    - Capacity to issue water use licences, and to monitor and enforce conditions of these licences;

- Capacity to determine and monitor the implementation of the ecological reserve for rivers and wetlands in the study area;
- Capacity to determine and implement Resource Quality Objectives for rivers and wetlands in the study area; and
- Capacity to monitor water quality and aquatic ecosystem condition.

- In DEA:
  - Capacity to evaluate and deal with cumulative impacts across the landscape;
  - Capacity to process EIAs; and
  - Capacity of Environmental Programmes to deal with invasive alien plants.
- In SANParks:
  - Capacity to fully implement biodiversity stewardship in buffer regions around National Parks;
  - Capacity to incorporate biodiversity offset receiving areas into the National Park network.
- In the Department of Mineral Resources (DMR); and
  - Capacity to declare sensitive areas (e.g. EBIS 1 areas) as off-limits for mining and prospecting, using Section 49 regulations of the MPRDA.

At the provincial level:

- In provincial conservation authorities (DENC, CapeNature, ECPTA):
  - Capacity to implement biodiversity stewardship, as discussed above;
  - Capacity to comment on development applications; and
  - Capacity to enforce restrictions on collection of firewood, medicinal plants, or animals with potential for the pet trade.
- In provincial environmental affairs departments (DENC, DEADP, DEDEAT):
  - Capacity to process development applications; and
  - Capacity to monitor and enforce requirements set out in Records of Decision – this is a critical concern, and mitigation should include increasing capacity of provinces in this regard.

At the municipal level:

- Capacity to treat waste water to acceptable limits – this is a critical concern, and mitigation should include increasing capacity of municipalities in this regard;
- Capacity to manage stormwater, including runoff from roads and new infrastructure;
- Capacity to enforce restrictions on off-road driving, including driving in wet conditions and driving at night;
- Capacity to enforce speed limits for vehicles on roads;

- Capacity to develop and implement emergency protocols for dealing with accidents and spills of hazardous materials;
- Capacity to enforce restrictions on movement of shale gas staff into natural areas beyond SGD sites;
- Capacity to accommodate shale gas staff in towns – important for limiting impacts at SGD sites; and
- Capacity to develop Land Use Schemes in terms of the Spatial Planning and Land Use Management Act (SPLUMA) (Act 16 of 2013) – a key mechanism for protection of EBIS-1 and EBIS-2 areas is to zone them appropriately (e.g. conservation) in Land Use Schemes.

Among consultants and specialists:

- Small number of biodiversity specialists (e.g. freshwater ecologists, botanists, zoologists, taxon experts) able to do site assessments and specialist reports for EIAs; and
- Limited capacity at museums, in science councils and universities to assist with identification of material collected in EIAs, especially for animals.

7.3 Risk assessment

This section begins with a brief explanation of how ecologically important and sensitive areas, which form the basis of the risk assessment, were identified. More detail is available in Digital Addendum 7B. It goes on to discuss the approach used for measuring risk, and the limits of acceptable change. It concludes with a risk assessment table which links the areas of EBIS to degrees of risk, with and without mitigation.

7.3.1 Identification of areas of EBIS

A hybrid approach to identifying areas of EBIS was taken, combining multi-criteria analysis with systematic biodiversity planning (also known as systematic conservation planning). The multi-criteria part of the analysis allows for identification of the ecologically important and sensitive areas features in the landscape where the whole feature falls within a specific level of sensitivity or importance (e.g. a riparian area or a buffer around a protected area). However, in landscapes such as the Karoo, where there is a great deal of choice of location for meeting targets for biodiversity features, it is usually not necessary to secure the whole ecosystem or habitat to ensure the ongoing integrity of the area, but nevertheless necessary to ensure that enough area of each feature remains intact. A multi-criteria approach does not allow for the identification of a set of areas which, if secured, would allow Karoo ecosystems, key ecological processes and important species to persist. Hence, a systematic biodiversity planning approach was also applied. This approach, which is widely accepted in South

Africa as best practice for the identification of spatial biodiversity priorities (see Section 7.1.4), aims to identify a set of areas which meets targets for all biodiversity features in a way that is ecologically sustainable, efficient and least conflicting with other activities and land uses. See Cadman et al. (2010) for an explanation of South Africa's systematic approach to prioritising within multi-use landscapes to conserve biodiversity and promote ecosystem resilience.

The biodiversity features on which the analysis was based included the full set of biodiversity pattern features (e.g. the individual habitat types and areas for key species) and ecological process features (e.g. portions of the landscape supporting key ecological process features such as hydrological processes or adaptation to climate change impacts).

Targets were set for the significant biodiversity pattern and ecological process features found within the landscape. These targets refer to the portion of the historical extent of a particular feature which needs to be kept intact in order for that feature to persist into the future. Targets were carefully determined in order to ensure that sufficient of each type of feature was included in the set of areas of EBIS. Targets for ecosystems, species and ecological process areas were set.

The approach aims to identify a *configuration of sites* which is ecologically sustainable. Although the total quantity of each feature is important to ensure that sufficient area is kept intact, in many ways a more important issue is making sure that the prioritised areas are *linked together in an ecologically connected way across the landscape*. It is critical that the individual areas that are identified are connected in a way that allows ecological process to take place at a variety of spatial scales. These scales can range from broad landscape-level linkages which are important for climate change adaptation, through to hydrological processes occurring in catchments and linked groundwater systems, to local-level processes such as pollination or the movement of small mammals. The analysis aims to identify a set of areas which fully secures all these key ecological processes across the landscape.

The set of areas is designed to be *efficient and least conflicting with other land uses*. Where possible, sites are selected which meet targets for a range of biodiversity features rather than just for a single feature. This ensures that the most important areas are selected, and also allows the targets to be met in the smallest possible area. Wherever possible, the analysis also aims to select areas which are in the best possible ecological condition, as these sites are likely to retain the fullest suite of biodiversity features and are more likely to persist into the future than sites in poorer ecological condition.

Importantly, the approach identifies a coherent set of areas which together meet targets for representation of biodiversity and maintenance of ecological processes in an efficient way. A key issue is that this whole identified set of priority areas needs to be kept ecologically intact (via means such as development controls, appropriate zoning in land use scheme, biodiversity offsets, or biodiversity stewardship and other forms of protected area expansion) in order to secure the Karoo's biodiversity against landscape-scale impacts in the remaining areas. Should any of the prioritised areas be lost, ecologically equivalent sites would need to be identified to sufficiently secure biodiversity and ecological integrity. Because the current set of areas of EBIS is as efficient as possible, any loss of these areas would require larger alternate areas to be selected to offset any loss.

The approach is built on the concept of spatial optimisation. Instead of identifying a large number of areas across the landscape with moderate levels of biodiversity importance, which could result in impacts being spread throughout the landscape and could compromise the ecological integrity and functioning of the entire area, an optimal set of areas has been identified. If kept intact, these areas would ensure that the ecological integrity of the Karoo is retained. This set of priority areas contains both irreplaceable sites (i.e. sites for which there is no choice of an equivalent site for meeting the targets for the biodiversity features concerned) and optimal sites (i.e. sites identified through the systematic biodiversity planning process as being the best option for meeting targets). In some cases there is little choice, and although a site is flagged as optimal rather than being truly irreplaceable, few viable alternatives may exist and it may not in practice be possible to find other sites to meet targets. In other cases, viable alternatives may be available and some exchange of sites (e.g. as part of a biodiversity offset process) could be possible.

The analysis builds in the concepts of both ecological *importance* and *sensitivity*. Importance refers to the sites which are most needed for meeting biodiversity targets (in other words are most irreplaceable) while sensitivity refers to sites containing features which are highly vulnerable to disturbance or where recovery is slow.

Four levels of EBIS were identified:

- **EBIS-1** – areas that contain extremely sensitive features, such as key habitat for rare, endemic or threatened species, or features that perform critical ecological functions. These sites are irreplaceable (i.e. no ecologically equivalent sites exist and there is no exchangeability between sites). SGD activities must be avoided in these areas, as impacts of SGD in these areas would undermine the ecological integrity of the Karoo. Ideally these areas should be secured through appropriate zoning, development controls, or protected area expansion through stewardship and other mechanisms.

- **EBIS-2** – areas that contain highly sensitive features and/or features that are important for achieving targets for representing biodiversity and/or maintaining ecological processes. These areas represent the optimal configuration for securing the species, ecosystems and ecological processes of the Karoo. Impacts of SGD in these areas are undesirable, and any impact would need to be offset and ecologically equivalent sites identified to represent the same suite of biodiversity features that were impacted.
- **EBIS-3** – other natural or semi-natural areas that do not contain currently known sensitive or important features, and are not required for meeting targets for representing biodiversity or maintaining ecological processes. Provided that EBIS-1 and EBIS-2 areas are secured, loss of habitat in EBIS-3 areas should not compromise the ability to achieve biodiversity targets in the Karoo, as long as the impacts in EBIS-3 areas do not extend into adjacent areas of higher importance or sensitivity. However, if any impacts occur in EBIS-2 areas, additional sites from EBIS-3 areas may be required as alternatives for representing biodiversity and maintaining ecological processes.
- **EBIS-4** – areas in which there is no remaining natural habitat, e.g. urban areas, larger scale highly degraded areas, large arable intensively farmed lands. SGD activities in these sites should result in minimal biodiversity loss, as long as the impacts do not extend to adjacent EBIS-1 or EBIS-2 areas.

The extent of the study area falling within each of these categories of importance and sensitivity is provided in Table 7.4, a map of the categories is shown in Figure 7.12, and a summary of features included in each category is provided in Table 7.5. See Digital Addendum 7B for more detail on the methodology.

Figure 7.11: Mountainous and topographically heterogeneous areas are generally more diverse for both fauna and flora than the intervening open plains. A significant proportion of the areas identified as being of high importance for biodiversity are mountainous and therefore would tend not to be suitable for SGD.

Table 7.4: Extent of areas of EBIS within the study area (hectares and percentage)

	Extent (Hectares)	Extent (%)
Protected areas	828 191	5
EBIS-1	2 253 544	13
EBIS-2	6 348 763	37
EBIS-3	7 593 740	44
EBIS-4	156 900	1
Total	**17 181 138**	**100**

Table 7.5: Summary of features included in each category of EBIS.

Features included	**Ecological and Biodiversity Importance and Sensitivity (EBIS)**				
	Protected areas	**EBIS-1** Irreplaceable sites (no choice exists)	**EBIS-2** Optimal sites (some choice exists)	**EBIS-3** Sites not required to meet targets	**EBIS-4** No site-specific ecological or biodiversity importance
Biodiversity features	--	• Wetlands, springs (including intact buffers) • Specific sites important for Threatened species and for range-restricted endemic or near-endemic species (fauna and flora) • High priority habitat for Threatened species or for range-restricted endemic or near-endemic species	• Rivers and associated habitats (including intact buffers) • Special habitats e.g. rocky outcrops, escarpment areas, riparian vegetation • Sites selected through a systematic biodiversity planning process to meet targets for terrestrial or aquatic ecosystems in an efficient configuration that aligns with other biodiversity features and priority areas	• Severely modified areas that retain some importance for supporting ecological processes (e.g. agricultural fields within buffers around rivers and wetlands) • Natural habitat which is not irreplaceable and has not been selected as part of the optimal sites	• Areas that have been severely or irreversibly modified and that are not important for supporting provision of ecological processes
Other biodiversity priority areas	• Areas declared or recognised in terms of the Protected Areas Act	--	• Incorporates all Freshwater Ecosystem Priority Areas (FEPAs), both rivers and wetlands • Includes Critical Biodiversity Area One (CBA 1) from relevant provincial biodiversity plans • Buffers around protected areas (intact areas) • UNESCO Biosphere Reserve	--	--

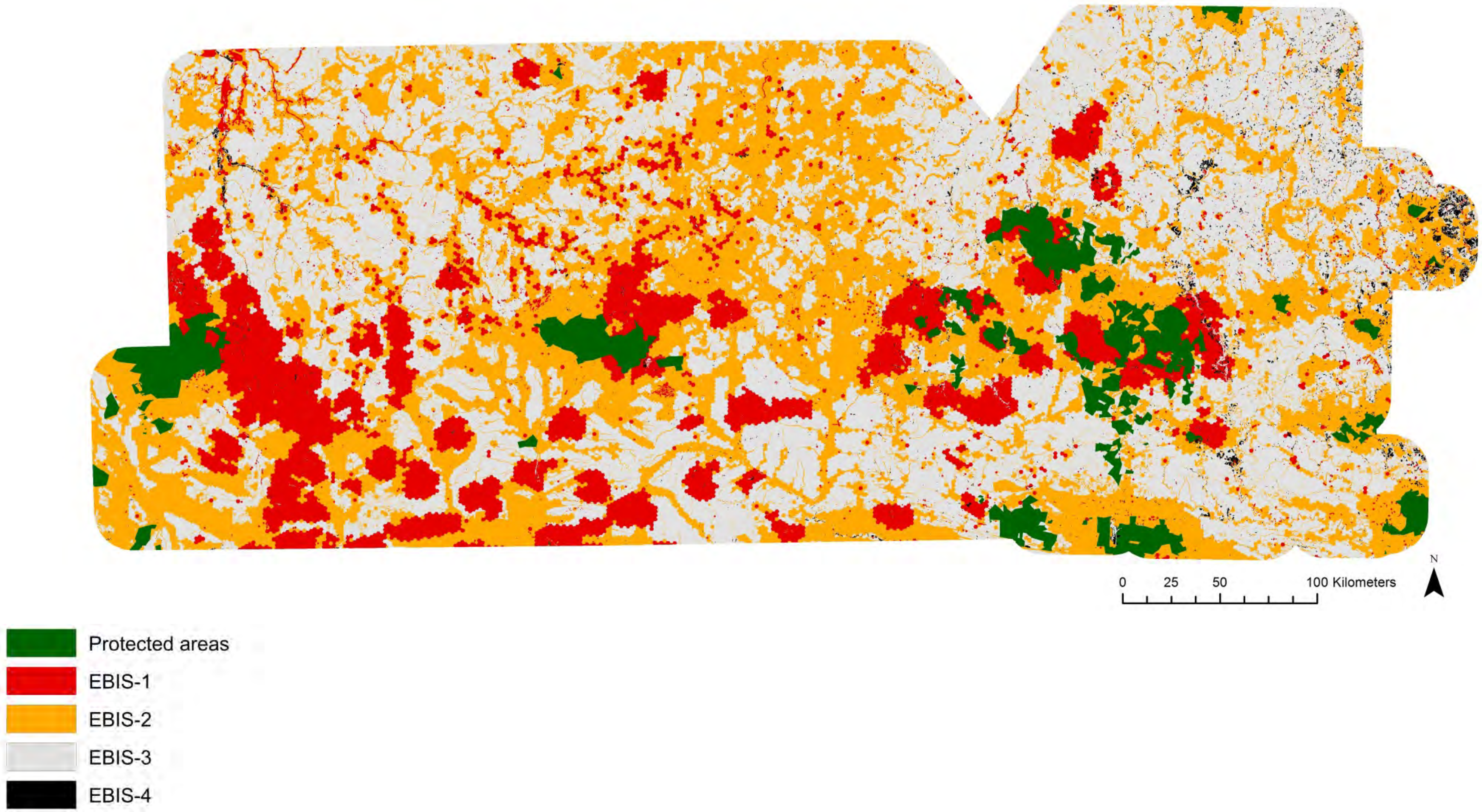

Figure 7.12: Map of Ecological and Biodiversity Importance and Sensitivity (EBIS) in the study area. Protected areas (5% of study area) are legally protected. EBIS-1 areas (13% of study area) contain extremely sensitive features and are irreplaceable. EBIS-2 areas (37% of study area) contain highly sensitive features and/or features that are important for achieving targets for representing biodiversity and/or maintaining ecological processes. Protected areas, EBIS-1 areas and EBIS-2 areas collectively meet targets for representation of biodiversity and maintenance of ecological processes in the study area. EBIS-3 areas (44% of the study area) are natural areas that do not contain currently known sensitive or important features. In EBIS-4 areas (1% of study area) there is no remaining natural habitat.

7.3.2 How the risks are measured

For biodiversity and ecological impacts, risk is measured in terms of disruption of ecological processes, loss or degradation of ecosystems, and/or loss of species. The degree of risk is assessed against targets for maintaining the functioning of all key ecological processes, maintaining a proportion of each ecosystem in good ecological condition, retaining all threatened species, and retaining a representative sample of all endemic or near-endemic species. In measuring and assessing risk, a key focus is on the need to maintain the ecological integrity of the landscape as a whole, rather than simply on retaining individual biodiversity features in and of themselves. Protected areas, EBIS-1 areas and EBIS-2 areas collectively meet targets for representation of biodiversity and maintenance of ecological processes in the study area, in a spatial configuration that ensures connectivity in the landscape. The assessment of risks can therefore be expressed in terms of loss or degradation of these areas.

Opportunity is measured in terms of strengthening protection of ecological processes, ecosystems and species, for example through protected area expansion (including through biodiversity stewardship contracts) and/or biodiversity offsets, especially in EBIS-1 and EBIS-2 areas. It is possible to mitigate almost all impacts in EBIS-2 areas by securing ecologically equivalent sites. This opportunity to mitigate risk through securing sufficient intact areas is a viable and practical approach to dealing with impacts associated with SGD, so long as sufficient areas are properly secured before any large-scale impacts occur, and broad regional impacts of development are carefully managed through the application of robust site-level management procedures even in EBIS-3 and EBIS-4 areas.

7.3.3 Limits of acceptable change

The limits of acceptable change relate to the ability to meet biodiversity targets for ecological processes, ecosystems and species, which underpin the identification of areas of EBIS. As discussed in Section 7.3.1, the identification of these areas is based on targets for biodiversity features relating to biodiversity pattern and ecological processes.

No loss or degradation of EBIS-1 areas is acceptable. These areas are irreplaceable and no ecologically equivalent areas exist for securing the features they contain.

In EBIS-2 areas, loss or degradation is acceptable only if ecologically equivalent sites are identified and secured through biodiversity offsets or equivalent mechanisms. An ecologically equivalent site means a site that contains equivalent ecological processes, ecosystems and species, and that compensates for the full ecological impact of the activity as identified through a detailed study. In addition, loss or degradation of EBIS-2 areas will result in the need to identify additional sites from within EBIS-3 for inclusion in EBIS-2, in order to meet targets for ecological processes, ecosystem and/or species. The limits of acceptable change in EBIS-2 areas are determined by the ability to find ecologically equivalent sites in the remaining intact EBIS-3 areas.

Loss or degradation of In EBIS-3 areas is acceptable, as long as there is no impact on EBIS-1 or EBIS-2 areas. Activities that are authorised in EBIS-3 areas need to be assessed for potential impacts on EBIS-1 or EBIS-2 areas.

In EBIS-4 areas, site-level impacts are not significant from a biodiversity or ecological point of view. Change is acceptable as long as it does not impact on EBIS-1 or EBIS-2 areas.

7.3.4 Risk assessment table

Table 7.7 sets out the assessment of risk for each of the scenarios, based on the consequences and likelihood of occurrence of impacts of SGD, with and without mitigation. The consequence levels used in Table 7.7 have been calibrated based on a series of thresholds, set out in Table 7.6. The thresholds for species are linked to thresholds used in IUCN Red List assessments, and those for ecosystems and ecological processes are linked to thresholds used in national assessments of ecosystem threat status and in biodiversity planning in South Africa.

The assessment of *risk with mitigation* is based strongly on the application of the mitigation hierarchy at the landscape scale, as set out in Section 7.2.3, based on the map of EBIS shown in Figure 7.12. As discussed in Section 7.2.1, the primary mitigation for SGD in the Karoo as a whole is securing the EBIS-1 and EBIS-2 areas, which effectively makes EBIS-3 and EBIS-4 areas available for SGD. This sort of strategic mitigation at the landscape level, in addition to mitigation at the site or operational level is essential in order to reduce risk levels.

EBIS-1 and EBIS-2 areas need to be retained in a natural state and secured through appropriate zoning or legal mechanisms that limit habitat loss or degradation in these areas. As long as EBIS-1 and EBIS2 areas have been secured, overall ecological integrity and retention of the biodiversity value of Karoo ecosystems would be ensured. Subject to reasonable on-site operating rules to reduce unnecessary impacts, and careful minimisation of any broader impacts on adjacent EBIS-1 and EBIS-2 areas, biodiversity loss within EBIS-3 areas could be absorbed without compromising the overall function and integrity of the Karoo ecosystem as a whole. Impacts restricted to EBIS-4 areas are unlikely to be of ecological significance.

Table 7.7 shows that under the Big Gas scenario *without mitigation*, the risk is very high for EBIS-1 areas and high for EBIS-2 areas – it is very likely that there would be impacts with extreme consequences for the biodiversity and ecological features in EBIS-1 areas and severe consequences for those in EBIS-2 areas. *With mitigation*, the risk is reduced to moderate. Although there is no change in the consequence level of impacts in EBIS-1 and EBIS-2 areas, the likelihood of occurrence of these impacts is substantially reduced, as mitigation requires avoiding SGD activities altogether in EBIS-1 areas and avoiding or offsetting impacts in EBIS-2 areas. *This strategic form of mitigation at the landscape level allows for the risks of SGD to be reduced to moderate levels even under a Big Gas scenario*.

Figure 7.13 presents a risk map of impacts on ecology and biodiversity across four SGD scenarios, with and without mitigation.

The same logic applies under the Small Gas scenario where risk levels *with mitigation* are moderate for EBIS-1 areas and low for EBIS-2 areas. Under the Exploration Only scenario *with mitigation*, EBIS-1 areas must be avoided altogether, and impacts in EBIS-2 areas must be minimised with thorough application of the strategic mitigation measures set out in Table 7.2, resulting in very low risk levels.

Risk levels drop off rapidly as one moves away from EBIS-1 and EBIS-2 areas, emphasising the importance of locating infrastructure and activities associated with SGD outside of these areas.

Table 7.6: Consequence levels used in the risk assessment, with thresholds for species, ecosystems and ecological processes. Thresholds for species are linked to thresholds used in IUCN Red List assessments, and those for ecosystems and ecological processes are linked to thresholds used in national assessments of ecosystem threat status and in biodiversity planning in South Africa.

	Consequence level →	**Slight**	**Moderate**	**Substantial**	**Severe**	**Extreme**
	Impact ↓					
Species of special concern	Reduction in population or occupied area*	<20% (Least Concern, LC)	20-30% (Near Threatened, NT)	30-50% (Vulnerable, VU)	50-80% (Endangered, EN)	80-100% (Critically Endangered, CR)
Ecosystems (habitat types)	Reduction in intact area**	<20% (Least Threatened, LT)	20-40% (Least Threatened, LT)	40-60% (Vulnerable, VU)	60-80% (Endangered, EN)	80-100% (Critically Endangered, CR)
Ecological processes	Disruption of ecological functioning***	<20%	20-40%	40-60%	60-80%	80-100%

* In relation to national distribution (except for keystone species – in relation to study area).
** In relation to national distribution.
*** In relation to their functioning within the study area.

Table 7.7: Risk assessment table which sets out the assessment of risk for each of the scenarios, with and without mitigation. No SGD takes place in the Reference Case scenario, while limited shale gas production takes place in the Small Gas scenario, and extensive SGD takes place in the Big Gas scenario.

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Ecological and biodiversity impacts	Reference Case	In EBIS-1 areas	Slight	Likely	Very low	Slight	Likely	Very low
	Exploration Only		Moderate	Likely	Low	Slight	Not likely (mitigation = avoid)	Very low
	Small Gas		Severe	Likely	High	Severe	Not likely (mitigation = avoid)	Moderate
	Big Gas		Extreme	Very Likely	Very high	Extreme	Not likely (mitigation = avoid)	Moderate
	Reference Case	In EBIS-2 areas	Slight	Likely	Very low	Slight	Likely	Very low
	Exploration Only		Moderate	Likely	Low	Slight	Likely	Very low
	Small Gas		Substantial	Likely	Moderate	Substantial	Not likely (mitigation = avoid or offset)	Low
	Big Gas		Severe	Very likely	High	Severe	Not likely (mitigation = avoid or offset)	Moderate
	Reference Case	In EBIS-3 areas	Slight	Likely	Very low	Slight	Likely	Very low
	Exploration Only		Slight	Likely	Very low	Slight	Likely	Very low
	Small Gas		Slight	Likely	Very low	Slight	Likely	Very low
	Big Gas		Moderate	Very likely	Low	Moderate	Likely	Low risk
	Reference Case	In EBIS-4 areas	Slight	Likely	Very low	Slight	Likely	Very low
	Exploration Only		Slight	Likely	Very low	Slight	Likely	Very low
	Small Gas		Slight	Likely	Very low	Slight	Likely	Very low
	Big Gas		Slight	Likely	Very low	Slight	Likely	Very low

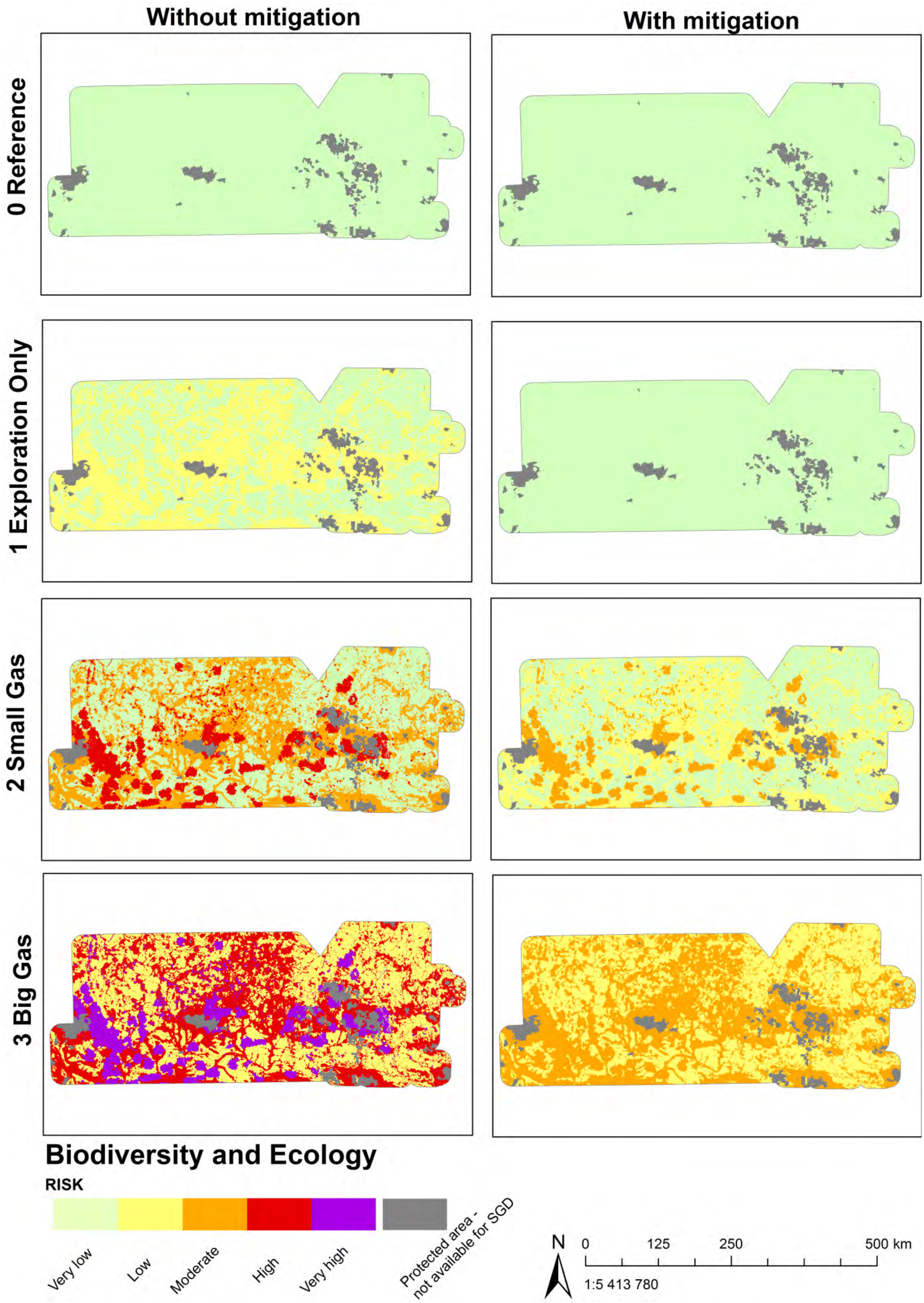

Figure 7.13: Map indicating the risk to ecology and biodiversity across four SGD scenarios, with- and without mitigation.

In summary:

EBIS-1 areas are irreplaceable. Any SGD-related activities in these areas are assessed as very high risk. Impacts in these areas would undermine the ecological integrity of the study area (and more broadly the Karoo).

The primary mitigation for SGD is securing EBIS-1 and EBIS-2 areas, which effectively makes EBIS-3 and EBIS-4 areas available for development. Strategic mitigation at the landscape level, involving avoidance and securing of EBIS-1 and EBIS-2 areas, is essential as the impacts of SGD cannot be effectively mitigated on-site or at the operational level.

EBIS-1 and EBIS-2 areas make up an estimated 50% of the study area. Loss or degradation of habitat in these areas must be avoided, and they should be secured through appropriate legal mechanisms. This may involve formal protected area declaration (including through biodiversity stewardship agreements), but can include other types of stewardship, protection under Section 49 of the MPRDA, appropriate designation in a land use scheme, or protection through other legal means. Securing EBIS-1 and EBIS-2 areas may lend itself to a fast-tracked, integrated protected area expansion strategy, similar to Operation Phakisa in the marine environment.

Where impacts in EBIS-2 areas are unavoidable, these should be offset by securing ecologically equivalent sites. Appropriate national and provincial biodiversity offset guidelines and methodologies should be applied to ensure no net loss.

Environmental compliance in EBIS-3 and EBIS-4 areas is still required. This includes specialist-led assessment of local sensitivities and identification of appropriate mitigation and it is necessary in order to ground-truth desktop assessments and avoid unnecessary impacts. Specific impacts are discussed in Section 7.2.1 and monitoring requirements are discussed in Section 7.4.

7.4 Best practice guidelines and monitoring requirements

7.4.1 Best practice guidelines

Best practice guidelines for SGD are captured broadly in the strategic mitigation measures set out in Table 7.2 as well as in the activity-specific mitigation measures set out in Table 7.3. In many cases, more detail on the application of activity-specific mitigation measures, especially those dealing with minimising or rehabilitating impacts, must be specified at the EIA stage. Detailed requirements for site-level monitoring should also be specified at the EIA stage, related to the specific characteristics of the receiving environment.

EIAs for SGD projects should include Biodiversity Specialist Studies, with more comprehensive studies required at higher levels of EBIS. Best practice guidelines for Biodiversity Specialist Studies within EIAs are outlined in Brownlie (2005) and De Villiers et al. (2005). EBIS-1 areas should be avoided altogether for SGD. This recommendation notwithstanding, should an SGD application go ahead in an EBIS-1 area, the highest level (i.e. most comprehensive) Biodiversity Specialist Study would be required. In EBIS-2 areas, the highest level of Biodiversity Specialist Study is required. In EBIS-3 areas, a less comprehensive Biodiversity Specialist Study is required. In EBIS-4 areas, the lowest level of Biodiversity Specialist Study is required. *If SGD takes place in the study area, specific guidelines for different levels of Biodiversity Specialist Study for EIAs for SGD should be developed,* equivalent to those developed as part of the recent SEA for Wind and Solar Energy (DEA, 2015b).

In addition, the Mining & Biodiversity Guideline (DEA et al., 2013) provides guidance on best practices for integrating biodiversity considerations in mining EIAs, and for managing impacts on biodiversity at different stages of the mining life cycle, from exploration through to closure.

7.4.2 Monitoring requirements

7.4.2.1 Summary of monitoring requirements and institutional arrangements

Monitoring is essential for assessing the impacts associated with SGD at the landscape, ecosystem and species level, and for informing appropriate responses. Monitoring should be linked to the biodiversity targets and limits of acceptable change which are discussed in Section 7.3, and should thus focus on species of special concern, ecosystems or habitat types, and ecological processes. In addition, because of the importance of cumulative impacts at the landscape scale in the context of the Karoo (see Section 7.2.2), monitoring should also take place at the landscape level.

Monitoring requirements from the species level through to the landscape level, including indicators and responsibilities, are summarised in Table 7.8, followed by more detailed recommendations on indicator species. Monitoring requirements do not change dramatically across the phases of SGD. This is because SGD is not distinctly partitioned and, apart from exploration, multiple phases of activity from well establishment to production happen concurrently in an SGD block.

In addition to monitoring once activities associated with SGD are underway, there is a need for baseline monitoring to establish reliable baselines for the study area. This is especially important given the large information gaps on many aspects of the biodiversity and ecology of the area (as discussed in Section 7.5). Depending on the natural variability of the variable of concern, as much as five years' worth of data could be required to establish a reliable baseline, against which trends during and after SGD can be evaluated. This is particularly important in the ephemeral aquatic ecosystems which characterise the Karoo, as they have a high intrinsic variability in terms of aquatic community responses to inundation patterns.

Institutional arrangements and responsibilities are fundamental to the success of monitoring efforts. There is a need for independent monitoring by third parties, not just monitoring by the SGD companies themselves. This will generally be led by government. SGD companies could be required to contribute to the cost of such government-led monitoring in proportion to the scale of their activities.

As highlighted in Table 7.8, the responsibility for SGD-related monitoring is shared across several organisations. These include the South African Environmental Observation Network (SAEON), which has an important role in landscape-level monitoring and maintaining benchmark sites for the evaluation of SGD impacts, as well as SANBI, provincial conservation authorities and DWS. Some of the capacity gaps discussed in Section 7.2.4 relate to monitoring requirements, and these would need to be addressed. In some cases there is potential for NGOs to play a vital supporting role.

It is important for SGD-related monitoring efforts to be co-ordinated. This requires an organ of state to convene the different organisations, researchers and other partners involved in monitoring, and SAEON may have a role to play in this regard. In addition, a system or process should be in place for integrating monitoring data from the site level, the ecosystem level and the landscape level into a coherent set of information for the study area as a whole, which can be used to inform planning and decision-making. Information from monitoring should feed into SANBI's programme of monitoring and reporting on the state of biodiversity nationally.

Table 7.8: Monitoring requirements at the landscape, ecosystem, species and site level, including indicators and responsibilities.

Feature of concern	Impact of concern	Indicator(s) (WHAT)	Selection of monitoring sites (WHERE)	Approach (HOW)	Responsibility (WHO)	Phase
Landscape-level	Loss of overall ecological integrity	- Progress in securing EBIS-1 and EBIS-2 areas through formal protection - Landscape-scale fragmentation relative to baseline prior to SGD (metric to be determined)	- Across whole study area - Across whole study area	- Based on protected area data, annually - Using aerial or satellite imagery or other appropriate data, annually	- DEA, SANBI - SAEON	Baseline Planning Construction Operations Decommissioning Monitoring and Evaluation (M&E) (post-closure)
Aquatic ecosystems and ecological processes	Loss of wetland extent and disruption of ecological functioning	- Assessment of changes in baseline extent of wetlands, watercourses and riparian areas	- Key wetlands, watercourses and riparian areas to be identified from EBIS map, representative of all aquatic ecosystem types in study area	- Desktop assessment to be done annually, using National Wetland/ Rivers Map as baseline, and aerial or satellite imagery for comparison.	- DWS, in collaboration with provincial conservation authorities	Baseline Planning Construction Operations Decommissioning M&E (post-closure)
Terrestrial ecosystems/ habitat types	Reduction in intact area	- Extent of each ecosystem/ habitat type still intact relative to baseline prior to SGD	- All habitat types in study area, including special habitats (e.g. quartz patches)	- Based on land cover data and other data on ecological condition, annually	- SANBI, SAEON	Baseline Planning Construction Operations Decommissioning M&E (post-closure)

Feature of concern	Impact of concern	Indicator(s) (WHAT)	Selection of monitoring sites (WHERE)	Approach (HOW)	Responsibility (WHO)	Phase
Species of special concern	Reduction in numbers or distribution	- Densities and distribution of indicator species – see recommended species below	- Species-dependent	- Various e.g. mark-recapture studies, camera trapping, fixed effort counts - Timing depends on species	- Conservation authorities - NGOs - Citizen science programmes	Baseline Planning Construction Operations Decommissioning M&E (post-closure)
Site-level monitoring	Compliance with mitigation measures	- Various, depending on the mitigation measure concerned - More detail to be specified in EIA	- All areas with SGD activities - In many cases important to include control sites as well as impact sites - More detail to be specified in EIA	- Various, depending on the mitigation measure concerned - Depends on measure being monitored - More detail to be specified in EIA	- Shale gas companies (Environmental Compliance Officers) - Provincial environmental affairs departments	Construction Operations Decommissioning

7.4.2.2 Recommended indicator species for monitoring

Although within any particular area or region of the Karoo, there are specific species of conservation concern that should be monitored to ensure that they are not impacted by SGD, there are also some more widespread species prevalent across large parts of the Karoo, which by dint of their ecological role or specific characteristics lend themselves to monitoring. These are briefly described below with reference to the type of issues or processes that these species represent. The advantage of using these more common and widespread species for monitoring is firstly, that impacts of SGD can be compared across regions or areas of different SGD intensity and secondly, these species are common and as such it should be more practical or feasible to monitor their abundance and response to SGD and thirdly, these species have been identified as being important or indicative of certain impacts due to their specific characteristics or vulnerabilities.

- **Tortoises** are widespread across the Karoo and are vulnerable to roadkill as well as illegal collection for food or trade. Tortoises are not highly mobile and as such, are representative of the local area equivalent to their home range, up to around 100 ha for the Leopard Tortoise, *Stigmochelys pardalis* (McMaster & Downs 2009). Tortoise movement and abundance is relatively easily assessed through radio tracking as well as mark-recapture studies and due to their longevity, lend themselves to long-term monitoring. As tortoises are present across the whole SGD area, they are identified as potentially good indicators of SGD impact across the whole study area.

- **Aardvark** are relatively wide ranging with average home ranges of 3.5 km^2 (van Aarde et al. 1992) and occur across the entire SGD area. This species is considered especially important as it creates fine-scale disturbance which is important for vegetation dynamics in arid ecosystems and its disused burrows are also used by a wide variety of other organisms including Ant-eating Chat, Porcupine, Aardwolf, tortoises, foxes, and various other small mammals and birds. As it has a moderately-sized home range, it is indicative of processes operating at the farm level and probably occurs at a relatively low but consistent density across the Karoo. This species is likely to be vulnerable to disturbance, poaching and roadkill and as it is generally not persecuted by farmers.

- Other animals of potential importance for monitoring include **Bat-eared Foxes**, which are particularly vulnerable to roadkill; Steenbok, which are common, widely distributed small antelope vulnerable to poaching; Riverine Rabbits which are Critically Endangered and indicative of riparian vegetation condition within the Central Karoo. **Kudu** are not present across the whole study area, but occupy the majority of the east and central part of the study area. Kudu are wide-ranging and not restricted by standard livestock fencing and tend to avoid noise and disturbance. As such they are likely to be good indicators of disturbance impacts on sensitive species.

The above examples focus largely on fauna, but there are likely a range of **plant species** that are also useful indicators, but these vary more across the study area and as such, there are likely to be a number of such species that would be useful depending on the exact location of SGD activity. Species that are likely to be useful indicators are species that are habitat specialists or are used for medicinal purposes or sought after by collectors. Potential target species include *Boophone disticha*, *Pelagonium sidoides*, the various cycads that occur within the study area, *Dioscorea elephantipes*, *Gasteria* spp. *Euphorbia* spp. and *Pleiospilos* spp. and other dwarf succulents.

Our limited knowledge of the **species that inhabit the aquatic ecosystems** of the more arid parts of the SGD study area, their ranges, population sizes, and habitat requirements, is a constraint on the determination of the best aquatic indicator species. In the absence of spatially comprehensive records of aquatic faunal species, assessments of the condition of aquatic ecosystems in South Africa tend to focus more on community composition at a taxonomic level higher than species. Knowledge of the distribution, densities and sensitivity of key indicator species is limited. This is particularly so for lentic (non-flowing water) species, and those that occur in the ephemeral aquatic ecosystems characteristic of the more arid parts of the study area. The collection of baseline data from these ecosystems is essential for the determination of indicator species. For instance, diatoms, which occur in wetlands and in rivers and are biotic indicators in comprehensive Ecological Reserve studies, can be collected and identified during the dry or wet phases, and are possibly good indicators of disturbance (Taylor et al., 2007). Zooplanktonic groups hatch and breed rapidly after the inundation of wetlands and rivers, and the succession of species throughout the wet phase are likely to respond to changes in water quality and quantity.

In the more mesic parts of the study area, sensitive **fish species** such as the Eastern Cape Redfin, *Pseudobarbus afer*; the Cape Rocky, *Sandelia bainsii; Barbus trevelyani*; *Pseudobarbus asper* and the Amatola Barb, *Barbus amatolicus*, are likely to be good indicators of changes in water quality and quantity in watercourses. The sensitive damselfly species, the Kubusi stream-damsel, *Metacnemis valida*, and the Basking malachite, *Chlorolestes apricans* are also restricted species that should be monitored. Several other riverine macro-invertebrate families, such as the Heptageniid mayflies and Notonemourid stoneflies, are known to be sensitive to deterioration in water quality and are thus suitable indicator species in perennial rivers, where their distribution is well documented.

7.4.2.3 Monitoring standards & approaches

The overall aim and purpose of monitoring shale gas activities in the Karoo should be to minimise, control and mitigate the impacts associated with SGD (Esterhuyse et al., 2014). As such, it is critical that monitoring is based on reliable baseline data as well as explicit statements on limits of acceptable change and the actions that should be taken when these limits are breached (Lindenmayer et al., 2013). However, there is a high risk that monitoring programs will fail to detect when a threshold has been breached and a consequent failure to implement interventions timeously. Consequently, monitoring programs must explicitly evaluate their ability to actually detect directional change against the backdrop of the high natural variability of arid systems (Fairweather, 1991). This ability needs to conform to a predefined standard and inform the intensity of monitoring required. As the natural variability of a system will influence how many samples are required to achieve the desired level of statistical power, the specific details of the required sample sizes will only become apparent with baseline monitoring. Using the initial results of baseline studies to define the final sampling protocol to be used in the long-term, is one of the most important aspects of adaptive management that should be implemented for monitoring SGD. Exactly what the desired thresholds for the statistical power of a monitoring program should be, cannot be defined here, but must represent a compromise between sampling effort and the consequences of failing to detect a decline beyond a certain specified threshold. For species of high conservation concern or significant ecological role, the bar should be set higher than for less important species or processes. By way of example, for a species of significant concern, a monitoring program could implement a level of sampling intensity that would provide a 75% chance of detecting a 30% drop in the population and a 90% chance of detecting a 50% drop, whichever yields the greatest sample effort. The thresholds used would correspond to those limits of acceptable change defined in Table 7.6.

Ultimately for monitoring to inform management and policy, it must be question driven, and if one is to identify potential interventions triggered when limits of acceptable change are breached, then these have to be underpinned by conceptual models of how the system works (Lindenmayer & Likens, 2010). In the context of the Karoo there are many unknown variables, and a coordinated approach is required to address the fundamental knowledge gaps in the face of SGD. Furthermore, in order to ensure that cumulative and emergent impacts are not overlooked through single SGD applications, an over-arching research and monitoring agenda should be developed. Salient variables, indicators and approaches are listed below in Table 7.9. Through the monitoring and study of these variables, the impacts of SGD can be better understood and more effective mitigation and avoidance measures developed and implemented.

Table 7.9: Additional information on species and features that could be monitored, with indicators and possible study approaches. Ideally a basket of indicators selected from each level of the hierarchy should be used in an integrated way, based on the characteristics of the receiving environment and assessed risks and impacts for that area.

Target	Examples of target taxa/features	Indicators	Sample approaches
Species	• Local endemics • Threatened species • Ecologically important species	• Density • Sub-population numbers • Age-structure • Reproductive success	• Mark-recapture studies • Camera trapping • Fixed-effort counts • Repeat photography • Roadkill/mortality counts
Habitats	• Quartz patches • Pans • Drainage lines • Localised habitats and landscape features	• Extent • Counts • Composition • Diversity	• Fine-scale mapping • Repeat photography • Fixed plots
Terrestrial ecosystems	• Vegetation types • Broad plant communities • Medium- to large faunal community	• Extent • Fragmentation • Diversity • Predator-prey ratios • Grazing pressure	• Remote sensing/satellite imagery • Camera trapping • Collars/satellite tracking • Fixed plots
Aquatic ecosystems	• Water-dependent ecosystems • Riparian vegetation • Pans • Aquatic fauna	• Discharge (rivers) • Water depth (wetlands) • Silt loads in rivers • Water quality • Stream flow • Topsoil loss rates & distribution • Species presence/absence/abundance • South African Scoring System	• Vadose zone monitoring • Fixed riparian plots • Flow rates of springs • Rapid Habitat Assessment Method or Index of Habitat Integrity (rivers) • EcoStatus indicators (rivers: riparian vegetation, invertebrates, fish), • WET-Health (wetlands: geomorphology, hydrology, vegetation)
Broad-scale processes	• Wide-ranging mammals • Large birds • Predators	• Dispersal • Connectivity • Gene flow	• Mark-recapture • DNA studies • Collars/satellite tracking

7.5 Gaps in knowledge

The map of EBIS and the overall assessment presented in this assessment are based on the best available data. However, data gaps and limitations remain, especially in relation to species information, impacts on ecological infrastructure, understanding of complex ecological interactions and feedback including trophic cascades, and knowledge of distributions of key features such as wetlands and groundwater dependent ecosystems. Given these uncertainties; use of the precautionary principle when making decisions about SGD is recommended.

In general, species occurrence data are fragmented across several different collection institutions (e.g. museums, South African Institute for Aquatic Biodiversity (SAIAB), Agricultural Research Council (ARC)), different formats are used for the data, and for locality data the levels of accuracy for co-ordinates vary. The exceptions to this are where SANBI or other Threatened Species projects have compiled integrated datasets across institutions, and cleaned and geo-referenced these. This is the case for reptiles and butterflies, and threatened and restricted range plants. There is only a limited amount of data for the area in general and it is under sampled for all taxa. This limits data availability and usefulness for the SGD scientific assessment. There is also incomplete knowledge of ecological requirements of many species of special concern, as well as interactions, cascading effects and impacts on processes. Should SGD proceed, it will be critical to improve the comprehensiveness and coverage of data on threatened- and keystone species.

The map of wetlands used in this assessment is based on the National Wetland Map (2011 version), which was edited and supplemented by limited newly digitised wetland data from SPOT imagery, as well as newly available data on dry river beds. However, there are still gaps in the map of wetlands. Data on hydrological areas are inconsistent across the study area, and ideally data quality should be improved. At such time as the National Wetland Map is updated, the new map should be used to revise the identification of areas of EBIS.

These data limitations mean that the current map of EBIS is appropriate for broad-scale planning, but not for fine-scale identification of sensitive features that may be present at a particular site. As such, the map provided here does not negate the need for specialist input when development is proposed or is taking place at a site level. Within any particular area, there are likely to be sensitive habitats and species present and specialist input should be obtained for any shale gas-related development, and mitigation and avoidance measures should be implemented as appropriate. This may require additional mapping of sensitive features at a fine scale (e.g. 1:10 000) to support EIA and local-level decision-making processes.

In addition to these data limitations in relation to the map of EBIS, there are limitations with regard to knowledge of the potential impacts of SGD on biodiversity and ecology. Impacts related to SGD are not well known anywhere in the world and completely unknown in South Africa. As a result, many of the presumed impacts are based on theoretical considerations and impacts associated with other similar industries. However, factors that make SGD unique and different from most other typical forms of development include the following:

- The very high traffic volumes that are required to bring the large amount of material that is required for SGD to site on a continuous basis. This may result in long-term impacts on and declines in sensitive species. As there are various different avenues by which traffic can generate impact, such as through noise, vibration, direct disturbance, and collision, it is difficult to predict the identity and severity of impact on all affected species.
- The potential extent and dispersed nature of SGD is comparatively large relative to other types of development that could take place in the Karoo. As a result, many impacts that would otherwise be confined to a small area may occur over a broad area and the cumulative impact of this may be large. Furthermore, some impacts such as disturbance or noise may extend well beyond the footprint of the development itself, and when the development occurs in a dispersed manner across the landscape as in SGD there may be few refuges remaining for sensitive species. There is also poor knowledge about specific species' responses to impacts (e.g. light impacts on nocturnal species and communities, and soil vibrations impact on ground-living species).

Another key knowledge gap is the lack of a conceptual model of the relationships between groundwater, aquatic ecosystems and climate in the study area. Monitoring is needed to collect information for baselines and trends in this regard. This means that there is not yet sufficient knowledge to set critical thresholds for abstraction and pollution of groundwater in relation to impacts on surface water ecosystems. This is also highlighted in Hobbs et al. (2016).

The above limitations notwithstanding the map of EBIS and accompanying risk assessment table (Table 7.7), together with the recommended mitigation measures, constitute a sound resource for limiting the impacts of SGD on the biodiversity and ecology of the Karoo. In addition, use of the precautionary principle when making decisions on SGD is recommended. The knowledge gaps discussed above reinforce the importance of securing EBIS-1 and EBIS-2 areas to ensure that, even if there are significant unforeseen impacts in the areas which are developed, the overall functioning and ecological integrity of the Karoo is maintained.

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7.8 Digital Addenda 7A – 7B

SEPARATE DIGITAL DOCUMENT

Digital Addendum 7A: Species of special concern in the study area

Digital Addendum 7B: Methodology used to identify areas of Ecological and Biodiversity Importance and Sensitivity (EBIS)

DIGITAL ADDENDA 7A – 7B

Digital Addendum 7A: Species of special concern in the study area

Table 7.1: Animal species of special concern in the study area (i.e. animal species that have more than 60% of their distribution in the study area, or that occur in the study area and are Threatened according to IUCN Red List criteria)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
Mammalia	***Bunlolagus monticularis***	Riverine Rabbit	Northern and Western Cape: only distributed in Central and south Karoo	Riparian bush on the narrow alluvial fringe of seasonally dry watercourses in the central Karoo.	SA Endemic and largely endemic to study area	**Critically Endangered** (global assessment: IUCN, 2008)
Mammalia	***Chlorotalpa sclateri shortridgei***	Sclater's Golden Mole	South Africa and Lesotho. Subspecies known only from Sutherland, but may range eastwards to Beaufort West.	Escarpment Mountain Renosterveld.	SA and Lesotho endemic, **subspecies a SA endemic and endemic to study area**.	**Least Concern** (global assessment: IUCN, 2015)
Mammalia	***Elephantulus pilicaudus***	Karoo Rock Sengi	Endemic to the Upper and Lower Karoo Bioregions of the Nama-Karoo, including Williston, Karoo National Park, Carnarvon, Calvinia, Loxton. Distribution not well understood.	Rocky habitat with an elevation of ≥ 1,300 m above sea level.	SA endemic, **may be a narrow endemic**	**Data Deficient** (global assessment: IUCN, 2013) **Least Concern** (national assessment, 2016)
Mammalia	***Felis nigripes***	Black-footed Cat	Found mainly in the Nama- and Succulent Karoo biomes but also in southern North West and Gauteng, marginally in Mpumalanga and KwaZulu-Natal, Free State, Northern Cape, Western Cape and Eastern Cape	Open habitat that provides some cover in the form of stands of tall grass or scrub bush. Use disused springhare or aardvark burrows or dens under calcrete slabs, or hollowed out termite mounds in which to lie up during the day.	Southern African endemic, in Botswana, Namibia and SA.	**Vulnerable** (global assessment: IUCN, 2016 and national assessment, 2016)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
Mammalia	***Mystromys albicaudatus***	White-tailed Mouse	Relatively widespread in South Africa: eastern North West, Gauteng, southern Mpumalanga, western high-lying KwaZulu-Natal, Free State, Eastern Cape and Western Cape.	They are generally, but not always, associated with grasslands, occurring in the fynbos and the Karoo and rocky areas	South African endemic	**Endangered** (global assessment, IUCN, 2008); **Vulnerable** (national assessment, 2016)
Mammalia	***Otomys unisulcatus***	Karoo Bush Rat	South Africa, with small intrusion into southern Namibia. Distributed widely from the Western Cape eastwards to western Eastern Cape and north through the Northern Cape.	Shrub and fynbos in areas with rocky outcrops and high plant cover and foliage density.	Near SA endemic, with approx. **60% of distribution in study area**	**Least Concern** (IUCN, 2008 assessment)
Mammalia	***Panthera pardus***	Leopard	Africa and Asia (may be different subspecies)	In a wide range of habitats but mainly associated with rocky outcrops and hills, mountain ranges.		**Vulnerable** (global assessment: IUCN, 2016 and national assessment, 2016)
Aves (Birds)	***Afrotis afra***	Southern Black Korhaan	South Africa, Swaziland and Lesotho. In Albany Thicket, Fynbos and Succulent Karoo biomes and the southern extreme of the Nama Karoo.	Fynbos, mainly Renosterveld and Strandveld. Prefers undisturbed habitat.	Southern African endemic	**Vulnerable** (2015 regional assessment)
Aves (Birds)	***Aquila rapax***	Tawny Eagle	Widespread throughout sub-Saharan Africa, with a small population in the grassy Karoo.	Lightly wooded savanna and thornveld and semi-desert. Mostly in protected areas.	African endemic.	**Endangered** (2015 regional assessment)
Aves (Birds)	***Aquila verreauxii***	Verreauxs' Eagle	Wide distribution throughout Africa; in South Africa across 5 biomes, but restricted to mountainous habitat; large areas of high density in study area.	Mainly restricted to mountainous terrain. May use pylons in Karoo for nesting.	African endemic.	**Vulnerable** (2015 regional assessment)
Aves (Birds)	***Ciconia nigra***	Black stork	Breeds widely in Palaearctic region and is a partial migrant in sub-Saharan Africa. In South Africa mostly in southern and eastern provinces, avoiding the dry interior and west.	Dams and shallow waterbodies with fish.		**Vulnerable** (2015 regional assessment)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
Aves (Birds)	***Circus maurus***	Black Harrier	South Africa. Core of range in Fynbos, but does extend to the southern reaches of the Karoo.	Mostly fynbos. In fragmented Renosterveld prefers high quality patches. Forages in high altitude grasslands, down to Karoo scrub.	SA endemic	**Endangered** (2015 regional assessment)
Aves (Birds)	***Cursorius rufus***	Burchell's Courser	Southern Africa, present in the Karoo.	Open desert and semi-desert areas. Habitats include grazed or burnt grassland, stony or gravel plains, dry river beds and edges of salt pans.	Near endemic to southern Africa.	**Vulnerable** (2015 regional assessment)
Aves (Birds)	***Gyps coprotheres***	Cape Vulture	Southern Africa, predominantly South Africa and Lesotho. Breeding colonies in Limpopo, North West and Gauteng, KwaZulu-Natal and Eastern Cape.		Southern African endemic.	**Endangered** (global assessment, IUCN, 2015, and 2015 regional assessment)
Aves (Birds)	***Neotis denhami***	Denham's Bustard	Wide but fragmented Afrotropical distribution. In the study area mostly in Eastern Cape grassland and lowland fynbos.	Generally avoid drier areas, but do occasionally occur marginally in Nama Karoo. Often in rocky areas and on plateaus. Occasionally use cultivated fields.	African endemic.	**Vulnerable** (2015 regional assessment)
Aves (Birds)	***Phragmacia substriata***	Namaqua warbler	South Africa and Namibia. Lower and mid Orange River, south to karroid regions of Western Cape, and central Free State and Eastern Cape.	Very specific habitat requirements - seldom more than 50 m from streams and rivers.	SA endemic with small intrusion in extreme southern Namibia. More than 60% of distribution in study area.	**Least Concern** (2014 SARC assessment)
Aves (Birds)	***Podica senegalensis***	African Finfoot	Throughout central and western Africa; mostly in Limpopo and Mpumalanga and KwaZulu-Natal, but are populations recorded in the Eastern Cape in the study area.	Perennial rivers or streams lined by thick riparian bush.	African endemic.	**Vulnerable** (2015 regional assessment)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
Aves (Birds)	***Sagittarius serpentarius***	Secretary Bird	Widespread throughout sub-Saharan Africa, mostly in open grassland and scrub.	Open grassland and scrub, with short ground cover and scattered trees for nesting.	African endemic.	**Vulnerable** (2015 regional assessment)
Aves (Birds)	***Stephanoaetus coronatus***	Crowned Eagle	Widespread throughout sub-Saharan Africa with high densities observed in the Somerset East area.	Mostly forest, including riverine forest but also woodlands and forested gorge sin savanna and grassland.	African endemic.	**Vulnerable** (2015 regional assessment)
Reptilia	***Afroedura karroica***	Karoo Flat Gecko	Central-western Eastern Cape and adjacent regions of the southern Northern Cape and north-eastern Western Cape in grassland and Nama-Karoo.	Between 1300 2200 m in dolerite outcrops in grasslands	Endemic (90%) in study area	**Least Concern** (2014 SARC assessment)
Reptilia	***Bitis inornata***	Plain Mountain Adder	Eastern Cape. Sneeuberg.	Above 1500 m in grassy habitats	Endemic to Karoo	**Endangered** (2014 SARC assessment)
Reptilia	***Cordylus cloetei***	Cloete's Girdled Lizard	Western Cape. Nuweveldberg: area of occurrence = 338 km^2.	Sandstone rocky habitats on Nuweveldberg	Endemic to Karoo	**Least Concern** (2014 SARC assessment)
Reptilia	***Cordylus minor***	Western Dwarf Girdled Lizard	South Africa. Western Karoo in Western and Northern Cape, from Komsberg range in the north to Majiesfontein in the south.	Rocky areas of mudstone shale lowlands	SA endemic, with about 70% distribution in study area.	**Least Concern** (2014 SARC assessment)
Reptilia	***Goggia braacki***	Braack's Pygmy Gecko	Western Cape. Nuweveldberg: 75 km^2 area of occurrence.	Dolerite outcrops in montane grasslands on Nuweveldberg	Endemic to Karoo	**Near Threatened** (2014 SARC assessment)
Reptilia	***Homopus boulengeri***	Karoo Dwarf Tortoise / Karoo Padloper	South Africa. From Pearston in the Eastern Cape to Touwsrivier in the Western Cape. In Northern Cape to Calvinia in the northwest and Carnavon in the northeast.	Dolerite outcrops 800 - 1500 m	SA endemic	**Near Threatened** (2014 SARC assessment)
Reptilia	***Pachydactylus kladaroderma***	Thin-Skinned Gecko	South Africa. Eastern Cape Fold Mountains and southern escarpment mountains of the Westen Cape and adjacent N Cape.	Large rock outcrops in mesic habitats from 750 – 1700 m, in both shale and in sandstone	SA endemic, with about 50% distribution in study area.	**Least Concern** (2014 SARC assessment)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
Reptilia	***Pseudocordylus microlepidotus namaquensis***		Western Cape. Nuweveldberg & Komsberg.	1500 – 1800 m	Endemic to Karoo	**Least Concern** (2014 SARC assessment)
Amphibia	***Cacosternum karroicum***	Karoo Caco	South Africa. Western and Northern Cape.	Rainwater pools in rocky areas of mountains	Endemic to Karoo. 60% in study area. Northern population is likely a separate species.	**Least Concern** (2011 assessment)
Actinopterygii (fin-ray fish)	***Barbus amatolicus***	Amatola Barb	Eastern Cape: Kabusi, Slang, Kubowa, Nqancule, possibly upper reaches of Buffalo Rivers.	No information	Endemic to Eastern Cape	**Vulnerable** (IUCN Red List, 2007 assessment)
Actinopterygii (fin-ray fish)	***Barbus trevelyani***		Eastern Cape: four or five locations at Tyume, main stream (Keiskama), Yellowwoods, Mgqawabe, Cwenqgwe Rivers.	No information	Endemic to Eastern Cape	**Endangered** (IUCN Red List, 2007 assessment)
Actinopterygii (fin-ray fish)	***Pseudobarbus afer***	Eastern Cape Redfin	Eastern Cape: Swartkops and Sundays River systems.	No information	Endemic to Eastern Cape	**Endangered** (IUCN Red List, 2007 assessment)
Actinopterygii (fin-ray fish)	***Pseudobarbus asper***		Eastern Cape: Gamtoos and Gourits Rivers (Groot).	No information	Endemic to Eastern Cape	**Endangered** (IUCN Red List, 2007 assessment)
Actinopterygii (fin-ray fish)	***Sandelia bainsii***	Cape Rocky	Eastern Cape: Nahoon, Buffalo, Ingoda, Gula, Keiskamma, Great Fish, Kowie Rivers.	No information	Endemic to Eastern Cape	**Endangered** (IUCN Red List, 2007 assessment)
Mollusca (terrestrial snails)	***Cochlitoma crawfordi***	*Crawford's Agate Snail*	Eastern and Northern Cape. Bedford, Cathcart, Toise River, Cookhouse, Douglas, Jansenville, NW Uitenhage, Middleton, Queenstown, Somerset East, SW Cradock, Zuurberg.	Grassy slope with rocks and scrubby forest; grassy hillside with rocks and stunted bushes; indigenous forest	South Africa endemic. 90% of distribution in study area.	Not evaluated
Mollusca (terrestrial snails)	***Gulella rogersi***	*Roger's Hunter Snail*	Eastern Cape. Alice, Cathcart, Cradock, Graaff-Reinet, Jansenville, Kei River Valley, Kuzuko GR, Penhoekberg, Queenstown, Riebeeck East, Sterkstroom, Stormber**g.**	Various habitats: S facing slope of watercourse, riverine forest; grassy slope with rocks; open thicket in calcrete area; gully between dolorite cliffs; rocky N facing hillside with aloes, noors and	Eastern Cape endemic. 90% of distribution in study area.	Not evaluated

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
				bush clump; grassy hillside with aloes and bush clumps; rocky veld with aloes; kloof with rock outcrops and cave.		
Mollusca (terrestrial snails)	***Prestonella bowkeri***	*Bowker's Karoo Rock Snail*	Eastern and Western Cape. Karoo National Park, Graaff-Reinet, Murraysburg, Nieu Bethesda area, Nuweveldberge, Sneeuberg, Somerset East.	Crevices in rocky areas, usually near waterfall or in indigenous forest; SE bank of river; S facing dolerite cliffs in wooded kloof, under overhangs and in crevices on shaded (northern) cliffs beside river.	South Africa Endemic, with >90% of distribution in study area	Not evaluated
Mollusca (terrestrial snails)	***Prestonella nuptialis***		Eastern and Western Cape. Adelaide, Beaufort West, Cradock, Fort Beaufort, Graaff-Reinet, Somerset East.	Indigenous forest, along water courses, waterfalls, S facing rocky ridges, In crevices in rocks.	South Africa Endemic. >90% distribution in study area.	Not evaluated
Mollusca (terrestrial snails)	***Sheldonia arnotti***	*Arnot's Tailwagger*	Eastern, Northern and Western Cape. Colesburg, Graaff-Reinet, Middleton, Nieu Bethesda, Wapadsberg Pass.	Grassy fynbos, bush, rocky grasslands, rocky riverine scrub.	South Africa Endemic. 90% of distribution in study area.	Not evaluated
Mollusca (terrestrial snails)	***Sheldonia asthenes***		Eastern and Western Cape. Cradock, Prince Albert, Somerset East, Graaff-Reinet, Queenstown, Sterkstroom.	S facing slope with Acacia and Rhus, in leaf-litter beneath bushes and under rock walls, in gullies between dolerite cliffs; rocky outcrop on hilltop ridge.	South Africa Endemic. 90% of distribution in study area.	Not evaluated
Crustacea, Anostraca (fairy shrimp)	***Branchipodopsis browni***		Southern Namibia, SA: Williston, Loxton, Fraserburg, Richmond.	Temporary waterbodies such as shallow, inundated areas.	Most records from Karoo, 80% in study area	Not evaluated
Crustacea, Anostraca (fairy shrimp)	***Branchipodopsis hutchinsoni***		Northern Cape: 30 km along dirt road from Hutchinson to Richmond –only one locality.	Temporary waterbodies, collected from inundated ditch along the side of road.	Endemic to Karoo - based on only one known locality	Not evaluated
Lepidoptera (butterflies)	***Aloeides dicksoni***	Dickson's Copper	Eastern Cape, Cradock in west to Seymour in east.	Grassland and Karoo. Montane >1000 m.	78% endemic to study area	**Least Concern** (SABCA 2013

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
						assessment)
Lepidoptera (butterflies)	***Aloeides kaplani***	Kaplan's Copper	Eastern and Northern Cape, from Patensie in south-east to Springbok in north	Mountain peaks and adjacent slopes. >1000 m.	69% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Aloeides pringlei***	Pringle's Copper	Eastern Cape. Winterberg, near Bedford.	Montane grassland, >1000 m; rocky places.	100% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Cassionympha camdeboo***	Camdeboo Brown	Eastern Cape. Aberdeen area.	Relatively moist woodland and scrub. >1000 m.	99% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Chrysoritis beaufortia beaufortia***	Beaufort Opal	Eastern Cape. From Nieuweveld mountains at Beaufort West in west and Kompassberg near Nieu Bethesda in east.	Mountain slopes. >1000 m.	92% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Chrysoritis beaufortia sutherlandensis***	Beaufort's Opal	Northern Cape, Roggeveld escarpment at and near Sutherland.	Rocky ridges. Montane >1000 m	63% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Chrysoritis midas***	Midas Opal	Northern and Western Cape, from Roggeveld escarpment in west near Sutherland to Nuweveldberge in east near Beaufort West	Top of cliffs or rocky ridges at high altitudes (above 1500 m).	71% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Chrysoritis violescens***	Violet Opal	Northern Cape. Roggeveld escarpment around Sutherland.	Rocky ridges on the slopes of hills and mountains. >1000 m.	81% endemic to study area	**Least Concern (Rare-Habitat Specialist)** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Durbaniella clarki belladonna***	Clark's Rocksitter	Eastern Cape, approx. 30 km north-east of Jansenville.	Low hills in Sundays Thicket; south facing slopes. Microhabitat consists of dolerite rocks. <1000 m.	59% endemic to study are	**Vulnerable** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Kedestes barberae bonsa***	Barber's Ranger	Eastern and Northern Cape, from Aberdeen in the south to Colesberg in the north.	Lowland <1000 m; grassy; watercourses	67% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Lepidochrysops victori***	*Victor's Blue*	Eastern Cape. Near Bedford.	Karoo Escarpment Grassland, Amatole Montane Grassland. >1000 m.	100% endemic to study area	**Vulnerable** (SABCA 2013 assessment)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
Lepidoptera (butterflies)	***Phasis clavum erythema***	Namaqua Arrowhead	Northern Cape, Roggeveld escarpment in region of Sutherland.	Gullies at high altitude on Roggeveld escarpment and lower slopes below peaks. Montane >1000 m.	64% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Phasis pringlei***	Pribgle's Arrowhead	Northern Cape, from Roggeberg escarpment near Sutherland.	Mainly riverine areas, also in rocky habitats where host plant occurs.	61% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Pseudonympha trimenii ruthae***	Trimen's Brown	Eastern Cape, near Steytlerville in south to Noupoort in north-west and Lady Grey in north-east.	Various biomes, at high altitudes on mountains and hillsides. >1000 m	61% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Tarsocera southeyae***	Southey's Widow	Eastern and Northern Cape. Calvinia in west and Jansenville in in east; used to occur near Willowmore.	Hillsides, gullies and ridges, around rocky places up to 1000 m.	86% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Thestor camdeboo***	Camdeboo Skolly	Eastern Cape. Mountains inland of Graaff-Reinet and Aberdeen.	Upper slopes of high mountains. >1000 m; Merxmuellera grass.	100% endemic to study area	**Least Concern (Rare-Restricted Range)** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Thestor compassbergae***	Compassberg Skolly	Eastern Cape. Compassberg around Nieu Bethesda.	Sparsely vegetated grassy areas or areas of open shale. High altitudes on mountain slopes. >1000 m; Merxmuellera grass; rocky places.	100% endemic to study area	**Lest Concern (Rare-Restricted Range)** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Thestor pringlei***	Pringle's Skolly	Northern and Western Cape. Roggeveld escarpment around Sutherland, outlier population at Matoosberg Station.	Rocky slopes and low ridges in mountain Renosterveld. >1000 m.	77% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Torynesis magna***	Large Widow	Western and Eastern Cape, from Swartberg near Oudtshoorn in west to Barkly East in east.	Grasslands in mountainous terrain. Slopes and hillsides. >1000 m; Merxmuellera grass.	67% endemic to study area	**Least Concern** (SABCA 2013 assessment)
Lepidoptera (butterflies)	***Trimenia wykehami***	Wykham's Silver-Spotted Copper	Northern and Western Cape, Roggeveld escarpment near Sutherland in west to Nuweveldberge near Beaufort	Rocky hillsides and slopes in dry karroid country. >1000 m.	79% endemic to study area	**Least Concern** (SABCA 2013 assessment)

Group	Scientific name	Common name	Distribution	Habitat	Endemism	IUCN Red List status
			West in east.			
Orthoptera (grasshopper)	***Batrachotetrix stolli***	Toad Grasshopper	Western, Eastern and Northern Cape. Aberdeen, Beaufort West, Graaff-Reinet, Jansenville, Kenhardt, Middleburg, Nelspoort, Prince Albert, Sutherland, Willowmore, Worcester, Bedford, De Aar.	Unknown	South Africa Endemic, with probably about 60% restricted to study area	Not evaluated
Orthoptera (katydid)	***Griffiniana capensis***	Cape Agile Katydid	Eastern and Northern Cape, 20 km S Aberdeen, vicinity of Teekloof Pass, 30 km south Fraserburg, Tankwa Karoo National Park.	Unknown	South Africa Endemic, with >60% of distribution likely to be in study area	**Least Concern (IUCN, 2014)**
Orthoptera (grasshopper)	***Plegmpaterus irisus***		Northern and Western Cape. Sutherland area, Ruiterskop Sta. 30 km NNE Laingsburg, Prince Albert area, 2 mi S Middelpos nr. Tankwa Karoo NP 3 mi SW Seekoegat, 4 mi N Merweville, 16 mi SE Loxton.	Unknown	South Africa Endemic, with >60% of distribution likely to be in study area	Not evaluated

Table 7.2: Plant species of special concern in the study area (i.e. plant species that have more than 80% of their distribution within the study area).

Family	**Scientific name**	**Common name**	**Distribution**	**Habitat**	**Habitat type**	**IUCN Red List Status** (2015 South African Plant Assessment)
Crassulaceae	***Adromischus cooperi***	Bontplakkie (Afrikaans)	Somerset East to Graaff-Reinet, Middelburg and Queenstown.	Rock crevices, usually on slopes or in the shade of other vegetation.	Kopies	Least Concern
Crassulaceae	***Adromischus fallax***	Graaff-Reinet Plakkie (Afrikaans)	Graaff-Reinet district.	Rock faces at high altitude.	Mountains	Rare
Crassulaceae	***Adromischus humilis***	Karooberg Plakkie (Afrikaans)	Nuweveld Mountains near Beaufort West, north of Laingsburg at Klipfontein, and at Oukloof Pass near Fraserburg.	Rock crevices.	Mountains	Least Concern
Rutaceae	***Agathosma sp nov. (Nick Helmeii)***		Roggeveld mountains.	Growing amongst boulders in dolerite outcrops.	Mountains	Rare
Aizoaceae	***Aloinopsis acuta***		Roggeveld to Nieuweveld.	Arid rocky escarpments.	Mountains	Data Deficient
Malvaceae	***Anisodontea capensis***	Wildestokroos (Afrikaans)	Victoria West to near Prince Albert.	Most often occurs near rivers.	Floodplains	Least Concern
Malvaceae	***Anisodontea malvastroides***	Wildestokroos (Afrikaans)	Escarpment ranges of Graaff-Reinet and Middelburg.	Arid escarpments.	Mountains	Least Concern
Aizoaceae	***Antimima dekenahi***		Williston to Sutherland and Fraserburg.	In crevices in shale.	Rocky / hilly lowlands	Least Concern
Aizoaceae	***Antimima emarcescens***		Sutherland.	In mountain renosterveld, scrambling in other bushes	Mountains	Rare
Aizoaceae	***Antimima ivori***		Sutherland to Fraserburg.	In crevices in exposed sandstone.	Rocky / hilly lowlands	Least Concern
Aizoaceae	***Antimima loganii***		Roggeveld	In crevices of sandstone rocks	Rocky / hilly lowlands	Data Deficient

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	IUCN Red List Status (2015 South African Plant Assessment)
Amaryllidaceae	***Apodolirion bolusii***	Maagbitterwortel (Afrikaans)	Valley of Desolation, Graaff-Reinet.	Karroid shrubland or in subtropical thicket on shale-derived soils.	Lowland flats	Data Deficient
Asparagaceae	***Asparagus mollis***	Wag-'n-bietjie (Afrikaans)	Jagerskraal, Verlatekloof Pass	On Dwyka tillite	Lowland flats	Least Concern
Asphodelaceae	***Astroloba congesta***	Katdoring (Afrikaans)	Cradock to Grahamstown.	Karroid flats.	Lowland flats	Least Concern
Iridaceae	***Babiana virginea***		Roggeveld Escarpment, Middelpos to Verlate Kloof.	Shale outcrops amongst the clumps of Merxmuellera.	Mountains	Least Concern
Aizoaceae	***Bergeranthus nanus***		Graaff-Reinet to the area between Somerset East and Cradock.	Exposed intrusive dolerite sills.	Lowland flats	Vulnerable
Asteraceae	***Berkheya cardopatifolia***		Roggeveld foothills and Laingsburg to Upper Karoo.	Dry hillsides and cliffs.	Mountains	Least Concern
Apocynaceae	***Brachystelma theronii***	Mohata-o-mosoeu (Southern Sotho)	Laingsburg to Williston.	Dolerite-capped shale hills.	Kopies	Least Concern
Apocynaceae	***Ceropegia filiformis***	Rankkambroo (Afrikaans)	Beaufort West to Luckhoff and east to Middleburg.	Growing in karroid scrub amongst low shrubs.	Lowland flats	Least Concern
Scrophulariaceae	***Chaenostoma rotundifolium***	Necklace vine (English)	Victoria West to Sneeuberg north to Griekwastad.	Cliff faces and rock outcrops.	Mountains	Least Concern
Aizoaceae	***Chasmatophyllum braunsii***	Bohlanya-ba-pere (Southern Sotho)	Laingsburg and Victoria West.	Nama Karoo.	Lowland flats	Data Deficient
Aizoaceae	***Chasmatophyllum nelii***		Prince Albert to Kliplaat to Cradock.	Rocky flats and hills of sandstone and dolerite origin.	Rocky/hilly lowlands	Least Concern
Aizoaceae	***Chasmatophyllum stanleyi***		Beaufort West, Aberdeen, Willowmore, Laingsburg to Prince Albert.	On stony to shaley slopes.	Rocky/hilly lowlands	Least Concern
Rosaceae	***Cliffortia arborea***	Anysberg star tree (English)	Hantamsberg Mountain to Nuweveld Mountains.	Cliffs and ledges of dolerite, sandstone, and shale escarpment.	Mountains	Vulnerable

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Colchicaceae	***Colchicum karooparkense***		Beaufort West within the Karoo National Park.	Stony flats.	Lowland flats	Least Concern
Crassulaceae	***Crassula vestita***	Cape May (English)	Roggeveld Mountains.	Amongst low shrublets, associated with rock outcrops.	Lowland flats	Least Concern
Scrophulariaceae	***Cromidon decumbens***	Smooth Hawk's Beard (English)	Hantamsberg and Roggeveld to near Graaff-Reinet.	Sheltering under rocks.	Kopies	Least Concern
Asteraceae	***Curio hallianus***	Suuroogblom (Afrikaans)	Central Karoo, between Prince Albert, Loxton and Merweville.	Sheltered among the roots of shrubs and in rocky crevices.	Kopies	Least Concern
Aizoaceae	***Cylindrophyllum calamiforme***		Graaff-Reinet to Somerset East S, from Willowmore to Jansenville.	Stony slopes and flats of karoo sediments.	Lowland flats	Least Concern
Boraginaceae	***Cynoglossum obtusicalyx***		Hantamsberg and Ceres and Beaufort West.	Often on screes below cliffs.	Mountains	Least Concern
Hyacinthaceae	***Daubenya aurea***	Swan Orchid (English)	Roggeveld Escarpment between Sutherland and Middelpos.	Arid shrubland, on seasonally damp, red clay flats along the base of dolerite ridges.	Mountains	Endangered
Aizoaceae	***Delosperma aberdeenense***	Abredeen Volstruisslaai (Afrikaans)	Aberdeen to Cradock and Somerset East.	Flats or hills of karoo sediments.	Lowland flats	Least Concern
Aizoaceae	***Delosperma aereum***	Prins Albert Volstruisslaai (Afrikaans)	Prince Albert to Klipplaat.	Occurs in lower karoo bioregion.	Lowland flats	Least Concern
Aizoaceae	***Delosperma concavum***	Sneeuberg Volstruisslaai (Afrikaans)	Sneeuberg mountains above Graaff Reinet.	Flats and hills of karoo sediments.	Mountains	Least Concern
Aizoaceae	***Delosperma karrooicum***	Graaff-Reinet Volstruisslaai (Afrikaans)	Queenstown to Graaff-Reinet District the Sneeuberg mountain range.	Slopes of karoo shales or siltstones.	Rocky/hilly lowlands	Least Concern
Aizoaceae	***Delosperma lootsbergense***	Karoo Volstruisslaai (Afrikaans)	Middelburg and Graaff-Reinet Districts.	Flats and hills of karoo sediments.	Lowland flats	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Aizoaceae	***Delosperma sphalmanthoides***	Sutherland Volstruisslaai (Afrikaans)	Sutherland.	In shallow soils over sandstone rocks, 1500 – 1600 m.	Mountains	Rare
Scrophulariaceae	***Diascia alonsooides***		Sutherland to Murraysburg and Graaff-Reinet.	South facing slopes in loamy soil.	Kopies	Least Concern
Scrophulariaceae	***Diascia ramosa***	Pensies (Afrikaans)	Somerset East, Boschberg.	Mountain slopes in Amathole Montane Grassland.	Mountains	Vulnerable
Iridaceae	***Dierama grandiflorum***	Devil Thorn (English)	Graaff-Reinet and Somerset East.	Grass slopes among rock outcrops.	Mountains	Vulnerable
Hyacinthaceae	***Drimia karooica***	Maerman (Afrikaans)	Roggeveld to Great Karoo.	Stony flats and slopes.	Lowland flats	Least Concern
Aizoaceae	***Drosanthemum lique***	Doublom (Afrikaans)	Karoo to Eastern Cape.	In loamy soils, often in disturbed areas.	Lowland flats	Least Concern
Apocynaceae	***Duvalia angustiloba***	Hotnotstoontjie (Afrikaans)	Great Karoo between Beaufort West, Rietbron, Aberdeen, Victoria West and Loxton.	Grows under shrubs in dry, flat areas or among dolerite outcrops.	Lowland flats	Least Concern
Ericaceae	***Erica passerinoides***	Sticky white heath (English)	Sneeuberg in the Koudeveld Mountains, Katberg Pass and Cata Forest Reserve.	Karoo-fynbos ecotone, on south-facing slopes.	Mountains	Vulnerable
Asteraceae	***Eumorphia corymbosa***		Nuweveld Mountains.	Seasonal wet soils along rivers and in marshy habitats.	Floodplains	Least Concern
Asteraceae	***Eumorphia dregeana***		Hanover to Graaff-Reinet.	Karoo Escarpment Grassland.	Mountains	Least Concern
Euphorbiaceae	***Euphorbia hypogaea***	Underground Spurge (English)	Sutherland to Great Karoo.	Karroid scrub, usually on flats under or alongside bushes.	Lowland flats	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Euphorbiaceae	***Euphorbia jansenvillensis***		Steytlerville to Klipplaat and Jansensville.	Open karroid shrubland, stony slopes and flats, in loose sandy soils under small shrubs, or wedged among stones.	Lowland flats	Vulnerable
Euphorbiaceae	***Euphorbia obesa***	Vetmensie (Afrikaans)	Graaff-Reinet to Rietbron.	Open karroid shrubland, stony slopes and flats, in loose sandy soils under small shrubs, or wedged among stones.	Lowland flats	Endangered
Euphorbiaceae	***Euphorbia polycephala***		Between Pearson, Cradock and Somerset East.	Karroid shrubland and thicket, on rocky hills and flats.	Lowland flats	Vulnerable
Euphorbiaceae	***Euphorbia stellispina***	Karoo Noorsdoring (Afrikaans)	North east of Calvinia to north of Laingsburg, widespread in Great Karoo.	Karroid scrub on stony slopes with scattered dolerite rocks.	Kopies	Least Concern
Euphorbiaceae	***Euphorbia suffulta***	Bosmelkbos (Afrikaans)	Merweville to Klaarstroom.	Stony gentle slopes, often inside other bushes.	Lowland flats	Least Concern
Asteraceae	***Euryops dentatus***		Bankberg, Toorberg and Sneeuberg in the Graaff-Reinet district.	Arid mountain slopes.	Mountains	Vulnerable
Asteraceae	***Euryops exudans***	Graaff-Reinet Harpuis (Afrikaans)	Sneeuberg between Graaff-Reinet and Cradock.	Karoo Escarpment Grassland.	Mountains	Least Concern
Asteraceae	***Euryops nodosus***	Nuweveld Harpuis (Afrikaans)	Nuweveld Escarpment.	Stony flats and hillsides, often dolerite, in renosterveld.	Mountains	Least Concern
Asteraceae	***Euryops petraeus***	Sneeuberg Harpuis (Afrikaans)	Sneeuberge and Winterhoek Mountains in the Graaff-Reinet district, and Nuweveld Mountains south of Fraserburg.	Rocky mountain summits, 1650 - 2450 m.	Mountains	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Asteraceae	***Euryops proteoides***	Proteaharpuis (Arikaans)	Southern Sneeuberg between Graaff-Reinet and Pearston.	Moist, south-facing escarpment slopes and below cliff-lines and along drainage lines, 1200 - 2000 m.	Mountains	Least Concern
Asteraceae	***Euryops sulcatus***	Waterharpuis (Afrikaans)	Roggeveld and Nieuweveld escarpment.	Rocky slopes. 1500 - 1860 m.	Mountains	Least Concern
Proteaceae	***Faurea recondita***	Kamdeboo Beechwood (English)	Kamdeboo Mountains north of Aberdeen.	South-eastern slopes in dense mountain fynbos, specifically Drakensberg-Amathole Afromontane Fynbos forest margins.	Mountains	Least Concern
Cyperaceae	***Ficinia compasbergensis***	Compasberg Ystervarkgras (Afrikaans)	Calvinia and Sutherland Districts to the Eastern Cape.	Mountain peaks and slopes.	Mountains	Least Concern
Aizoaceae	***Galenia glandulifera***	Bloubrakbossie (Afrikaans)	Great Karoo, Whitehill to Prince Albert.	Stony soil.	Lowland flats	Least Concern
Asteraceae	***Gazania caespitosa***	Botterblom (Afrikaans)	Graaff-Reinet district, Sneeuberge.	Unknown.	Mountains	Data Deficient
Iridaceae	***Geissorhiza cantharophila***	Syblom (Afrikaans)	Klein Roggeveld.	Clay and gravel slopes in renosterveld, WM	Mountains	Least Concern
Geraniaceae	***Geranium harveyi***		Nuweveld Moutains southwestwards to the mountains near Cala and southwards to Boschberg, Somerset East.	In sheltered areas on outcrops or grassy slopes in sand, loam or clay.	Mountains	Least Concern
Amaryllidaceae	***Gethyllis longistyla***	Koekoemakranka (Afrikaans)	Sneeuberg, Agter Sneeuberg and Nuweveld Mountains.	Tops of rocky, dolerite ridges.	Mountains	Least Concern
Iridaceae	***Gladiolus marlothii***	Roggeveld Gladiolus (English)	Roggeveld Escarpment and Komsberg	Stony slopes in clay, WM	Mountains	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	IUCN Red List Status (2015 South African Plant Assessment)
Asteraceae	***Gnaphalium simii***		Hanover.	Calcareous vleis.	Floodplains	Data Deficient
Scrophulariaceae	***Gomphostigma incomptum***	Besembossie (Afrikaans)	Roggeveld through Upper Karoo to near Colesberg.	Riverbanks.	Floodplains	Least Concern
Malvaceae	***Grewia robusta***	Kruisbessiebos (Afrikaans)	Beaufort West area southwards to George and Oudtshoorn.	Restricted to the arid areas of the Karoo and the arid parts of Eastern Cape. It generally favours dry scrub, often on stony hill slopes and in valley bushveld.	Lowland flats	Least Concern
Asphodelaceae	***Haworthia semiviva***	Baakhout (Afrikaans)	Roggeveld and Nuweveld mountains.	Shaded places under shrubs.	Lowland flats	Least Concern
Asphodelaceae	***Haworthiopsis nigra***		Widespread across the Great Karoo, extending southwards to Grahamstown and East London and eastwards to Queenstown.	Sheltered among the base of shrubs on karoo plains, as well as rocky ridges, outcrops and cliffs.	Lowland flats	Least Concern
Asteraceae	***Helichrysum albertense***	Sewejaartjie (Afrikaans)	Laingsburg to Leeu Gamka, eastwards to Klipplaat and southwards to Prince Albert.	Karroid shrubland, on low ridges and flats.	Lowland flats	Data Deficient
Asteraceae	***Helichrysum scitulum***		Nuweveld Mountains near Beaufort West to Witteberg near Lady Grey.	Rocky mountain summits, forming loose mats in rock crevices or cascading down steep cliffs and slopes, growing intertwined with grasses and other vegetation.	Mountains	Least Concern
Asteraceae	***Helichrysum tysonii***		Mountains between Murraysburg, Graaff-Reinet and Middelburg.	Bare, rocky areas, will colonise eroded places and hard, gravelly road verges.	Mountains	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Aizoaceae	***Hereroa concava***		Beaufort West.	Unknown.	unknown	Data Deficient
Aizoaceae	***Hereroa crassa***		Laingsburg to Prince Albert, Beaufort West.	On slopes with quartzite rock.	Mountains	Least Concern
Aizoaceae	***Hereroa herrei***		Graaff- Reinet.	Unknown.	unknown	Data Deficient
Aizoaceae	***Hereroa willowmorensis***	Sheeps ear (English)	Beaufort West to Willowmore and Aberdeen.	In shaley or gravelly soils.	Lowland flats	Least Concern
Malvaceae	***Hermannia grandiflora***	Ouma-se-kappie (Afrikaans)	Great Karoo to the Roggeveld, Tanqua Karoo.	In dry seasonal washes.	Floodplains	Least Concern
Malvaceae	***Hermannia linnaeoides***	Klokkiebos (Afrikaans)	Central Karoo to near Prince Albert.	In seasonally wet depressions.	Pans	Least Concern
Malvaceae	***Hermannia nana***	Klokkiebos (Afrikaans)	Matjiesfontein to Koup Karoo.	Stony slopes.	Kopies	Least Concern
Asteraceae	***Hertia cluytiifolia***	Goewernementsbossie (Afrikaans)	Carnavon to Sneeuberg.	Karroid plains.	Lowland flats	Least Concern
Iridaceae	***Hesperantha helmei***	Graaff-Reinet Aandblom (Afrikaans)	Graaff-Reinet, Nardousberg.	High elevations in regularly burned, rocky grassland, covered in snow during winter.	Mountains	Least Concern
Iridaceae	***Hesperantha teretifolia***	Aandblom (Afrikaans)	Roggeveld Escarpment.	Stony slopes, often growing in rock crevices.	Mountains	Least Concern
Apocynaceae	***Hoodia dregei***	Wolweghaap (Afrikaans)	Merweville, Beaufort West and Prince Albert.	Stony slopes of hills or stony flat areas.	Lowland flats	Vulnerable
Apocynaceae	***Hoodia grandis***	Grootghaap (Afrikaans)	Great and Little Karoo between Matjiesfontein, Merweville, Leeu-Gamka and Calitzdorp.	Among bushes on stony slopes.	Lowland flats	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Apocynaceae	***Hoodia pilifera subsp. annulata***	Stinkbos (Afrikaans)	Great Karoo from Aberdeen and Graaff-Reinet southwards to Rietbron and eastwards to Willowmore, Klipplaat and Steytlerville.	Flat areas between low hills on slightly gravelly ground, rarely on hill slopes.	Lowland flats	Least Concern
Apocynaceae	***Huernia humilis***	Karoo Toad Plant (English)	Widespread across the Great Karoo between Middelpos, Beaufort West, Willowmore, Richmond and De Aar.	Karroid shrubland, this species occurs wedged among rocks under small bushes.	Lowland flats	Least Concern
Apocynaceae	***Huernia kennedyana***	Cradock Toad Plant (English)	Cradock and Somerset East.	Occasionally on flat areas, more usually associated with slightly raised gravely spots, on low doleritic ridges, also on shale ridges in crevices among rocks.	Kopies	Least Concern
Fabaceae	***Indigofera asantasanensis***	Sneeuberg Lusernbos (Afrikaans)	Confined to the summit plateau of the Toorberg–Koudeveld–Meelberg in the western Sneeuberg, between 1700 – 2150 m.	Found exclusively on the dolerite-derived loamy-clays and black turf soils typical of this plateau. The vegetation type is Karoo Escarpment Grassland.	Mountains	Vulnerable
Fabaceae	***Indigofera magnifica***	Toorberg Lusernbos (Afrikaans)	Summit plateau of the Toorberg–Koudeveld–Meelberg in the western Sneeuberg, between 1700 – 2150 m.	Found exclusively on the dolerite-derived loamy-clays and black turf soils typical of this plateau. The vegetation type is Karoo Escarpment Grassland, typical of high altitudes in the Sneeuberg mountain complex.	Mountains	Vulnerable
Cyperaceae	***Isolepis expallescens***	Waterbiesie (Afrikaans)	Central Karoo, Fraserburg and Victoria West districts.	River Beds.	Floodplains	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	IUCN Red List Status (2015 South African Plant Assessment)
Iridaceae	***Ixia brevituba***	Roggeveld Kalossie (Afrikaans)	Roggeveld Escarpment southwest of Middelpos.	Stony, light clay in renosterveld.	Mountains	Least Concern
Iridaceae	***Ixia marginifolia***	Kalossie (Afrikaans)	Loeriesfontein to Fraserburg, Beaufort West and Matjiesfontein.	Clay or loamy ground in renosterveld or karroid scrub.	Lowland flats	Least Concern
Iridaceae	***Ixia pavonia***	Kalossie (Afrikaans)	Roggeveld Escarpment.	Shallow, rocky clay soils on steep slopes.	Mountains	Least Concern
Iridaceae	***Ixia rigida***	Witkalossie (Afrikaans)	Roggeveld Escarpment.	Rocky red clay soils on dolerite outcrops.	Mountains	Vulnerable
Iridaceae	***Ixia sobolifera subsp. sobolifera***	Bluebells (English)	Klein Roggeveld between Sutherland and Matjiesfontein.	Well-drained, rocky loam or clay soils in succulent shrubland.	Mountains	Least Concern
Scrophulariaceae	***Jamesbrittenia crassicaulis***		Middelburg east to Queenstown, and south from Graaff-Reinet to Cradock.	In montane cliffs and other rocky places.	Mountains	Least Concern
Scrophulariaceae	***Jamesbrittenia incisa***		Calvinia to Swartputs and Breekbeenkolk, and Sutherland to Fraserburg.	Among boulders in karroid vegetation.	Kopies	Vulnerable
Asphodelaceae	***Kniphofia acraea***	Wild Jessamine (English)	Cradock and Mountain Zebra National Park.	Grows in small seepage areas among rocks in grassy montane fynbos.	Mountains	Least Concern
Hyacinthaceae	***Lachenalia comptonii***	Viooltjie (Afrikaans)	Roggeveld Escarpment and Little Karoo.	Sandy Flats.	Lowland flats	Least Concern
Hyacinthaceae	***Lachenalia congesta***	Viooltjie (Afrikaans)	Sutherland and Calvinia.	Shale in karroid scrub.	Lowland flats	Least Concern
Hyacinthaceae	***Lachenalia isopetala***	Viooltjie (Afrikaans)	Bokkeveld Plateau, Roggeveld to Komsberg.	In stony doleritic clay.	Mountains	Least Concern
Hyacinthaceae	***Lachenalia longituba***	Viooltjie (Afrikaans)	Roggeveld Plateau and Escarpment	In small groups on moist, loam flats, WM	Lowland flats	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Hyacinthaceae	***Lachenalia whitehillensis***	Graceful Poker (English)	Komsberg to near Laingsburg.	Deep sand.	Lowland flats	Least Concern v
Iridaceae	***Lapeirousia montana***	Rooinaeltjies (Afrikaans)	Komsberg Pass area to Middelpos.	Clay soils in renosterveld.	Lowland flats	Least Concern
Asteraceae	***Lasiospermum poterioides***	Gansgras (Afrikaans)	Roggeveld to Williston.	Beaufort clay series.	Floodplains	Least Concern
Brassicaceae	***Lepidium bipinnatum***	Indiese platertjie (Afrikaans)	Fraserberg.	Unknown habitat.	unknown	Least Concern
Fabaceae	***Lessertia inflata***	Seeroogbossie (Afrikaans)	Calvinia to Upper Karoo.	In shaley soils.	Lowland flats	Least Concern
Fabaceae	***Lotononis azureoides***		Nuweveld Mountains.	Steep, rocky sandstone slopes at 1600 m.	Mountains	Least Concern
Fabaceae	***Lotononis venosa***	Silwerboom (Afrikaans); Molomo-monate (South Sotho)	Klein Roggeveld Mountains.	Open karroid scrub on sandy clay alluvium.	Mountains	Vulnerable
Scrophulariaceae	***Manulea chrysantha***	Egossa-rooipeer (Afrikaans)	Nuweveld Mountains through Great Karoo to Little Karoo.	Riverbeds and gravel patches.	Floodplains	Least Concern
Scrophulariaceae	***Manulea deserticola***		Fauresmith and Modder River.	Sandy soils.	Lowland flats	Data Deficient
Aizoaceae	***Mesembryanthemum excavatum***	Olifantslaai (Afrikaans)	Tanqua Karoo, Laingsburg, Fraserburg, Beaufort West.	Prefers disturbed areas.	Lowland flats	Least Concern
Geraniaceae	***Monsonia camdeboensis***	Karoo Bushman Candle (English)	Great Karoo between Beaufort West, Sterkstroom and Willowmore.	Rocky dolerite ridges, or rocky outcrops on shale plains.	Kopies	Least Concern
Iridaceae	***Moraea crispa***		Cederberg Mountains to Baviaanskloof, southern and western Karoo.	Clay slopes.	Mountains	Least Concern
Amaryllidaceae	***Nerine huttoniae***	Berg Lily (Afrikaans)	Great Fish River Floodplain.	Floodplains, in sandy alluvial flats.	Floodplains	Vulnerable

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Apocynaceae	***Ophionella arcuata subsp. Arcuata***		East of Willowmore through Steytlerville and Pearston to west of Somerset East.	Flats	Lowland flats	Least Concern
Apocynaceae	***Orbea miscella***	Engelseturksvy (Afrikaans)	Widely distributed in the Great Karoo, from Fraserburg north-eastwards to Richmond, Hanover and Cradock and south-eastwards to Willowmore and Steytlerville.	Occurs in flattish areas on low stony ridges where they grow among stones and small karroid bushes usually not taller than 30 cm.	Lowland flats	Least Concern
Hyacinthaceae	***Ornithogalum corticatum***	Roggeveld Chincherinchee	Roggeveld Escarpment.	Heavy clay soils derived from dolerite.	Mountains	Least Concern
Hyacinthaceae	***Ornithogalum verae***	Slang-gwaap (Afrikaans)	Roggeveld	Dolerite flats, WM	Lowland flats	Least v
Asteraceae	***Osteospermum thymelaeoides***	Onkruidbietou (Afrikaans)	Laingsburg, Roggeveld Escarpment and Nuweveld Mountains, as far as Molteno Pass.	Upper south-facing slopes, 1036-1676 m.	Mountains	Least Concern
Asteraceae	***Othonna pavonia***		De Aar to Beaufort West and east to Cradock.	Karoid plains and slopes.	Lowland flats	Least v
Asteraceae	***Othonna rhamnoides***	Slangblom (Afrikaans)	Roggeveld to Sneeuberg.	Stony calcrete flats.	unknown	Data Deficient
Oxalidaceae	***Oxalis pocockiae***		Tanqua-Karoo, to Prince Albert and Carnarvon.	Unknown.	unknown	Least Concern
Apocynaceae	***Pectinaria longipes subsp. longipes***	Joemapitsuring (Afrikaans)	Kleinroggeveld Mountains, Roggeveld plateu to Fraserberg	Flat gravelly areas under low growing Asteraceous shrubs	Mountains	Least Concern
Aizoaceae	***Peersia frithii***		Laingsburg to Aberdeen.	Slopes or flats of finely weathered Ecca shales.	Lowland flats	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Geraniaceae	***Pelargonium aestivale***	Malva (Afrikaans)	Widespread in the summer rainfall areas of the central Karoo, from Murraysburg to Fraserburg.	Grassy karroid shrubland wedged between rocks on hillsides or flats.	Lowland flats	Least Concern
Geraniaceae	***Pelargonium griseum***	Dassie Buchu (Afrikaans)	Lady Grey from Joubert's Pass eastwards to the Oudeberg near Graaff-Reinet.	Mountainous areas with hot summer and cold winter conditions and an annual precipitation of 200 – 300 mm.	Mountains	Least Concern
Pteridaceae	***Pellaea rufa***	Hard fern (English); Maagpynbossie (Afrikaans)	Ladismith to Willowmore.	Rock outcrops.	Kopies	Least Concern
Aizoaceae	***Phyllobolus rabiei***		Fauresmith to Victoria West and Cradock.	Karroid scrub on floodplains.	Floodplains	Least Concern
Asteraceae	***Phymaspermum scoparium***	Geelblombos	A poorly collected species from near Graaff-Reinet in the Eastern Cape to Hanover in the Northern Cape.	Floodplains.	Floodplains	Least Concern
Apocynaceae	***Piaranthus comptus***	Gooseberry (English)	Beaufort West to Laingsburg and Willowmore.	Gravelly flats under bushes.	Lowland flats	Least Concern
Aizoaceae	***Pleiospilos bolusii***	Quagga Kos (Afrikaans)	Willowmore to Beaufort West and Aberdeen.	Quartz flats in karroid shrubland.	Quartz patches	Vulnerable
Aizoaceae	***Pleiospilos nelii***	Kwaggavygie (Afrikaans)	Willowmore Karoo.	Quartz covered flats in sparse karoo vegetation.	Quartz patches	Near Threatened
Fabaceae	***Polhillia involucrata***		Roggeveld Escarpment.	Mountain renosterveld on well-drained, sandy loams.	Mountains	Endangered

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Fabaceae	***Psoralea margaretiflora***	Sneeuberg Fountain-bush (English)	Kamdeboo, Toorberg, Koudeveld and Coetzeesberg mountains in the Sneeuberg Mountain Complex, Graaff-Reinet and Pearston districts.	Rich turf soils and colluvium associated with dolerite on lower and middle slopes at Karoo Escarpment Grassland-Mountain Fynbos ecotones, as well as closed Otholobium macradenium shrubland.	Mountains	Least Concern
Asteraceae	***Pteronia erythrochaeta***	Boegoekaroo (Afrikaans)	Upper Karoo (extends up to Carnavon) and Great Karoo and into Western Free State		unknown	Least Concern
Asteraceae	***Pteronia tricephala***	Bloukeur (Afrikaans)	Roggeveld Escarpment to Upper Karoo.	Habitat unknown.	unknown	Least Concern
Apocynaceae	***Quaqua arenicola subsp. pilifera***		Roggeveld plateau, south of Middelpos to Fraserburg	Stony dolerite slopes, usually at the base of bushes	Mountains	Least Concern
Aizoaceae	***Rabiea difformis***	Cradock Clock Plant (English)	Middelburg and Cradock Districts.	Rocky outcrops of karoo sediments.	Kopies	Least Concern
Scrophulariaceae	***Reyemia chasmanthiflora***		Between Calvinia and Middelpos.	In karroid vegetation on very dry stony flats.	Lowland flats	Least Concern
Scrophulariaceae	***Reyemia nemesioides***		Hantamsberg to Roggeveld to Nuweveld Mountains.	Dolerite hills.	Kopies	Least Concern
Aizoaceae	***Rhinephyllum broomii***		Carnarvon to Fraserburg Road and Beaufort West.	On bare stony, gentle slopes, in shale.	Lowland flats	Least Concern
Aizoaceae	***Rhinephyllum graniforme***		Fraserburg, frequent in patches between Laingsburg and Prince Albert.	On shaley flats.	Lowland flats	Least Concern
Aizoaceae	***Rhinephyllum obliquum***		Fraserburg, near Luttig.	Ecology unknown.	unknown	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Iridaceae	***Romulea albiflora***	Wit Froetang (Afrikaans)	Roggeveld Escarpment.	Shale flats on escarpment edge.	Mountains	Critically Endangered
Iridaceae	***Romulea eburnea***	Klein Roggeveld Froetang (Afrikaans)	Klein Roggeveld.	Shale soils.	Mountains	Vulnerable
Iridaceae	***Romulea hallii***	Froetang (Afrikaans)	Roggeveld Plateau southwest of Sutherland.	Shale soils, 1500 m.	Mountains	Vulnerable
Iridaceae	***Romulea komsbergensis***	Komsberg Froetang (Afrikaans)	Komsberg Pass to Middelpos.	Seasonally damp clay flats, 1400 m.	Mountains	Near Threatened
Iridaceae	***Romulea syringodeoflora***	Roggeveld Froetang (Afrikaans)	Roggeveld Plateau.	Stony shale flats and slopes.	Mountains	Vulnerable
Asteraceae	***Rosenia glandulosa***	Klierbos (Afrikaans)	Calvinia to Stettynsburg.	Arid shrubland.	Lowland flats	Least Concern
Asteraceae	***Rosenia spinescens***		Whitehill to Murraysburg.	Stony clay flats.	Lowland flats	Least Concern
Aizoaceae	***Ruschia acocksii***		Roggeveld Mountain slopes	Mudstone soils	Lowland flats	Least Concern
Aizoaceae	***Ruschia beaufortensis***		Beaufort West.	In arid nama karoo mountains.	Mountains	Least Concern
Aizoaceae	***Ruschia campestris***		Besemgoedberg	On shale in renosterveld	Lowland flats	Least Concern
Aizoaceae	***Ruschia dejagerae***		Fraserburg to Beaufort West.	In shallow soil, among rocks, covered in snow during winter.	Mountains	Least Concern
Aizoaceae	***Ruschia indurata***		Beaufort West and Great Karoo to Steynsburg and Steytlerville, Eastern Cape.	On dolerite rock sheets.	Kopies	Least Concern
Aizoaceae	***Ruschia mariae***		Eastern Cape: Steytlerville.	Unknown.	Unknown	Data Deficient

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Aizoaceae	***Ruschia parviflora***		Beaufort West to Eastern Cape.	On stony hills.	Kopies	Least Concern
Aizoaceae	***Sceletium emarcidum***	Kougoed (Afrikaans)	Prieska, Beaufort West, Cradock and Calvinia.	Karroid areas, climbing in other bushes.	Generalist includes flats	Least Concern
Poaceae	***Secale strictum subsp africanum***	Rog (Afrikaans)	Roggeveld.	River banks.	Floodplains	Critically Endangered
Scrophulariaceae	***Selago bolusii***		Graaff-Reinet, Sneeuberg mountain range.	Rocky areas on cliffs or mountain summits, among boulders.	Mountains	Least Concern
Scrophulariaceae	***Selago centralis***		Graaff-Reinet, Aberdeen-, Jansenville- and Cradock Districts.	With grass and shrubs in open areas.	Lowland flats	Least Concern
Scrophulariaceae	***Selago crassifolia***		Victoria West to Murraysburg.	Sandstone outcrops.	Kopies	Least Concern
Scrophulariaceae	***Selago magnakarooica***		Fraserburg to Middelburg.	Sandstone outcrops.	Mountains	Least Concern
Scrophulariaceae	***Selago persimilis***	Amandelaarbossie (Afriakaans)	Burgersdorp S to Middelburg and Cradock.	Unknown.	Unknown	Least Concern v
Scrophulariaceae	***Selago rigida***		Bokkeveld Plateau and Roggeveld Escarpment to Nuweveld Mountains.	Shaley slopes.	Mountains	Least Concern
Asteraceae	***Senecio acutifolius***		Widespread in the central Karoo from Beaufort West to Cradock and south to Steytlerville.	Stony hills and flats.	Lowland flats	Least Concern
Asteraceae	***Senecio cotyledonis***		Roggeveld and Upper Karoo to Little Karoo.	Stony karroid slopes.	Kopies	Least Concern
Lamiaceae	***Stachys cuneata***	Vaaltee (Afrikaans)	Upper, central and western Karoo.	Found in dry watercourses on dolorite hills.	Floodplains	Least Concern

Family	Scientific name	Common name	Distribution	Habitat	Habitat type	**IUCN Red List Status** (2015 South African Plant Assessment)
Apocynaceae	***Stapeliopsis pillansii***		Great Karoo, from west of Rietbron sporadically eastwards to near Somerset East, Pearston and Jansenville.	Low stony ridges or flat gravelly areas under small shrubs.	Kopies	Least Concern
Aizoaceae	***Stomatium difforme***	Karoo Tierbekvygie (Afrikaans)	Sutherland to Laingsburg	In pockets of shallow gravel on bare dolerite sheets	Kopies	Least Concern
Aizoaceae	***Stomatium loganii***	Klein Roggeveld Tierbekvygie (Afrikaans)	Laingsburg: Klein Roggeveld	Unknown	Unknown	Least Concern
Aizoaceae	***Stomatium suaveolens***	Fraserberg Tierbekvygie (Afrikaans)	Williston, Sutherland, Fraserburg.	In shallow pans.	Pans	Least Concern
Aizoaceae	***Stomatium viride***		Beaufort West.	Ecology unknown.	Unknown	Least Concern
Iridaceae	***Syringodea pulchella***	Crane Flower's Bill (English)	Sneeuberg Mountains.	Karoo Escarpment Grassland.	Mountains	Least Concern
Aizoaceae	***Tetragonia acanthocarpa***	Waterslaaibos (Afrikaans); umSwi (Xhosa)	Karoo to Free State and the Eastern Cape.	In open ground often found near brak pans.	Pans	Least Concern
Asphodelaceae	***Trachyandra thyrsoidea***	Veld Cabbage (English); Watertoue (Afrikaans)	Matjiesfontein and Laingsburg to Oudtshoorn.	Rocky, well-drained slopes.	Mountains	Least Concern
Aizoaceae	***Trichodiadema obliquum***	Hairy Nipple Vygie (English)	Beaufort West.	Ecology unknown.	Unknown	Data Deficient
Aizoaceae	***Trichodiadema olivaceum***	Stervygie (Afrikaans)	Somerset East to Steynsberg.	Slopes and flats of weathered karoo sediments.	Lowland flats	Least Concern
Iridaceae	***Tritonia tugwelliae***	Karoo Kalkoentjie	Prince Albert, Leeu-Gamka and Laingsburg.	Deep loamy-sand in Nama Karoo shrubland.	Lowland flats	Least Concern
Crassulaceae	***Tylecodon faucium***	Klipnentacotyledon (Afrikaans)	Mountains south of Sutherland.	Shaded rock crevices, often on south-facing slopes, 1100 - 1400 m.	Mountains	Least Concern

Family	**Scientific name**	**Common name**	**Distribution**	**Habitat**	**Habitat type**	**IUCN Red List Status** (2015 South African Plant Assessment)
Apocynaceae	***Xysmalobium gomphocarpoides var. parvilobum***		Karoo basin around Beaufort West.	Dry sandy river beds.	Floodplains	Least Concern
Scrophulariaceae	***Zaluzianskya marlothii***	Roggeveld Drumsticks (English)	Uitkyk and Sneeukrans in the Roggeveld.	Arid slopes, 1500 - 1700 m.	Mountains	Data Deficient
Scrophulariaceae	***Zaluzianskya pilosissima***	Carnarvon Drumsticks (English)	Roggeveld to Carnarvon.	Sandy and gravelly flats and streambeds.	Lowland flats	Least Concern

Digital Addendum 7B: Methodology used to identify areas of Ecological and Biodiversity Importance and Sensitivity (EBIS)

As explained in Section 3.1, a hybrid approach was taken to identifying EBIS'. This approach combines multi-criteria analysis with systematic biodiversity planning (also known as systematic conservation planning). The multi-criteria part of the analysis allows for identification of the ecologically important and sensitive areas features in the landscape where the whole feature falls within a specific level of sensitivity or importance (e.g. a riparian area or a buffer around a protected area). However, in landscapes where there is a great deal of choice of location for meeting targets for biodiversity features such as the Karoo, it is usually not necessary to secure the whole ecosystem or habitat to ensure the ongoing integrity of the area, but nevertheless it is necessary to ensure that enough area of each feature is left intact. A multi-criteria approach does not allow for the identification of a set of areas, which if secured, would allow Karoo ecosystems, their key ecological processes and important species to persist. Hence, a systematic biodiversity planning approach was also applied to the spatial mapping of EBIS'. This approach, which is widely accepted in South Africa as best practice for the identification of spatial biodiversity priorities, aims to identify a set of areas which meets targets for all biodiversity features in a way that is ecologically sustainable, efficient and least conflicting with other activities and land uses. Details of the methodology are described below.

Features included in the analysis

Areas which are currently legal protected, including five National Parks (Karoo, Tankwa Karoo, Mountain Zebra, Camdeboo and Addo Elephant National Parks), 17 Nature Reserves (Commandodrift, Oviston, Somerset East and Tsolwana) and 3 Protected Environments (Compassberg, Noorsveld, and the newly declared Mountain Zebra-Camdeboo Protected Environment) were fully included into the planning process. Buffers corresponding to NEMA EIA requirements of 10 km around the national parks and 5 km around nature reserves were also built in to avoid impacts on these key sites, but no buffers were included around the Protected Environments as this is not provided for under NEMA regulations. All reserves that are included in the current and developing World Heritage Site designations for Fynbos and Succulent Karoo were included. The UNESCO designated Gouritz Cluster Biosphere Reserve was included.

Critical Biodiversity Areas (CBAs) from the existing systematic biodiversity plans which cover the area were strongly included in the analysis, with full inclusion where possible and a strong weighting where the areas were too broad. These included the very high value landscapes of the Bokkeveld-Hantam-Roggeveld captured in the Namakwa District Biodiversity Sector Plan (Desmet & Marsh, 2008), the highest priority areas from the Central Karoo District Biodiversity Sector Plan (Skowno et al., 2009), the irreplaceable areas from the Eastern Cape biodiversity plan (Berliner & Desmet, 2007) and CBAs from the new Northern Cape biodiversity plan (Oosthuysen & Holness, in prep.). All of these spatial plans include comprehensive assessment of areas required to meet targets for ecosystems (especially threatened and endemic ecosystems), key species and ecological process areas (including key corridors and linkages for climate change adaptation).

Although the CBAs from the existing systematic biodiversity plans which cover the area provided a robust starting point for the identification of priority areas in the study area, they were not sufficient or at a fine enough scale that all key ecosystems were fully incorporated. As the available habitat maps for the area were not sufficiently refined to support the detail of planning required, a proxy habitat map was developed by combining the existing national vegetation map, the land type map (which identifies different areas based on soils, topography and other environmental variables) and catchment boundaries. The map includes 350 distinctive habitat units and 7047 separate mapped units. The analysis ensured that sufficient representative areas of each of these 350 habitat types were secured.

A set of hydrological process areas were identified based on all rivers, wetlands and springs. Features were buffered based on an expert assessment of the area required to secure water related processes (Table 7.3 and Table 7.4).

Table 7.3: Rivers were buffered based on their designation with the NFEPA project (Nel et al., 2011) and their ecosystem threat status. Values are in meters.

River priority from the FEPA project and Ecosystem Threat Status	**River or Fish FEPA, Fish Support Area, Fish Corridor**			**Phase 2 FEPA, Upstream Management Area**			**Other Non-FEPA prioritised rivers**		
	Critically Endangered and Endangered	**Vulnerable**	**Least Threatened**	**Critically Endangered and Endangered**	**Vulnerable**	**Least Threatened**	**Critically Endangered and Endangered**	**Vulnerable**	**Least Threatened**
Mountain & Upper Foothill	100	100	100	100	100	50	100	50	50
Lower foothill	200	200	200	200	200	50	100	50	50
Lowland river	200	200	200	200	200	100	200	100	100

Table 7.4: Wetlands and related features were buffered based on their type and ecosystem threat status. Values are in meters.

Wetland type	Critically Endangered and Endangered	Vulnerable	Least Threatened and unclassified systems
Priority wetlands (FEPA)	200	200	100
Channelled and un-channelled valley bottom wetlands, floodplain wetlands, seeps.	200	200	100
Depressions and Flats	100	100	50
Dry watercourses	50	50	50
Springs			500

Threatened, endemic and near-endemic plants were carefully prioritised. Endemic and near-endemic plants were identified by checking all plants listed in the three regional floras that cover this region (Snijman, 2013; Maggee & Boatwright, in prep; Bredenkamp, in prep). Plant species that have either 80% of their entire global range (near endemic) or that occur entirely within the area demarcated for SGD (endemics) were selected. In total 193 priority plant species occur within the SGD area. Of these 20 are too poorly known and 57 are locally common and widespread within this area and not likely to lose a significant proportion of their population to SGD, even under the Big Gas scenario. The remaining 119 plant species were included in the analysis (see Digital Addendum 7A). These species are of conservation concern and the areas where they are concentrated need to be avoided during the roll out of SGD. The majority of the restricted species (75 or 63%) occur in the mountains and are concentrated in the botanical centres of endemism, the Roggeveld Escarpment around Sutherland (46), the Cape Midlands Escarpment that includes the Sneeuberg Massif that surrounds Graaff-Reinet (23) and the Nuweveldberge (12) just west of Beaufort West. The 44 restricted endemic species that occur on the flat plains of the Karoo are mainly succulent plants from the families Aizoaceae (the Vygies); Euphorbiaceae (Euphorbias) and Apocynaceae (Stapeliads). Many of these occur in dolerite outcrops; however 25 species are restricted to the clay and gravel flat areas and would be highly vulnerable to the impacts of SGD. All known locations for the 119 priority species were buffered by 1 km and these areas were fully included in the plan. In addition, the habitat requirements for each species were identified and these areas were included based on a sliding scale with species with small known ranges having high proportional targets and ones with larger ranges being allocated lower proportional targets. Finally, the specific ecosystem units associated with high numbers of special species were separately identified, and these landscapes were included as features in their own right.

Animals of concern (Digital Addendum 7A) were considered to be those whose threat status could decline (i.e. their assessed risk of extinction increase) if habitat were to be lost in the exploration area. This means that species with 60% or more of their distribution within the shale gas exploration area, or those that are threatened at a global scale that occur in the focus area were considered to be species of concern. There are 11 species that are threatened at a global scale that occur in the exploration area, including one that is Critically Endangered (Riverine Rabbit); eight that are Endangered (the Cape Vulture; two damselfly species, the Kubusi Stream-damsel and the Basking Malachite; the Plain Mountain Adder and four freshwater fish species, the Eastern Cape Redfin, Cape Rocky, and two fish species without common names, *Barbus trevelyani* and *Pseudobarbus asper*); and three that are Vulnerable (Black-footed Cat, Victor's Blue Butterfly, and one freshwater fish species, the Amatola Barb). There are also two reptile species that are Near Threatened, the Karoo Padloper and Braack's Pygmy Gecko. The levels of endemism for vertebrates in the study area are relatively low, with most of the species occurring in the area having wide distributions. The Riverine Rabbit and the Karoo Rock Sengi, *Elephantulus pilicaudus,* are exceptions, and are near endemic to the study area. No bird species were considered to be endemic or near endemic to the area. Five species or subspecies of reptile are endemic or near endemic to the exploration area (Cloete's Girdled Lizard, *Pseudocordylus microlepidotus namaquensis* (no common name), Karoo Flat Gecko, Western Dwarf Girdled Lizard and the Thin-skinned Gecko. The five threatened fish species are all near endemics. There is one frog species, the Karoo Dainty Frog, *Cacosternum karroicum*, that is near endemic. Habitat requirements for all these species were built into the spatial analysis. Several terrestrial invertebrate groups include species with narrow ranges, but in many cases there is insufficient data to be able to identify endemics with any certainty. Butterflies are relatively well surveyed (Mecenero et al., 2013) and 19 species or subspecies have more than 60% of their range in the study area, and 4 of these are only known from the study area (Pringle's Copper, Victor's Blue, Compassberg Skolly, and the Camdeboo Skolly). Terrestrial molluscs often have narrow distributions, and seven species appear to be largely restricted to the study area. Threatened animal species were prioritised in a similar way to the plants, and both the known distribution points and priority mapped occupied range were incorporated into the planning process.

Special habitats (e.g. rocky outcrops, koppies, dolerite dykes, boulder fields, woody vegetation on outwash plains) which are critical for many threatened species and often support key local ecological processes were identified using backscatter from synthetic aperture radar (SAR) data (See Thenkabail, 2016 for background on this method).

Targets for biodiversity pattern and ecological process features

Targets for features were set as follows:

- Ecosystem targets were linked to national targets set by the National Biodiversity Assessment (NBA) 2011 (Driver et al., 2012). These targets ranged from 16% to 28% of their original extent.
- Threatened, and endemic and range restricted plants: Firstly, a 100% target was used for the immediate 1 km buffer around threatened species locations. Secondly, targets for special species

habitat requirements were scaled against habitat extent, with the smallest required areas having a target set at 100% ranging down to a 20% target for the species with the broadest range. Finally, targets of 100% of the highest value landscapes with multiple threatened species were set.

- Threatened species habitat (animals): Targets were scaled as for the threatened, endemic and range restricted plants.
- Hydrological process areas: As these areas are highly sensitive to impacts, support many processes and species in the Karoo, and form a potential conduit through which contaminants could be transferred through to the rest of the landscape, rivers, wetlands, springs and their buffers were included with a 100% target.
- Special habitats: Special habitats (e.g. rocky outcrops, koppies, dolerite dykes, boulder fields, woody vegetation on outwash plains etc.) were included with a 100% target.
- Designated protected areas and their buffers: An effective 100% target was used for Protected Areas (National Parks, Nature Reserves and Protected Environments) and buffers around these features (10 km around National Parks and 5 km around Nature Reserves).
- Known priority areas: Irreplaceable CBAs covering the region were included with a 100% target.

Spatial analysis process

The analysis process was undertaken as follows: Irreplaceable features were identified and fixed into the spatial analysis using a multi-criteria approach. Individual distributions of biodiversity features were then analysed using the conservation planning software MARXAN. The analysis identified the best portfolio of sites which meets all the targets in a configuration that is most efficient, least cost and least conflicting with other activities. The approach identifies all the sites which are either always required (i.e. irreplaceable) or near-irreplaceable (Very High ecological importance), and an additional set of areas which represents a best possible configuration of areas to meet the remaining targets (i.e. the set of optimal sites) (High Ecological importance). Finally, there are a set of sites which are in a natural or near-natural condition but are not required to meet targets, as long as the irreplaceable and optimal sites are secured (Medium to Low ecological importance). The features included in each category are summarised in Table 7.5 in the body of the assessment.

CHAPTER 8

Agriculture

CHAPTER 8: AGRICULTURE

Integrating Author:	Noel Oettle[1]
Contributing Authors:	Lehman Lindeque[2], Justin du Toit[2], Igshaan Samuels[3]
Corresponding Authors:	Antony Osler[4], Susi Vetter[5], Emma Archer Van Garderen[6]

[1] Environmental Monitoring Group Trust, Nieuwoudtville, 8180

[2] Department of Agriculture, Forestry and Fisheries (DAFF), Pretoria, 0001

[3] Agricultural Research Council, Pretoria, 0001

[4] University of the Free State (UFS), Bloemfontein, 9301

[5] Rhodes University, Grahamstown, 6140

[6] Council for Scientific and Industrial Research, Pretoria, 0184

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Executive Summary

Agriculture is an important contributor to the regional economy. The total Gross Farm Income (GFI) of the region is just over five billion rand (R 5006 million). The agricultural sector in the study area provides a direct source of income for about 38 000 people. Considering the average size of families in the study area of approximately 4.5 persons, this translates to supporting the livelihoods of around 133 000 people.

The biggest risk of shale gas development (SGD) to agricultural production in the study area relates to the use, availability and quality of water resources. In the Central Karoo, groundwater is essential for human and livestock consumption, and surface water is also utilised for livestock and irrigation purposes. In the dryer central and western parts of the study area, farming communities rely exclusively on boreholes for the provisioning of water for humans and livestock consumption. This is due to the unreliable and limited rainfall in the area and high evapotranspiration rates, resulting in limited quantities of available surface water. SGD poses a risk to groundwater aquifers and surface water resources in the region which will affect agricultural production and land-based livelihoods. Opportunities also do however exist to utilise treated water from SGD operations, or that sourced from saline deep aquifers for productive purposes, should it be either of an acceptable quality or amenable to purification (see Hobbs et al., 2016).

Although the risks of SGD on agriculture can be reduced if sensitive areas are avoided and the threat to groundwater is adequately mitigated, the likelihood of negative impacts of SGD on agricultural productivity remains. The central and western parts of the study area are areas of low potential productivity in a national context, yet have made a relatively constant contribution to regional Gross Domestic Product (GDP), and sustained local livelihoods. Due to low and variable rainfall and inadequate access to water resources, the area offers limited options and opportunities for intensive farming operations. The area is thus typified by large, extensive farms and low levels of population. There is a trend amongst land users to move towards alternative sources of land-based incomes such as eco-tourism and hunting. Local land users draw on profound local knowledge to sustainably use these vulnerable land-based resources. Farming has proven to be a sustainable land use for centuries and most farmers live in equilibrium with scarce natural resources. The potential short-term benefits of SGD pose a threat to that equilibrium of this relationship (Section 8.2.1).

The resilience of both the area and its land users will be put at risk by any activity that destroys current land-based livelihoods. This risk can be reduced by careful planning to reduce fragmentation of the landscape. In the light of the North American experience, disturbance of agricultural landscapes can be expected to effect on average 2.7 ha of land per wellpad (Drohan and

Brittingham, 2012). Rehabilitation of soil surrounding wellpads post production may not restore the full soil functionality; which will limit the success of revegetation. Some land will be taken out of production while SGD is underway (leased or purchased) which would potentially have a positive impact on the incomes of agricultural land users. On the other hand, if farmers lease their farms in entirety this would have a negative impact on the continuity of the farming practices in the area, especially if farmers take up alternative employment for the period of the lease.

Local economic development associated with the SGD will provide some stimulus for local markets for agricultural products. Significant numbers of locally-based staff of SGD companies will increase demand for agricultural products to a limited extent. SGD operations are likely to attract non-employees in service enterprises who will also contribute to the local economy and consume agricultural products.

SGD will put the protection of the privacy and security of land users at risk. Currently land users enjoy high levels of control over the farm-based resources resulting in minimal losses of livestock and other property, and good levels of overall safety and security of rural communities, including land users, farm workers and their families. This is in part a result of minimal through-traffic on most farms, and relatively stable local populations. The anticipated influx of work seekers and staff of shale gas companies and the situating of exploration and extraction operations on farm land will expose farm property, for example livestock, to theft and increase vulnerability of local communities to farm attacks and violence. The international experience also indicates that influxes of work seekers and broader social disruption are likely to increase alcohol, drug and domestic abuse in SGD areas (see Atkinson et al., 2016).

SGD may put the agricultural landscape at risk if undertaken in sensitive areas or in a careless fashion. The current trend of investment in agricultural land in the study area is associated with multiple perceived benefits including deriving incomes from eco-tourism and agricultural-based tourism or lifestyle farming (see Toerien et al., 2016). SGD could pose a risk to these growing industries and perceived benefits of land ownership by eroding the aesthetic integrity of the area (see Oberholzer et al., 2016), impinging on privacy and undermining lifestyle choices based on appreciation of pristine environments.

Sufficient policy, legislation and regulation exist to protect agricultural resources; however, enforcement of these instruments and institutional capacity remains inadequate. Current legislative and policy instruments include the Conservation of Agricultural Resources Act (CARA), Act 70 of 1970 (Subdivision of Agricultural Land), the Spatial Planning and Land Use Management Act (SPLUMA), and the National Policy on Food and Nutrition Security. However, the institutional capacity, skills and knowledge to implement or enforce these measures are limited, especially at local implementation level. It is recommended that SGD operators be obliged to enter into binding contractual agreements that guarantee the protection of the natural resource base and oblige them to finance any necessary rehabilitation and provide adequate compensation to affected land users for environmental damage. In addition, government must invest sufficient resources to build the capacities of responsible institutions to address these deficiencies in order to ensure the sustainable utilisation of natural resources and to protect rural livelihoods.

Long-term monitoring and evaluation is essential to measure the effectiveness and efficiency of mitigation measures applicable to all SGD scenarios, and thus to ensure continuous improvement through immediate corrective actions and positive impact of these measures on the sustainable use of agricultural resources. The effective implementation of mitigation and rehabilitation measures is important to limit the negative impacts of SGD. In order to measure effective implementation and maintenance of infrastructure, monitoring and evaluation of key variables (as described in Section 8.8.2) is necessary. The effective implementation of such a long-term monitoring programme depends on the availability of adequate resources, especially at the level of local implementation. Sufficient capacity and skills must be developed within the appropriate institutions to ensure the effective implementation thereof over the necessary time-scales. It is further recommended that monitoring outcomes and evaluation processes be fed back to relevant stakeholders to ensure continuous improvement.

CHAPTER 8: AGRICULTURE

8.1 Introduction and scope

8.1.1 Relevance of the agriculture for the region

Agriculture has been identified as the dominant land use in the Karoo region of South Africa, which covers virtually the entire study area. The value of agricultural production in South Africa was R 218 045 million in 2014, while its contribution to the Gross Domestic Product (GDP) was approximately R 69 423 million. The primary agricultural sector has grown by an average of approximately 11.8% per annum since 1970, while the total economy grew by 14.9% per annum over the same period, resulting in a decline in agriculture's share of the GDP from 7.1% in 1970 to 2.0% in 2013. Wool sales from South Africa realised R 3 749 million in 2015 (Wool SA, 2016), with the majority of this coming from the Eastern, Western and Northern Cape Provinces.

Agriculture's prominent, indirect role in the economy is a function of backward and forward linkages to other sectors. Purchases of goods such as fertilisers, chemicals and implements form backward linkages with the manufacturing sector, while forward linkages are established through supplying raw materials to the manufacturing industry. About 70% of agricultural output is utilised in other industries as intermediate products, thus contributing far more to overall GDP than is apparent from the statistic above. Agriculture is therefore a crucial sector and an important engine of growth for the rest of the economy (Department of Agriculture, Forestry and Fisheries (DAFF), 2014).

8.1.2 International and national context

While the impacts of shale gas development (SGD) on agricultural production have been a concern in Queensland, Australia (Thomas, 2015), the most thorough research on the impact of these activities on small to medium scale farms was conducted in Pennsylvania (Malin and DeMaster, 2015) and Wyoming (Haggerty and McBride, 2016). Bamberger and Oswald (Bamberger, 2012, 2014) report serious adverse effects of the chemicals used for hydraulic fracturing ("fracking") in the USA on livestock, including respiratory, reproductive, and growth-related problems in animals with major implications for farming and the food system. All of these studies point to the double-edged sword of unconventional gas projects providing an alternative income to those farmers who are burdened with high debt loads while compromising their natural resources and leading to conflict and often termination of farming.

Since the possibility of SGD is very new in South Africa, it is met with the expected fears and suspicion. Even though the larger study area is not known for large areas of productive crop fields, it supports a vast area dominated by meat production and smaller niche areas of high-value irrigated crops. There are currently no policies in South Africa for the assessment and management of shale gas impacts on agriculture. Therefore it is important that lessons learned from the international agricultural communities impacted by these activities be used to inform policies and legislation that will prevent these impacts as far as possible from occurring in the study area and the rest of the country.

8.2 Scope of the study

8.2.1 Agricultural parameters

Land, according to Gwartney (Wessels & Willemse, 2013), is defined as "*everything outside of people themselves or the products they make. It includes all natural resources, air, soil, minerals and water is included in the definition of land*". In other words, everything that is freely supplied by nature, and not by man, is categorised as land. Land is important and plays a pivotal role in social, political, environmental, economic and agricultural disciplines.

In contrast to this, agriculture as a study field can be defined as *"the cultivation of plants, animals, fungi and other life forms for food, fibre, biofuel, medicinal and other products used to sustain and enhance human life" (*International Labour Organisation, *1999).* For the purpose of this Chapter agriculture will therefore entail food and fibre production from natural resources to support the livelihoods of land users (and their employees), both within the cash economy and for subsistence and cultural purposes. It is considered to be the effective management of the synergies between climate, soil, vegetation, water and livestock that sustains the livelihoods of most people in the Karoo.

Agriculture also functions on different levels or scales, including both a social subsystem and an ecological subsystem. Decision-making within agriculture needs to consider both these subsystems, the agroecosystems agriculture depends on, as well as the governance systems organising and regulating agriculture in the study area, for example. According to Rivera-Ferre et al. (2013), agriculture can therefore be seen as a complex socio-ecological system and both these aspects need to be considered in decision-making related to agriculture (Figure 8.1). The complexity of agriculture and the importance to focus on both the social and ecological aspects related to decision-making within the agricultural field is further illustrated by the linkage between the Agriculture Chapter and other Chapters of this study.

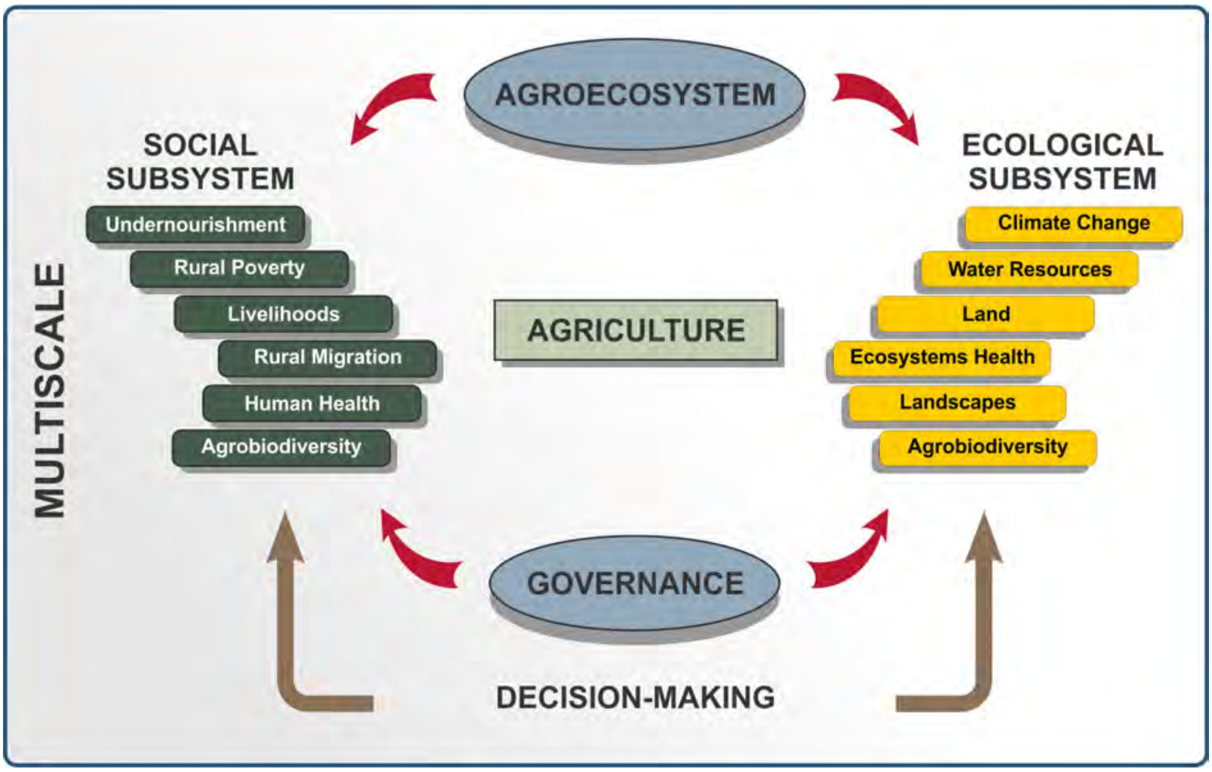

Figure 8.1: Agriculture as a complex socio-ecological system (Rivera-Ferre et al., 2013)

8.2.2 Links to other strategic issues

Considering the definition of land, the direct dependency of agriculture on land, but also the important role land plays in other disciplines like social, political, environmental and economical disciplines; one could expect the agricultural chapter to have linkages with other study fields. Figure 8.1 indicates the relative strength of the linkages between the agricultural field and other study fields' that are part of this scientific assessment.

The strong dependency of agriculture in the study area to the basic natural resources, terrestrial biodiversity and water, is clearly indicated in Figure 8.1. The anticipated impacts described in the scientific assessment should thus be kept in mind when reading the Agriculture Chapter. In the South African context, agriculture is primarily about people utilising natural resources to sustainably produce food and fibre to ensure food security for a growing South African population whilst generating sustainable incomes and creating employment of significant numbers of rural dwellers. Farmers are part of a bigger community, and rely on each other, farm workers, townspeople and other users of agricultural produce to make a living and provide them with a sound raison d'être. This relationship, secondary to their dependency on natural agricultural resources, is demonstrated in the relative strength of the linkages between this chapter and those addressing spatial planning and infrastructure (van Hussteen et al., 2016), tourism (Toerien et al., 2016), sense of place (Seeliger et al., 2016) and social fabric (Atkinson et al., 2016).

8.3 Legislation applicable

The National Environmental Management Act (Act 107 of 1998) (NEMA) (South Africa, 1998a) creates a legislative framework within which degradation of the environment regulated and sanctioned. In addition, the following South African legislation specifically applies to the conservation of agricultural resources:

The Conservation of Agricultural Resources (Act 43 of 1983) (CARA) (South Africa, 1983) states that the degradation of the agricultural potential of soil is illegal, and requires the protection of land against soil erosion and the prevention of waterlogging and salinisation of soils by means of the construction and maintenance of suitable soil conservation works. The sustainable utilisation of marshes, water sponges and watercourses on agricultural land is also regulated in terms of the Act.

The National Water Act (Act 36 of 1998) (NWA) (South Africa, 1998b) is concerned with the quality and quantity of water used, including for agriculture. Any impacts caused by shale gas activities on the volume and quality of water available for authorised agricultural water use, will be an infringement of this Act.

CARA was promulgated more than three decades ago, and did not anticipate all of the current potential impacts of new developments on agricultural resources. To ensure more sufficient protection of agricultural resources, it is recommended that the International Finance Corporation (IFC) Performance Standards on Environmental and Social Sustainability that became effective on 1 January, 2012 also be considered. With regards to the impacts on agricultural resources, the following standards and guidelines are of most relevance:

- IFC Performance Standard 3: Resource Efficiency and Pollution Prevention provides guidelines on project-level approach to resource efficiency and pollution prevention, in this case specifically for land management.
- IFC Guidelines for Mining which recommend practices for sustainable land use and topsoil management.
- IFC General Environmental, Health and Safety Guidelines: Contaminated Land for the detection, remediation and monitoring of contaminated land.

8.4 Purpose of the Chapter

The main purpose of this chapter is to identify the potential risks and impacts of SGD on agriculture, the vulnerability of the area to these operations and making strategic policy recommendations towards the sustainable management of these risks, impacts and vulnerabilities. To enable the authors to describe the potential impacts, risk and vulnerabilities, agriculture within the study area needs to be put into context, different agricultural systems in the Karoo need to be described, as well as their relative importance and some recent trends. As previously explained, agriculture within the study area is not only complex, but depends largely on a very limited supply of natural resources making it a very vulnerable system when considering the potential impact of climate change over the long-term and climate variability in the short and medium-term. The authors have thus developed a vulnerability map of the study area to provide an index value (on a quaternary catchment scale) indicating the relative vulnerability of agriculture to fracking within specific catchments.

8.5 Agriculture in the study area

8.5.1 General overview

Agriculture in the study area is heavily dependent on water, especially from aquifers since surface water resources are very limited. First introduced in 1874; wind pumps raising groundwater made permanent farms and towns in the Karoo possible. Underpinning the Karoo's economy are its 7 million sheep, divided between three million hardy Dorpers and 4.3 million wool-bearing sheep like Merinos, according to Cape Wools SA and National Wool Growers Association. There are also approximately a million goats. The Karoo has long been a good producer of fibre, contributing 13 million kg of South Africa's annual 44 million kg of wool. It also produces all of South Africa's 2.4 million kg of mohair annually – around than 60% of the world's production – from some 670 000 Angora goats. Most of the wool and mohair is exported and brings in billions in foreign revenue for South Africa.

Primary types of farming in the area comprise:

- Livestock, both extensive and intensive, for commercial and subsistence purposes;
- Dryland cultivation, including subsistence, small-scale and commercial;
- Cultivated irrigated land, both small scale and commercial;
- Game farming; and
- Tourism-related production, including both eco-tourism and farm-stays.

8.5.2 Main farming types

Almost the entire extent of the study area is used for extensive commercial livestock and/or wildlife production. Municipal commonage adjacent to all towns within the study area is utilised for communal farming by small livestock producers. A small section of the study area east of Queenstown (historically part of the Transkei) is farmed communally. Some commercial farms (both extensive and intensive) within the study area have been purchased by the national government in the context of its Land Reform Programme for the benefit of aspirant farmers. Where water is available, pastures or crops (including horticultural crops) are cultivated. Where livestock is produced, farms are invariably divided into multiple paddocks to contain animals (with different rotational systems), allowing for better animal control and veld management. Below follows a generic description of the most widely used animal production systems with the study area.

8.5.2.1 Commercial sheep production in the arid west

The arid western region of the study area (approximately west of 24°E) is predominantly Karoo vegetation. Vegetation is described as ‘sweetveld’, meaning that the quality of forage is high enough throughout the year to allow animals to increase or at least maintain body weight (‘sourveld’ in contrast has a low forage value during winter meaning that animals require supplementary feeding to avoid losing weight). Carrying capacity of the veld is low, ranging from 17-90 ha/AU (ca. 3-15 ha/SSU). Veld provides most forage for animals, though during droughts supplementary licks, pelletised feed or hay may be provided. Where available, irrigated pastures (lucerne in particular) provide additional feed for animals, and may be used during the lambing season for improved management and protection from predators. The carrying capacities of irrigated areas are orders of magnitude higher than those of rain fed areas of the study area.

8.5.2.2 Commercial sheep and/or cattle production in the east

The eastern section of the study area (approximately east of 24°E) experiences sufficient rainfall to allow perennial grasses to contribute significantly to available forage for livestock, thereby allowing for cattle to be farmed. Sheep and cattle are often produced together, though sheep-only and cattle-only farms do occur. Veld here is a mixture of sweetveld (lower lying, lower rainfall areas) and sourveld (higher lying, higher rainfall), often with both types of veld occurring on single farming units, in which case they would be separately fenced into different paddocks. On farms with sweetveld and sourveld, animals typically utilise the sourveld during the summer months when the quality of grazing is good, and move to the sweetveld when forage quality decreases and the weather turns cold. On farms with a significant proportion of sourveld, animals are supplemented with nitrogen licks and sometimes fed additional forage during the winter. Forage is usually produced on arable lands on the farm.

8.5.2.3 Commercial goat production in the south-east

Goat production, either for meat or for mohair, takes place primarily in the savannah or thicket biomes where trees and shrubs provide forage, with some production in the grassland and Nama-Karoo biomes. Sheep and cattle may also be present depending on the vegetation type. Angora goats can easily die in wet and cold conditions, particularly if they have recently been shorn. Herd management must thus be of a high standard, and ensure that Angoras are generally not farmed in areas that regularly experience cold, wet weather. Boer goats are hardier animals.

8.5.2.4 Wildlife farming

Wildlife is present on most freehold farms across the study area. Dedicated ‘game-farms’ usually have a tall perimeter fence (a ‘game-fence’) to prevent animals from foraging beyond the boundaries of the farm. Within the farm boundary, animal movement is often unrestricted; though some wildlife species are contained by normal livestock fencing (there are arguments for rotation of certain wildlife species types at certain densities). In some areas several farms are combined to form conservancies. Here, the movement of some wildlife species is unrestricted within the conservancy. In the case of farms where lions are produced, two tall, parallel, electrified boundary fences are required for containment.

8.5.2.5 Commercial ostrich farming

Ostrich production is centred in the arid south-western portions of the study area, but ostrich farms also occur as far south as Grahamstown. Ostrich production is semi-intensive to intensive, with animals relying on natural veld for only a small proportion of their dietary requirements. The remainder of their feed is either bought or from irrigated pastures.

8.5.2.6 Communal sheep, goat, and sheep production in the far eastern section

In the far eastern section of the study area livestock is produced under communal farming tenure. Wool production has been steadily increasing over the past approximately two decades and provides a highly significant source of income for some farmers. The communal areas occur primarily in sourveld, though some patches of sweetveld do occur. Animals are often not constrained within fenced paddocks but are kraaled at night for protection against predators. Animal movement is controlled by herders. Animals graze veld throughout the year, though in winter often rely on crop residues (e.g. maize stover) and riverine areas for nutrition.

8.5.2.7 Small-scale and subsistence farming

Around hamlets, villages, and towns, small-scale farming or production is common. Production enterprises range from 'kitchen gardens' through to small-holdings. Vegetable, fruit, pork and poultry production are common, but are seldom the sole source of income. Small-holdings are usually confined to riverine areas close to towns (e.g. Graaff-Reinet and Cradock). In towns without rivers (e.g. Middelburg) there are very few (if any) small-holdings. On many small-holdings near towns, arable lands have been invaded by the exotic alien plant *Solanum elaeagnifolium* (satansbos/ silver nightshade), which is highly persistent, very difficult to eradicate, and which greatly reduces agricultural potential.

8.5.3 Current agricultural trends in the study area

8.5.3.1 Agricultural employment in the study area

Recent and reliable employment figures for the agricultural sector are not readily available. AGRI-SA estimate the Karoo Region supports around 100 000 permanent and seasonal jobs (see http://karoospace.co.za/fracking-vs-farming-karoo/)

However, the 2002 Agricultural Census data provided to the team by AGRI-SA offer more reliable employment data for the agricultural sector in the study area. The employment figures for the district municipalities within the study area are summarised in Table 8.1. Where districts fall only partly within the study area, the figures have been proportionally adjusted.

Table 8.1*:* 2002 Agricultural employment figures for the SGD study area

Owners who farm themselves and part-time farmers	Family members involved in farming operations	[A] Total full time paid employees	[B] Total Casual and seasonal workers	Total paid employees [A+B]
2 950	823	15 015	19 764	34 779

When looking at the employment figures for 2002, it is clear that for each full-time or part-time farmer who farms themselves, at least five full-time employees were in full-time service on farms in the study area. These figures differ substantially between the high productive fruit growing areas of the Western Cape to the more communal farming areas of the Eastern Cape Province and the drier livestock producing areas of the Northern Cape. For example, in Ceres there were 89 owner-farmers and part-time farmers in the study area alone (and not the whole district) who employed in total 5732 full-time employees. On the other hand, in Sterkstroom in the Eastern Cape 52 owner- and part-time farmers employed only 17 full-time employees. Sutherland in the Northern Cape had 135 owner- and part-time farmers who employed only 59 full-time employees.

Considering the types of farming operations in the study area (ranging from horticulture, fodder production and livestock farming) and the seasonality of these operations, the relatively high number of casual and seasonal workers employment (19 764 for study area in 2002) is not surprising. Seasonal and casual workers are mainly employed for fruit and vegetable picking, working in pack houses, undertaking sheep and angora goat shearing and for general farm maintenance.

In summary, in 2002 the agricultural sector within the study employed about 35 000 people. Including the 2 950 owners and part-time farmers who farm themselves, the agricultural sector in the study area provides a direct source of income for about 38 000 people. Considering the average size of families in the study area of approximately 4.5 persons, this translates to a sustainable livelihood for 133 000 people. The figures may currently be higher than this, but considering the very substantial increase in minimum wages since 2002, low profit margins within the agricultural sector in general, and the mechanization of farming enterprises, it may be expected that these figures will currently be more or less the same.

8.5.3.2 Economic trends

The Census of Commercial Agriculture 2008 reflected a 31% decline in the number of farmers since 1993, resulting in the industry being left with fewer than 40 000 farms. The maize, wheat and dairy sectors have been the hardest hit. Although the number of farming units has dropped during this time, gross farm income (GFI) has increased by more than 300%. With expenses growing by a relatively low 285%, net farm income (NFI) grew by a staggering 410% over this period. Because of this growth, the net farm income per farm unit has increased significantly to five times more than what it was in 1993. This may in part be ascribed to economies of scale resulting from operations taking place within fewer, but larger units.

Agricultural land values have increased throughout the study area in the past two decades. For example, land values in the Graaff-Reinet area have increased from between R 170 – R 325 per hectare in 1995 to between R 2 700 – R 5 900 per hectare in 2016. (Derek Light Attorneys and Conveyancers 2016: Deeds Registry, Cape Town).

Local and national markets for agricultural products from the study area have shown steady growth. International markets for fibre are both stable and lucrative. Returns from game farming industry show a strong positive tendency, reflecting the success of this industry in marketing its products and services nationally and internationally.

In contrast to this, many smaller and more marginal farmers had to quit their farming enterprises as a result of rising input costs and shrinking profits. These farmers had frequently been reliant on subsidies and soft funding from institutions such as the Land Bank, and faced a situation where government support was phased out at the same time as the markets opened to allow competition from cheap imports.

8.5.3.3 Agricultural activities and their economic importance in the study area

To our knowledge, there is no single, comprehensive, methodologically consistent report that details the economic contribution from agriculture in the study area. Rather, a picture must be developed from several sources. The most comprehensive description derives from the 2007 census of commercial agriculture. When values are adjusted for inflation, this provides a robust background overview of the economic contribution of agriculture to the economy of the study area. However, the economic contribution of hunting was further scrutinised as much of the income for this activity is not associated with the sale of produce, which is what the census results detail.

Census results from 2007

To quantify the primary agricultural activities and their economic importance, data provided by Statistics South Africa (StatSA, 2007a, 2007b, 2007c) were used. This is the most recent comprehensive survey available. In these reports, agricultural data are provided per province on a per-district basis. For the purposes of this report, data were included if the town used to describe the district fell inside the study area.

Economic data are presented in the form of Gross Farming Income (GFI) which reflects income from the sale of agricultural products. Values were multiplied by a factor of 1.693 to account for inflation from 2007 to 2016 based on the ZACPI Index (FXTOP, 2016).

Thirty-one districts across the three provinces, including 30 agricultural practices, were described (Table 8.2). Agriculture is primarily livestock-orientated, with wool and sheep present in all districts, cattle in 29 districts, and milk and cream in 27 districts.

Table 8.2: Important agricultural activities in 30 districts in the study area.

Province	District	Animal products				Animal sales							Field crops				Horticulture														
		Eggs	Milk and cream	Mohair	Wool	Cattle	Chickens	Game	Goats	Ostriches	Pigs	Sheep	Barley	Lucerne	Maize grain	Wheat	Cabbages	Lemons	Naartjies	Onions	Oranges	Peaches	Pears	Pineapples	Potatoes	Table grapes	Tomatoes	Wine grapes	Pumpkins	Carrots	Apples
Eastern Cape	Aberdeen	1	1	1	1	1		1	1	1	1	1		1	1	1		1	1		1				1		1				
	Adelaide		1	1	1	1		1	1			1		1	1				1		1										
	Albany		1	1	1	1		1	1	1		1		1	1						1			1	1		1				
	Bedford		1	1	1	1		1	1	1	1	1		1	1																
	Cradock		1	1	1	1		1	1	1	1	1		1	1	1			1		1				1						
	Fort Beaufort	1	1	1	1	1	1	1	1			1		1		1		1	1		1										
	Graaff-Reinet		1	1	1	1		1	1	1	1	1		1	1						1			1							
	Hofmeyr		1	1	1	1		1	1			1		1	1						1										
	Jansenville		1	1	1	1		1	1	1		1		1																	
	Middelburg		1	1	1	1		1	1		1	1		1	1	1									1						
	Molteno		1		1	1						1			1																
	Pearston			1	1	1		1	1	1		1		1																	
	Queenstown	1	1	1	1	1	1	1	1		1	1		1	1										1						
	Somerset East		1	1	1	1	1	1	1	1		1		1	1	1									1						
	Sterkstroom	1	1	1	1	1	1		1			1		1																	
	Steynsburg		1	1	1	1		1			1	1		1	1																
	Tarka[stad]		1	1	1	1		1	1			1		1	1																
	Venterstad				1	1		1	1			1		1																	
	Victoria East		1	1	1	1						1		1	1	1									1		1				
Northern Cape	Carnarvon		1		1	1		1	1			1			1																
	Colesberg		1		1	1	1	1	1			1			1																
	Fraserberg		1		1	1			1			1			1	1															
	Noupoort		1		1	1						1																			
	Richmond		1		1	1		1	1			1																			
	Sutherland		1		1				1			1	1																		
	Victoria West		1		1	1		1	1			1			1					1											
	Williston				1	1			1			1																			
Western Cape	Beaufort West		1		1	1				1	1	1													1						
	Ceres	1	1		1		1			1		1	1			1	1			1	1	1	1		1	1	1	1	1	1	1
	Laingsburg		1		1	1	1			1		1	1			1	1					1				1		1			
	Prince Albert		1		1	1	1			1	1	1			1	1				1		1	1		1			1			

The total GFI of the region is just over five billion rand (R 5006 million), of which 48% is from the Eastern Cape, 10% from the Northern Cape, and 41% from the Western Cape. The sale of animals accounts for 39% of GFI, animal products 19%, field crops 4%, and horticultural crops 38%. These rankings are relatively consistent across the three provinces (Figure 8.2), except for Horticultural production in the Western Cape. The GFI of districts varies considerably, with the Ceres district being the highest and Victoria West the lowest (Table 8.2).

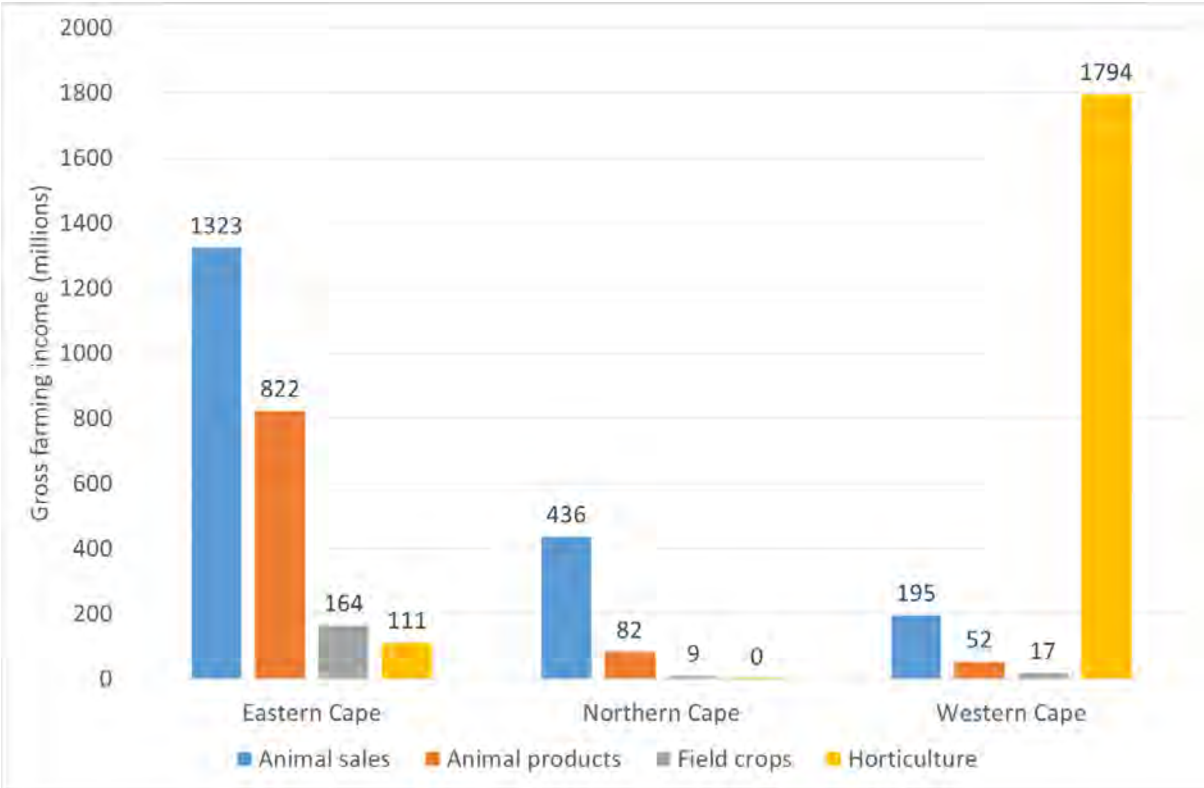

Figure 8.2: Gross farming income (2007 values adjusted to 2016 values) in millions of Rands of major agricultural products in the three provinces in the study area (StatSA, 2007a, 2007b, 2007c).

Table 8.3: Gross farming income (millions of Rands) of four main classes of agricultural products for all districts within the study area (StatSA, 2007a, 2007b, 2007c).

District	Animal sales	Animal products	Field crops	Horticulture	Grand Total
Ceres	21.4	24.3	14.5	1774.8	1834.9
Cradock	209.9	169.0	69.6	15.4	464.0
Queenstown	166.8	94.1	18.0	8.0	286.9
Aberdeen	112.5	75.2	8.2	31.5	227.4
Somerset East	116.8	93.7	7.0	0.3	217.8
Albany	85.7	67.3	1.4	21.5	175.9
Graaff-Reinet	112.3	47.9	6.2	2.5	169.0
Middelburg	106.7	28.6	20.3	0.8	156.5
Jansenville	61.6	80.7	0.9		143.1
Carnarvon	124.1	8.3	1.4		133.9
Bedford	59.4	67.8	5.8		133.0
Beaufort West	87.7	17.7		9.2	114.7
Victoria West	81.3	25.4	0.2	0.2	107.1
Adelaide	59.1	32.4	0.6	0.9	93.0
Tarka[stad]	58.0	16.4	2.2		76.6
Colesberg	58.5	12.0	3.7		74.3
Prince Albert	47.7	6.6	0.8	7.6	62.8
Williston	55.5	3.9			59.4
Fraserberg	41.1	9.2	3.7		54.0
Laingsburg	38.4	3.6	1.8	2.9	46.7
Richmond	31.8	13.2			45.0
Fort Beaufort	16.4	5.4	1.1	20.8	43.7
Steynsburg	32.4	8.2	1.8		42.5
Molteno	34.1	6.8	0.3		41.2
Hofmeyr	18.0	7.8	10.0	0.8	36.6
Sterkstroom	27.0	8.5	0.9		36.4
Sutherland	30.2	3.9	0.0		34.1
Pearston	23.7	8.9	1.3		33.9
Venterstad	20.4	2.3	1.2		23.9
Noupoort	13.8	5.9			19.7
Victoria East	2.4	0.8	7.0	8.2	18.4
Grand Total	**1955.0**	**955.9**	**189.8**	**1905.5**	**5006.1**

Forty-five percent of all income derives from extensive animal production (Table 8.4). Of this, 46% is from the sale of sheep, 26% from the sale of cattle, 16% from the sale of wool, and the remaining 12% from mohair, goats, and game.

Fifty-five percent of all income derives from intensive agricultural activities (Table 8.5). Of this, 24% is from apple sales, which occurs exclusively in the Western Cape. Other important contributors (between 10 and 20%) are pears, milk and cream, and onions.

Table 8.4: Gross farming income (in millions of Rands) from extensive livestock production activities across the three provinces within the study area (StatSA, 2007a, 2007b, 2007c).

Product	Eastern Cape	Northern Cape	Western Cape	Grand Total
Sheep	480.7	389.5	163.9	1034.0
Cattle	525.9	32.1	10.6	568.6
Wool	256.9	76.8	26.9	360.6
Mohair	126.2			126.2
Goats	82.7	9.0		91.8
Game	79.7	5.6		85.3
Grand Total	**1552.0**	**513.0**	**201.4**	**2266.4**

Table 8.5: Gross farming income (in millions of Rands) from intensive agricultural production activities across the three provinces in the study area.

Product	Eastern Cape	Northern Cape	Western Cape	Grand Total
Apples			647.2	647.2
Pears			468.0	468.0
Milk and cream	417.0	5.0	20.0	442.1
Onions		0.2	372.0	372.2
Peaches			146.6	146.6
Potatoes	21.0		98.3	119.3
Lucerne	91.7			91.7
Ostriches	71.3		16.4	87.7
Pigs	80.2		0.2	80.4
Maize grain	63.2	7.4	0.7	71.2
Oranges	34.9		0.5	35.4
Eggs	21.7		5.3	27.1
Wheat	8.9	1.6	15.3	25.8
Tomatoes	23.0		0.4	23.5
Table grapes			21.8	21.8
Pineapples	19.2			19.2
Carrots			16.2	16.2
Wine grapes			14.4	14.4
Lemons	9.3			9.3
Cabbages			8.0	8.0
Chickens	2.8	0.2	4.1	7.2
Naartjies	3.4			3.4
Pumpkins			1.1	1.1
Barley		0.0	1.1	1.1
Grand Total	**867.7**	**14.4**	**1857.7**	**2739.8**

The Hunting Industry

The economic contribution from the hunting industry (R 85 million in 2016 prices) in the study area is probably underestimated in the data from the 2007 census because: a) there has been a significant increase in the hunting industry since 2007; and b) the census reports only on the number of animals sold, and does not consider on-farm income directly associated with hunting, notably accommodation.

To calculate the contribution of hunting to the economy of the study area, an estimate of the economic contribution of hunting (accommodation and animals) to the economy of South Africa was sourced, and the proportional contribution of each of the three provinces in the study area was calculated based on data from Department of Environmental Affairs (DEA, 2014), and the contribution of each of the three provinces for the portions within the study area were calculated by scaling linearly with area (Table 8.6).

The contribution of hunting (animals and accommodation) to the South African economy was R 1.5 billion in 2014 (DEA, 2014), which corrected for inflation is R 1.7 billion (FXTOP, 2016). As a comparison, the contribution of the entire value chain (including food, transport, crafts and curios, additional sight-seeing activities, permits, licensing fees, clothing, ammunition, hunting accessories, taxidermy and trophy shipping fees), has been estimated at R 6.2 billion (Kings, 2013) which corrected for inflation is R 7.25 billion.

In summary, the contribution of hunting is likely higher (R 189 million) than was estimated using the census data (R 85 million).

Table 8.6: Contribution of hunting to economies of the three provinces in the study area (DEA, 2014).

	Eastern Cape	**Northern Cape**	**Western Cape**	**Total**
Proportional contribution to hunting economy in SA (DEA, 2014)	21%	8%	0.4%	
Proportion of province within study area	41%	31%	17%	
Contribution of activities directly associated with hunting to economy within the study area	R 1.7 billion x 0.21 x 0.41 = R 146 million	R 1.7 billion x 0.08 x 0.31 = R 42 million	R 1.7 billion x 0.004 x 0.17 = R 1.1 million	R 189.1 million

8.5.3.4 Land use changes

Following the main agricultural trends in North America, Europe and Australia, land use changes are also taking place in South Africa. To some extent land use change is being driven by investors purchasing farmland as a financial investment without necessarily intending to farm it productively. Research by Wessels and Willemse (2013) in the South-Eastern Nama Karoo confirmed that purchasers do indeed buy farmland at prices much higher than the actual productive value of land, primarily as an investment. Motivated by the sheer beauty and natural magnificence of the land, which they believe will increase in value as natural land becomes scarcer; they believe that purchasing land is a sound investment for the future.

The perception that the deeply rural ‘platteland’ areas such as the study area are economically dwindling and under pressure, may be somewhat misplaced considering the on-going investment by relatively wealthy urban people buying land for investment purposes. According to Wessels and Willemse (2013), although life is still rewarding in these areas, the economic value of production is exported to the cities and sold at a relatively low cost, whereas services are imported at a premium, creating relative impoverishment in rural areas. The scarcity of farmland and the desire of many city dwellers for a more relaxed rural lifestyle that is closer to nature combine to produce the significant and steady increases in farm prices seen in recent years.

The significance of natural beauty as a motive for investment in buying farms in remote rural areas is very important when considering the impact of SGD on agriculture. Although not directly linked to agricultural production, it highlights the important link to other Chapters of this assessment, namely Atkinson et al. (2016), Seeliger et al. (2016) and Oberholzer et al. (2016).

8.5.3.5 Farm management practices

Farm management practices in the study area reflect resilience in the face of an increasingly globalised market for agricultural products. Since the withdrawal of market protection and extensive subsidies to the commercial agricultural sector prior to 1994, the majority of farmers in the study area have adapted their practices and re-aligned their enterprises in response to emerging realities and new opportunities. As a result of a combination of low product income, high input costs and interest rates as well as the present disaster drought, some farmers in the study area are currently facing the problem that their farms cannot produce enough net income to allow their enterprises to thrive, or even survive. Many farmers have adapted or switched their enterprises in recent decades in response to new market opportunities. These changes have included incorporating or switching to game farming (see next section for a discussion in this regard), adding on-farm value to livestock products, or diversifying in other ways such as poultry or eco-tourism.

8.5.3.6 Game farming

Right of ownership lays the foundation for wild animals to become a financially viable alternative land use option in South Africa. However, sweeping structural changes in the rest of the agricultural sector also made a notable contribution towards the development of the local wildlife industry. South Africa and especially the study area, is resource poor compared with major agriculture producing regions such as Europe and the Americas.

As explained above, many commercial farmers whose operations focussed on conventional agricultural enterprises face severe financial challenges. Since 1995 South African farmers have been obliged to compete in a global market for agricultural products, despite having access to poorer resources than their counterparts in other parts of Africa and on other continents. This resulted in lower prices for agricultural produce whilst at the same time being exposed to the subsidised dumping of agricultural surpluses from other, better endowed countries. Simultaneously, other structural and environmental changes also forced farmers to re-assess their land use practices. These included deregulation of the agricultural sector immediately prior to 1994, followed by a subsequent decline in political power of farmers and (associated with this) the successive weakening of financial support from government, the extension of labour legislation to the agricultural sector, and the land reform process. Broader structural changes in the economy also increased the cost of doing business. Furthermore, on-going loss of productivity and climate change have had negative effects on the agricultural sector.

As a result, in the early 1990s, the pioneers of private game ranching started to explore alternative land use options in the form of wildlife ranching. Game ranching – initially primarily valued as a means of satisfying the personal needs of landowners, their families and acquaintances – rapidly changed when conservation, profit and sustainability of wildlife production become the main drivers of transformation. The result is what is regarded by many as one of the greatest agricultural transformations in history. Most land utilised for game production is also farmed with domestic livestock. Today South Africa boasts the largest privately owned wildlife industry in the world (Cloete et al., 2015).

The wildlife ranching industry has four pillars: breeding, hunting, ecotourism and game products (Cloete et al., 2015). International tourism to South Africa has grown strongly since 1994, and has a strong focus on nature-related tourism. This includes wildlife and ecotourism activities, 4x4 and hiking trails, nature photography and corporate team building. Hunting tourism, especially biltong and trophy hunting has experienced exponential growth. All of these factors have driven transformation from traditional livestock farming to wildlife ranching, and make it an attractive option for farmers.

Table 8.7 below reflects the methods by which individuals have become game farm owners. It is notable that over 50% of the respondents confirmed they had converted a farm (either bought or inherited) from livestock or crops to game farming.

Table 8.7: Methods of acquiring a game farm (Cloete et al., 2015)

Category	%
Bought a livestock or crop farm and converted it into game farm	46
Bought an existing game farm	23
Bought a livestock or crop farm already partially converted to game farm	9
Inherit livestock and crop farm and converted it into game farm	6
Inherit livestock and crop farm already partially converted into game farm	8
Other	8

Although the Karoo has seen a sizeable increase in game ranching activities over the past decade, the region is not especially known for wildlife production and it is the least profitable of the game ranching regions in South Africa. Despite this, game ranching in the Karoo provides farmers there with a financially superior option to traditional livestock practices, especially cattle. A small game ranch in the Karoo (3 000 ha) has the ability to generate an estimated R 371/ha worth of economic output compared to an average of R 165 for conventional livestock farming. Return on Investment (ROI) will range from 2% to 2.8% depending on the size of the ranch.

8.6 Agricultural sensitivity evaluation

8.6.1 Agricultural characteristics of the study area

As previously described, all forms of agricultural production and agriculture-related activities like agricultural or farm tourism depend largely on the natural agricultural resources, including soil, vegetation, water, climate and the topography of the area. A negative impact on any of these resources will result in the loss of the agricultural production potential of the area.

8.6.2 The Impact System

SGD on agricultural production systems will primarily impact upon the rangeland veld resource and surface- and groundwater, upon which sustained production of livestock production depends (see Section 8.6).

Use of heavy prospecting equipment is anticipated to cause long-term damage to veld (and in some cases, to soils) where it moves over the landscape. Natural landscapes can be damaged when vehicles drive over them, and in arid areas the damage may take decades or longer to repair unless effective remedial action is taken. The degree of damage depends on various factors, including the type of vehicle, whether the vehicle is travelling straight or turning, the nature of the vegetation, and the number of times the vehicle drives over the same place (Redi, 2005; Schlacher, 2008). While the effect of vehicle tracks on system degradation appears not to have received adequate attention in the Karoo, it has been recognised as a problem in other arid ecosystems as it is recognised that vehicles can destabilise and compact soils, and increase water and wind erosion (Webb & Wilshire, 1983). In the Karoo biome it has been demonstrated that various types of physical impact, including ploughing, trampling by animals, and overgrazing, can lead to degradation (Keay-Bright, 2007). If such disturbances take place on highly erodible soils, the effect can be the formation of 'badlands', which are landscapes with deep, eroded gullies (Boardman, 2008). A lesser effect, but nevertheless of aesthetic and ecological significance, is the formation of semi-permanent tracks in the veld. The cumulative effect of these impacts will be a degree of fragmentation of the landscape (Drohan, et al., 2012).

In the absence of previous studies on the effects of vehicles on Karoo vegetation, it is difficult to recommend best-management practices. Nevertheless, impacts of SGD on agricultural landscapes have been well-researched elsewhere (Drohan, et al., 2012; Fink, 2015), and on the basis thereof, best-practice recommendations have been compiled for SGD in agricultural lands (Eshleman, 2013). This literature would suggest that an important mitigation would be to reduce the amount of traffic over the veld to a minimum. Additionally, wide tyres and light vehicles reduce the pressure on the ground and thus damage to vegetation and compaction of topsoil. Track formation (and hence erosion potential) can be reduced by avoiding repeated driving over the same ground.

During initial exploration phases (Scenario 1 – Exploration Only) there will be opportunity to monitor the effect of vehicles on Karoo soils and vegetation. Monitoring should take the form of describing traversed and non-traversed vegetation over time. Key factors that should be monitored are vegetation composition and the proportion of bare ground, and these should preferably take place in permanent quadrats with backup photographic monitoring. Invasive alien plants tend to thrive in disturbed areas, and as vehicle tyres provide an effective vector, monitoring should include assessing the spread and density of alien plant populations.

Construction of roads for the installation of other infrastructure for gas extraction and transportation of inputs, outputs and waste will fragment the agricultural landscape, remove significant amounts of land from production and render even larger areas unproductive through other effects, advance soil erosion and create opportunities for invasive species to colonise disturbed areas. Eshleman and Elmore (2013) recommend "minimising the amount and impact of new road and pipeline construction as much as practicable by (1) limiting the linear distance of new roads through strategic siting of operations; and (2) co-locating project infrastructure with current roads, power lines, and pipelines”.

Water will be required for the fracking process, and will have to be transported to the sites from source (which may well be outside the Karoo, because the Karoo is generally water stressed). Large volumes of water will thus have to be transported by road.

The zones in which fracking will take place are likely to be so far down in the rock strata as to render the danger of pollution of groundwater used for agriculture of lesser significance. Nevertheless, leaking encasements could cause pollution of aquifers (see Hobbs et al., 2016). A proportion of the water that is used in the fracking process will be permanently lost, but what is returned or delivered to the surface will comprise both flowback (injected water contaminated with toxic fracking fluids ejected from the well in the days immediately following fracking) and produced water (a mixture of the originally injected water contaminated with toxic fracking fluids and so-called formation water, which is brackish water from the targeted shale). Indications from international experience are that between 15-80% of the water will be returned to the surface, where it will have to be contained before disposal or re-use, and leakages and pollution of surface and shallow groundwater by flowback and produced water will be a threat to agricultural production (Vengosh, 2014; Warner, 2013). Radioactivity of produced water is a serious threat to the agricultural environment (Vengosh, 2014). If ingredients similar to those that have been used elsewhere are utilised, the sites of containment dams may be rendered permanently contaminated by toxins, carcinogens and salts (Bamberger, 2012, 2014), with serious health implications for humans and animals.

Veld fires are relatively unusual in the Karoo because a) it is not a standard veld management practice and b) fuel loads are usually too low to allow it. However, veld fires do occasionally burn in the Karoo, particularly in the grassier eastern parts of the study area, and during periods of high rainfall, and are most frequently caused by lightning or accidentally by humans (du Toit, O’Connor, & van den Berg 2015). Fires pose a risk to human and animal life, and to infrastructure such as buildings and fences. Additionally, fires can destroy vegetation that would otherwise have been available as grazing. Longer-term effects include changes in species composition (notably the eradication of fire-intolerant shrub species), often resulting in a temporary change in vegetation structure from dwarf-shrubland to arid sparse grassland (du Toit et al., 2014). This effect is strongly exacerbated by grazing by livestock following the fire (du Toit et al., 2015), and veld should accordingly be rested for several years (probably between three and five) following a fire.

Usually, a naked flame is needed to ignite a veld fire. However, if the fuel is suitably dry then sparks or embers will suffice (Cheney & Sullivan, 2008). Sparks and embers may be emitted by machinery, tools, vehicles, cooking fires, and cigarettes, and there are recorded examples of these having caused veld fires in the Karoo (Cheney & Sullivan, 2008; du Toit et al., 2015; du Toit et al., 2014).

It is anticipated that the increased activity of people and machinery in the event of prospecting or drilling for gas will lead to an increased likelihood of fires in the Karoo, particularly during dry weather and if fuel loads are high. Although fracking poses a risk of increased incidence of fire in the Karoo, appropriate mitigation measures, including training on how to avoid igniting fires and how to extinguish fires, and the provision of equipment to immediately extinguish fires should one ignite, should reduce the risk of fire significantly. Should a fire be ignited during the process of SGD, farmers or landowners should be compensated for the destruction of property, including grazing resources and the loss of production from rested veld, which will typically require a decade to recover its productivity and stability.

The influx of skilled workers during the exploration and production phases will create limited market opportunities for agricultural products. Security considerations could oblige farmers to remove livestock from the areas surrounding wellpads, although these areas will only occupy a very small percentage of existing agricultural land. SGD will probably create limited employment opportunities for local people (see van Zyl et al., 2016) meaning that local farm labour availability should not be affected to a great degree.

8.6.3 Agricultural Sensitivity

Natural agricultural resources consist of soil, climate, natural vegetation and water. Agricultural production in the study area strongly relies on these resources for continued and sustained agricultural production. A negative impact on any of these natural agricultural resources will result in the loss of the agricultural production potential of the area. To obtain an indication on the vulnerability of the study area to the potential impact of the SGD on agricultural production, a combined agricultural sensitivity index was developed which takes into consideration the vulnerability of the basic natural agricultural resources, including climate. To determine the sensitivity of agriculture within the study area to the potential impacts of SGD, an agricultural sensitivity index was developed by DAFF (Lindeque, 2016).

As a result of the authors being limited to using only existing data sources, and the absence of resources to undertake further research relating to the relevant topics; accessing reliable available data sources at national level to be integrated into an Agricultural Sensitivity Map presented something of a challenge. As the study area covers three provinces, it was necessary to use national datasets to ensure data availability for all the quaternary catchments of the study area. In some cases, detailed data was available for the Western Cape part of the study area, but not for the Eastern Cape areas. In order to ensure uniformity of the data presented, this more detailed data could not be used for developing the sensitivity maps. Furthermore, in the light of comments received by reviewers of this assessment, it was decided to not make use of certain data sources (for example the borehole dataset) due to the incompleteness of the data.

The Agricultural Sensitivity Index aimed to demarcate a four tier approach pertaining to the sensitivity for the study area in relation to agricultural production potential and to include both cultivation and rangeland related aspects. The four tiers are defined as Very High Sensitivity; High Sensitivity; Moderate Sensitivity; Low Sensitivity. The sensitivity index rating was based per quaternary catchment located within the study area. The following input data sets were used to calculate the sensitivity index:

- Land capability 2016;
- Grazing capacity 2016;
- Cultivated Fields 2015;
- Irrigated Areas 2016;
- Surface water
    - Rivers
    - Dams.

Each of the Agricultural Sensitivity Index Input factors (see Table 8.8) was mapped on a quaternary catchment scale and data sets were classified using sensitivity values between 1 and 4 (4 being the most sensitive to potential impacts by SGD) (Figure 8.8). These values were equally weighted when added to a single agricultural sensitivity rating.

Table 8.8: Description of factors contributing towards agricultural sensitivity index.

Agricultural Sensitivity Index Input factors	Description
Soil, Climate & Terrain (combination of factors provides Land Capability Classes)	The newly 2016 refined national land capability data set was used. This data set was derived on a 1:50 000 scale and based on an evaluation of the land capability for the area concerned for possible agricultural production. It does not take any crop suitability into consideration but focusses on the capability of the area concerned pertaining to soil, climate and terrain capability. The national land capability evaluation is classified into 15 land capability classes with 15 being the highest (Very High land capability evaluation rating) and 1 being the lowest (Very Low land capability evaluation rating). The study area’s highest land capability classification is 10. The sensitivity index was therefore based on an evaluation of the range of applicable land capability evaluation classes (1 – 10) and not on the complete national land capability evaluation classification range of values. The dominant (majority value) per quaternary catchment was used to determine

Agricultural Sensitivity Index Input factors	Description
	the applicable Land Capability Evaluation Sensitivity Index value for the catchment (Figure 8.3). Four-Tier classification: Land Capability Evaluation Sensitivity Index: Very High Land capability evaluation classes 8 - 10 High Land capability evaluation classes 6 - 7 Moderate Land capability evaluation classes 3 - 5 Low Land capability evaluation classes 1 - 2
Natural vegetation (referred to as Grazing Land)	The newly derived grazing capacity potential for South Africa was used as input data set to determine the potential for the study area pertaining to grazing. This data set is to replace the 1993 Grazing Capacity Regulation under the Conservation of Agricultural Resources Act, 43 of 1983. The range of Grazing capacity potential values for the study area ranges from 2.5 Ha/LSU[1] – 140 Ha/LSU. The dominant (majority value) per quaternary catchment was used to determine the applicable Grazing Capacity Sensitivity Index value for the catchment (Figure 8.4). 4-Tier classification: Grazing Land Sensitivity Index Value (Ha/LSU): Very High 2.5 – 10 Ha/LSU High 11 – 30 Ha/LSU Moderate 31 – 60 Ha/LSU Low 61 – 140 Ha/LSU
Surface water (River Sensitivity Index as well as Dams Sensitivity Index)	Surface water is represented by the occurrence of the water source within the quaternary catchment that includes rivers, streams and open water (dams). The latest available river data set obtained from the Department of Water and Sanitation (DWS) was used as the input data set. The total length of the river, in kilometre, within the quaternary catchment was used as the basis for the calculation of the range within the complete study area, which was again then further reclassified into the 4-tier River Sensitivity Index. The more surface water present in a catchment, the more sensitive the area towards SGD impacts. As is the case with boreholes, data relating to the actual yield of water for agricultural purposes extracted from the river concerned (as well as the volume of available water and data relating to the sustainability of the river for the supply of water) would have greatly assisted in conducting a more accurate and in-depth evaluation of the availability of water as well as use within the study area per quaternary catchment.
Irrigated land	The study area in question mostly resides in areas with a limited annual rainfall, resulting in the conclusion that areas under irrigation, due to the availability of water should be assessed against these areas' agricultural sensitivity. An assessment was therefore made pertaining areas under irrigation per quaternary catchment. There is currently no data layer indicating areas under irrigation and the approach followed was based on an analysis of available data layers as well as indigenous knowledge of the area. Use was made of the Land cover 2000 data layer where in irrigated areas were included in the legend. This layer was however complemented by the 2015 cultivation data layer where pivot irrigated areas are specifically classified. This was further supported by the presence of a water source as well as the intensity of cultivated areas. The total irrigated area, in hectares, were calculated per quaternary catchment, to determine the range (min / maximum areas) within the study area, where after these areas were reclassified into the four-tier Irrigation Sensitivity Index using a Geometrical Interval approach (Figure 8.7).

[1] LSU: Large Stock Unit, equivalent to one adult cow.

Agricultural Sensitivity Index Input factors	Description
	Four-Tier classification: Irrigation Sensitivity Index Values (ha). Very High 803 – 4077 ha High 154 – 802 ha Moderate 25 – 153 ha Low 0 – 24 ha
Cultivated Fields	The 2015 release of the national Field Crop Boundary data set per province was used as input data set. This data set demarcate all cultivated areas in South Africa and is done on a 1:10 000 or finer scale using SPOT satellite imagery as well as the latest available aerial photography. The total area, in hectares, used for cultivation (irrespective whether it is rain-fed or irrigated, commercial or subsistence) were calculated per quaternary catchment, to determine the range (min/maximum areas) within the study area, where after these areas were reclassified into the four-tier Agricultural Cultivation Sensitivity Index using a Geometrical Interval approach (Figure 8.6). 4-Tier classification: Agricultural Cultivation Sensitivity Index Value (ha): Very High 1075 – 4077 ha High 1074 – 272 ha Moderate 271 – 58 ha Low 0 – 57 ha
Surface water, rivers	The latest available river data set obtained from the DWS was used as input data set. The total length of the river, in kilometre, within the quaternary catchment was used as basis for the calculation of the range within the complete study area which was again then further reclassified into the four-tier River Sensitivity Index (Figure 8.5). As is the case with the boreholes the actual yield/available of water for agricultural purposes extracted from the river concerned (as well as the sustainability of the river for the supply of water) would have greatly assisted in conducting a more accurate and in-depth evaluation of the availability of water as well as use within the study area per quaternary catchment. Four-Tier classification: River Sensitivity Index Values (km): Very High >201 High 101 - 200 Moderate 51 - 100 Low 0 - 50
Surface water, dams	The latest available dam data set obtained from the DWS was used as input data set. The area, in hectare taken up by the dam, as a percentage of the quaternary catchment, was calculated to determine the range within the study area, which was then reclassified into the four-tier index determining the Dam Sensitivity Index. As is the case with boreholes and rivers the availability and use of the water for agricultural purposes and extraction from the dam would have given a more accurate evaluation but this information is not available. Four- Tier classification: Dams Sensitivity Index Values (%): Very High 14 – 29% (there were no values between 4.1 – 13.9%) High 2 – 4% Moderate 1 - 1.9% Low <1%

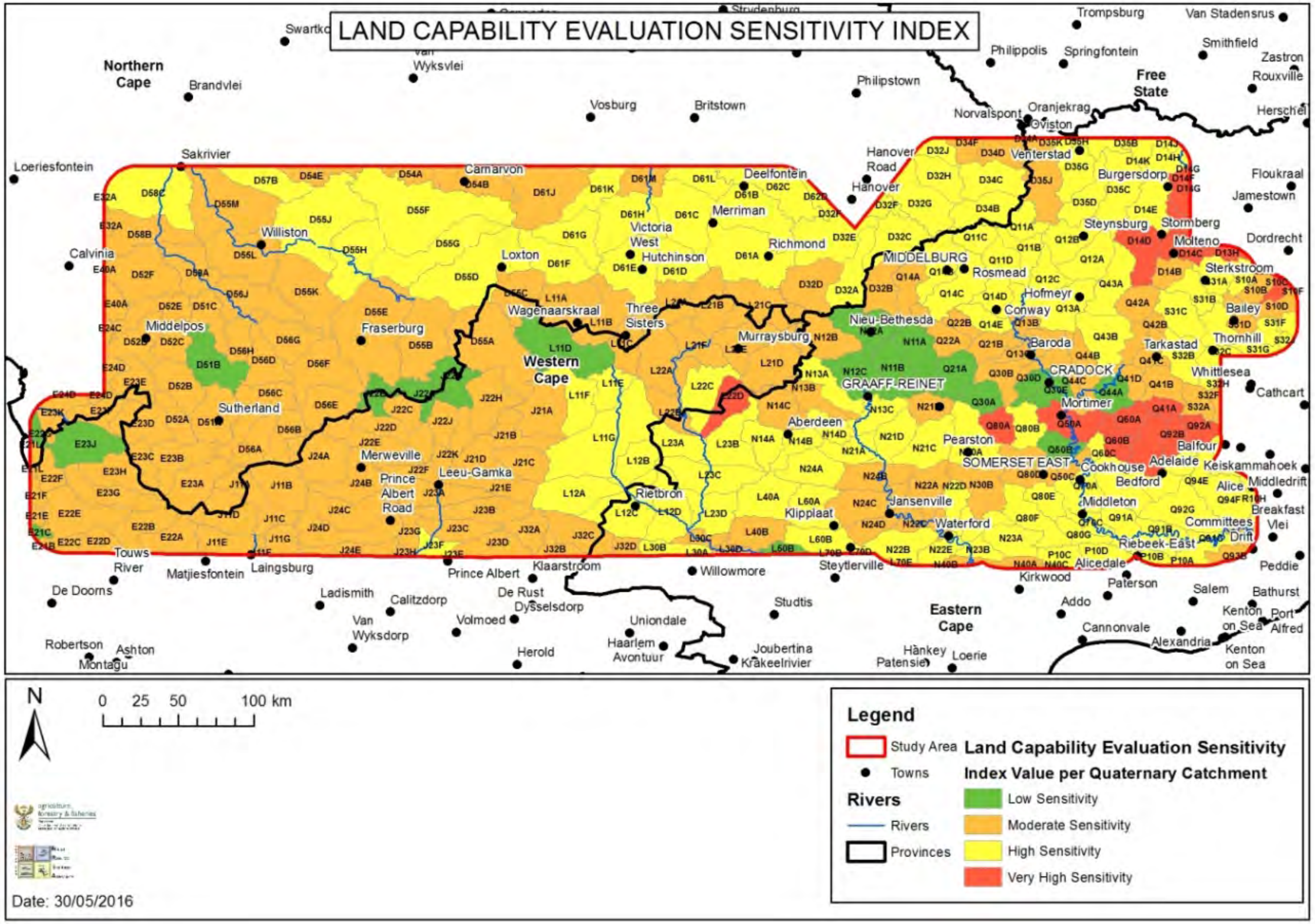

Figure 8.3: Land capability sensitivity index value per quaternary catchment (Collett, 2016d).

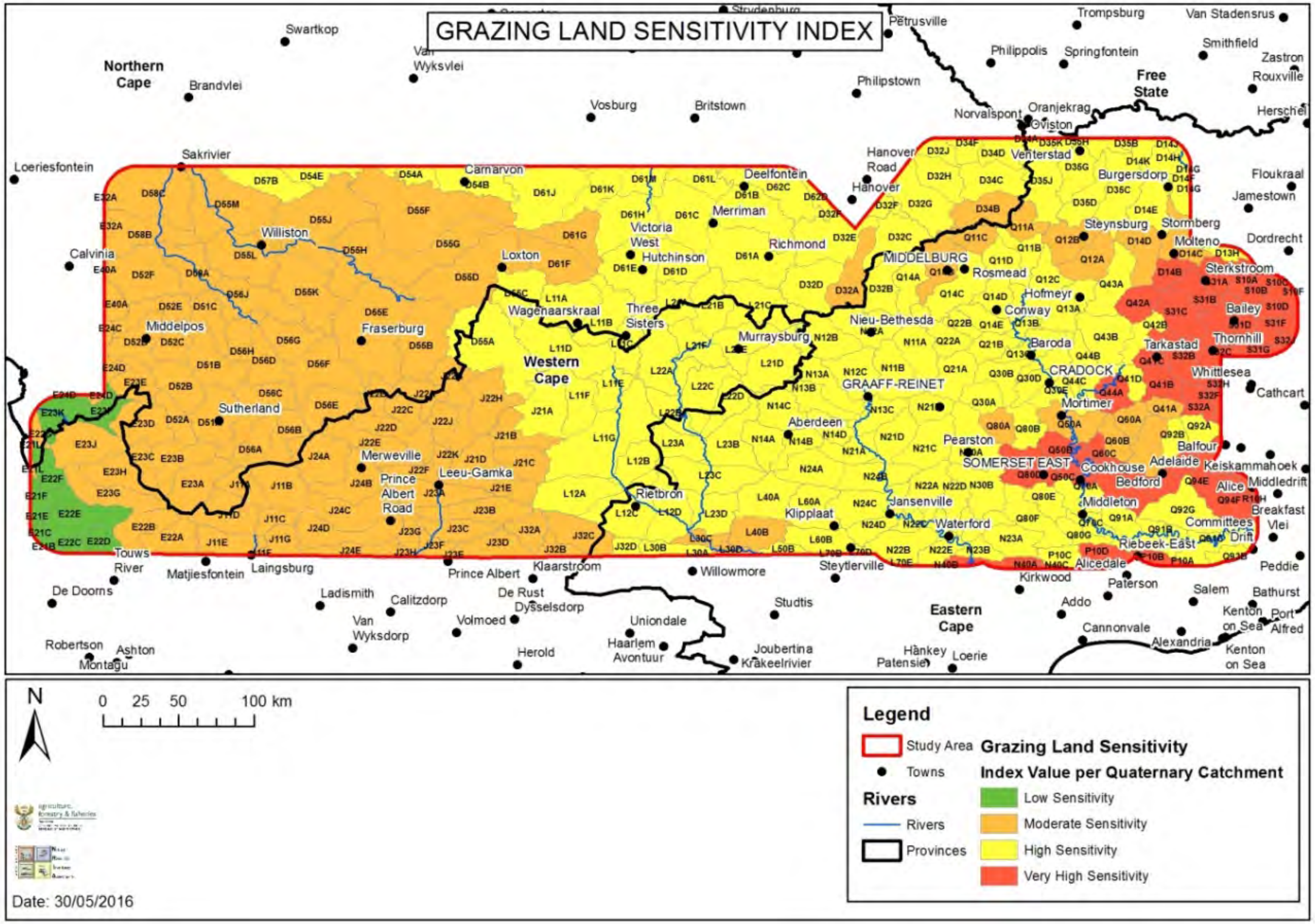

Figure 8.4: Grazing land sensitivity index (Collett, 2016c).

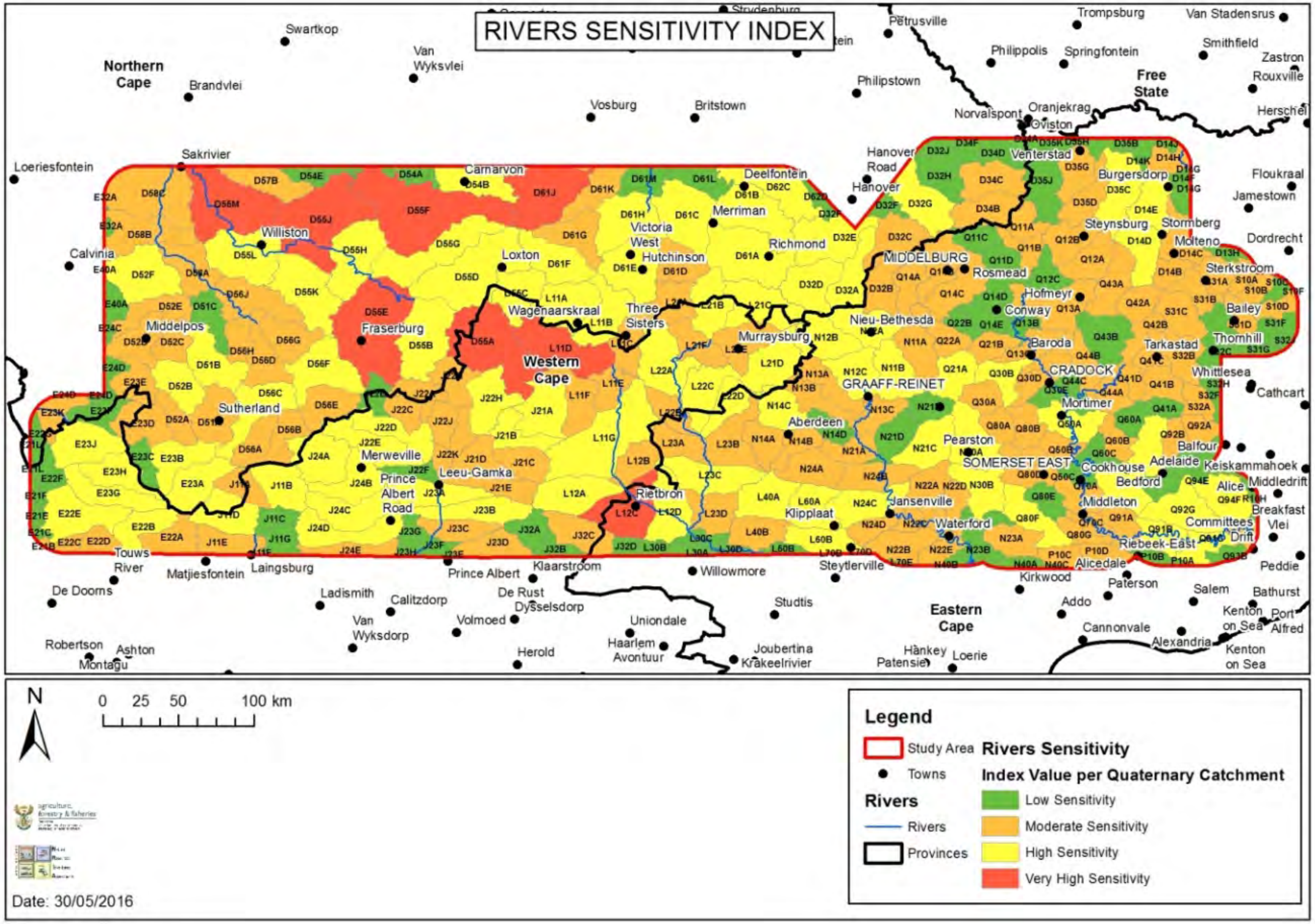

Figure 8.5: River sensitivity index per quaternary catchment (Collett, 2016f).

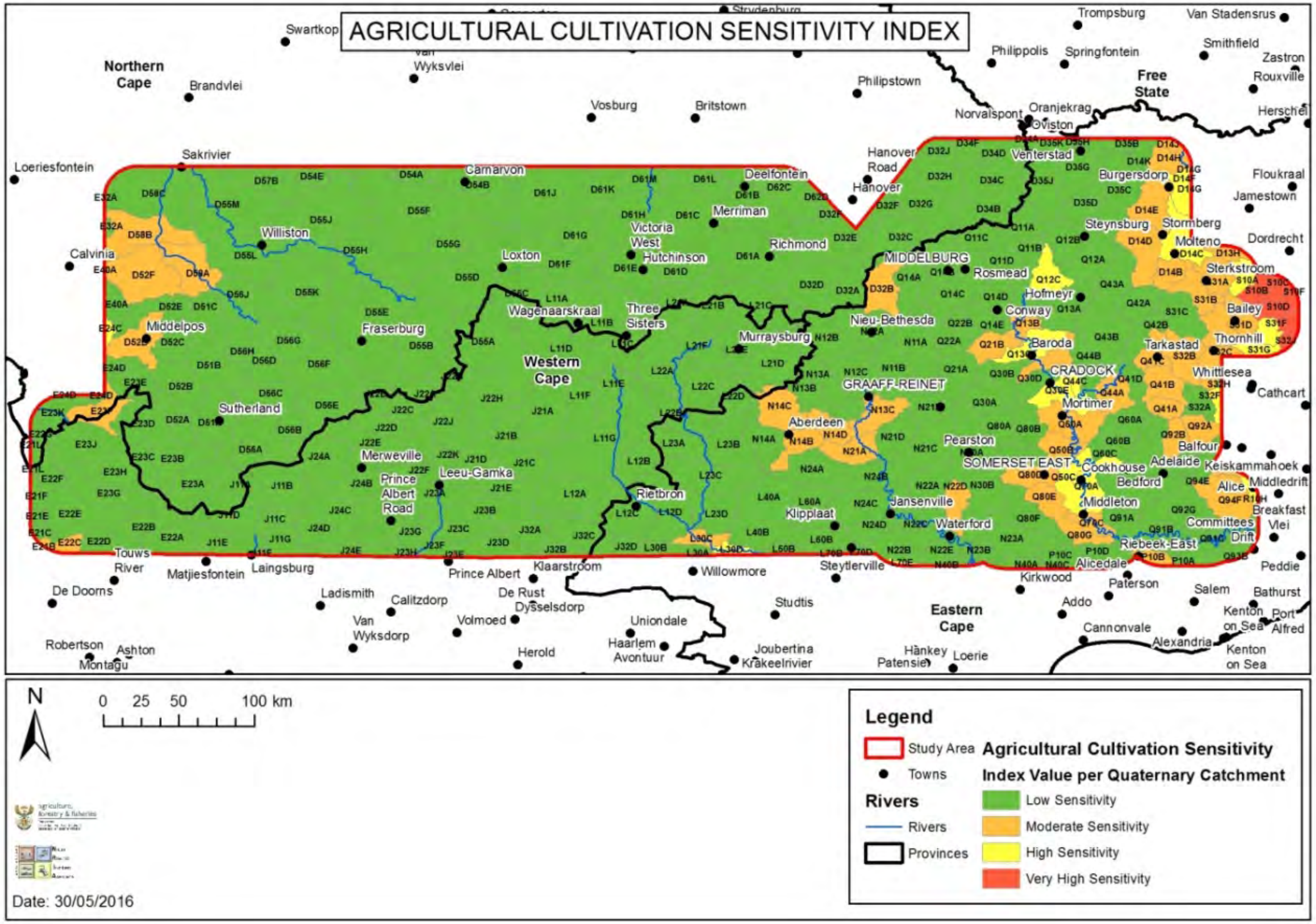

Figure 8.6: Agricultural cultivation sensitivity index value per quaternary catchment.

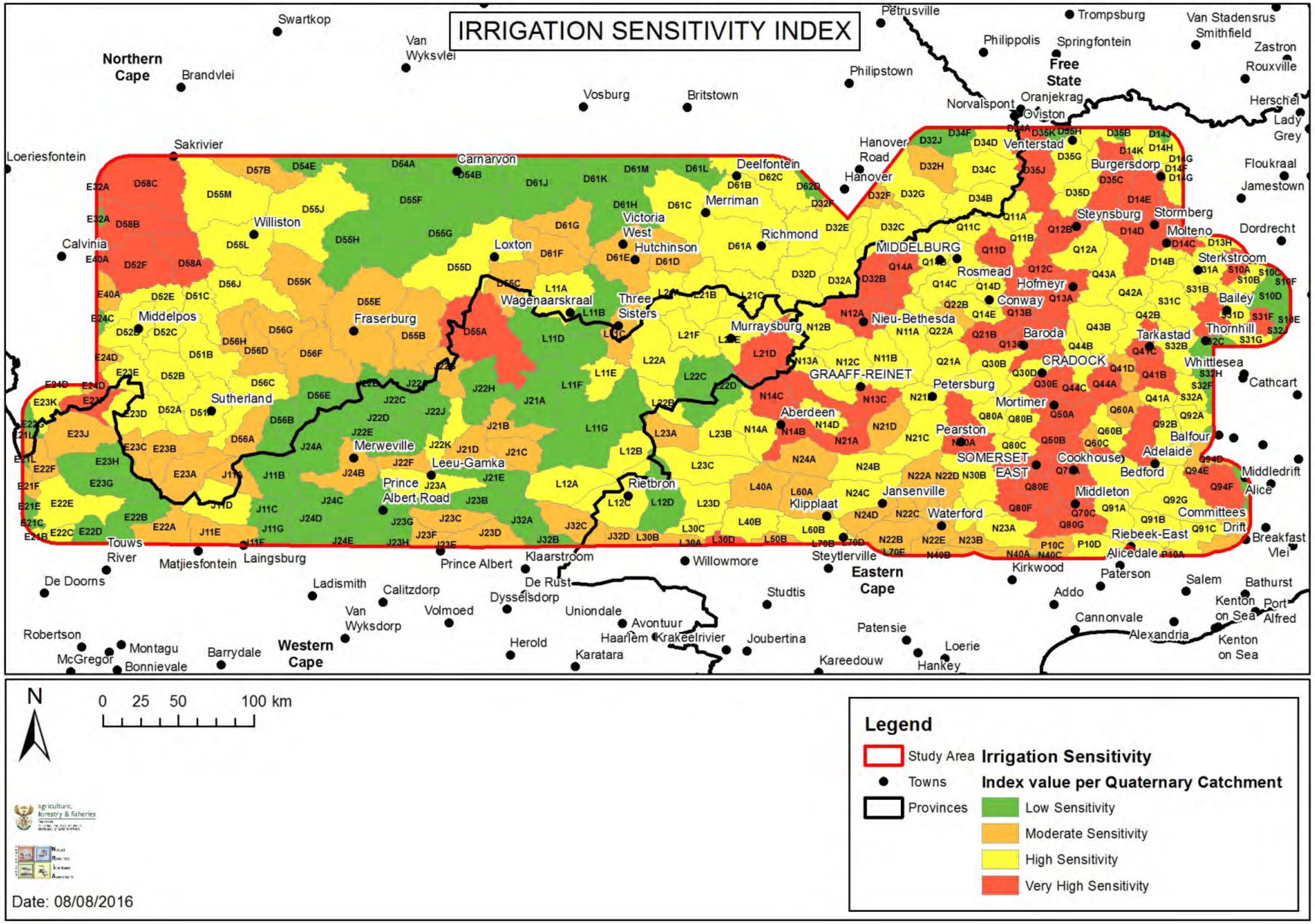

Figure 8.7: Agricultural Irrigation Sensitivity (Collett, 2016b, 2016e, 2016g).

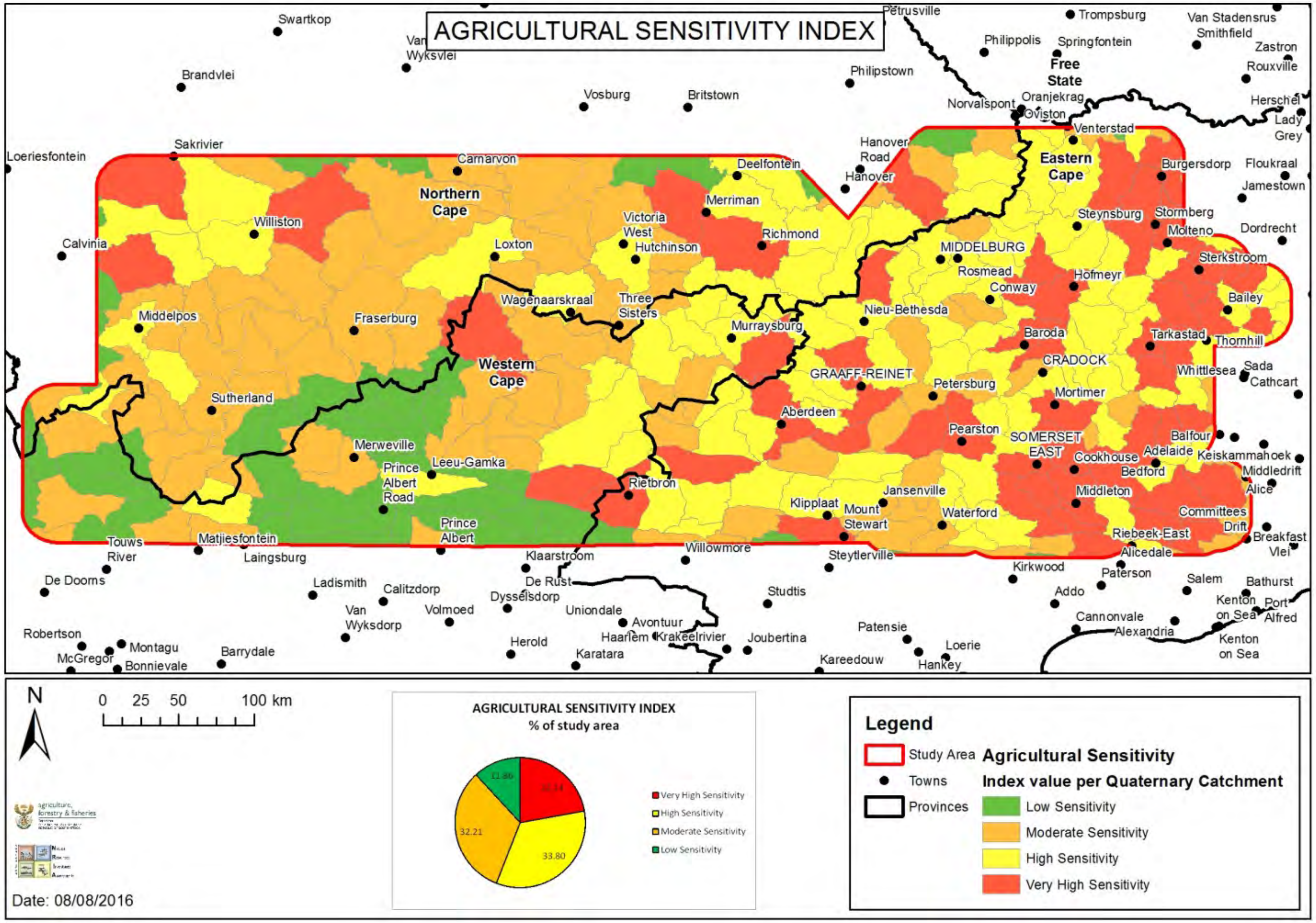

Figure 8.8: Agricultural Sensitivity Map for the study area per quaternary catchment (Collett, 2016a).

The potential maximum value for the agricultural sensitivity index is 24 (4 X 6 input datasets). However the range obtained for the agricultural sensitivity was from 6 – 19. Due to the fact that the land capability evaluation values as well as the grazing capacity values were classified according to the range within the study area, it was decided to reclassify the agricultural sensitivity range based on the values obtained (6 – 19) to the four-tier classification of agricultural sensitivity classes based on a natural interval approach (see Table 8.9 and Table 8.10, and Figure 8.9).

Table 8.9: Four-tier classification of Agricultural Sensitivity Index values

4-Tier classification:	Agricultural Sensitivity Index values:
Very High	16 - 19
High	14 – 15
Moderate	11 – 13
Low	6 - 10

Table 8.10: Percentage (%) land coverage per each Agricultural Sensitivity Classification.

Agric Sensitivity class	Total ha	% per catchment
Very High Sensitivity	3 800 904.94	22.14
High Sensitivity	5 803 508.82	33.80
Moderate Sensitivity	5 530 762.60	32.21
Low Sensitivity	2 035 981.18	11.86
Total	**17 171 157.54**	**100**

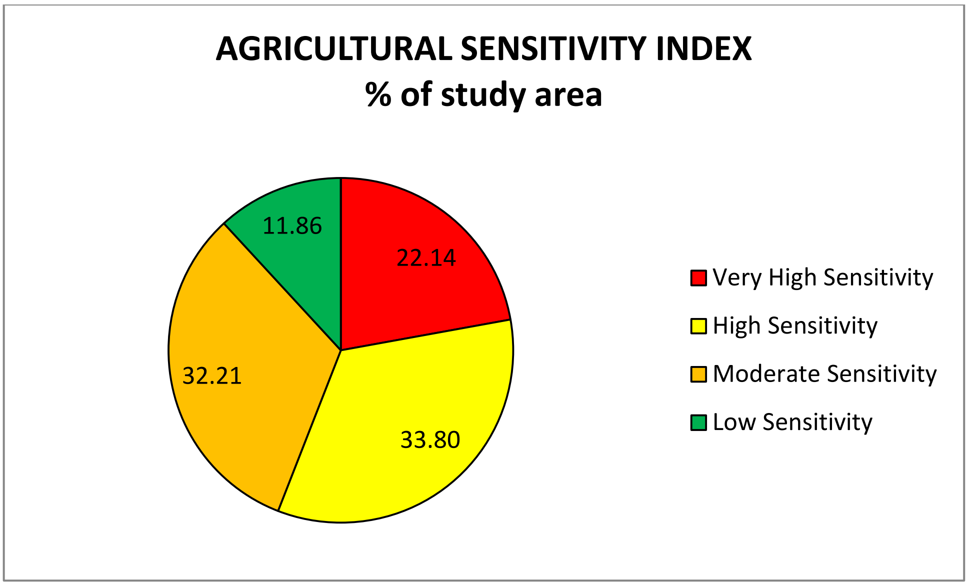

Figure 8.9: Agricultural Sensitivity Index reflecting percentages of the study area.

8.6.3.1 Potential negative impacts

Table 8.11 below describes the potential degree of agricultural impacts in relation to their location, extent, time scale and overall intensity for the four scenarios.

The main agricultural impact of SGD on agriculture will be the intrusion of industrial and mining type of activities and facilities into the study area, altering the rural and agricultural dominated character of the Karoo and affecting the natural agricultural resources base the agricultural sector depend upon for future sustainable production of agricultural goods and fibre.

Table 8.11: Potential agricultural impacts

Agricultural impact (Detail risk assessment in Table 8.12**)**	**Agricultural Sensitivity Index Zone**	**Scenario**	**Extent**	**Timescale**	**Intensity**
The intrusion of industrial and mining type activities and facilities into the study area, altering the rural and agriculturally dominated character of the Karoo and affecting the natural agricultural resources base that the agricultural sector depends upon for future sustainable production of agricultural goods and fibre.	Very High Sensitivity Zone	**Scenario 0:** Reference Case	None	None	None
		Scenario 1: Exploration Only	Local	Long term	Severe
		Scenario 2: Small Gas	Local	Long term	Severe
		Scenario 3: Big Gas	Regional	Long term	Extreme
	High Sensitivity Zone	**Scenario 0:** Reference Case	None	None	None
		Scenario 1: Exploration Only	Local	Long term	Substantial
		Scenario 2: Small Gas	Local	Long term	Severe
		Scenario 3: Big Gas	Regional	Long term	Extreme
	Moderate Sensitivity Zone	**Scenario 0:** Reference Case	None	None	None
		Scenario 1: Exploration Only	Local	Long term	Substantial
		Scenario 2: Small Gas	Local	Long term	Substantial
		Scenario 3: Big Gas	Regional	Long term	Severe
	Low Sensitivity Zone	**Scenario 0:** Reference Case	None	None	None
		Scenario 1: Exploration Only	Local	Long term	Substantial
		Scenario 2: Small Gas	Local	Long term	Substantial
		Scenario 3: Big Gas	Regional	Long term	Substantial

8.7 Risk assessment

The risks to agricultural production in the study area are assessed in the context of four anticipated scenarios:

Scenario 0: Reference Case

Agricultural production systems in the Karoo are relatively stable, and demand for agricultural products from the region will continue to grow under virtually all future economic development scenarios. The productive capacity of the rangeland has not been affected to a great degree by degradation, and most rangeland is managed sustainably. A significant number of farmers have adopted, or are moving to less environmentally damaging production systems.

With the exception of an area surrounding Beaufort West, water resources are adequate for sustained livestock production and the associated low-density farm population.

The study area is affected by cyclical changes to weather patterns, resulting in a relatively high level of climate variability and afflicting agricultural production with severe cyclical droughts associated with the El- Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). Climate change projections for the area show an increase peak and average temperatures, with some impact upon livestock production. In the winter rainfall area in the far west of the designated area winters are likely to become shorter and drier as a result of the predicted pole-wards shift of the rain-bearing cyclonic systems. There would also be an increase in extreme events such as droughts and floods. However, most of the designated area receives the majority of its rainfall in the summer and late summer. Future rainfall predictions for these areas are characterised by a greater degree of uncertainty, with some models indicating significant increases in overall precipitation.

Scenario 1: Exploration Only

In addition to the anticipated impacts of the Reference Case, the movement of heavy prospecting equipment through the landscape will impact on the soil and vegetation. Seismic exploration would entail traversing watercourses and other ephemeral water bodies. This will result in physical disturbance such as compaction and surface disturbance within watercourses and catchments areas, which is likely to diminish infiltration and increase runoff. It is likely that this will result in higher rates of runoff, soil erosion and sedimentation. Impacts of this nature have been described as associated with wellpad and pipeline construction in shale and coal seam gas exploration and production in the USA and Australia (Brantley, 2014; Cavaye et al., 2016).

Scenario 2: Small Gas

In addition to the cumulative effects from the previous two scenarios, the Small Gas scenario will include more extensive prospecting and the construction and installation of infrastructure within designated areas. Within these areas this will necessitate removal of natural vegetation and disturbance of drainage and infiltration systems in the course of construction of roads, wellpads, water storage facilities, accommodation and other facilities. The mitigation measures required will be similar to those described in the Exploration Only scenario, albeit on a wider scale and over a longer period of time.

Land users will incur higher management costs to maintain optimal use of their grazing resources and to minimise losses from wandering of flocks, injury, contamination or theft with the presence of contaminated waste water reservoirs on their land and in the face of on-going movement of people and equipment through the landscape (Cavaye et al., 2016).

Scenario 3: Big Gas

Should the reserves of shale gas prove to be bounteous and should the market price provide sufficient economic motivation and justification, very extensive prospecting (with more extensive impact upon the veld) will be followed by construction and installation of infrastructure over large areas of the Karoo. The cumulative effects described for the Small Gas scenario will occur on landscape scale. Construction roads will be more heavily used and the dangers of waste water spillages and leakages into groundwater resources will increase exponentially.

A risk assessment matrix is provided in Table 8.12 below, including risk levels ‘without’ mitigation and ‘with’ mitigation. The table is based on the description of the four scenarios and the identification of agricultural sensitive zones in the previous section. These are combined with the potential intensity of the agricultural impacts (derived from Table 8.11), and the likelihood (probability) of the impact occurring, to provide an overall risk evaluation.

Table 8.12: Risk assessment matrix.

Impact	Agricultural sensitivity zone	Scenario	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
The intrusion of industrial and mining type of activities and facilities into the study area, altering the rural and agricultural dominated character of the Karoo and affecting the natural agricultural resources base the agricultural sector depend upon for future sustainable production of agricultural goods and fibre.	Very high agricultural sensitivity	Reference Case	Moderate	Not likely	Low	Slight	Extremely unlikely	Very low
		Exploration Only	Substantial	Likely	Moderate	Moderate	Very unlikely	Low
		Small Gas	Severe	Likely	High	Substantial	Not likely	Moderate
		Big Gas	Severe	Very likely	Very high	Severe	Likely	High
	High agricultural sensitivity	Reference Case	Moderate	Not likely	Low	Slight	Extremely unlikely	Very low
		Exploration Only	Moderate	Likely	Moderate	Moderate	Very unlikely	Low
		Small Gas	Moderate	Likely	Moderate	Substantial	Not likely	Low
		Big Gas	Severe	Likely	High	Substantial	Likely	Moderate
	Moderate agricultural sensitivity	Reference Case	Slight	Very unlikely	Very low	Slight	Extremely unlikely	Very low
		Exploration Only	Moderate	Not likely	Low	Slight	Extremely unlikely	Very low
		Small Gas	Substantial	Likely	Moderate	Moderate	Not likely	Low
		Big Gas	Severe	Likely	High	Severe	Likely	Moderate
	Low agricultural sensitivity	Reference Case	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
		Exploration Only	Moderate	Not likely	Low	Slight	Extremely unlikely	Very low
		Small Gas	Substantial	Likely	Moderate	Moderate	Not likely	Low
		Big Gas	Substantial	Likely	High	Moderate	Likely	Moderate

Figure 8.10 presents a risk map of impacts on the natural agricultural resources base across four SGD scenarios, with- and without mitigation.

8.8 Management of potential agricultural impacts

8.8.1 Potential Positive Impacts

SGD offers a number of potential positive impacts on the agricultural sector:

Increased local demand for agricultural outputs: The anticipated influx of staff employed by SGD operators and the attendant increase in local economic activity can be expected to stimulate limited demand for agricultural produce. It is also anticipated that demand for farm-stay Bed and Breakfast accommodation in the area will increase in response to the need for skilled technicians, management personnel and specialist service providers to have access to suitable overnight accommodation in the vicinity of shale gas operations.

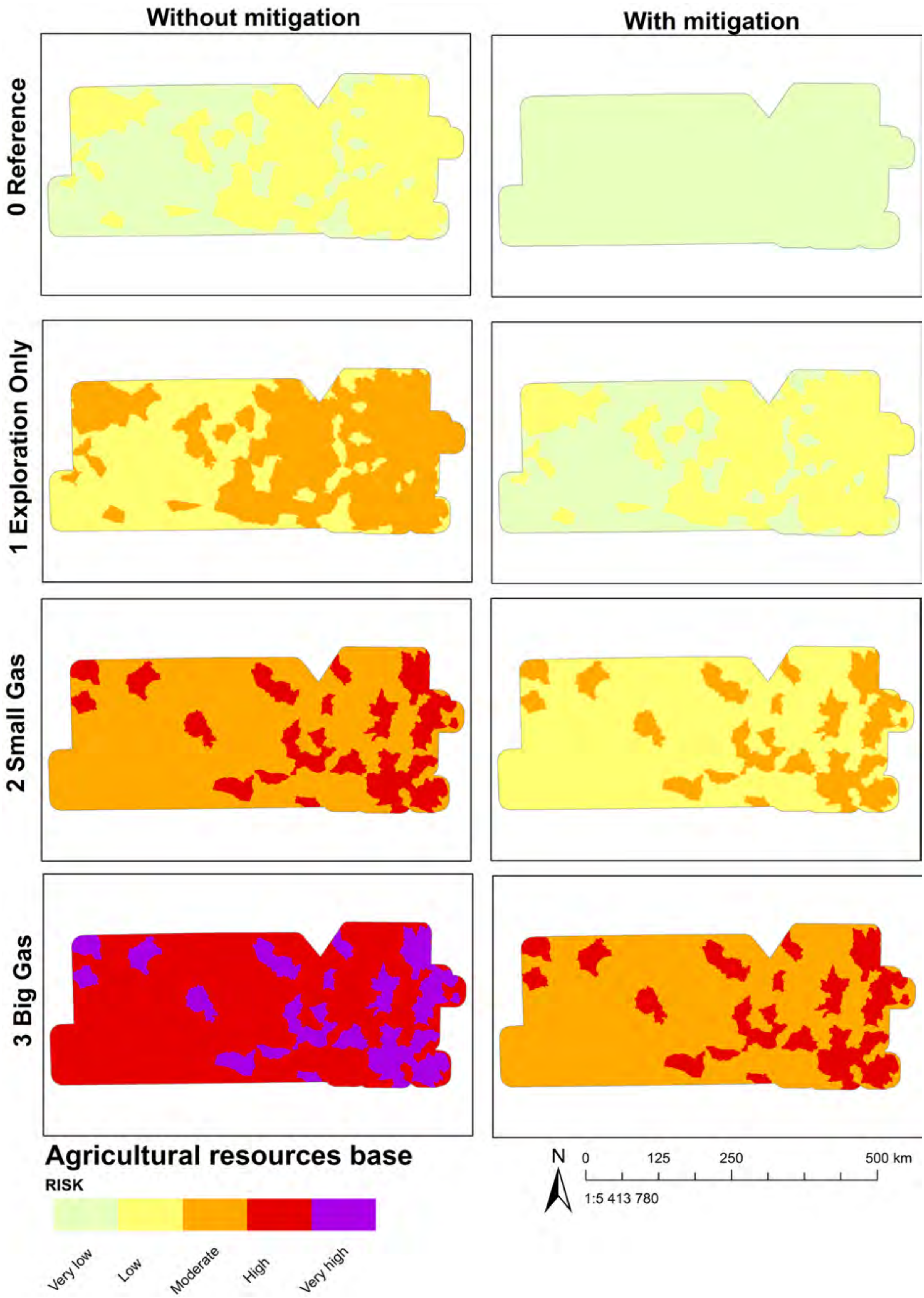

Figure 8.10: Map indicating the risk to the natural agricultural resources base across four SGD scenarios, with- and without mitigation.

Improved infrastructure: SGD will require the construction of improved road access to otherwise remote areas of the study area. This will potentially improve access to these areas for land users, and reduce wear and tear of their vehicles. It will be important that contractual provision is made to maintain and improve such infrastructure over time. On the other hand, increased vehicular travel on existing road infrastructure will impact negatively on its condition and necessitate more frequent maintenance or even upgrading. Increased short-term demand for telecommunication services will stimulate mobile network operators to improve coverage in the longer term by investing in improved hardware or construction of additional transmission stations.

Job creation potential and employment opportunities: Although likely to be limited in terms of scope and duration, it is anticipated that SGD activities will create some spin-off employment opportunities in service industries, which could benefit agricultural communities and their dependents.

Supplementary sources of on-farm income: Farmers will have a range of opportunities to enhance their incomes by leasing parts of their land or land-based resources (water, gravel for roads, etc.) to SGD operations.

Veld improvement through extended resting periods: Should shale gas operators seek to lease land on which extractive operations are to take place; opportunity will be created for veld improvement through extended resting periods.

8.8.2 Management strategies

Strategies for the management of potential negative impacts can be divided into mitigation, avoidance and offsets.

- *Mitigation*

Mitigation will involve reducing the effects of the shale gas activities on agricultural receptors through all project phases. These receptors include the farming community, the economic viability of farming operations as well as the biophysical components of agriculture such as soil and water.

- *Avoidance*

This is a preventative approach relying on the planning phase to identify areas of high sensitivity to agricultural impacts and to avoid it. In the case of SGD, the siting of wells is determined by geological and economic considerations, limiting the potential for avoidance. Avoidance is possible at the project scale where measures can be taken to avoid quaternary catchments with very high and high agricultural sensitive index values.

- *Offsets*

Offsets is a strategy of acknowledging and quantifying irreparable damage to natural resources and/or loss of livelihood and to replacing it with areas or projects of similar or better value elsewhere.

8.8.2.1 Mitigation measures

In the absence of SGD: Sustainable management of the agricultural resources of the study area requires on-going management interventions on the part of the land user. Without such interventions, even in the absence of SGD, the agricultural landscape will continue to degrade and its productivity will diminish. This section is included to draw attention to the necessity to promote on-going improvement in land management and effective planning to enable farmers, other residents and itinerant visitors to cope with anticipated impacts. Mitigation of anticipated climatic change in the study area should include interventions to ensure that vegetation in catchment areas and stream- and riverbeds is conserved so as to increase infiltration capacity of the soil and slow runoff waters. Compacted soil surfaces should be rehabilitated to restore vegetative cover. The construction standards for roads, railroads, pipelines, telephone and transmission lines should be revised to accommodate higher levels of peak run-off and associated sedimentation. Biodiversity loss and veld degradation from long-term selective grazing on farms should be addressed via increased investment in supporting biodiversity stewardship, including in situ conservation of biodiversity and the introduction and large-scale adoption of rangeland ‘best management practices’ suitable for this area.

During exploration: Mitigation would require that heavy prospecting equipment should not transgress main watercourses and pans, and be excluded from areas subject to hydrological extremes in the case of floods and droughts. Mitigation will also require active rehabilitation of compacted or otherwise disturbed surfaces of watercourses, pans and catchment areas that have been affected by the movement of prospecting equipment. Without active rehabilitation, disturbed surfaces in catchment areas that have lost their vegetative cover and become compacted might not recover. Because Karoo veld is very slow to regenerate after disturbance and some species do not easily recruit or recolonise, it may be necessary to re-seed disturbed areas (Esler, Milton, & Dean, 2006). Australian research shows the timing of remediation (minimising delays, especially during drought) is critical as it can lead to surrounding areas also remaining out of production (Cavaye et al., 2016).

The movement of heavy prospecting equipment across the landscape is likely to distribute the seeds of undesirable plants between and within agricultural properties. Similar impacts will be experienced in the course of regular maintenance operations. Seeds may be collected on the moving parts of the machinery that are in contact with the soil surface either en-route to the prospecting site or during the traversing process. The areas that will be at most risk of alien plant invasion are the roads to the wellpads, and the disturbed areas around the wellpads. Without mitigation there is a high likelihood of the spread of invasive plants. Mitigation would need to include cleaning and sanitisation of the parts of prospecting machinery before it enters a property, and after it has been thorough an area infested with invasive plants. Aftercare would require that prospecting sites were monitored and managed to control new infestations of invasive plants for a period of approximately five years after prospecting.

During operations: Mitigation of these threats could include rental of the farmers' land by the gas operator at a rate linked to, but higher than the current livestock-based financial returns, thus allowing farmers to destock those areas. Providing farmers with the resources to increase their on-farm security and strengthen their existing farmer security networks would also mitigate this problem. Farm workers displaced by rental of the farms on which they have worked and resided should be guaranteed employment in the agricultural sector, or provided with settlement packages that will enable them to receive training, accommodation and social services support to facilitate any necessary adjustment to life in communities that are new to them. The groundwater resources upon which agriculture in the Karoo is entirely dependent is vulnerable to pollution by leakage of toxic fracking fluids (Davenport, 2012; Pichtel, 2016; Sneegas, 2016). Furthermore, such leakage will release toxic chemicals into the environment that will undoubtedly have a negative impact on the health of livestock that have access to these areas (Bamberger, 2012, 2014). Surface water resources within the extraction zone will be at risk from disturbances of catchment areas and pollution for leakage of toxic fluids used for fracking (Atangana & van Tonder, 2014; Davenport, 2012; Perry, 2012). Ground-to-surface water contamination may take place as a result of the degradation of well seals and liners over relatively long periods of time (Hobbs et al., 2016). Mitigation should include avoidance of areas where surface-groundwater linkages are likely, and enforced long-term and on-going monitoring and maintenance of wells and easements (Hobbs et al., 2016; Pichtel, 2016).

Despite assurances from prospecting companies such as Shell™ that they do not intend to utilise groundwater resources for fracking, the increased populations that will enter the area to undertake the prospecting and gas production will undoubtedly add to water use for personal consumption, sanitation and other purposes. This may well lead to over-exploitation of scarce groundwater resources in some areas. Mitigation should include assessment of available resources for agricultural purposes before allowing use of these resources for other purposes, trucking in water if need be and also employing minimum water usage technologies on site. If farming land is rented by gas companies for the duration of the production period, this would be an effective mitigation of this potential problem. In the Australian experience, a major impact of gas personnel on farms has been time required by farmers to meet and communicate with staff and manage gas impacts on their farms (Cavaye et al., 2016).

During rehabilitation and post closure: Mitigation measures along the lines described above will be required on a landscape level, and over the entire lifecycle of the gas extraction process, including closure and subsequent rehabilitation of wellpad areas.

Table 8.13 below discusses the agricultural impacts in more detail and provides options for mitigation of these impacts.

8.8.2.2 Offsets

A possible offset for SGD in the Karoo would be the extension of existing game farms and the incorporation of these farms into wilderness or scenic rural corridors, linking with existing protected areas. The involvement of the Stewardship program could be of great benefit to manage agricultural resources in a sustainable way, while protecting the unique biodiversity of the study area.

Another possible offset could be to protect important catchments, especially rivers and streams of importance for water supply for humans, animals and also important agricultural industries. Typical these catchments will have large storage dams or reservoirs and these areas have also a fair amount of irrigation areas. These values have all been considered in the sensitivity map developed for the purposes of this assessment.

8.8.3 Limits of acceptable change

Natural agricultural resources in South Africa are protected by the CARA, Act 43 of 1983. The objective of this legislation is to protect and control the use of natural agricultural resources through regulations controlling the use of natural veld, water sources, wetlands and the use and protection of cultivated fields and irrigated areas. Other, related legislation control water pollution, air pollution or noise. Another important piece of legislation is the Subdivision of Agricultural land (SALA), Act 70 of 1970 (South Africa, 1970). This legislation will have a direct impact on the fragmentation of agricultural land.

The tipping point for the limit of acceptable change would be related to adhering to CARA legislation and other related legislation discussed earlier in this chapter, such as the NEMASALA, and NWA. Setbacks and exclusion zones would to some degree define levels of acceptable change. A number of these are listed in Table 8.14.

Table 8.13: Possible agricultural impacts and options for mitigation.

Scenario	Possible agricultural impact	Options for mitigation of impacts
Reference Case	Status quo	Not applicable
Exploration Only	Localised soil degradation in the form of compaction, soil pollution and soil erosion.	• Introduce soil conservation measures and structures as soon as possible. • Revegetation with adapted local species.
	Localised vegetation degradation in the form of cleared vegetation strips, the loss of productive potential and the possibility of soil erosion and the introduction of weeds and invasive species.	• Retain scrubs and trees where possible. • Revegetation with adapted local species. • Control weeds and invader plants, mechanical, herbicides and biological control, depended on sensitivity of area. • Careful planning of access roads and infrastructure. Rather improve existing roads than build new ones.
	Localised and limited degradation of surface water resources, mainly due to obstacles to water flow and possible point source pollution (mostly accidental events).	• Planning to avoid activities near water bodies. • Cleaning up operations immediately after a spill or pollution event.
	Visual pollution having an impact on game ranching and eco-tourism activities, littering from construction sites and accommodation camps.	• Include litter control and education in the Environmental Management Programme (EMPr).
	Limited influx of people (outsiders) into the area will decrease safety and security on farms (farm attacks and livestock theft).	• Implement a farm visit protocol. • Improve security in area, both formally through police service and private security firms and informally through community policing and patrols.
Small Gas	Increased soil degradation in the form of compaction, soil pollution and soil erosion.	• Implement soil conservation measures and structures. Re-shaping and revegetation with adapted local species.
	Increased vegetation degradation in the form of cleared vegetation strips, the loss of productive potential of land and the possibility of soil erosion and the introduction of weeds and invasive species.	• Retain scrubs and trees where possible. • Revegetation with adapted local species. • Control weeds and invader plants, mechanical, herbicides and biological control, depended on sensitivity of area. • Careful planning of access roads and infrastructure.

Scenario	Possible agricultural impact	Options for mitigation of impacts
		Rather improve existing roads than building new ones.
	Increased possibility of degradation of surface and groundwater quality due to waste water from the fracking process (flowback) and pollution through spills, leakages and accidents.	• Planning to avoid activities near water bodies. • Cleaning up operations immediately after a spill or pollution event.
	Increased demand on available water sources leading to a decrease in water quantity (availability) from both surface and groundwater sources for agricultural activities.	• Water harvesting measures. • Re-use of waste water. • Import water from outside study area.
	Increased traffic, noise and dust during the construction phase.	• Cluster target areas where possible, upgrade existing roads, law enforcement on roads to avoid speeding and limit likelihood of accidents.
	Fragmentation and industrialisation of the landscape, wilderness and rural areas. Fragmentation of farms and land management units/sections on specific farms.	• Confine wellpads to carefully selected areas with low agricultural sensitivity.
	Effect on the rural agricultural character of the study area by shale gas activities.	• Minimise footprint of wellpads as far as possible within the production block.
	Localised effect of wellpads on views from farmsteads, possibly affecting property values.	• Consider setbacks from farmsteads. • Create shelterbelts for visual screening.
	Loss of productive land (localised) through changes in land use and fragmentation of the landscape.	• Confine wellpads to carefully selected areas with low agricultural sensitivity.
	Changes in social fabric of community, community values and the possibility of conflict between those farmers for and those farmers against fracking (or those benefiting from SGD and those not benefiting at all).	• Consider alternative, renewable energy sources like wind and solar. • Consider a more representative compensation system. • Consider payment for use and loss of ecosystem services by fracking companies.
	Farmers unhappy with impacts of SGD sell their land - loss of traditional knowledge and experience.	• Consider alternative, more environmental friendly “green” energy sources.
	Loss of privacy and control over property with an increase in crime, damage to property, stock theft and possible farm attacks.	• Implement a farm visit protocol. • Improve security in area, both formally through police service and private security firms and informally through community policing and patrol.

Scenario	Possible agricultural impact	Options for mitigation of impacts
Big Gas	Increased soil degradation in the form of compaction, soil pollution and soil erosion.	• Implement soil conservation measures and structures. Re-shaping and revegetation with adapted local species.
	Increased vegetation degradation in the form of cleared vegetation strips, the loss of productive potential of land and the possibility of soil erosion and the introduction of weeds and invasive species.	• Retain scrubs and trees where possible. • Revegetation with adapted local species. • Control weeds and invader plants, mechanical, herbicides and biological control, depended on sensitivity of area. • Careful planning of access roads and infrastructure. Rather improve existing roads than building new ones.
	Increased possibility of degradation of surface and groundwater quality due to waste water from the fracking process (flowback) and pollution through spills, leakages and accidents. Increased demand on available water sources leading to a decrease in water quantity (availability) from both surface and groundwater sources for agricultural activities.	• Planning to avoid activities near water bodies. • Deep well injection. • Cleaning up operations immediately after a spill or pollution event. • Water harvesting measures. • Re-use of waste water. • Import water from outside study area.
	Increased traffic, noise and dust during the construction phase.	• Cluster target areas where possible, upgrade existing roads, law enforcement on roads to avoid speeding and accidents.
	Widespread fragmentation and industrialisation of the landscape, wilderness and rural areas. Fragmentation of farms and land management units/sections on specific farms by wellpads, pipelines and access roads.	• Confine wellpads and production blocks to carefully selected areas with low agricultural sensitivity. • Minimise footprint of wellpads as far as possible within the production block.
	District-wide or regional effect on the rural agricultural character of the study area by SGD.	• Consider setbacks from farmsteads. • Create shelterbelts for visual screening. • Wildlife and rural corridors as possible offset.
	Diminished recreation amenity and agri- and eco-tourism attraction, including the environments of private game farms and lodges.	• Confine wellpads to carefully selected areas with low agricultural sensitivity. • Shelterbelts for visual screening.

Scenario	Possible agricultural impact	Options for mitigation of impacts
	General effect of wellpads on views from farmsteads, possibly affecting property values.	• Avoid areas with very high and high agricultural sensitivity index score.
	Loss of productive land (localised) through changes in land use and fragmentation of the landscape, especially within production blocks.	• Consider a more representative compensation system. • Consider payment for use and loss of ecosystem services by fracking companies.
	Changes in social fabric of community, community values and the possibility of conflict between those farmers for and those farmers against fracking (or those benefiting from SGD and those not benefiting at all).	• Consider alternative, more environmental friendly “green” energy sources.
	More farmers unhappy with SGD sell their land, loss of traditional knowledge and experience, impact on property values.	• Consider alternative, renewable energy sources like wind and solar.
	Loss of privacy and control over property with an increase in crime, damage to property, stock theft and possible farm attacks.	• Implement a farm visit protocol. • Improve security in area, both formally through police service and private security firms and informally through community policing and patrol.

Table 8.14: Potential exclusion zones for shale gas activity.

Agricultural resource	Exclusion zone
Terrain	Restricting development on steep slopes (NEMA) (South Africa 1998a) l).
Major rivers and water bodies	Restrictions within 500 m of water courses and 1 km of wetlands (Regulation for Petroleum Exploration and Production) (South Africa, 2015).
Human settlements	Provisions included in local authority planning documents (Integrated Development Plans, Municipal Zoning Schemes and Overlay Schemes).

8.9 Conclusion and recommendations

We conclude that SGD is likely to have a wide range of potential impacts on the agricultural production systems of the study area. Although many of these are likely to be of a negative nature, opportunities do exist for the activities and impacts of these processes to contribute to the improvement of the lives of some the people of the area. These anticipated benefits must be weighed carefully against the likelihood that a currently resilient agricultural resource will be degraded as a result of pollution of water resources and rangeland. In a water scarce country that has limited agricultural resources to support an ever-growing population, any permanent loss of agricultural productivity should be avoided, despite the allure of short- to medium-term financial gain.

This study has been undertaken in the context of the requirements of the NEMA. Chapter 5 of NEMA addresses integrated environmental management so as to give effect to the general objectives of the Act relating to the potential impact on the environment, socio-economic conditions and the cultural heritage. Section 24 (7) (b) of the Act outlines how the precautionary principle must be applied in assessing the potential impact and cumulative effects of proposed activities on the environment, socio-economic conditions and cultural heritage. These must be outlined and an assessment made of the significance of that potential impact. Mitigation measures must be investigated to “keep adverse impacts to a minimum”, and the option of not implementing the activity must also be considered. Agriculture is an enterprise that both depends and impacts upon all three of these elements: the environment, socio-economic conditions and cultural heritage. The linkages between them are inextricable, and should one be compromised by SGD, so too will the others.

Realising net positive benefits for at least some members of the farming communities of the area will require careful planning, strict regulation and skilful mediation of the interactions between land-based communities and gas exploitation companies. The international experience demonstrates that the interventions of petro-chemical companies in landscapes have frequently caused environmental and social damage and disruption, and set in train events that have had negative impacts that are of a lasting nature. Financial contributions by the relevant companies to mitigate these costs have likewise frequently been inadequate. If such costs are externalised and must be borne by local populations, governments and their citizens, the future of communities and nations will be ransomed for relatively short-term benefit.

The farming communities of the study area have learned over many generations how to live in a water-scarce environment, and to sustainably produce unique and highly valued agricultural outputs. This production is entirely reliant on groundwater resources, and it is therefore indisputable that if groundwater resources are polluted or abnormally depleted, the entire agricultural system in this semi-arid area will collapse.

Many of the physical impacts of SGD can be mitigated with a combination of careful planning to meet stringent environmental and social standards, vigilant management of operations, active enforcement of laws, regulations and standards and engagement of local stakeholders in seeking appropriate solutions to perceived challenges and threats. Nevertheless, SGD will change the nature and quality of many of the physical and social conditions upon which the agricultural productivity and the livelihoods of agriculturally-dependent communities are grounded. Environmental pollution from leakage or spillage of water containing toxic chemicals is likely, and the United States experience indicates that it will have a long term, negative impact on the people, livestock and wildlife of the study area that will outlast any short-term economic benefits.

Globally, agricultural resources are recognised as a finite resource that is rapidly shrinking due to land transformation and degradation. As this resource is crucial to meeting the needs of an exponentially expanding human population, its conservation should be regarded as a priority higher than that of short-term energy benefits of SGD.

Investment in land in the study area is coupled with the unspoiled natural beauty of the region, and its demonstrated potential to attract nature, farm and game tourists. Intimately linked to this is the farming lifestyle of the region, which motivates urban-based investors to envisage a higher quality of life for themselves and their families should they relocate there and to transfer wealth back from urban centres of accumulation to these rural landscapes. Sustaining the value of such investment, and ensuring that it is able to continue to generate further returns and create benefits for the people of the study area is dependent on retaining the natural beauty of the environment. If SGD is perceived as degrading or destroying this natural beauty, the fast-growing game farming sector and the associated agri-tourism and eco-tourism sectors will all be negatively impacted. Should this happen, local populations will inevitably be disrupted, and agricultural skills will probably be eroded or permanently lost.

In conclusion, notwithstanding the short-term gains that may be realised from SGD in the study area, it will be of crucial economic and social importance to ensure that the long-term future of the region and its peoples is firmly grounded upon diverse and sustainable agricultural land use.

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CHAPTER 9

Impacts on Tourism in the Karoo

CHAPTER 9: IMPACTS ON TOURISM IN THE KAROO

Integrating Author:	Daan Toerien[1]
Contributing Authors:	Gerrie du Rand[2], Caroline Gelderblom[3], Melville Saayman[4]

[1] Centre for Environmental Management, University of the Free State (UFS), Bloemfontein, 9301

[2] Department of Consumer Science, University of Pretoria, Pretoria, 0028

[3] Gelderblom Consulting, Cape Town

[4] Tourism Research in Economic Environs & Society (TREES), North-West University, Potchefstroom, 2790

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Executive Summary

Experience indicates that mining and tourism invariably end up in conflict with each other. The impacts of shale gas development (SGD) in the study area might, therefore, result in risks for its tourism sector.

The tourism sector in the study area is important. Currently it houses about 830 enterprises, the most of any business sector. It employs between 10 100 and 16 400 people and annually adds between R2.3 billion and R 2.7 billion (2010 Rand) to the regional gross value added (GVA). The tourism sector in the study area has diversified considerably in recent years, which has dispersed tourism activities throughout the study area, also into the rural areas. Some towns of the study area have much stronger tourism sectors than others and their sensitivity to impacts is probably higher. Consequently locations with very high sensitivity are distinguished from those with high sensitivity and those with medium sensitivity.

The risk associated with an impact equals its consequences times the likelihood of its occurrence. Expected impacts of SGD on the tourism sector are: large numbers of slow-moving trucks on roads leading to and criss-crossing the study area and hindering tourist access, causing road degradation and resulting in noise pollution; reduction of the scenic beauty of the Karoo and its mountainous access routes; replacement of the Karoo brand as a ‘place to get away from it all’ with an industrial image; crowding out of regular tourists by SGD personnel’s use of tourism facilities; problems with basic services such as safe water provision; increased complexity of the integrated management of tourism activities; and exposure to earthquakes. The major consequences of SGD impacts are expected to be a reduction in the number of tourists leading to a decline in the regional GVA added by the tourism sector and a reduction in the number of tourism employees, most of whom are semi-skilled local people with women particularly well represented.

Three broad groups of tourists visit the study area: 1) Those seeking unique Karoo experiences (‘getting away from it all’, adventures, agri-tourism, hunting, heritage sites, Karoo food, festivals, etc.); 2) Those travelling through; and 3) Business travellers visiting towns for business reasons and people visiting friends and relatives (VFR tourists). The risks from SGD for these groups are expected to differ.

Four scenarios guided the risk analysis; Scenario 0: Reference Case which involves no exploration; Scenario 1: Exploration Only (probably in 2018 to 2025); Scenario 2: Small Gas, in which exploration is followed by limited production of shale gas (probably during 2025 to 2045); and Scenario 3: Big Gas, in which exploration is followed by large-scale production of shale gas (probably from 2025 to beyond 2050). The upper risk limit was determined by the limit of acceptable change, set at a 20% loss of tourism enterprises. Presently such a loss could result in losses of about 170 tourism enterprises, 2 700 tourism jobs and R 500 million (2010 Rand) in annual regional GVA.

The Reference Case and Exploration Only scenarios are not expected to have significant risks for the tourism sector in the period 2018 to 2025. If the Small Gas scenario is realised, probably during 2025 to 2045, high risks are expected for all tourist groups and locations (losses of up to 16% of tourism enterprises, shedding of up to 2 100 jobs and a decrease of up to R 400 million (2010 Rand) per annum in the regional GVA). If the Big Gas scenario is realised, possibly between 2025 and beyond 2050, very high risks that could reach the upper risk limit could occur in locations with very high sensitivities, e.g. Nieu-Bethesda, Prince Albert, Graaff-Reinet, Sutherland and Colesberg. In areas with high sensitivity, e.g. Cradock and Beaufort West, the risks could be high, possibly reaching losses of 16% of enterprises, 2 100 tourism jobs and R 400 million (2010 Rand) per annum in regional GVA. If either the Small Gas or Big Gas scenarios are realised, mitigation procedures could probably reduce but not eliminate risks for the tourism sector.

A challenge for various government role players as well as the mining and tourism industries is to timeously find ways and means whereby risks could be mitigated. Such an approach has been applied elsewhere. Mitigation procedures could require that: 1) Consensus be reached on the need to protect the tourism sector of the study area; 2) A partnership be developed between the mining and tourism sectors; 3) Tourist access to the study area be protected by declaration of a tourist access route (e.g. the N9) and the barring of shale gas traffic from it; 4) The issue of the fragmented management of tourism across provincial and municipal boundaries be addressed by the possible establishment of an officially empowered tourism agency to manage and support tourism in the study area, and eventually to be funded by a levy on gas producers; 5) Potential impacts of noise, visual, water pollution and other impacts on the tourism sector be handled by using additional exclusion zones to reduce such impacts, also during environmental impact assessment (EIAs) in the rural parts of the study area. However, if either the Small - or Big Gas scenarios are realised, complete recovery of the tourism sector might take an additional decade after termination of gas production and full recovery of disturbed areas.

It should be noted that this was a desktop assessment which used the best available data and that there is currently a lack of information about many important aspects of the tourism sector in the study area (and Karoo), including detailed knowledge of the dispersed tourism enterprises of the Karoo, their tourist offerings and vulnerability to impacts. This should be addressed by adequate baseline studies.

CHAPTER 9: IMPACTS ON TOURISM IN THE KAROO

9.1 Introduction and Scope

Mining and tourism are important sectors of the South African and Australian economies, yet invariably they end up in conflict (De Klerk & Heath, 2015; McLennan et al., 2015). Tourism in the Karoo and shale gas development (SGD) might, therefore, be irreconcilable (Ingle & Atkinson, 2015). This Chapter analyses the potential impacts of SGD, if implemented, on tourism in the study area (Figure 9.3). A lack of standard tourism information (such as bed nights sold and tourist spend) in the study area necessitated the use of quantified empirical information about tourism enterprises in the study area to examine the potential impacts. Four different scenarios: Scenario 0 (Reference Case) which involves no exploration, Scenario 1 (Exploration Only), Scenario 2 (Small Gas) which involves the small-scale production of shale gas, and Scenario 3 (Big Gas) which involves the large-scale production of shale gas (described fully in Burns et al., 2016) are considered. Potential mitigation of negative impacts is also considered.

The management of tourism in South Africa (SA) is complex. The Department of Tourism (DoT) guided by the Tourism Act of 2014 (Government Gazette, 2014) is primarily responsible. The Act addresses issues such as the promotion of quality tourism products and services and enhancing cooperation and coordination between all stakeholders. It seeks to avoid negative economic, environmental and social impacts, and promotes involvement of local people in tourism.

What is tourism?

Tourism comprises the activities of persons traveling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes (Go2HR, n.d.)

Tourism is a large world-wide industry and its international receipts in 2014 were worth US$1.245 trillion (United Nations World Tourism Organisation, 2015). Even in arid and semi-arid areas it has become an important economic driver, e.g. in Egypt, Dubai, Oman and Israel desert tourism is a growing industry (Hobbs and Tsunemi, 2007; Ryan and Stewart, 2009; Zekri et al., 2011).

In the Karoo, farm stays, game farming and hunting, all of which tap into alternate markets, have become key sources of externally derived income (Hoogendoorn & Nel, 2012).

South African Tourism is an agency tasked with marketing the country as a tourism destination. The SA Tourism Review Committee (2015) remarked: “There is a planning hierarchy in government which serves to clarify and position the mandate that SA Tourism carries, starting with the National Development Plan which identifies tourism as an essential part of our economy into the future. Tourism is a key sector contributing to Outcome 2 (decent employment through economic growth) in the state’s Medium Term Strategic Framework for 2014 – 2019. The DoT is charged with developing and implementing the National Tourism Sector Strategy which sets the overall framework for how the country plans to grow the tourism economy. This in turn creates the context within which SA Tourism's Tourism Growth Strategy spells out the strategic approach to the marketing effort."

Several policies and strategies impact upon tourism in the study area. These are implemented by different authorities and government agencies, a situation that is adding to management complexity (Atkinson, 2016). At the national level, guidance is provided by the National Planning Commission (NPC, 2011), the Marketing Tourism Growth Strategy for South Africa (South African Tourism, 2010) and the National Tourism Sector Strategy (DoT, 2011). The Rural Tourism Strategy (DoT, 2012) highlights the importance of rural areas for tourism and emphasises the fact that rural areas contain important tourism attractions.

At provincial and regional level there are: an Integrated Tourism Development Framework (Western Cape Department of Economic Development and Tourism, 2006), an Eastern Cape Tourism Master Plan (Eastern Cape Department of Economic Development and Economic Affairs, 2009) and a Northern Cape Tourism Master Plan Review (Grant Thornton, 2014). The Non-Government Organisation (NGO); The Karoo Development Foundation (2012), produced a Karoo Tourism Strategy and Kyle Business Projects (2009) produced a Camdeboo Responsible Tourism Sector Plan. In essence the strategies of these organisations are to: develop and market unique tourism products, grow domestic and international tourism arrivals and spend, create sustainable economic benefits and to protect the environment.

9.1.1 The historic importance of tourism in the Karoo

People have visited the Karoo for a long time. The area formed part of the hunting grounds of hunter-gatherers and of the grazing areas of nomadic Khoikhoi pastoralists (Elphick, 1979). The settlement of colonial farmers ("trekboers") in the Karoo from ca. 1760 (Guelke, 1979) led to the establishment of churches (Fransen, 2006), then towns (Tamarkin, 1996) and later boarding houses to accommodate travellers.

Up to the 1850s there were no proper roads in the Cape Colony (Solomon, 1983), yet people travelled through the Karoo (Green, 1975). By the late 1860s and thereafter goods were ferried across the Karoo by transport riders and ox wagons to the markets of Kimberley and Johannesburg and passenger coaches transported passengers. Hotels appeared and Jewish owners played an important role in their establishment (Kollenberg & Norwich, 2007).

Later railways displaced both transport-riding and passenger coach services (Solomon, 1983) and during the South African War (1899 –1902) large numbers of soldiers and goods were transported across the Karoo, often by train. The arrival of motor vehicles and improvement of roads after World War II rapidly increased travel in South Africa, also in the Karoo (Solomon, 1983). Later air conditioning of motor vehicles eased the plight of travellers driving through the Karoo during the hot summer months. Places such as Swartberg Pass and Gamkaskloof ('Die Hel') started receiving increasing numbers of visitors (Milton & Dean, 2010; Toerien, 2012a).

9.1.2 The present importance of tourism in the Karoo

The scope of tourism in the Karoo; its spatial distribution and its growth or decline is examined here. Enterprises in different business sectors of South African towns are present in fairly constant ratios of the total number of enterprises in towns (Toerien & Seaman, 2012a). This is also true for the tourism sector of towns of arid and semi-arid South Africa (Toerien, 2012b). Regularities observed between economic characteristics such as gross value added (GVA) and enterprise numbers if Karoo towns (Toerien, 2014) indicate that more enterprises in a particular business sector of one town than another reflects higher levels of economic value addition in that business sector. In 2015 the tourism sector was the most numerous enterprise (business) sector in the study area, comprising 828 (i.e. 22.2%) out of a total of 3737 enterprises (Figure 9.1). Tourism is, therefore, a major source of income in the study area.

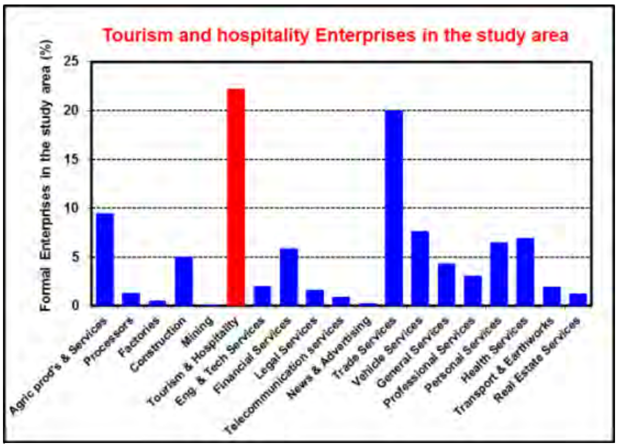

Figure 9.1: The enterprises of the tourism sector (in red) in relation to other business sectors in the study area.

Tourism is, however, not equally distributed through the study area: smaller towns are generally, but not always, proportionally more dependent on this sector than larger towns as shown by an increasing trend of tourism enterprises relative to total enterprises (see red arrow) in smaller towns (Figure 9.2). Even very small towns in the study area have some tourism enterprises.

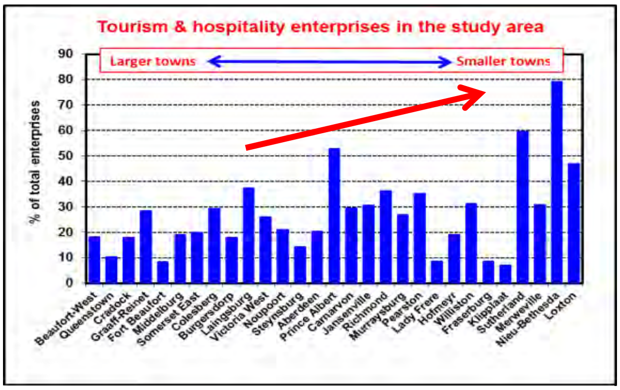

Figure 9.2: The tourism sector in relation to the population sizes of study area towns, ordered from left to right according to their 2011 population sizes.

This does not mean that larger towns and their surrounding areas are not important with regard to tourism. They have the highest total number of tourism enterprises (Figure 9.3) and also have more balanced local economies with a diversity of other business sectors in addition to tourism.

In a number of towns the tourism sector is exceptionally strong, i.e. Graaff-Reinet, Colesberg, Loxton, Prince Albert, Sutherland and Nieu-Bethesda. Towns on national routes (N1, N6, N9, N10 and N12) that cross the study area generally have more tourism enterprises than towns further away from the main routes (Figure 9.3).

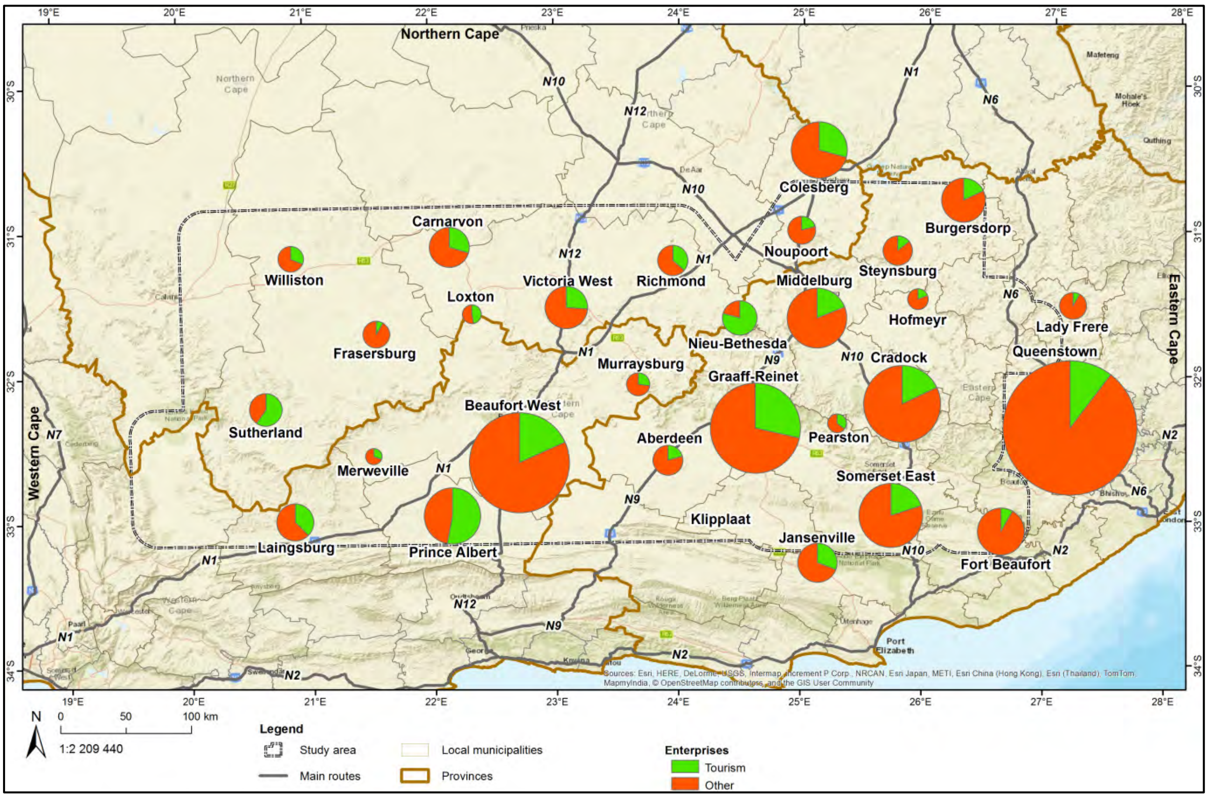

Figure 9.3: Total and tourism enterprises in or close to the study area towns.

Clustering (i.e. grouping) of the study area towns on the basis of their enterprise profiles [done according to the method of Toerien & Seaman (2010)] revealed two clusters of towns that differ markedly in terms of the contribution of tourism to their economies: cluster 1 (red in Figure 9.4) towns has an average of 15.5% and cluster 2 (blue in Figure 9.4) towns an average of 37.4% of their enterprises in the tourism sector. Klipplaat is an outlier with a single tourism enterprise.

Cluster 2 towns include many of the towns usually identified as tourism destinations in the Karoo (e.g. Nieu-Bethesda, Graaff-Reinet, Prince Albert, Sutherland, Colesberg and Beaufort West). These towns and their surrounding areas could, therefore, be very sensitive to negative impacts from SGD, if implemented (also see Section 9.2.2). A number of these towns occur in or close to the area identified as having the highest likelihood of the presence of shale gas (Figure 1.18 in Burns et al., 2016). These towns are currently marketed as areas where 'one can get away from it all' and it is in these sensitive areas that mitigation would be most needed should SGD take place.

All towns in the study area have enterprises providing accommodation (bed & breakfasts [B&Bs], lodges, hotels, self-catering establishments, etc.) (Figure 9.4). Some smaller towns in cluster 2, such as Prince Albert, Sutherland and Nieu-Bethesda have many tourism enterprises relative to their sizes. Most of the very small towns (e.g. Lady Frere, Hofmeyr, Klipplaat and Fraserburg) do not have any 'food & drink' enterprises (Figure 9.4). On the other hand, Graaff-Reinet, Prince Albert and Nieu-Bethesda, all cluster 2 towns, seem to be important destinations for typical Karoo food. Towns on national routes (e.g. Beaufort West, Queenstown, Somerset East, Cradock and Colesberg) also have many 'food & drink' establishments (Figure 9.4) but many of their offerings are fast foods and not typical food of the region.

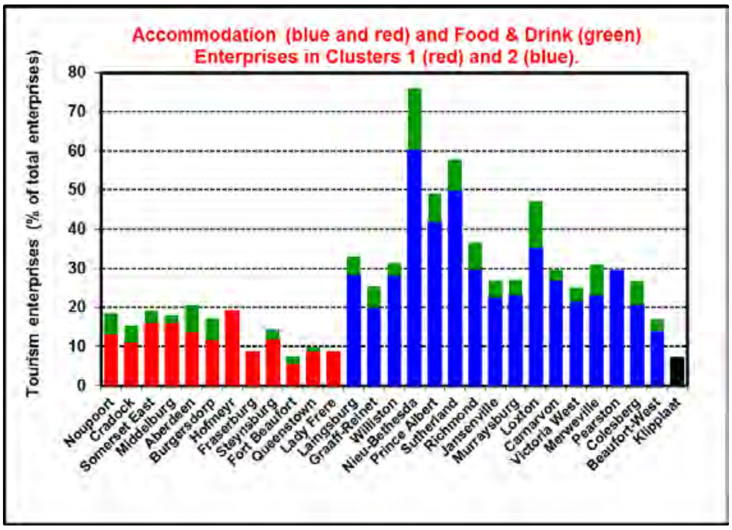

Figure 9.4: The contributions of accommodation and 'food and drink' enterprises to the enterprise profiles of two clusters of study area towns – cluster 1 (red) and cluster 2 (blue).

To establish whether the tourism sectors of the study area towns are stable, declining or growing we compared their sizes in 2006/08 with those of 2015/16 (Figure 9.5). The 2006/08 starting point was chosen because the use of smart phones for marketing purposes started taking off from 2007 (e.g. Lunden, 2013). Use of telephone directories of 2006 should, therefore, provide an overview of tourism enterprises at that time. Internet marketing is now used widely in the tourism industry in South Africa, also in the Karoo (e.g. Lekkeslaap, 2016; RoomsForAfrica, 2016: SafariNow, 2016). Internet searches were, therefore, used to obtain 2016 information of tourism enterprises.

With few exceptions (e.g. Colesberg, Fort Beaufort, Fraserburg, Klipplaat and Victoria West) the growth in the tourism sector of the towns outpaced the growth of the total enterprise numbers, further substantiating the growing importance of tourism in the study area. In Aberdeen, Carnarvon, Cradock, Graaff-Reinet, Jansenville, Loxton, Murraysburg, Nieu-Bethesda, Noupoort, Pearston, Prince Albert, Queenstown, Richmond, Somerset East, Sutherland and Williston tourism growth exceeded total enterprise growth by far (Figure 9.5). Not only does the tourism sector have the highest number of enterprises of all business sectors, but it is also growing more rapidly than other business sectors in the majority of towns. As suggested by Hoogendoorn & Nel (2012) many Karoo towns have entered a post-productive phase in which tourism has replaced the declining role of agriculture. The dispersed tourism activities across the farming areas are likely to be sensitive to negative impacts of SGD, should it be implemented. It is, therefore, of concern that the Karoo, and the study area, straddles the borders between some provinces (Atkinson, 2016). Integrated management and promotion of tourism across provincial borders is needed but will be complex, and this situation will increase the difficulty of mitigating the impacts of SGD, if implemented. Cooperation between provincial, mining and tourism stakeholders would be needed.

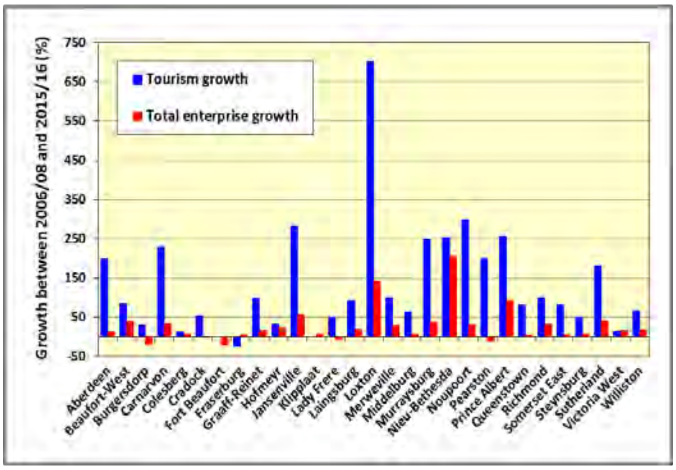

Figure 9.5: The growth (%) in the number of tourism (blue) and total (red) enterprises of the study area towns over 2006/08 to 2015/16.

9.1.3 Why do tourists visit the Karoo?… Its tourism assets

Apart from business travellers and those visiting friends and relatives (VFR travellers) who visit towns for business and personal reasons, it is important to understand why other tourists visit the Karoo. A recent study by Atkinson (2016) used questionnaires to determine why people visit the Karoo. She found that 35% of tourists (respondents): seek authentic and unique experiences, 34% seek convenience (a useful stay-over place), 16% are curious (finding out what the Karoo is about), 7% seek excitement (e.g. sport, hunting, adventure), 5% have loyalty (enjoyed previous visits) and 3% seek rest (having a holiday). Atkinson (2016) concluded that the tourism reputation of the Karoo has shifted profoundly from being hostile, dangerous and boring to being attractive, enticing and spiritual.

"Die Niks"

Nama Karoo landscapes are spectacular in a bleak and dramatic way. There is plenty of 'niks' (nothingness) affording wide viewsheds for the crowd-weary traveller and hunter (Milton & Dean, 2010). The Karoo is, therefore, defined by natural open spaces with the occasional koppie or windmill and is populated by authentic local people. The emptiness and undeveloped nature of the Karoo ("Die Niks") provides an escape for stressed people living in overcrowded cities and is the recognised brand used to market the region.

Scenery, especially mountains, and nature feature prominently in earlier tourist surveys. The Swartberg Pass, Seweweekspoort and Gamkaskloof ('Die Hel') are highlighted as important experiences. This highlights the importance of mountain passes and other scenic routes as key tourism assets for the region. The wide open spaces are also an important asset. Many respondents indicated that the lack of development and the unspoilt nature of the area attracted them. Getting away from it all and the peace and tranquillity (“The Nothingness” or “Die Niks”) of the Little Karoo is especially important to repeat visitors (Gelderblom, 2006).

Formal Protected Areas as well as private conservation initiatives are important tourist attractions. The Karoo National Park (close to Beaufort West and established in 1979), Mountain Zebra National Park (close to Cradock and established in 1937) and Camdeboo National Park (close to Graaff-Reinet and established in 2005) have experienced increased visitor numbers and investment (South African National Parks (SANParks), 2015a, 2015b).

Saayman et al. (2009) examined the socio-economic impact of the Karoo National Park on the local economy. At that stage only a small percentage (4%) of businesses in Beaufort West owed their existence to the park. For the park to have a greater impact, it was imperative to increase its accommodation capacity, offer more activities and promote activities and attractions in the region. Since then there has been substantial investment in the tourist experience in the parks including the re-introduction of lions and buffaloes in the Karoo and Mountain Zebra National Parks and the expansion of facilities.

The recent significant national and international investment in the establishment and expansion of Protected Areas in the Karoo attracted over 100 000 tourists in 2014/2015 to its National Parks. There is also substantial private investment in conservation including several private nature reserves and the newly declared Protected Environment established on private land between the Camdeboo and Mountain Zebra National Parks (SANParks, 2016).

Agri-tourism is on the increase in the Karoo. The growth in the number of game farms in South Africa, including the Karoo, has been significant (Saayman et al., 2011). Many commercial farmers are either introducing game into their normal farming operations or they are changing from commercial to game farming. The greatest source of income for game farms is hunting and the Northern Cape and Eastern Cape are key hunting provinces in South Africa, visited by local and foreign hunters (Saayman et al., 2011; Van der Merwe & Saayman, 2013; Van der Merwe et al., 2014).

Many visitors to the Karoo view the undeveloped nature of the area including the gravel roads as part of the appeal of the area. This lack of development is particularly important to adventure tourists such as motor bikers, hikers, 4x4 enthusiasts, hunters and mountain bikers. The absence of light pollution is also an important asset attracting both amateur and professional stargazers.

In tourist surveys in the region, small towns were generally more popular and their relative freedom from crime and hospitable, genuine people are strong attractions (Gelderblom, 2006). Towns with a historic character are particularly important assets for tourism (Orton et al. (2016) provides information about historic towns and important historical sites scattered through the landscape). Prince Albert is one of the most important of the tourist towns in the study area. Its visitors come to rest and enjoy the attractive architecture and mountain scenery. Some 25% of visitors preferred more active recreation such as hiking, cycling and participation in guided tours to see historic sites, the Swartberg Pass, birds or the night skies. Others came to visit friends, trace family history, and escape the Cape Town winter weather or to invest in property (Milton, 1998). Some also explore the area's rich biodiversity under the guidance of local experts.

9.1.4 Food tourism and the Karoo

Food tourism is world-wide a growing tourism product (Long, 2003). It includes any tourism experience in which one learns about, appreciates, and/or consumes food and drink that reflects the local, regional, or national cuisine, heritage, culture, tradition, or culinary techniques of a specific area (Ontario Culinary Tourism Association, 2010). Food tourism is not limited to urban regions and five-star restaurants (Boniface, 2003), but can include farms, farm stalls, fruit-picking sites, cheese manufacturers, honey producers, processors of foods such as preserves and confectionary, cafes, tea gardens and bars as potential sites. The importance in these offerings is that establishments are local and products authentic (Boniface, 2003; Hall et al., 2004).

Food tourism is also a growing tourism industry in the Karoo and has the potential to create unique culinary experiences (Green, 1975). Thus tourism and local food systems are being integrated to promote economic development, respond to the demand for quality food and dining experiences and to build on the cultural and culinary heritage of the region.

Cuisine

Skilled, thoughtful, refined cooking belonging to a particular style and group of people is identified as ***cuisine*** and is the foundation on which food tourism is based (Long, 2003). A ***regional cuisine*** is necessary to develop food tourism products that can form the basis of regional development (Gössling & Hall, 2013). It is a unified style of cooking common to most people living in a culinary region and is defined by three criteria: geography, homogenous food culture and defining dishes that are unique and noteworthy (Sackett & Haynes, 2012).

The Karoo has many assets that are supporting this development, including a culinary heritage and regional cuisine. The tourism offerings in the Karoo are authentic, within original small town atmospheres. Traditional foods such as ‘roosterkoek” have been passed down through generations in the Karoo. The climate and topography have also allowed the propagation and cultivation of local produce shaping the very specific cuisine of the region. Local produce such as Karoo Lamb have been recognised with a designation of origin providing quality and geographical recognition and simultaneously achieving international acclaim (Hoosain, 2015; Kirsten, 2012).

Plans are on the way to establish an association, ‘Karoo Food’, a public, non-profit organisation, to stimulate economic growth and job creation by working towards the sustainability of Karoo hospitality and camaraderie in the food tourism industry (Wright and Wright, 2015). The food and drink tourism offerings in many Karoo towns culminate in very popular food festivals, e.g. the Karoo food festival of Cradock which has become an annual event attended by many visitors.

9.1.5 The drivers of tourism in the Karoo

The recent increase of tourism in the study area (Figure 9.5) prompts the need to understand the phenomenon. Based on Sections 9.1.3 and 9.1.4, this section focuses on those factors believed to have been the main drivers of tourism in the Karoo.

One of the key contributing factors is the generally **improved road infrastructure** after World War II (Solomon, 1983). The national routes (N1, N6, N9, N10 and N12) that connect Gauteng and Western Cape, the two economically strongest provinces, via the study area have all been improved and this plays a vital role in increasing the flow of people through and to the region. The improved roads also benefit tourists to the study area, including business and VFR travellers visiting towns for business or personal purposes.

The **Karoo has also become a destination** in its own right, in line with an international trend towards “desert tourism”, which is often associated with adventure and a desire to “get away from it all”. Its establishment as a popular destination has been associated with a measurable increase in publicity and a change in perceptions regarding the area (Atkinson, 2016). It has been linked with the **development of tourism routes** that combine the use of national roads with tourism offerings, e.g. the N12 Treasure Route, the N12 Battlefields Route and the Friendly N6 Route.

Expanding National Parks and increased conservation-based activities have also stimulated tourism. These parks have also **introduced 4x4 and hiking routes**. There is also a **growth in private conservation initiatives**. The most recent development has been the establishment of a Protected

Environment of over 250 000 ha which includes 65 landowners in a corridor linking the Mountain Zebra and Camdeboo National Parks (SANparks 2016).

The **growth in niche tourism** based on festivals and events (e.g. Prince Albert), arts (e.g. Nieu-Bethesda) and science (e.g. Sutherland) also enhances tourism to the Karoo (Saayman et al., 2009; Saayman & Saayman, 2010). The Karoo has a **rich historic heritage** (see Orton et al., 2016), which also enhances Karoo tourism (Maguire, 2009; Koekemakranka Tourism, 2015).

The **rise of agri-tourism** in all its forms (e.g. farm stays, game farming, hunting, etc.) is one of the greatest drivers of modern tourism in the Karoo. **Increased agri-tourism services** offered by farms in the study area include wedding venues and conference facilities, game breeding, hunting, 4x4 and hiking trails, a variety of accommodations, stargazing, horse riding, fishing, and other water activities, especially on the Fish River in the Cradock region. Karoo tourism has over time moved from being more concentrated in the towns to being more dispersed over the rural Karoo farming areas.

There was (in 2015) a broad, but statistically significant correlation between town size (measured by total number of enterprises) and tourism enterprise numbers in the towns of the study area (Figure 9.6). Larger towns generally have more tourism establishments than smaller towns despite not necessarily being labelled as tourist destinations. This relationship indicates that the **business tourism** group (e.g. visits of business people, officials, etc.) and the **VFR** group are important. The larger a town, the more of these tourists visit it. Unfortunately the data did not distinguish between who visits a town for business/administrative purposes and who visits for VFR purposes. The two groups are, therefore, considered together.

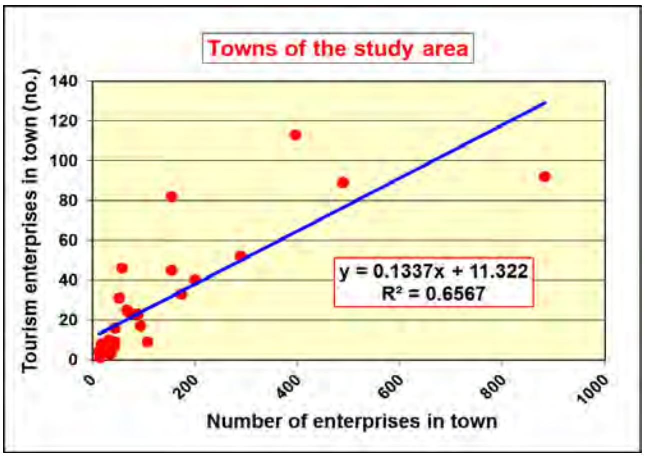

Figure 9.6: The broad correspondence between town size and the number of tourism enterprises in 2015/16 in the study area

9.1.6 Tourism impacts recorded elsewhere from SGD

Some information is available regarding the actual and projected economic impacts of SGD (see also van Zyl et al., 2016). For instance IHS Global Insight (2009) reported on the economic and energy impacts of proposals to regulate hydraulic fracturing ("fracking") in the United States (US). There are, however, few formal studies of the impacts on tourism and those available focus mostly on expected and not actual impacts. Newspaper reports sourced from the New York Times provided some stories of impacts on American towns but there is not much by way of quantified estimates.

Buttler & Fennell (1994) observed that development of the North Sea oil proved both beneficial to the tourism industry through improved infrastructure and guaranteed access to an affluent market. However, it was negative to the pleasure element of the industry, which was displaced and ignored for over a decade. Studies in Pennsylvania (Upadhyay & Bu, 2010), New York State (Rumbach, 2011), Newfoundland (Bezzina, 2013) and Queensland, Australia (McLennan et al., 2015) of shale or coal seam gas development also suggested that some impacts might be beneficial and others detrimental to tourism.

Negative impacts of the development of shale- and coal seam gas on tourism

- Air pollution through release of methane gas that must be flared off.
- Continuous noise pollution as a result of drilling, construction and fracking activities.
- Heavy truck traffic because each single-well fracking wellpad requires an estimated 890 to 1,340 truck trips.
- Visual impacts when drilling operations and fracking wells are within sight of residents, visitors and travellers. Flaring of gas adds to the visual impacts.
- Increased seismic activity.
- Disposal of hazardous wastes with the danger of toxic spills during storage or transport of wastes.
- Contributions to climate change and its potential impacts on tourism.
- Negative impacts on tourism products, promotion and visitor perceptions of tourism brands.
- Institutional shifts towards the resources sector.
- Structural lock-in to the resources sector with a two-speed economy and lack of affordable accommodation.
- Negative impacts on infrastructure and support. services

Rumbach (2011) suggested that although the tourism sector creates a significant number of jobs in the Southern Tier region of New York, it is likely that the value of gas drilling, measured simply by jobs created and wages generated might exceed the value of tourism in the short term. Rumbach (2011) expected the employment ‘boom’ of gas drilling to be relatively short-term and non-local. However, gas production in the Gladstone region of Queensland has resulted in the region becoming a major industrial cluster, with strengths in the export of resources, engineering, construction and manufacturing (McLennan et al., 2015).

In the immediate vicinity of the shale or coal seam gas production, enterprises such as hotels, restaurants, and shopping venues benefited from an influx of gas workers (Rumbach, 2011; Bezzina, 2013, McLennan et al., 2015). Many of the communities where drilling proceeded in North America were relatively sparsely populated and drilling led to a shortage of available hotel rooms (Price et al., 2014), thereby inhibiting ‘normal’ tourism.

Rumbach (2011) considered whether drilling would permanently damage the carefully developed ‘tourism brand’ of the Southern Tier region in New York State. The region’s ability to attract tourists could be damaged in the long-term if the perception of the region as an industrial landscape outlasts the employment and monetary benefits of gas drilling. Other regions where concerns have been raised about regional brand degradation include Newfoundland (Bezzina, 2013), Queensland (McLennan et al., 2015), Tasmania (Department of Primary Industries, Water and the Environment, 2015) and Romania (Muresan & Ivan, 2015). Farmers in the region of the Marcellus Shale Play in the US that produce organic products for high end and organic restaurants were concerned about the preservation of their brands should water pollution occur as a result of fracking (Ong, 2014).

The pace and scale of SGD is a crucial determinant of the overall impact on the tourism economy (Rumbach, 2011). Bezzina (2013) concluded that the overall impact of fracking on tourism would be negative in western Newfoundland. Bezzina (2013) expected a short-term economic boom for the region, including increased occupancy rates for hotels, but predicted a long term negative impact on the regional tourism brand. Tourists are currently attracted to western Newfoundland by landscapes and scenery, camping facilities, hiking trails and boat tours and these nature-based attractions may be negatively impacted.

Upadhyay & Bu (2010) estimated the visual impacts at different distances of gas drilling and wellpads in Pennsylvania. They indicated that such activities were visually not overly intrusive at distances exceeding about 3 km, but lights at wellpads and flaring of gases could be readily seen at night. Visitors flying in to a region with wellpads will, however, see them with potentially negative impacts (see Oberholzer et al. (2016) for more details about visual impacts).

Deutch (2011) and Morse (2014) commented on the good news resulting from SGD. Krauss (2011) remarked that a 17 mile stretch of road between a forsaken South Texas village, Catarina, and the county seat of Carrizo Springs, was until 2010 rundown and a patchwork of derelict gasoline stations and rusting warehouses. By 2011 the region was in the hottest new oil play in the country, with giant oil terminals and sprawling recreational vehicle (RV) parks replacing fields of mesquite. In the Rust Belt of Ohio transformation spread as a result of a surge in domestic oil and gas production and entire economic sectors like manufacturing, hotels, real estate and even law were reshaped (Schwartz, 2014).

Not all impacts lasted. A tumble in gas prices due to increased competition caused the boom in western Colorado, a region rich in natural resources and where oil and gas jobs formed the bedrock of the local economy, to dry up (Healy, 2012). Main Street businesses were struggling and big new schools built to accommodate a surge of students from the previous energy rush found their enrolments dwindling.

Potential synergies between mining activities and tourism could be exploited, e.g. mining becoming a possible tourism post-boom product (McLennan et al., 2015).

9.2 Consequences, Risks and Sensitivities

An extractive industry such as mining and tourism invariably end up in conflict (McLennan et al., 2015). SGD in the study area would, therefore, create risks for the tourism sector of the study area. The physical steps in SGD, if approved and implemented in South Africa, would not differ materially from those used in the US (see Burns et al., 2016). The negative impacts listed by Upadhyay & Bu (2010), Rumbach (2011), Bezzina (2013) and McLennan et al. (2015) (see sidebar in Section 9.1.6) could also be experienced in the Karoo. A further complexity is that in South Africa mineral resources belong to the State and not the landowners, whereas in the US it is the opposite. The Karoo also falls under the jurisdiction of more than one province (Atkinson, 2016), which adds complexity to the possibility of integrated tourism management in the study area.

Bezinna (2013), McLennan et al. (2015) and others have remarked that the use of local tourist accommodation by gas and oil workers ‘crowd out’ regular tourists but benefit local tourism entrepreneurs. SGD therefore results in an internal restructuring of the tourism industry (McLennan et al., 2015), which could lead to problems following a mining boom. Butler & Fennell (1994) suggested that it can take ten years or longer for tourism to recover from mining.

The development of an understanding of the consequences and risks associated with potential SGD required a special analysis (see digital Addendum 9A) which informed this section.

9.2.1 Tourist groups

Three groups of tourists (see Section 9.1.5) visit the study area: 1) Those seeking unique Karoo experiences (‘getting away from it all’, adventures, heritage sites, Karoo food, festivals, etc.); 2) Those travelling through; and 3) Business and VFR travellers.

The three groups are expected to react differently to SGD impacts. The tourists passing through are on their way to other destinations and will continue travelling through the study area whether SGD takes place or not, unless congestion of roads and noises associated with SGD-related traffic become a nuisance to them. Business and VFR groups visit towns for business/administrative/personal reasons and the size of these groups is determined by the size of towns. In fact, the size of these groups could increase because of the likelihood of business visits related to SGD activities and personal visits related to SGD workers. Tourists visiting the study area for unique Karoo experiences are expected to be negatively impacted by the problems associated with SGD (see Section 9.1.6). Dependent on their association with one or more tourist groups, different risk profiles are therefore expected for towns in the study area. Digital Addendum 9B presents an analysis of this aspect.

9.2.2 Consequences of impacts on the tourism sector of the study area

The consequences of SGD on the tourism sector of the study area are examined with the aid of a five point scale: slight but noticeable, moderate, substantial, severe and extreme. Table 9.1 summarises the expected impacts associated with different consequence levels.

Table 9.1: Consequences and impacts of potential SGD on tourism in the study area.

Consequence level	Impacts
Slight, but noticeable	Little densification of traffic on the roads of the study area; slight increase in truck noises; no rig noises; visual impacts no worse than those of railways, roads, wind pumps, power and telephone lines in the study area. The ability of municipalities to deliver services is unencumbered by SGD. Business and VFR tourist numbers are in step with the size of towns and their growth. Numbers of tourists travelling through are not affected and tourists seeking Karoo experiences visit the study area in growing numbers because of further growth of agri-tourism, ecotourism, adventure tourism, culinary tourism, etc.
Moderate	More pronounced traffic densification because of transport of some SGD equipment, materials and workers; truck noises are more pronounced but still acceptable; municipalities, even the small ones, are able to provide the services needed, e.g. road repairs, safe water, etc.; noise associated with exploration (e.g. seismic and drilling) increases in rural areas; the presence of rigs and flaring of gas have some visual impacts; visits of technical experts associated with exploration increase the number of business visitors to the study area; some crowding out of regular tourist groups is experienced in towns and areas close to exploration activities. VFR tourist numbers are not impacted much; through tourists continue as before and tourists seeking Karoo experiences still visit the study area, although some might come in close contact with the noise and visual impacts of exploration activities; the limited scale of exploration activities does not affect the image of the study area as a tourist destination; the Karoo tourism brand is not negatively influenced.
Substantial	Substantial traffic densification because of the transport of SGD equipment, materials and workers; with no mitigation, large numbers of slow-moving trucks on all of the major and many of the minor roads of the study area interfere with the access of tourists to the study area; truck

Consequence level	Impacts
	noises are very pronounced as large numbers of trucks ferrying materials and wastes continuously pass through towns or close to rural tourism facilities; all groups of tourists are affected by noise pollution, especially those using accommodation close to routes used by SGD trucks; drilling rigs operating in rural areas intrude through noise and visual impacts; the growth of towns and visits of technical and other experts associated with SGD increase the number of business visitors to the study area; crowding out of all regular tourist groups is a regular occurrence in towns and areas close to SGD activities; an influx of job seekers and SGD workers to the study area; VFR tourist numbers increase as town populations grow; most municipalities struggle to provide adequate services such as road repairs, provision of safe water, etc.; tourists passing through avoid study area roads and stay over in the towns outside the study area; tourists seeking Karoo experiences increasingly exposed to the presence of SGD operations with their associated noise, visual and other impacts; the study area increasingly gets an industrial image to the detriment of the Karoo's brand as a 'place to get away from it all'; some tourism enterprises are no longer viable concerns and cease to exist; many workers in the tourism sector become redundant and lose their jobs; the negative impacts on the tourism industry of the study area extend at least a decade after SGD had been terminated and rehabilitation activities completed.
Severe	Still higher truck densities on major and minor roads; more truck noises in towns as well as rural areas; more visual impacts; more business tourists; more crowding out of regular tourist groups; increasing deterioration of roads; more municipalities that struggle to provide safe water, adequate waste handling and adequate road repairs; tourists in rural areas are increasingly in contact with SGD operations; the number of tourists that seek Karoo experiences dwindle; the Karoo brand suffers and is replaced by an industrial image; the agricultural sector in the study area loses a main differentiator through the decline of the tourism sector and the study area's attraction as a place to have Karoo experiences diminishes; many tourism enterprises, especially in the rural areas, are no longer viable and disappear; many workers in the tourism sector become redundant and lose their jobs; the negative impacts on the tourism industry of the study area extend at least a decade after gas production has been terminated and rehabilitation activities completed.

The above analysis suggests that the major expected negative impacts of potential SGD on the tourism sector in the study area are a reduction in the numbers of 'regular' tourists, losses of tourism enterprises, a reduction in regional economic value addition by the tourism sector and declining tourism employment. The potential losses of enterprises, value addition and employment in the tourism sector of the study area are interlinked: if the number of tourists declines, the number of tourism enterprises declines, and then the economic value added by the tourism sector and the number of employment opportunities in the sector decline in step. The consequences terms are calibrated here (Table 9.2) and can be used in risk analyses.

Table 9.2: Calibration of consequences terms.

Impact	Slight	Moderate	Substantial	Severe	Extreme
Loss of tourism enterprises	<5%	5 - 9.99%	10 – 14.99%	15 – 20%	>20%
Loss of economic value added	<5%	5 - 9.99%	10 – 14.99%	15 – 20%	>20%
Loss of tourism employment	<5%	5 - 9.99%	10 – 14.99%	15 – 20%	>20%

9.2.3 Risk assessment

Should SGD be implemented in the study area, the likelihood of impacts on the tourism sector and the severity of their consequences determine the risks to which the tourism sector of the study area would be subjected. The lack of trustworthy publicly available tourism information (e.g. the number of bed nights sold and tourist spending at tourism establishments) bedevils assessment of the risks from SGD to the tourism sector in the study area. To overcome the problem, use was made of Standard Industry Classification (SIC) data available for 16 of the 29 towns of the study area to develop insight into these risks (see Digital Addendum 9A for details of the full analysis).

The dataset used included the nominal total GVA for 2010 and the GVA contributions of the following nine broad economic sectors: agriculture, mining, manufacturing, electricity supply, construction, trade, transport, financial services and other services to the economies of the 16 towns. It also included total employment as well as employment numbers in each of the above broad sectors. Census 2011 population data and 2015/16 enterprise numbers (total and tourism-related) of the 16 towns completed the dataset.

The presence of positive correlations between a number of economic, demographic and entrepreneurial characteristics of the 16 towns enabled three different analyses by which losses of tourism enterprises could be interpreted in terms of losses of employment and losses in economic value addition. Thereafter the analysis was extended to the towns not included in the dataset in order to develop a complete picture of the risks to the tourism sector in the study area (see Digital Addendum 9A).

The upper risk limit is determined by the limit of acceptable change, which was set at a 20% loss of tourism enterprises (see Section 9.2.2). Losses in excess of that figure could be catastrophic to the tourism sector and its role players of the study area. Using the calibrated consequences (Table 9.2) the expected losses of: (i) employment and (ii) economic value addition by tourism was developed for a range of risks (Table 9.3). The table presents an analysis of the risk levels that might arise under the different scenarios of SGD in the study area. It takes into account three sensitivity levels (medium, high and very high) to expected SGD impacts at different locations in the study area as well as the likelihood of their occurrence (see Digital Addendum 9B for detailed analysis).

Table 9.3: The losses in tourism enterprises, employment and value addition that may be associated with negative impacts by gas exploration and production on the tourism sector in the study area.

Loss in tourism enterprises	Tourism employment loss	Loss in GVA R million (2010 Rand p.a.)	Risk
< 4%	<530	<100	Very low
4 – 8%	530 - 790	100.1 - 200	Low
8.1 – 12%	791 – 1 580	200.1 - 300	Moderate
12.1 – 16%	1 581 – 2 110	300.1 - 400	High
16.1 – 2 0%	2 111 – 2 660	400.1 - 500	Very high
>20%	>2 660	>500	Limit

The expected consequences of the Reference Case, for the tourism sector in the study area were estimated to be slight (Table 9.1) and extremely unlikely (Table 9.3). In fact, it is expected that overall the tourism sector will continue to grow during the next three decades. Business and VFR tourist numbers would be proportional to the size of towns and tourists driving through the study area would continue to travel through and use accommodation and other services. Tourists seeking Karoo experiences would increase because farmers in the study area are expected to remain financially stressed (Oettle et al., 2016) and more would diversify their activities into agri-tourism. Towns are also targeting the tourism industry for economic growth and job creation. Tourism facilities and products would, therefore, increase in the rural areas as well as in the towns, attracting even more tourists. Mitigation procedures would not be necessary.

According to the Exploration Only scenario; exploration activities might start in 2018 and continue to about 2025 (Burns et al., 2016). This would result in some exposure of tourists seeking Karoo experiences to the consequences of the expected impacts in the study area: some traffic densification, some noise and visual disturbances and some crowding out of regular tourists (see Table 9.3). However, the consequences are expected to be moderate (Table 9.1) and without mitigation the risk for the tourism sector should be low (Table 9.4): losses of tourism enterprises less than 8%, losses of tourism employment < 790, loss of regional GVA <R 200 million per annum (Table 9.3). Mitigation steps could decrease the risk for the tourism sector to very low: losses of tourism enterprises less than 4%, losses of tourism employment < 530, and loss of regional GVA < R 100 million per annum (Table 9.3). It is, however, doubtful whether mitigation procedures would be justified in the period 2018 to 2025 unless they require a long time to put in place (see Section 9.3).

Should the Small Gas scenario become reality; the consequences of SGD during 2025 to 2045 would increase to severe. All of the impacts described in Table 9.1 would be experienced: traffic densification, noise and visual impacts, reduced tourist access to the region, crowding out of regular tourists and losses of tourists, especially those that seek Karoo experiences, and a decline in the Karoo tourism brand. These impacts are expected to be very likely and the risks for the tourism sector to be high (Table 9.4). Without mitigation of the impacts, the study area could lose up to 16% of its tourism enterprises, shed up to 2 100 jobs in the tourism sector, and the regional GVA could decrease by R 400 million (2010 Rand) per annum (Table 9.3).

Mitigation would reduce, but not eliminate, the risks. With mitigation the risk level to the tourism sector could decline to moderate, i.e. loss of tourism enterprises 8 to 12%, loss of tourism jobs 800 to1 600 and reduction in regional GVA R 200 million to R 300 million (2010 Rand) per annum (Table 9.3). Should the SGD activities of the Small Gas scenario terminate around 2048 and full rehabilitation has been established (Burns et al., 2016), the tourism sector could still take at least another decade to recover.

The consequences of the Big Gas scenario for the tourism sector in the study area from about 2025 to beyond 2050 would range from severe to extreme and are expected not to be spread evenly across the study area (Table 9.4). For locations with very high sensitivity (Figure 9.7), the consequences would be extreme and very likely (Table 9.4), which translates into very high risks for the tourism sector in these localities, i.e. losses of up to 20% of tourism establishments, a concomitant loss of tourism employment and a reduction in the regional GVA. Mitigation steps are expected to reduce the risks in the highly sensitive locations to high (Table 9.3 and Table 9.4), but some tourism enterprises and jobs would probably still be lost and the tourism contribution to the regional GVA be reduced.

For locations with medium and high sensitivity (Figure 9.7) the consequences are estimated to be severe and very likely. This would result in high risks (Table 9.4) and without mitigation of the impacts, these localities could lose up to 16% of their tourism enterprises, shed many jobs in the tourism sector, and the regional GVA contributions could decrease substantially (Table 9.3). Timely mitigation procedures are expected to reduce the risks in these locations, but would not eliminate them. After SGD ceases beyond 2050 and total rehabilitation is finally effected (see Section 1.4.3.1 in Burns et al., 2016), full recovery of the tourism sector would probably take at least another decade.

Table 9.4: Risk assessment for different tourism sectors from negative impacts of gas exploration and production and for different scenarios and with or without mitigation.

Impact	Scenario	Location*	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Tourism impacts	Reference Case	Very High Sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Moderate	Very unlikely	Low	Slight	Extremely unlikely	Very low
	Small Gas		Severe	Very likely	High	Substantial	Likely	Moderate
	Big Gas		Extreme	Very likely	Very high	Severe	Likely	High
	Reference Case	High Sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Moderate	Very unlikely	Low	Moderate	Very unlikely	Low
	Small Gas		Substantial	Likely	High	Substantial	Likely	Moderate
	Big Gas		Severe	Very likely	High	Severe	Likely	High
	Reference Case	Medium Sensitivity	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Slight	Very unlikely	Very low	Slight	Very unlikely	Very low
	Small Gas		Substantial	Likely	High	Substantial	Likely	Moderate
	Big Gas		Severe	Very likely	High	Severe	Likely	High

** See Figure 9.7*

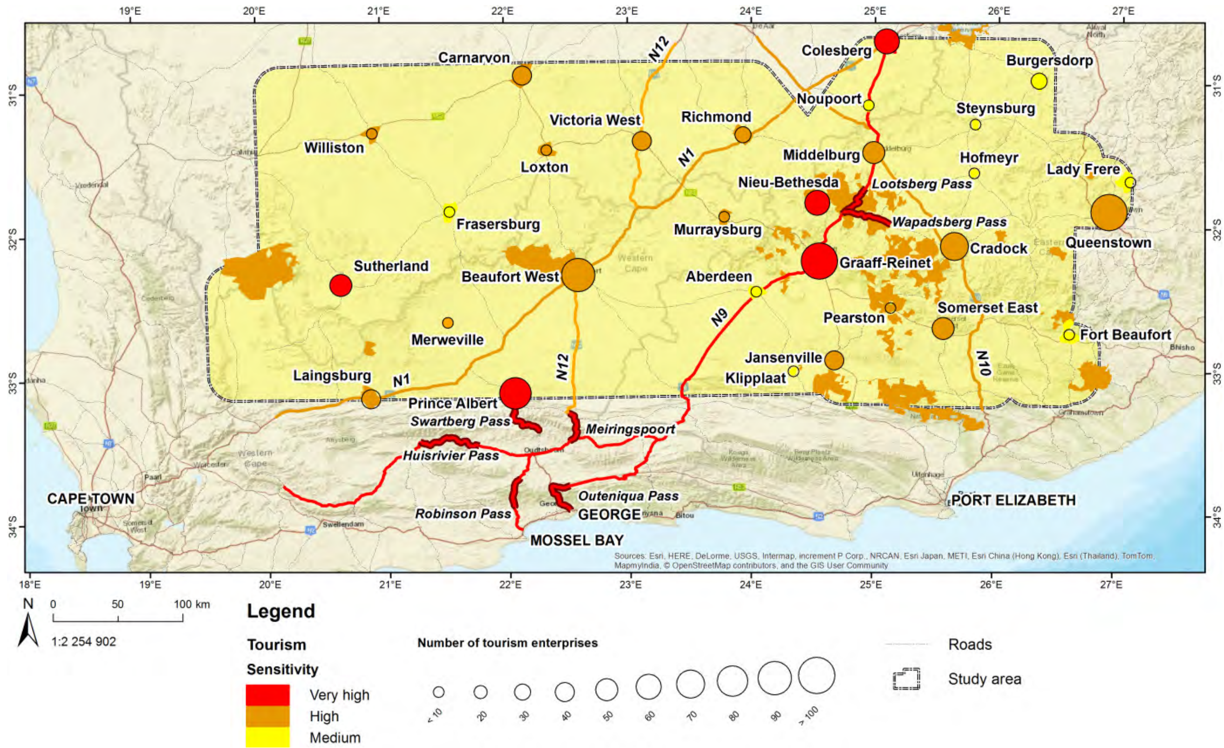

Figure 9.7: Map of the sensitivities to negative impacts of SGD on protected areas, major roads and the tourism sectors of towns of and the access routes from the south to the study area

Figure 9.8 presents a risk map of local community exposure to air pollutants across four SGD scenarios, with- and without mitigation.

9.2.4 Sensitivity of the tourism sector to negative impacts

Once risks were identified (Table 9.4) the evaluation of the sensitivity to impacts of SGD on the tourism sectors of towns, the rural areas, and access routes to the study area from the south was enabled (see detailed analysis in Digital Addendum 9B).

The evaluation firstly considered the access routes of tourists to the study area and for reasons outlined in digital Addendum 9B certain passes over and 'poorts' through mountains were judged to have a very high sensitivity. Atkinson (2009) identified six Karoo tourist routes, three of which cross or skirt the study area.

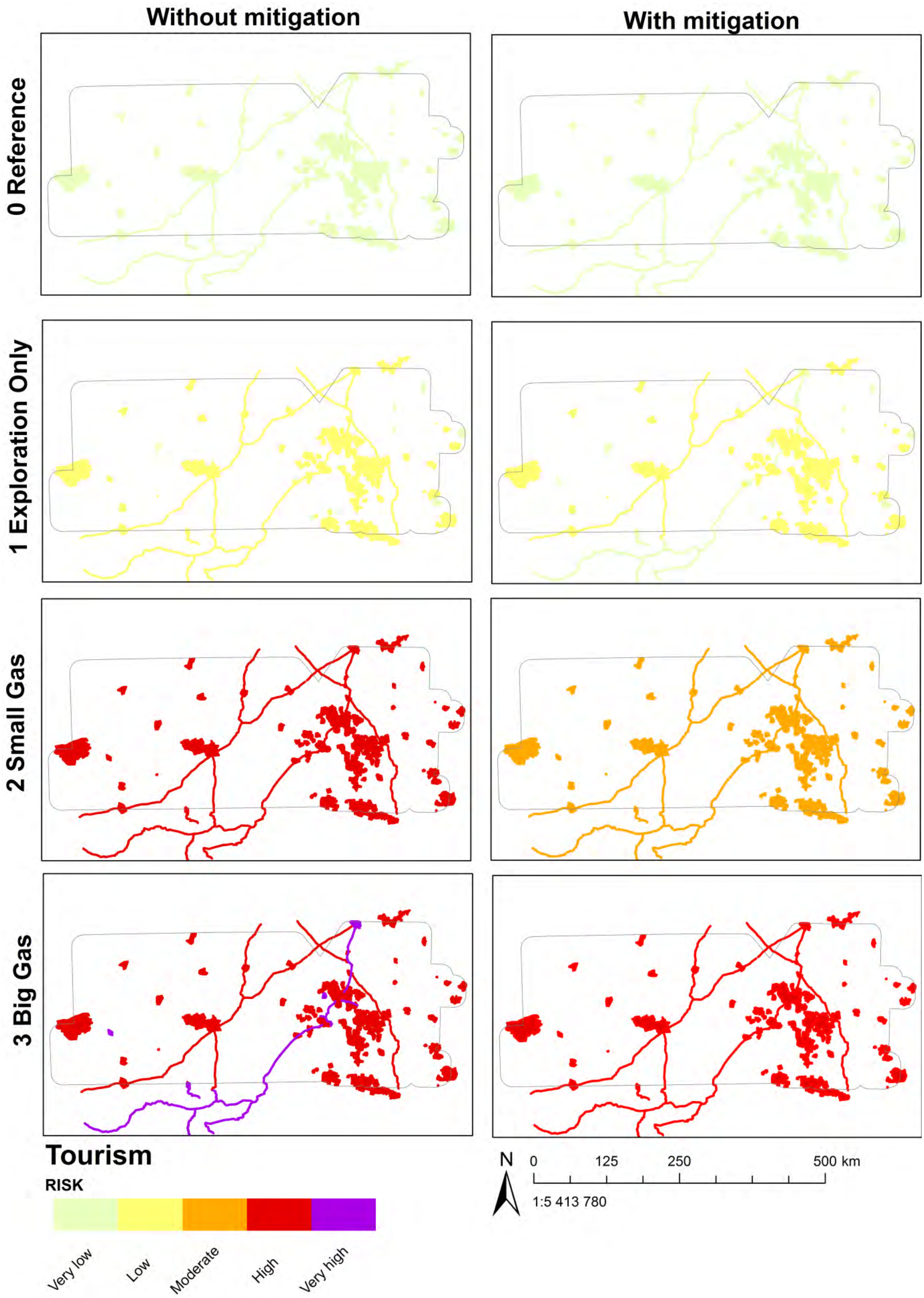

Figure 9.8: Map indicating the risk to tourism across four SGD scenarios, with- and without mitigation. Note: the risk of regional impacts to dispersed tourism facilities are not presented in this map.

The Camdeboo Route (N9) provides access to the central part of the study area and is an important access route. It features in mitigation proposals in this assessment (see Section 9.2.2) and is judged to have a very high sensitivity. The Great Karoo Route on the N1 passes partly through the study area and carries a lot of north-south traffic. The Sundays River Route on the N10 skirts the study area. The sensitivity of both of the latter routes is judged to be high.

Agri-tourism, eco-tourism and other niche tourism activities have contributed to the dispersal of tourism facilities throughout the study area. There is, however, a lack of information on the precise location of these facilities. Therefore, the whole of the study area was judged to have a medium sensitivity except where otherwise indicated. As better information about the location of tourism facilities and assets becomes available, the sensitivity estimates of specific locations might have to be adjusted.

The sensitivity assessment of the tourism sector of towns was based on two tests: (i) Does a town have more or fewer enterprises than the average number of tourism enterprises per town in the study area (i.e. the total number of tourism enterprises in the study area divided by the number of towns) (Figure 9.9). This test considers a town's relative contribution to the tourism sector of the study area. (ii) Does a town have a higher percentage of enterprises in the tourism sector than the average for the study area (total number of tourism enterprises in the study area divided by the total number of enterprises in the study area and expressed as a percentage) (Figure 9.10). This test considers a town's relative dependence on the tourism sector.

It should be noted that the data for each town also includes tourism enterprises in the surrounding countryside and thus each town deemed to have a certain sensitivity level would also have a surrounding countryside with the same sensitivity level.

Towns that exceeded the norm in either test were designated leaders and those that did not, were designated laggards.

Figure 9.9: Leading (green bars) and lagging (red bars) towns in the study area in terms of number of tourism enterprises per town. Regional average is total number of tourism enterprises in the study area divided by the number of towns.

Taking into account that all towns in the study area have one or more tourism enterprises, the minimum sensitivity accorded to towns in the study area is medium. The sensitivities of leading towns in both categories have been judged to be very high. The sensitivities of towns that are leaders in one but not the other category have been judged to be high. The sensitivities of towns that are laggards in both categories have been judged to be medium. Table 9.5 summarises the results.

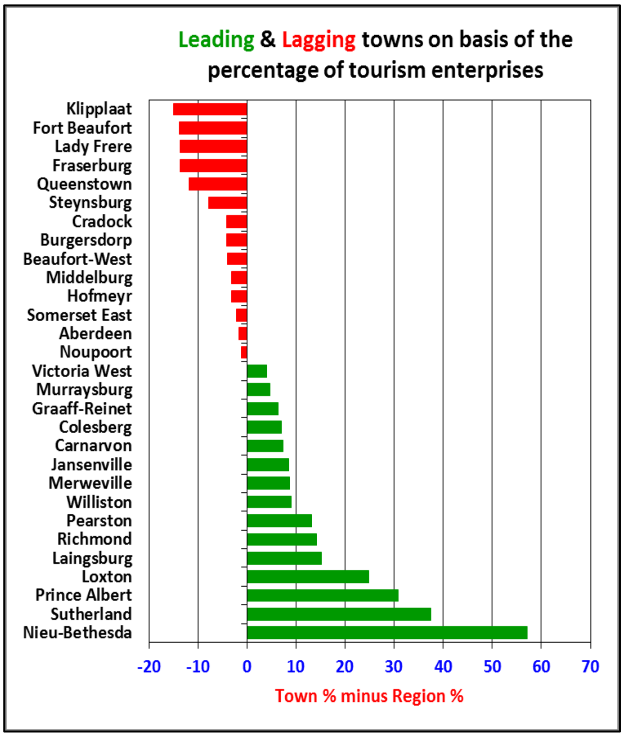

Figure 9.10: Leading and lagging towns in terms of the strength of their tourism sectors (expressed as % of total enterprises). The norm is the average strength of the tourist sector (% of all enterprises) for the whole of the study area.

Five towns are deemed to be very sensitive: Graaff-Reinet, Nieu-Bethesda, Prince Albert, Sutherland and Colesberg. All of these towns have reputations as tourist destinations. Colesberg is additionally positioned as an overnight stop for travellers between the metropolitan areas of Johannesburg and Cape Town.

The sensitivity of Beaufort West, Cradock, Middelburg, Queenstown and Somerset East is deemed to be high. These are all large towns and derive their enterprise number leadership probably partly from the business and VFR travellers and partly from overnight visitors. Cradock also attracts some niche visitors, such as for culinary experiences of Karoo food and aquatic activities.

Two tourism assets seem to play significant roles in the group of small towns that are laggards in the number of tourism enterprises but leaders in tourism sector strength: (i) overnight visitors on main routes from inland to the south (N1 and N12 routes) or to the West Coast (R63 route) benefit Carnarvon and Williston on the R63, Laingsburg and Richmond on the N1, and Victoria West on the N12; and (ii) a Google search confirmed that many hunting opportunities are advertised in the vicinities of all of the towns in this group. The Square Kilometer Array (SKA) is also being constructed close to Carnarvon and this town's tourism enterprises are benefiting from business tourism associated with this activity.

Table 9.5: Assessment of the sensitivity to negative impacts by SGD on the tourism sector of towns in the study area.

Town	Enterprise numbers	Tourism sector strength	Sensitivity
Graaff-Reinet	Leader	Leader	Very high
Nieu-Bethesda	Leader	Leader	Very high
Prince Albert	Leader	Leader	Very high
Sutherland	Leader	Leader	Very high
Colesberg	Leader	Leader	Very high
Beaufort-West	Leader	Laggard	High
Cradock	Leader	Laggard	High
Middelburg	Leader	Laggard	High
Queenstown	Leader	Laggard	High
Somerset East	Leader	Laggard	High
Carnarvon	Laggard	Leader	High
Jansenville	Laggard	Leader	High
Laingsburg	Laggard	Leader	High
Loxton	Laggard	Leader	High
Merweville	Laggard	Leader	High
Murraysburg	Laggard	Leader	High
Pearston	Laggard	Leader	High
Richmond	Laggard	Leader	High
Victoria West	Laggard	Leader	High
Williston	Laggard	Leader	High
Aberdeen	Laggard	Laggard	Medium
Burgersdorp	Laggard	Laggard	Medium
Fort Beaufort	Laggard	Laggard	Medium
Fraserburg	Laggard	Laggard	Medium
Hofmeyr	Laggard	Laggard	Medium
Klipplaat	Laggard	Laggard	Medium
Lady Frere	Laggard	Laggard	Medium
Noupoort	Laggard	Laggard	Medium
Steynsburg	Laggard	Laggard	Medium

Aberdeen, Burgersdorp, Fort Beaufort, Fraserburg, Hofmeyr, Klipplaat, Lady Frere, Noupoort, and Steynsburg are laggards in the number of tourism enterprises and in tourism sector strength (Table 9.5). The tourism sector has not yet become a major strength of these towns, and the sensitivity of their tourism sectors was judged to be medium, the same as that of the rest of the study area.

The study area contains many protected areas such as national and private nature reserves. The sensitivity of these areas was judged to be high.

The above analysis enabled the development of an integrated map of the sensitivities of the tourism sector of the study area to negative impacts of SGD (Figure 9.7), which shows that if SGD is implemented, the Protected Areas, roads and towns with high and roads and towns with very high sensitivities will have to be considered carefully.

9.3 Mitigation of Impacts on the Tourism Sector of the study area

Mining and tourism invariably end up in conflict (De Klerk & Heath, 2015; McLennan et al., 2015). The dispersion of tourism activities throughout the study area and tourism's sensitivity to negative impacts from SGD (Figure 9.7), suggest that if the Small or Big Gas scenarios (see Burns et al., 2016) become reality, such conflict could be unavoidable in the study area. In fact, two camps have already emerged in the Karoo's 'great shale debate' (De Wit, 2011). De Wit (2011) states that conservationists argue that SGD will leave massive irreparable environmental scars on one of South Africa's iconic landscapes. Others argue that there is a strong empirical correlation between energy use and wealth, and gas burns almost 50% cleaner than coal. Toerien (2015) suggested that the nature of the conflict is a dilemma between the conservation and utilisation of resources and creation of a win-win situation requires special efforts.

This prompts the question whether mitigation of negative impacts on the tourism sector is possible. Rumbach (2011) suggested that individual impacts in gas and oil production in Newfoundland are unlikely to have serious and long-term consequences, but without mitigation they could cumulatively do substantial damage to its tourism sector. He also suggested that municipal and county governments have many tools at their disposal to help mitigate the impacts of SGD.

Earlier analyses have shown that the tourism sector has the most enterprises of all business sectors in the study area; it generates a lot of employment and adds a lot of economic value (see Section 9.1.2). Should SGD operations result in a 20% decrease in tourism enterprises, more than 2500 employment opportunities and R 500 million (2010 Rand) in economic value per annum could be lost to the study area (Table 9.2). The majority of these jobs are held by semi-skilled local people, of which a high proportion is women. These facts provide powerful reasons to consider mitigation.

The impairment of the tourism sector in the study area during 2025 to 2045 by either the Small or Big Gas scenarios could result in significant risks for this sector (Table 9.3). The following problems are expected and should be considered for mitigation purposes: traffic densification that complicates tourism access to the study area, its associated noise pollution, degradation of roads by heavy traffic and ‘crowding out’ of regular tourists by workers of the SGD sector. Visual impacts, water pollution, the presence of hazardous wastes, increases in earthquakes and the carbon footprint could also negatively influence the perceptions of tourists about the study area. As a result the Karoo tourism brand could be degraded and require rejuvenation following SGD.

Possible mitigation steps should be considered timeously. Issues to be considered are: provision of relatively hassle-free access of tourists to the study area, cooperation between government authorities, cooperation between the mining and tourism industries to minimise SGD impacts on tourism, cooperation between all levels of government and the tourism industry to overcome the fragmented management of tourism in the study area, the general lack of tourism-related information in the study area (especially in its rural areas) and active cooperation between local municipalities and the tourism industry to minimise local impacts on the tourism sector. Mitigation would, therefore, require active participation of different role players: central government in the form of different departments, some provincial governments, all local municipalities in the study area, and the mining and tourism industries.

9.3.1 Reaching consensus on the need to protect the tourism sector of the study area

Should exploration activities start in 2018 (see Burns et al., 2016) it would be advisable for the Department of Environmental Affairs (DEA) to initiate an activity to bring the role players in the tourism sector of the study area together to seek consensus on the need to protect this sector should either the Small or Big Gas scenarios (see Burns et al., 2016) become reality. The role players should include the DEA, the Department of Energy (DME), the Department of Transport (DoTr), the provincial governments of the Northern Cape, the Eastern Cape and the Western Cape, all local municipalities in the study area, the mining industry (possibly through the South African Oil and Gas Alliance, [SOAGA]) and the tourism industry (e.g. through the South African Tourism Board and/or the Karoo Development Foundation).

Once the role players, and in particular the mining industry, have agreed that tourism is an important business sector in the study area and that the SGD activities of either of the Small or Big Gas scenarios (Burns et al., 2016) would create risks for the sector, the seeking of win-win situations to minimise impacts on the tourism sector could be pursued. Two considerations could then be addressed: (i) mitigation of negative impacts, and (ii) creating partnerships between the different role players.

9.3.2 Developing a partnership between SGD and the tourism sector

De Klerk & Heath (2015) suggested that ecotourism destinations and SGD can co-exist if certain critical factors are considered and applied. This can lead to a long-term partnership between the two industries that should be enforceable beyond mine closures. McLennan et al. (2015) observed that there are key synergies between mining and tourism in two regions in Queensland, Australia. Strategies that could enhance the co-existence of the two sectors include, *inter alia*: (i) the development of trust, communication and partnership between the two sectors, (ii) development of a joint long-term vision and strategy, (iii) development and improvement of industrial tourism products and industry tours, and (iv) improvement of information flows.

The importance of tourism in the study area and the likelihood that SGD might adversely impact on the tourism sector over a long period (2025 to beyond 2050) suggest that the creation of a partnership between SGD and the tourism sector in the study area is advisable. Such a partnership would enable: (i) the development of trust between the two sectors, (ii) an understanding of the needs of the other sector, and (iii) creation of good information flows between the two sectors. The DEA should perhaps play a role bring leaders of the two industries together before exploration activities start (possibly in 2018). The discussions should focus on the possibility of creating an active partnership between the two sectors, possibly with the involvement of the DEA and DoT.

Only a few companies are involved in the potential exploration and production of shale gas in the study area. Cooperation between these companies should be possible in order to enter into a partnership with the tourism sector and SAOGA could perhaps facilitate representation of the mining sector. The South African Tourism Agency could perhaps facilitate representation of the tourism industry.

9.3.3 Tourist access to the study area

Traffic congestion as result of the large numbers of slow-moving, heavily laden trucks envisaged in the Small and Big Gas scenarios (see Table 9.1) would hinder tourists on their way in or out of the study area. This is expected to result in a shift of tourists to areas not affected by SGD.

Many tourists access the Karoo (and study area) from the south using routes that have mountain passes over or 'poorts' through mountains (Figure 9.7 and Digital Addendum 9B). The scenic beauty of the mountains adds to their tourist experiences. Traffic congestion on the passes or in the 'poorts' would negatively influence the experiences of these tourists. To deal with a potential high risk of a loss of tourists to the study area (Table 9.3), it is necessary to consider a strategy by which relatively hassle-free access of tourists to the study area can be protected. The routing of shale gas trucks hauling supplies have to be considered with this problem in mind.

One possibility is that the N9 national road, a major south to north route through the study area, should be kept free of SGD truck traffic. The idea of the exclusion of trucks from specific routes is not new. For instance, in California commercial vehicles with three or more axles, or a gross vehicle weight of 9 000 pounds or more, are prohibited on Route 2 between the City of La Canada Flintridge and County Route N4 (California Department of Transportation, 2016).

To implement this idea, agreement would be necessary: (i) between the mining sector and the tourism sector that it is in the best interests of both sectors to ensure that there is at least one relatively unhindered (by SGD trucks) tourist access route to the study area, and (ii) between the DoT (as policy maker), the South African National Roads Agency and the mining industry that SGD trucks will be barred from the N9 route.

The N9 route could be proclaimed a 'Tourism Protection Route'. This route would be a logical extension of the R62 Route (Figure 9.7), which has been successfully developed as an internationally known tourist route in the Little Karoo (Route 62, 2016). The Route 62 brand name is legally protected and the intellectual property belongs to a close corporation of stakeholders (G. Lubbe, *pers. comm.*). The process to achieve the necessary legal protection for the R62 and to market it internationally took about eight years and required leadership and champions (J. Marais, *pers. comm.*). Protection of tourist access to the study area by proclaiming and marketing the N9 as a Tourism Protection Route would probably also require a long lead time. Luckily professional experience and know-how are available to guide the pursuance of this option, but given the long lead time required, action should not be delayed too long after exploration activities start in order to have the route operative before 2025 should either of the Small Gas or Big Gas scenarios be implemented.

9.3.4 Resolving the issue of fragmented management of tourism in the study area

Relationships in the tourism sector of the study area are complex. Several central government departments, three provinces and a number of municipalities (district and local) are linked in one way or another with the tourism sector in the study area. Each of these role players pursues its own strategies and Atkinson (2016) pointed out that the jurisdiction of more than one province over the Karoo adds complexity to coherent management of tourism in the Karoo. To overcome this complexity and to develop an effective management model, policy makers in government, particularly in the DEA, DMR, the DoT, the provincial governments of the Eastern Cape, Northern Cape and Western Cape, and the district and local municipalities involved in the study area should together consider the problem of fragmented management of tourism in the study area in case either the Small Gas or Big Gas scenario (Burns et al., 2016) becomes reality.

One way to improve integrated tourism management in the study area and to protect its tourism sector could be to create a tourist agency in the study area timeously. Such an agency should be fully authorised and empowered, perhaps as a statutory body, to manage tourism holistically in the study area. The proposed agency could then become a body to speak and negotiate on behalf of the tourism industry in the study area.

The agency could with the support of the mining sector also drive a process to develop industrial tourism products and tours associated with mining as suggested by McLennan et al. (2015). This might help to minimise negative impacts on the tourism sector in the study area.

Because of the potential negative impacts of SGD on the tourism sector in the study area and in the period prior to gas production (i.e. 2018 to about 2025), the proposed tourism agency could perhaps be funded from government sources. Once gas production starts, a tourism levy on such production could be used to fund the agency's activities.

9.3.5 Handling noise, visual, water pollution and other impacts

Mitigation of visual (Oberholzer et al., 2016), noise (Wade et al., 2016) and water pollution (Hobbs et al., 2016) as well as the handling of hazardous wastes (Durrheim et al., 2016 and Oelofse et al., 2016) requires world class practices during the exploration and development phases. However in some instances and from a tourism perspective, government policy makers (e.g. in the DEA) might have to supplement these steps further. For example, the impacts of visual and noise disturbances on rural niche tourism (i.e. agri-tourism, ecotourism, adventure tourism, heritage tourism, hunting, etc.) in the study area and their mitigation should be considered by government officials (e.g. officials of the DEA) as well as professionals involved in Environmental Impact Assessments (EIAs) of specific exploration and production activities.

The use of buffers (exclusion zones) around rural tourism facilities (e.g. cabins, cottages, houses, lodges, conference venues, etc.) during exploration activities (which might start by 2018) requires early consideration. The buffer distances mentioned in Holness et al. (2016), Oberholzer et al. (2016), Orton et al. (2016) and Wade et al. (2016) provide some indication of what would be required and these would need to be systematically integrated by EIA professionals to determine the appropriate buffer for each tourism facility from a tourism perspective. More important routes and sites should of necessity require larger buffer distances.

Water pollution can potentially have a significant impact on the provision of safe water to all tourist categories. This includes niche tourists that visit rural tourism facilities such as farm stays, game farms and the like. Problem incidents with water supply in rural areas during the exploration phase could cause avoidable embarrassment. In addition to the implementation of world class practices (see Section 5.7 in Hobbs et al., 2016), it could be considered by the Department of Water and Sanitation (DWS) that the water supplies of all rural tourism establishments in the vicinity of exploration activities in the study area be subjected to regular water tests. It might also be advisable that tourism entrepreneurs in the rural areas undergo special training in how to ensure the provision of safe and acceptable water to their tourist clients. The DEA, DWS and the DoT could take the lead in the handling of this issue and the potential tourism agency could be involved in managing training programs.

Earthquakes have the potential to scare and possibly harm tourists visiting or passing through the study area (Table 9.2) and can also damage heritage architecture which attracts tourists. Durrheim et al. (2016) examines this aspect and considers mitigation possibilities.

9.4 Gaps in knowledge and Monitoring needs

Although knowledge about tourism in the Karoo has expanded much in the past decade (e.g. Atkinson, 2016), this analysis has re-emphasised that there is a general lack of tourism-related information in the study area (especially about tourism facilities and products in its rural parts). Gathering of information would require active participation of different role players: central government in the form of different departments, some provincial governments, all local municipalities in the study area, and the mining and tourism industries. The lack of information also necessitates active cooperation between local municipalities and the tourism industry to address the many information gaps.

Four such gaps are of particular importance if the Exploration Only scenario becomes reality and the lead time from about 2018 to 2025 offers a time window in which these gaps could be addressed:

1. The location of tourism enterprises and the types of tourism products they offer in the rural parts of the study area.
2. The degree to which different tourist groups (niche, pass through and business tourists) utilise tourism facilities in the different towns and rural areas of the study area.
3. The number, needs and wants of the pass through tourism group.
4. The number, needs and wants of business and VFR tourists and their economic importance to Karoo towns.

Studies to address these information gaps should be initiated in follow up activities of the Strategic Environmental Assessment (SEA). Should the proposed tourism agency become reality, it could become the lead organisation to ensure that the lacking information is collected during the 2018 to 2025 time window.

9.3 Acknowledgements

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9.7 Digital Addenda 9A – 9B

SEPARATE DIGITAL DOCUMENT

Digital Addendum 9A: Estimates of employment, value addition and the potential impact of shale gas development (SGD) on the tourism sector of the study area. **Digital Addendum 9B**: Tourism sensitivity

DIGITAL ADDENDA 9A - 9B

DIGITAL ADDENDUM 9A: Estimates of employment, value addition and the potential impact of shale gas development (SGD) on the tourism sector of the study area.

Standard Industry Classification (SIC Codes) (Statistics South Africa, 2012) analyses do not include tourism as a separate entity and it's economic and employment contributions are partly hidden in other categories such as 'Other services'. Assessments of the value of tourism as part of the economic development of South African towns and regions are, therefore, usually based on measures such as bed nights and general estimates of money spent by tourists (Kyle Business Projects, 2009). Some of the data is derived from completed questionnaires, which usually represent only a fraction of all questionnaires distributed. In addition a number of assumptions based on national and other data are used to estimate economic and employment contributions of the tourism sector (see model described in Kyle Business Projects, 2009). Quantification of tourism enterprise numbers does not form part of such assessments.

In contrast, SIC data is used here firstly to estimate the economic value added and employment created by the tourism sector of the study area. These estimates are then compared with national data reported by the SA Tourism Review Committee (2015).

The first approach is based on regularities (in the form of linear regression equations) observed in enterprise development and dynamics of South African towns (Toerien, 2012b, 2014, 2015; Toerien & Seaman, 2010, 2012a, 2012b). These studies revealed statistically significant correlations (and linear regression equations) between economic (i.e. gross value added [GVA] and total personal income), demographic (i.e. population numbers), employment (i.e. total as well as sector employment numbers) and entrepreneurial (i.e. number of total as well as sector enterprises) characteristics of South African towns. These regularities also apply to the tourism sector (Toerien, 2012b).

Kahneman, (2011) indicated that simple algorithms often predict more effectively than experts. So if in Karoo towns, the GVA, total employment, total enterprise numbers and tourism enterprise numbers are statistically significantly correlated with one another, it would be possible to estimate the portion of employment due to tourism of the towns in the study area.

To determine if such regularities are present, use was made of economic, demographic and entrepreneurial characteristics of towns of the study area. The economic and employment data was obtained from IHS Global Insight for a range of Karoo towns. The dataset includes the nominal total GVA for 2010 and the GVAs of the following nine broad economic sectors: agriculture, mining, manufacturing, electricity supply, construction, trade, transport, financial services and other services.

It also includes total employment as well as employment in each of the above broad sectors. Sixteen of the 29 towns of the study area form part of the dataset. This meant that a significant portion of the 29 towns of the study area was included. The dataset also includes Census 2011 populations and 2015/16 enterprise numbers (total and tourism-related) of the 16 towns.

The total GVA, total employment, total enterprise numbers and tourism enterprise numbers of the 16 towns were highly significantly ($P<0.01$) correlated with one another (Table A9.1). Regularities were thus observed as in other regions.

Table A9.1: Correlation coefficients and regression equations of the relationships between GVA (gross value added), total employment, total enterprises and tourism enterprises of 16 Karoo towns.

Characteristics	**Correlation**	**Var. Expl. (%)**	**Regression coefficient**	**Intercept**	**n**
GVA - employment	0.95	89.9	4.87	511.0	16
GVA - total enterprises	0.92	85.1	0.289	0.7	16
GVA - tourism enterprises	0.77	58.6	0.056	9.0	16
Employment - total enterprises	0.90	80.1	0.055	-15.72	16
Employment - tourism enterprises	0.70	49.6	0.010	7.45	16
Total enterprises - tourism enterprises	0.88	77.3	0.205	7.22	16

Var. expl. (%) = percentage of variance explained

This indicated that the ratio of tourism enterprises to total enterprise numbers for each town could be used to estimate the tourism sector’s contribution to its GVA and employment. The basic premise was that because: (i) GVA and tourism enterprises, and (ii) employment and tourism enterprises, are correlated, the assumption could be made that tourism employment (or tourism GVA) is proportional to total employment (or total GVA) according to the ratio of tourism enterprises to total enterprises.

Three ways were identified to use this approach with the available data. Firstly, the total GVA, total employment, total enterprises and tourism enterprises could be used in an analysis summarised in Table A9.2. This analysis suggests that there are 11 632 tourism employees in 589 tourism enterprises in the 16 towns, which equates to nearly 20 employees per tourism enterprise. According to this analysis, tourism contributed just below R 2 billion to the economies of the 16 towns (Table A9.2), which equates to an average value addition of R 3.325 million per tourism enterprise.

This analysis, however, suffers from a significant weakness, i.e. in South Africa there is no database that provides information on the current number of farming operations in specific areas. Consequently, the number of enterprises (farming operations) that generate a major portion of the

Table A9.2: The 2010 gross value added (GVA), 2010 total employment, 2015/16 total enterprises and 2015/16 tourism enterprises of 16 Karoo towns

Town	2010 GVA (nominal R million)	Total enterprises towns	Total employment (no.)	Tourism enterprises	Fraction Tourism (%)	Estimated Tourism GVA R Million	Estimated Tourism Employment
Aberdeen	207.723	44	1,739	9	20.5	42.489	356
Beaufort West	1202.421	489	6,482	89	18.2	218.846	1180
Carnarvon	349.808	78	1,382	23	29.5	103.149	408
Colesberg	401.133	154	2,211	45	29.2	117.214	646
Cradock	1135.393	289	7,610	52	18.0	204.292	1369
Graaff-Reinet	1469.052	396	6,172	113	28.5	419.199	1761
Hofmeyer	56.680	21	746	4	19.0	10.796	142
Jansenville	225.190	75	1,817	23	30.7	69.058	557
Middelburg	853.806	174	4,612	33	19.0	161.929	875
Pearston	61.369	17	888	6	35.3	21.660	313
Prince Albert	183.170	155	2,058	82	52.9	96.903	1089
Somerset East	748.280	200	5,258	40	20.0	149.656	1052
Steynsburg	143.421	42	1,123	6	14.3	20.489	160
Sutherland	228.016	52	1,324	31	59.6	135.933	789
Victoria-West	409.467	88	2,449	23	26.1	107.020	640
Williston	255.670	32	943	10	31.3	79.897	295
Total	7930.598	2306	46814.000	589	452.1	1958.528	11632
Average	495.662	144	2925.875	37	28.3	122.408	727
Std Dev*	445.294	140	2288.706	33	12.6	100.631	466
Median	302.739	83	1937.500	27	27.3	105.084	643

*Std Dev = standard deviation

GVA attributable to agriculture in the 16 towns is not known. Although some of these farming enterprises are associated with tourism activities such as farm stays, game farming and hunting, and contribute to tourism GVA and employment, these contributions are probably still less than 10% of that of agriculture. Nevertheless the exclusion of farming enterprises in the analysis might result in an overestimate of employment in the tourism sector.

To overcome this problem, the agricultural GVA and agricultural employment data as well as the agricultural enterprises serving the farming community were excluded in a second analysis. This analysis assumed that employment (or GVA) in tourism is proportional to non-agricultural employment (or non-agricultural GVA) according to the ratio of tourism enterprises to non-agricultural enterprises.

The non-agricultural GVA, non-agricultural total employment, non-agricultural enterprise numbers and tourism enterprise numbers of the 16 towns were highly significantly ($P<0.01$) correlated with one another (Table A9.3) and regularities similar to the earlier ones were observed.

Table A9.3: Correlation coefficients and regression equations of the relationships between non-agricultural GVA (gross value added), total non-agricultural employment, total enterprises and tourism enterprises of 16 Karoo towns.

Characteristics	Correlation	Var. Expl. (%)	Slope	Intercept	n
GVA - employment	0.97	94.7	4.40	264.6	16
GVA - total enterprises	0.88	77.4	0.266	12.4	16
GVA - tourism enterprises	0.76	57.5	0.057	12.1	16
Employment - total enterprises	0.90	81.0	0.060	-2.93	16
Employment - tourism enterprises	0.73	53.7	0.012	10.34	16
Total enterprises - tourism enterprises	0.88	77.8	0.219	8.78	16

The ratio of tourism enterprises to total non-agricultural enterprise numbers for each town was used to estimate the tourism sector's GVA and employment contributions (Table A9.4). This analysis suggested that there are 9 618 tourism employees in 589 tourism enterprises in the 16 towns, which equates to just more than 16 employees per tourism enterprise. According to this analysis, tourism contributed about R 1.9 billion to the economies of the 16 towns (listed in Table A9.2); which equates to an average value addition of R 3.24 million per tourism enterprise. Although the second analysis does not include GVA and employment data contributed by farm-based tourism products, it includes contributions by sectors that are clearly not associated with tourism, i.e. the mining, manufacturing, electricity supply, construction, trade, transport and financial services sectors. This might also distort quantification of the GVA and employment contributions of the tourism sector.

Table A9.4: The 2010 non-agricultural gross value added (GVA), 2010 total non-agricultural employment, 2015/16 total non-agricultural enterprises and 2015/16 tourism enterprises of 16 Karoo towns

Town	2010 non-agriculture GVA	Non-agricultural enterprises towns	Non-agricultural employment (no.)	Tourism enterprises	Fraction Tourism (%)	Tourism GVA R Million	Tourism Employment
Aberdeen	170.394	37	1207	9	24.3	41.447	294
Beaufort West	1063.860	472	5635	89	18.9	200.601	1063
Carnarvon	254.163	62	973	23	37.1	94.286	361
Colesberg	333.241	148	1623	45	30.4	101.323	493
Cradock	1056.959	250	5797	52	20.8	219.848	1206
Graaff-Reinet	1423.233	354	5405	113	31.9	454.309	1725
Hofmeyer	50.492	17	349	4	23.5	11.881	82
Jansenville	193.766	54	1211	23	42.6	82.530	516
Middelburg	821.777	141	3780	33	23.4	192.331	885
Pearston	46.327	16	422	6	37.5	17.373	158
Prince Albert	134.973	150	1196	82	54.7	73.785	654
Somerset East	690.229	164	3438	40	24.4	168.349	839
Steynsburg	122.011	32	702	6	18.8	22.877	132
Sutherland	121.463	47	671	31	66.0	80.114	443
Victoria-West	307.934	72	1770	23	31.9	98.368	566
Williston	150.118	29	589	10	34.5	51.765	203
Total	6940.939	2045	34769	589	520.6	1911.2	9618
Average	433.809	128	2173	37	32.5	119.4	601
Std Dev	434.157	131	1963	33	13.1	111.0	449
Median	223.965	67	1209	27	31.2	88.4	505

Std dev = standard deviation

Consequently a third analysis was done. It was assumed that the GVA and employment contributions of the tourism sector are mostly included in the 'other services' sector. The use of the ratio of the number of tourism enterprises to the number of enterprises in the 'other services' sector was used to estimate the GVA as well as employment contributions of the tourism sector. In this analysis all enterprises serving sectors not included in the 'other services' sector were excluded.

The GVA, employment and enterprise numbers in the 'other services' sector of the 16 towns were significantly ($P<0.01$) correlated with one another as well as with the tourism enterprise numbers (Table A9.5). Regularities were again observed. The ratio of tourism enterprises to the 'other services' enterprise numbers for each town was used to estimate the tourism sector's GVA and employment contributions in the 16 towns (Table A9.6).

This analysis suggested that there are 7 224 tourism employees in 589 tourism enterprises in the 16 towns, which equates to just more than 12 employees per tourism enterprise. According to this analysis, the tourism industry contributes just over R 1.6 billion to the local economies of the 16 towns, which equates to an average value addition of R 2.77 million per tourism enterprise to local economies.

Table A9.5:Correlation coefficients and regression equations of the relationships between GVA (gross value added), employment, and enterprises in the 'other services' sector as well as tourism enterprises of 16 Karoo towns.

Characterisics	Correlation	Var. Expl. (%)	Slope	Intercept	n
Other services GVA – other services employment	0.96	91.8	3.75	147.2	16
Other services GVA – other services enterprises	0.74	54.9	0.227	24.1	16
Other services GVA - tourism enterprises	0.65	42.3	0.094	16.7	16
Other services employment – Other services enterprises	0.80	64.7	0.063	12.93	16
Other services employment - tourism enterprises	0.67	44.5	0.025	13.41	16
Other services enterprises - tourism enterprises	0.94	88.0	0.444	4.61	16

The three analyses provide information about the likely lower and upper levels of economic and employment contributions of tourism enterprises in the 16 towns: 12 to 20 employees per tourism enterprise and each tourism enterprise adding between R 2.77 million and R 3.33 million of economic value to their local economies.

Extending the analyses to all of the towns of the study area

The ratios reported in the previous section were used to assess the likely lower and upper levels that the tourism sector contributes to employment and GVA in the 13 towns not included in the previous analyses (Table A9.7). Combination of the information in Tables A9.2, A9.4, A9.6 and A9.7 shows that there are 828 tourism enterprises in the study area employing between 10 100 and 16 400 workers and adding between R 2.3 billion to R 2.7 billion to the local economies of the study area.

Reality check

A review of South African tourism estimated that in 2013 tourism contributed R 103.6 billion to the South African GDP and employed 655 509 persons (SA Tourism Review Committee, 2015). This relationship suggests that the tourism employment estimates of this study (10 100 to 16400 persons) are equivalent to a GDP contribution of between R 1.6 billion and R 2.6 billion. This is in reasonable agreement with the estimates of the present study that were used to quantify the SGD risks for the tourism industry in the study area.

Quantification of the risks involved with SGD

The overall risk methodology prescribed for the assessment of risks associated with SGD uses five levels of risk: very low risk, low risk, moderate risk, high risk and very high risk. These risk levels are functions of the likelihood of occurrence and the consequences of occurrence of events (Scholes et al., 2016).

The upper risk limit is set by the limit of acceptable change, which in this case was determined from the combined experience and insights of the project team. This team set the limit at a 20% decrease in tourism enterprises.

With the aid of the previous analyses the limit of acceptable change and the risk levels can be quantified in terms of potential losses in employment and negative economic impact in the study area. To do this the averages of the lower and upper estimates of employment and economic value addition per tourism enterprise are used, i.e. 16 employees per enterprise and R3.0 million economic value-added per tourism enterprise. The expected impacts are summarised in Table A9.8 and provides measures whereby Table 9.2 in Toerien et al. (2016) can be interpreted.

Table A9.6: The 2010 gross value added (GVA), 2010 employment and 2015/16 enterprises in the other services sector as well as the 2015/16 tourism enterprises of 16 Karoo towns

Town	2010 Other services GVA	Other services enterprises per town	Other services employment (no.)	Tourism enterprises	Fraction Tourism (%)	Tourism GVA R Million	Tourism Employment
Aberdeen	72.913	22	472	9	40.9	29.828	193
Beaufort West	332.678	234	1963	89	38.0	126.532	747
Carnarvon	157.566	38	411	23	60.5	95.369	249
Colesberg	144.473	73	613	45	61.6	89.059	378
Cradock	619.609	130	2762	52	40.0	247.843	1105
Graaff-Reinet	738.531	210	2435	113	53.8	397.400	1310
Hofmeyer	35.532	10	203	4	40.0	14.213	81
Jansenville	79.126	36	528	23	63.9	50.553	337
Middelburg	483.463	76	1897	33	43.4	209.925	824
Pearston	24.021	12	250	6	50.0	12.010	125
Prince Albert	48.049	109	456	82	75.2	36.147	343
Somerset East	329.134	97	1687	40	41.2	135.725	695
Steynsburg	77.035	14	267	6	42.9	33.015	114
Sutherland	22.582	38	233	31	81.6	18.422	190
Victoria-West	174.373	41	773	23	56.1	97.819	433
Williston	70.831	20	199	10	50.0	35.416	99
Total	3410	1160	15146	589	839.2	1629.3	7224
Average	213	73	947	37	52.5	101.8	451
Std Dev	225	69	881	33	13.2	105.3	377
Median	112	40	500	27	50.0	69.8	340

Std dev = standard deviation

Table A9.7: The estimated contribution of the tourism sector to employment and economic value addition in the towns of the study area that did not form part of the dataset used in the earlier analyses.

Town	Tourism enterprises (no.)	Total enterprises (no.)	Estimated tourism employment	Estimated tourism GVA contribution (R million)
Burgersdorp	17	94	204 - 340	47.1 - 55.25
Fort Beaufort	9	108	108 - 180	24.9 -29.3
Fraserburg	3	35	27 - 60	8.3 - 9.8
Klipplaat	1	14	9 - 20	2.8 - 3.3
Lady Frere	3	35	27 - 60	8.3 - 9.8
Laingsburg	25	67	300 - 500	69.3 - 81.3
Loxton	8	17	96 - 160	22.2 - 26.0
Merweville	4	13	48 - 80	11.1 - 13.0
Murraysburg	7	26	84 - 140	19.4 - 22.8
Nieu-Bethesda	46	58	552 - 920	127.4 - 149.5
Noupoort	8	38	96 - 160	22.2 - 26.0
Queenstown	92	882	1104 - 1840	254.8 - 299.0
Richmond	16	44	192 - 320	44.3 - 52.0
	239	1431	2868 - 4780	662.0- 776.8

Table A9.8: Quantification of risks to the tourism sector of the study area in terms of losses in employment and economic value addition.

Loss in tourism enterprises	Tourism employment Loss	Loss in GVA R million	Risk
< 4%	<530	<100	Very low
4 – 8%	531 - 790	100.1 - 200	Low
8.1 – 12%	791 - 1580	200.1 - 300	Moderate
12.1 – 16%	1581 - 2110	300.1 - 400	High
16.1 – 20%	2111 - 2660	400.1 - 500	Very high
>20%	>2660	>500	Limit

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DIGITAL ADDENDUM 9B: Tourism sensitivity

Sensitivities of tourism facilities and assets in towns and elsewhere in the study area to impacts of Shale Gas Development (SGD)

Mining significantly transformed the Australian economy and in the process the resources sector increasingly encroached on the tourism sector. This resulted in increased conflict between the two sectors (McLennan et al., 2015). It is inevitable that should SGD happen in the study area, the tourism industry will be negatively impacted. To develop an understanding of the geographic spread of the sensitivities of the area to negative impacts, it is necessary to identify the sensitivity levels of different components of the tourism industry in the area.

Levels of sensitivity

Five levels of sensitivity have been considered in this analysis: none, low, medium, high and very high. Allocation of a sensitivity level is mostly a judgment call of the project team, but where possible quantified measures were employed.

Access of tourists to the study area

Tourists enter the study area either by road, rail or air. Rail services in South Africa no longer carry many tourists and flight services to Karoo towns are limited. Consequently, road access is important for tourists to access the study area. Most of the tourists entering this area from the south have to negotiate passes over or ‘poorts’ through the mountains (e.g. Robinson Pass between Mossel Bay and Oudtshoorn, Outeniqua Pass between George and Oudtshoorn, Huisrivier Pass between Calitzdorp and Oudtshoorn, Meiringspoort on the N12 between De Rust and Beaufort West and Swartberg Pass on the R328 between Oudtshoorn and Prince Albert). Whilst crossing the passes or driving through the ‘poorts’, scenery adds to the tourist experience. In the study area several mountain passes also add to tourist experiences, e.g. Lootsberg Pass on the N9 route and Wapadsberg Pass on the R61 between the N9 and Cradock. The densification of traffic through the passes by large numbers of slow-moving trucks ferrying materials for SGD will negatively impact on tourists’ perceptions about the Karoo as a tourist destination. Tourists’ sensitivity to heavy traffic on the passes or through the ‘poorts’ are expected to be very high. Tourists accessing the Karoo from directions other than the south do not have to negotiate mountain passes.

Atkinson (2009) identified six Karoo tourist routes, three of which cross or skirt the study area. The Camdeboo Route (N9 national highway) is especially important because it provides access to the study area and many of its tourism assets. The N9 route also forms part of the mitigation proposals of this study and is considered to be very sensitive to negative impacts. The Great Karoo Route on the

N1 passes partly through the study area and carries a lot of north-south traffic. The Sundays River Route on the N10 skirts the study area. The sensitivity of both of the latter routes is judged to be high.

Noise pollution

Table 1.3 in Burns et al. (2016) and Section 2.5.2 of Wade et al. (2016) provide estimates of the large number of shale gas truck visits expected should SGD be implemented from about 2025 onwards. Based on experiences elsewhere, a continuous stream of trucks (in the Small and Big Gas scenarios, Burns et al., 2016) passing through towns where tourists overnight, will negatively impact on these tourists and tourist facilities close to through roads. These tourists are likely to seek accommodation elsewhere where intrusive noises are absent. Truck traffic on dirt roads in areas with dispersed tourist accommodation will be audible over long distances and is bound to influence perceptions about the study area as a place ‘to get away from it all’.

Dispersed tourist attractions

The rise of various niche tourism activities in rural Karoo (e.g. agri-tourism, ecotourism) has dispersed tourism activities and facilities throughout the study area. There is a lack of information about the precise location of these activities. Therefore the whole of the study area should be considered to have a medium sensitivity to negative impacts except where otherwise indicated. As better information about the location of tourism facilities and assets becomes available, the sensitivity estimates of specific locations might have to be adjusted.

Sensitivity of the tourism sectors of towns and their surrounding areas

Quantified data on the tourism enterprises of the study area is now available. There are two ways to use the data to determine the tourism sensitivities of towns and their surrounding areas (for simplicity’s sake hereafter referred to as towns) re: SGD. Firstly, the tourism enterprise numbers of towns can be compared to the regional average number of tourism enterprises per town. This identifies leading and lagging towns in terms of the regional average number of tourism enterprises per town. Secondly the relative strength of the tourism sector (normalised as a percentage of total enterprises) of a town can be compared to the strength of the tourism sector relative to all enterprises in the study area.

Graaff-Reinet is the leading study area town based on numbers of tourism enterprises (Figure B9.1) and based on composition (tourism percentage) it is also one of the leading towns (Figure B9.2). Part of the strength of Graaff-Reinet probably resides in its role as a tourist destination for niche-seeking tourists and it is expected to have a very high sensitivity to negative impacts on its tourism sector.

Graaff-Reinet is clearly differentiated from the other large towns (Queenstown, Beaufort West, Cradock, Middelburg and Somerset East), which are leaders as far as tourism enterprise numbers are concerned (Figure B9.1) but are lagging in the relative strength of their tourism sectors (Figure B9.2). The large number of tourism enterprises in Queenstown, Beaufort West, Cradock, Middelburg and Somerset East (Figure B9.1) are probably mostly a function of their business and VFR tourism sector. In terms of relative strength (percentage of tourism enterprises) the tourism sectors of these towns are lagging the region's average (Figure B9.2). Niche tourism probably plays a relatively limited role in these towns. The towns are expected to have a high sensitivity to negative impacts.

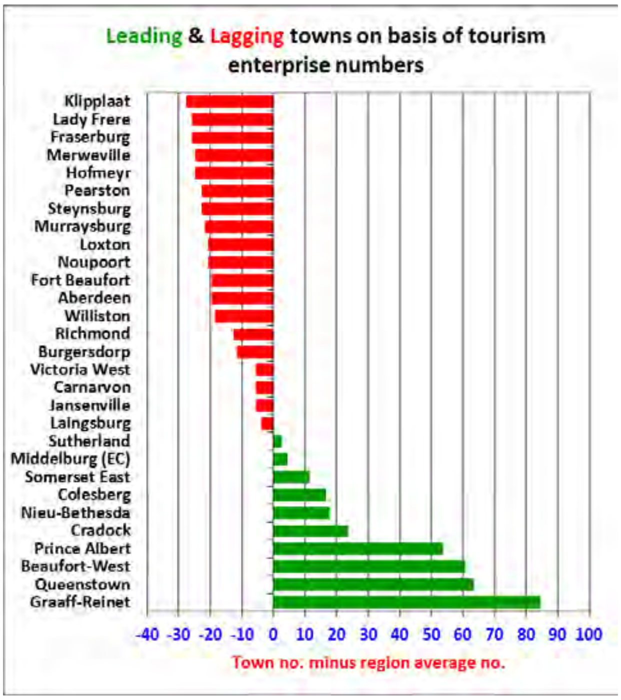

Figure B9.1 Leading (green bars) and lagging (red bars) towns in the study area in terms of number of tourism enterprises. Regional average is total number of tourism enterprises divided by number of towns.

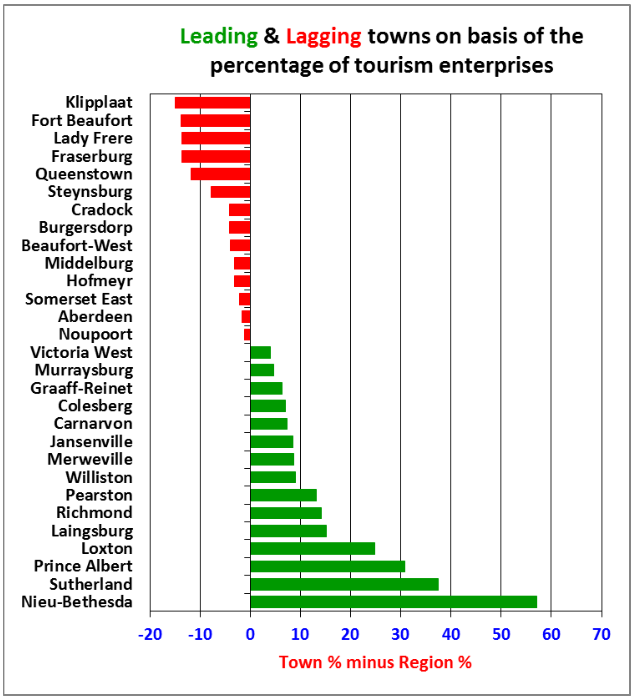

Figure B9.2 Leading (green bars) and lagging (red bars) towns in the study area based on their relative % of tourism enterprises. Regional % is total number of tourism enterprises in the study area divided by total number of enterprises and expressed as %.

Despite being fairly small towns, Prince Albert, Nieu-Bethesda and Sutherland are leaders as far as the numbers of tourism enterprises are concerned (Figure B9.1), as well as the relative strength (percentage of total enterprises) of their tourism sectors (Figure B9.2). They are tourist destinations and are considered to have a very high sensitivity to negative impacts on their tourism sectors.

Colesberg is a leader in terms of tourism enterprise numbers as well as the strength of its tourism sector (Figures B9.1 and B9.2). This town also benefits from its position as a stopover for travellers on the N1. It is expected to have a very high sensitivity.

A number of towns (Loxton, Laingsburg, Richmond, Pearston, Williston, Merweville, Jansenville, Carnarvon, Murraysburg and Victoria West) are leaders as far as the strengths of their tourism sectors (percentage tourism enterprises) are concerned (Figure B9.2) but lag in the number of tourism enterprises (Figure B9.1). Laingsburg, Richmond and Victoria West are located on national roads with lots of traffic and benefit from that. The rest of these towns are probably benefitting from niche tourism (including hunting), but being small, they have not been able to expand their tourism sectors to the extent that Prince Albert, Nieu-Bethesda and Sutherland have been able to do. The sensitivity to negative impacts on the tourism sectors of these towns is judged to be high.

A number of towns (Noupoort, Aberdeen, Hofmeyr, Burgersdorp, Steynsburg, Fraserburg, Lady Frere, Fort Beaufort, Klipplaat) are laggards in terms of number of tourism enterprises (Figure B9.1) and in tourism sector strength (percentage tourism enterprises) (Figure B9.2). They are judged to have a medium sensitivity to negative impacts on their tourism sectors.

Geographic representation of sensitivities

The information in this analysis was used to develop a geographic representation of tourism sensitivities in the study area. The map of the sensitivities is presented in Figure 9.9 of this assessment (Toerien et al., 2016).

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CHAPTER 10

Impacts on the Economy

CHAPTER 10:
IMPACTS ON THE ECONOMY

Integrating Author:	Hugo Van Zyl[1]
Contributing Authors:	Saliem Fakir[2], Tony Leiman[3], Barry Standish[4],
Corresponding Authors:	James Kinghorn[1]

[1] Independent Economic Researchers, Cape Town, 8001

[2] Worldwide Fund for Nature (WWF) South Africa, Cape Town, 7700

[3] School of Economics, University of Cape Town (UCT), Rondebosch, 7701

[4] Stratecon Consulting, Sun Valley, 7985

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Executive Summary

Shale gas development (SGD) has the potential to yield highly significant economic opportunities, but also bears risks engendered by the extractive nature of SGD. In both respects it parallels other divisions of the mining sector.

Previous South African research into the macro-economic opportunities associated with SGD reveals little agreement on likely benefits, their extent, or the appropriate mechanisms for their measurement. Despite this ambiguity and uncertainty, certain aspects are clear. Highly positive impacts on the balance of payments can be expected from SGD irrespective of whether they come in the form of import substitution alone or combined import substitution and export growth. If the large scale production scenario (Big Gas) is assumed, gas revenue could be equivalent to between 8% and 16% of the current account deficit thereby making a potentially substantial contribution to deficit alleviation. This has the potential to precipitate exchange rate appreciation. It is not, however, possible at this stage to predict the likelihood of such an appreciation or whether it would have potentially damaging effects on other sectors[1].

The achievement of long term macro-economic benefits will necessarily depend on the uses to which the proceeds of shale gas, especially those accruing to Government, are put. More specifically, recent government expenditure allocation patterns in South Africa show an upward trend in recurrent consumption expenditure such as that on salaries and arguably too little capital expenditure more clearly directed at boosting longer term growth potential. Concerted efforts will need to be directed at ensuring that that the lion's share of shale proceeds accruing to government are used to enhance the long term prospects of the country.

Ex-post assessments of the local and regional impacts of SGD on jobs and incomes indicate that impacts can be substantial though they seem often to have been over-stated by earlier predictive assessments, especially those that applied questionable static models. It is likely that the jobs suiting the average unemployed resident of the study area would be restricted to unskilled and semi-skilled positions. However, local participation could increase as the industry matures and local skills levels rise. It is estimated that the Big Gas scenario would eventually require roughly 2 275 operational staff for drilling and transport and 300 to operate the power plants. If study area residents are assumed able to initially fill 15% to 35% of positions, this would translate into between 390 and 900 direct jobs to locals. It should not be assumed that indirect and induced impacts in terms of jobs within the region would reach the same level as direct impacts. Over time, however, a vibrant local industry could

[1] These effects could be associated with so-called 'Dutch Disease' which refers to a situation in which businesses either cannot compete with imports or are squeezed out of export markets as a result of the appreciation of their home currency.

emerge representing a potentially substantial opportunity – this would be dependent on factors such as the willingness of industry players to foster local enterprise development, entrepreneurial responses and the formation of clusters that expand value-chains. Purchasing processes, hiring and training of staff and local socio-economic development initiatives/projects should act as a departure points to ensure that economic benefits to local communities are maximised. Measures could, for example, borrow from enhanced Social and Labour Plan (SLP) requirements which apply to the mining industry and the Independent Power Producers (IPP) Procurement Programme which are arguably superior to SLP requirements in some respects.

The risk that gas based development will ‘crowd out’ other sectors in the study area by causing rises in interest rates is regarded as zero, crowding out through increases in the prices of labour and other inputs, is generally considered low. Although it has also mostly been found to be low in the United States, the reasons were different. One exception is water, a resource in short supply in the Karoo. An important proviso is therefore that SGD does not seriously compete with local water users, or pollute local supplies. Note that movements in relative prices of business inputs are characteristic of a market economy and not necessarily indicative of market failures requiring intervention. The possibility of physical externalities, in which SGD imposes technical or physical costs on others, is a more serious problem. The assessment of such external costs, and recommendations for their mitigation, are the primary responsibility of the other specialist studies forming this scientific assessment. This study does, however, discuss their implications for the finances of public bodies and land owners.

Unless carefully managed, the externalities associated with SGD could impose significant budgetary strain on local authorities and public finances in general. Three key challenges are likely to emerge in this regard for municipalities in SGD areas: 1) not to overspend and be burdened with stranded infrastructure; 2) to smooth out their revenue streams through boom and bust cycles; and 3) to ensure financial sustainability after SGD activity ceases. In contrast to the United States, where significant local and state-wide revenue raising and retention are possible, South African local, regional and provincial authorities are constrained in both of these respects. It is thus likely that municipalities will face significant stresses as SGD expands particularly under the Big Gas scenario. These should include accessing additional human and financial resources to accommodate for environmental and other approvals and management, dealing with strain or damages to roads and other services such as water provision and sewerage services and addressing the long-term externality problems associated with abandoned or decommissioned wells.

In the event of the Big Gas scenario, impacted local authorities will have to estimate additional budgetary needs and be able access or generate funding to meet them. This will require the consideration of a number of measures. Additional staff, possibly from other municipalities and even secondments from other countries that have extensive shale gas experience, should be considered.

Dealing with road damage, for example, will require municipalities to consider special policies and measures such as a levy or bond for road haulage. National government will also need to be particularly responsive to legitimate municipal financial needs. It will be critically important that tax-payers are not burdened with the potentially highly significant rehabilitation costs after the abandonment or decommissioning of wells. In the South African mining industry, there has been some progress in this regard for currently operational mines. However, in common with experiences in other countries, substantially more needs to be done prompting the strengthening of the regulations governing financial provisions for mine rehabilitation and closure in 2015. These regulations should act as a key departure point, alongside experiences from countries where hydraulic fracturing ("fracking") occurs, when crafting and implementing regulations for well abandonment or decommissioned.

Risks to property values in drilling areas are likely to vary significantly depending on factors such as drilling locations and trucking routes in relation to sensitive receptors. The evolution of the existing stigma associated with fracking will also play a key role. It is likely that property values in towns within SGD regions would increase on balance despite negative externalities. This would be in keeping with increased commercial activity and should endure to the extent that SGD activities continue. The application of mitigation measures outlined in the other studies forming part of the scientific assessment such as those focused on visual, noise and water impacts should also reduce risks to property values. There are, however, likely to be externalities that cannot be avoided requiring compensation payments to land owners. Compensation principles to be applied and, to the degree possible, fair minimum amounts or conventions/formulas for establishing compensation will need to be determined in consultation with land owners if they are to be protected from bearing costs and to ensure that they have a stake in the process. It is important to bear in mind that, aside from ensuring the fair treatment of land owners, compensation which goes beyond what is strictly required by law should also play an important role in facilitating the development of SGD. Interactions with land owners would be less likely to be acrimonious, reaching agreement would take less time and turning to the law to force land owners to grant access to their land is less likely to be necessary.

As in the case of other extractive industries, setting regulation for SGD through laws, policies and other guidelines is likely to be more straightforward when compared with implementing them successfully. Past and present environmental and associated socio-economic impacts from mining in South Africa are instructive in this regard. The industry remains a key driver of beneficial economic development and yet, if one considers the Mpumalanga coal fields among other examples, it is evident that the benefits of mining could be achieved at a substantially lower cost to the environment and society. This will be the challenge associated with the regulation of SGD and one that is unlikely to be addressed using a business-as-usual approach.

CHAPTER 10: IMPACTS ON THE ECONOMY

10.1 Introduction and scope

International evidence (albeit much of this is from the United States (US)), a high-income economy and one where mineral rights do not belong to the state) indicates that shale gas development (SGD), like other mining related activities, offers both economic opportunities and risks. The production process could result in significant value addition and injections of expenditure, both of which could increase commercial activity, employment opportunities and income. Positive outcomes in this regard could also flow from the beneficiation of the gas-to-power (GTP) plants, gas-to-liquids (GTL) plants and other applications. These would enhance energy security and decrease imports. The risks stem from negative externalities. Prominent among these are competition for, and impacts on, scarce water resource in the semi-arid Karoo (Hobbs et al., 2016), and possibilities of land degradation (Hollness et al., 2016), visual impacts (Oberholzer et al., 2016), increased noise levels (Wade et al., 2016), air quality impacts (Winkler et al., 2016) and social ills (Atkinson et al., 2016) - particularly in the small relatively isolated communities that characterise the area. These risks would impact on land owners, residents and municipalities and are likely to be more concentrated at a local scale when compared to benefits. From a sectoral perspective, the two economic activities most reliant on natural resources and most clearly at risk are agriculture, the dominant sector in the area, and tourism which continues to grow in importance. This assessment responds to the need for a strategic consideration of the aforementioned economic impacts. Its focus and content is guided by the particular needs of the scientific assessment in combination with the other specialist input to it.

Clarifying the scope of the scientific assessment is particularly important given its strategic nature, time and resource limitations and the potential for overlap with other specialist inputs. The following needs to be borne in mind here:

- The scientific assessment has been carried out at a strategic level and relies on existing information[2]. It does not, therefore, gather primary data nor does it attempt to undertake any economic modelling.
- The scenarios assessed by all specialists contributing to the scientific assessment essentially *assume* that financially viable production <u>*can*</u> be achieved. Consequently, the question of viability becomes somewhat moot within the scientific assessment. It is nevertheless important to recognise the key factors that will ultimately determine viability aside from size, quality and depth of any finds. They are explored in detail by Fakir (2015: 6) and include: 1)

[2] To the degree possible, this information has been validated or reality-checked and preference has been given to peer reviewed sources where choices between sources were present.

the rate of technology learning and efficiencies[3], 2) knowledge and understanding of the geology, 3) market demand and a high enough price for gas and other incentives, 4) the timing and scaling of drilling intensity, and 5) the cost of mitigating the externalities for both the short and long-term. The availability of general economic infrastructure such as roads and gas-to-market infrastructure are also key.

- The primary focus or end-point is the identification of management and mitigation measures including measures for the enhancement of opportunities. Assessment of impacts is therefore limited to that which is required to understand impacts at a strategic level and identify such measures which may be developed further in an overall Strategic Environmental Assessment (SEA) of the opportunities and risks of SGD.
- The scientific assessment management team holds primary responsibility for the overall integration of all specialist findings and ensuring that all risk and opportunities are appropriately and holistically addressed. This study therefore limits itself to drawing on selected other specialist studies in order to understand key externalities and risks. The assessment does not, however, necessarily assess or quantify these risks further from an economic point of view and explicitly avoids overall integration through, for example, a cost-benefit or multi criteria analysis. Note that the lack of basic information such as the size of the gas resource also means that a cost-benefit analysis would be premature.
- Comparisons between alternative energy sources are not made in this study. The effects of SGD on national energy planning and energy security are, however, assessed in Wright et al. (2016).
- The assessment of environmental risks and externalities are the primary focus of the other specialist studies forming part of the scientific assessment. This dictates that less emphasis is placed on these risks in this study. It does not in any way imply that they are somehow less important from an economic perspective.

Taking into account the above clarifications of scope into account, the following overall impact categories were chosen for assessment recognising that the lines are often blurred between these impacts:

- Macro-economic impacts;
- Local and regional impacts from project ownership and spending;
- Impacts on municipal and public finances; and
- Impacts on property values.

[3] This includes technology learning and efficiencies and the timing and scaling of drilling intensity in terms of capabilities.

It is important to recognise that agriculture and tourism are the key economic sectors in the study area that are likely to face increased risks from SGD. Given the potential seriousness of these risks, separate specialist studies where commissioned focusing specifically on impacts on agriculture and on tourism including their socio-economic implications. This obviated the need to address these impacts in this report bearing in mind that the findings of the specialist studies will be integrated into the overall scientific assessment thereby ensuring that risk are considered.

10.2 Key potential impacts and their mitigation

The following sections address the impacts identified for assessment starting with macro-economic impacts. Each new impact section starts with a description of impacts followed by an assessment impacts and recommendations for mitigation and benefit enhancement measures. Risk and opportunity ratings are provided for impacts in Section 10.3.

10.2.1 Macro-economic impacts

10.2.1.1 Description of impacts

SGD offers both macro-economic opportunities and risks. Opportunities lie in the potential for a significant boost to the economy. This would be felt as increases in real Gross Domestic Product (GDP), in jobs, household incomes and tax revenues, and in a net foreign exchange inflow potentially relieving stresses like those recently borne by the balance of payments. The increase in GDP would be brought about by two factors. The first is the short term impact of increased expenditure – i.e. monies spent on opening up and operating the shale operations – capital and operational expenditure. The greater the proportion of these being spent on locally produced goods and services, the greater the impact on GDP. Second are the longer term structural changes in the economy that might ensue from a burgeoning gas beneficiation sector. These would largely be determined by the linkage effects of the gas sector, i.e. the extent to which shale gas provides upstream and downstream economic opportunities.

A subset of these benefits is that there would also be direct increases in government revenues. These would accrue directly from royalty payments, on the one hand, and indirectly from increased tax payments. These increased tax payments would come from shale operators, firms operating upstream and downstream of the shale industry, and indirect tax increases as a result of the multiplier effects.

The key macro-economic risks identified are as follows:

- The first is that government commits too much expenditure against the expected reserves and expected increases in government revenues. Avoiding this will require careful evaluation of expenditure and other forms of support to the SGD sector through, for example, cost-benefit and risk analyses and associated planning at various stages.
- The potential that the macro-economic benefits of SGD are overstated, even by the critics, creates risks. These estimates should form an important part of overall government decision-making processes.
- There is a further risk that the expenditure could be wasteful and that the long-term cumulative proceeds from SGD would not be put to their best productive uses. The consequence could be that even if short-term benefits outweigh costs, this may be reversed over the longer-term. The achievement of long term macro-economic benefits would depend on how the proceeds of shale gas were put to use, particularly those proceeds accruing to government.
- Improvements in the balance of payments can cause a currency appreciation. Such a currency appreciation may be benign, e.g. lowering the cost of imported capital goods. However, it could be problematic if it resulted in the so-called 'Dutch Disease' (see box for explanation) in which businesses either cannot compete with imports or are squeezed out of export markets as a result of Rand strength. An assessment of likely changes in the real exchange rate is needed to draw any concrete conclusions.

'Dutch Disease' Simplified: The term 'Dutch Disease' describes impacts similar to those suffered by the Dutch manufacturing sector following the discovery of North Sea gas. The extraction of gas caused an appreciation of the (then) Dutch currency, the Guilder. This resulted in a loss of competitiveness of traditional Dutch exports while making imports appear more attractive.

10.2.1.2 Assessment of impacts per scenario

Assessment in this section focuses on the potential for the macro-economic opportunities and risks outlined above.

10.2.1.2.1 Opportunities

Previous research in South Africa has focused on the estimation of macro-economic opportunities or benefits (see Econometrix, 2012; Wait and Rossouw, 2014; McKinsey Global Institute, 2015). Unfortunately, little agreement is evident with respect to likely benefits or even an appropriate approach for their measurement. Wait and Rossouw (2014) relied heavily on a dynamic computable general equilibrium (CGE) model and are critical of Econometrix (2012) who employed a more static modelling approach[4]. They point out the key benefits of dynamic modelling, primarily referring to its ability to better take into account how economies adjust through the action of prices and markets which static models tend to treat as (unrealistically) fixed. A similar static approach seems to have been used by the McKinsey Global Institute (2015) although limited details on approach are provided[5]. Table 10.1 below provides a comparison of the results of these studies focused on employment and GDP. Significant differences are evident with respect to both indicators even where similar production volumes are assumed. These are clearly the consequence of the different assumptions and approaches followed. It is beyond the ambit of this assessment to conduct an in-depth analysis of such differences.

Table 10.1: Summary of national employment and GDP results from previous research on SGD in South Africa.

	Econometrix (2012)		**Wait and Rossouw (2014)**				**McKinsey Global Institute (2015)**	
Total size of resource in trillion cubic feet (tcf)	20	50	20	50	20	50	Focuses on production per year	
Timeframe	by 2035	by 2035	2-3 yrs	2-3 yrs	>10 yrs	>10 yrs	by 2035	by 2035
Potential life of resource (years)	25	25	25	25	25	25	Not given	
Ave production per year (tcf/yr)	0.8	2	0.8	2	0.8	2	0.3	0.7
Contribution to annual GDP (%)	3.3	9.6	3.5	6.9	4.4	10.4	Not given	
Contribution to annual GDP (Rbn)	35	90	26	52	32	77	up to 138	251
Potential permanent employment	300 000	700 000	1 441	2 471	Not provided – assumed exogenous to model		44 000	102 000 - 328 000

Macro-economic impact findings from the US are also instructive. On the whole, these studies found highly significant benefits in absolute terms and less so in relative terms when placed with the context of the large US economy. Hausman and Kellogg (2015) examined the impact of SGD on consumer and producer welfare and estimated that it resulted in an overall boost equal to 0.33% of US GDP[6]. Feyrer et al. (2015) focused on employment and found that 725 000 jobs were associated with new gas and oil extraction between 2005 and 2012. This translates to a 0.5% lowering of aggregate unemployment in the US over the period if one makes the arguably strong assumption of zero displacement from other employment (i.e. assuming that all the jobs created in the sectors were new jobs). Spencer et al. (2014) estimated that unconventional gas and oil added 0.88% to US GDP from

[4] The Econometrix (2012) approach is also criticised by De Wit (2013) and Fakir (2012).
[5] See Section 10.2.2.1.2.1 for further discussion of the limitations of static models such as Input-Output models when applied at a regional or local scale.
[6] This assessment drew on a similar albeit less detailed assessment by Mason et al. (2014) which found qualitatively relatively similar impacts.

2007/8 to 2012 and will add about 0.84% to US GDP over the longer-term between 2012 and 2035. Houser and Mohan (2014) focused on the gas and oil sector as a whole predicting that it would add between 0.6% (conservative) and 2.1% (optimistic) per annum to US GDP between 2013 and 2020 thereafter decreasing to a contribution of between 0.4% and 1.0% of GDP between 2021 and 2035.

When considering the above results it must be borne in mind that the oil and gas sector in the US is well established and integrated into the rest of the economy allowing for greater benefits. Gas usage for residential and industrial purposes is also widespread. Despite the unique contextual and structural variations that prevent a strict replication, some scholars argue that the shale gas experience in the US is clearly still valuable as a source of policy making and learning for other countries (see Nülle, 2015 and Lozano Maya, 2013). Positive impacts on the balance of payments should be expected for three reasons:

- The opportunity for increased coal exports (to the degree that gas replaces coal in power generation) and lower oil imports (to the degree that gas replaces oil as a feedstock for fuel production in the large scale gas production scenario)[7];
- Gas production levels in excess of the production and use scenarios assumptions of the scientific assessment could allow for exports; and
- The likelihood of foreign capital inflows both in the form of foreign direct investment (into shale) and foreign portfolio investment (into associated equity and bonds).

Balance of payment impacts will occur irrespective of whether they come in the form of only import substitution or import substitution and export growth. A basic calculation was done to determine the potential magnitude of the revenue that could be generated directly from the shale gas[8]. The estimate excludes potential imports of capital equipment during construction and small imports for maintenance. The value of these imports is currently not known. Given the wide range of estimates of potential gas revenues it is not clear that this is a material omission.

For the small scale production scenario (Small Gas), the value of revenue/turnover could reach between R 3.5 billion and R 7 billion per year increasing to between R 14 billion and R 28 billion per year if Scenario 3 (Big Gas) materialises. To put these values in perspective the annual current account deficit for 2015 was R 174 billion[9]. Total gas revenue could thus meet between 8% and 16%

[7] Note that one should not necessarily assume that all of the ‘excess’ coal no longer needed for energy generation would readily find foreign buyers particularly if the ‘Big Gas’ scenario (and associated power generation from gas) is exceeded. Lower grades of higher sulphur thermal coal are probably least likely to be exported.
[8] Calculation used annual production (total production volume per scenario smooth over 60 years) multiplied by a gas price range of between $3 and $6 per MMBtu and Rand/Dollar exchange rate of 14:1.
[9] https://www.resbank.co.za/Research/Statistics/Pages/OnlineDownloadFacility.aspx

of the current account deficit for the Big Gas scenario. Note that these estimates are highly approximate and ignore all upstream and downstream changes, induced effects, structural changes, offsetting effects of machinery imports, etc. Nevertheless, one can conclude that SGD should make a substantial contribution to alleviating the current account deficit especially for the Big Gas scenario. Gas finds that exceed this scenario would only increase this significance. It is debatable but can be argued that the bulk of the revenue from gas would offset imports (oil, for example) or allow those fuels currently produced domestically to be exported (coal, for example).

10.2.1.2.2 Risks

10.2.1.2.2.1 Overstated Benefits

The conflicting results from other South African studies on the benefits of SGD outlined above raise concerns of creating unhelpful confusion and of possible overstatement. A study and/or transparent fact-based expert process focused on achieving the highest possible degree of neutrality would probably be needed before clarity emerges on this issue. Data on the extent of the resource does limit the accuracy of the macro-economic analysis. However, it is preferable to make some macro-economic estimates before the fact recognising the limitations of such estimates. These should then be repeated, to more carefully inform policy, as the extent of the resource becomes know.

10.2.1.2.2.2 Risks linked to the use of proceeds

Government can use the taxes (and other benefits such as royalties and any government free carried interest/stake in new oil and gas ventures which is being considered) for either consumption expenditure or capital expenditure. Consumption expenditure, a large portion of which is for the payment public servants, helps in the running of government but make a more limited contribution to long term growth in the economy. Capital expenditure on items such as roads, harbours and communication networks result in a more immediate impetus to economic growth. There is clearly also a need for growth in human capital through, for example, expenditure on education and health. This type of expenditure is made up of both consumption and capital expenditure. Education, for example, needs teachers – a form of consumption expenditure – as well as equipment such as computers and laboratories.

Recent government expenditure allocation patterns in South Africa show an upward trend in consumption expenditure and arguably too little capital expenditure directed at boosting longer term growth potential[10]. If this trend remains in place, or even accelerates, it will become less likely that

[10] As a proportion of GDP, government consumption expenditure grew from just over 19% in 2007 to over 22% in 2013. In 2014, the latest available year, this declined slightly to just over 20%. In general South African

lasting benefits from SGD would be realised. Concerted efforts will need to be directed at ensuring that that the lion's share of shale proceeds accruing to government are used to enhance the long-term prospects of the country. Without these, long-term costs are likely to exceed long-term benefits even if net benefits are experienced in the short-term.

10.2.1.2.2.3 Balance of payments risks

The magnitude of the beneficial impact on the balance of payment discussed above indicates that there is the potential for some exchange rate impacts. At this stage it cannot be known whether this would result in Dutch Disease. There may also be cumulative effects (i.e. SGD alone may not cause Dutch Disease, but could contribute to risks in combination with exchange rate effects from existing resource exports). Further research is needed on the likely changes in the real exchange rate and its associated impacts. This can be undertaken as needed if exploration confirms the existence of a significant recoverable gas resource. It must be stressed that presently the impacts are uncertain. A stronger Rand could also benefit the economy by making imported capital goods more affordable, and would promote the non-tradable segment of the economy (local services, etc.) ahead of the traditional tradable sectors such as mineral exports. By facilitating the import of capital equipment it might also encourage local value addition to primary products.

10.2.1.3 Options for mitigation or benefit enhancement

The dual objectives of mitigation should be the maximisation of macro-economic benefits and the minimisation of risks. Much will depend on macro-economic policy and management discussed below. Based on their review of the literature, Corrigan and Murtazashvili (2015: 1) note that, for example, the resource curse is not inevitable and that "political features of the economy, in particular the quality of governance, determine the extent resource wealth is a blessing rather than a curse." The critical importance of governance is also clearly not limited to dealing with resource curse risks - it applies equally to all aspects of SGD if it is to proceed sustainably (see, for example, APERC, 2015).

In the short-term the use South African firms and labour should be encouraged where possible and include training programmes. Consideration could be given to some form of local content requirements bearing in mind the potential costs of such requirements. It is anticipated that the Department of Trade and Industry (DTI) along with the Department of Energy (DoE) and National Treasury would take the lead in this process. Indeed, the Industrial Policy Action Plan (IPAP) 2015/16 – 2017/18 proposes a Long Term Strategic Framework to leverage the opportunities presented by

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government consumption expenditure has grown consistently since the 1970s. (source data: http://www.tradingeconomics.com/south-africa/general-government-final-consumption-expenditure-percent-of-gdp-wb-data.html) petroleum and gas resources. Among other aspects, it notes that such a strategy would need to consider the way in which forward and backward linkages can be developed along the value chain assisted by investment and skills development. These measures are seen as a way “to demonstrate a serious commitment to avoiding the characteristic policy and regulatory errors that have given rise to the idea of the ‘resource curse’” (DTI, 2015: 123). The DTI has also recently announced that it will be establishing a unit to manage gas industrialisation that intends replicating the success of the Independent Power Producers (IPP) programme unit in the DoE (Mathews, 2016).

The only available mitigation measure to address the issue of the potential for overstated benefits is to commission an independent study, probably conducted by a small panel of acknowledged independent experts, to comprehensively assess the macro-economic benefits that could arise from SGD. Such an exercise could be repeated after some degree of activity to either prove or disprove the resource (i.e. through seismic exploration only) and once the size of the resources is known.

The minimisation of long-term risks is highly dependent on political decisions about the use of increased tax and other revenues originating from SGD. Ideally these need to be directed to maximising the growth potential of the economy. Here there are two overarching options to consider. The first would be some form or tacit arrangement in which government income from shale is directed to growth enhancing investments. It is not clear that this is a realistic option particularly as such an arrangement does not currently exist for other extractive industries such as mining. There does not appear to be any enforcement mechanism other than political will. The second would be based on the same principle just with the formal earmarking or ring fencing of tax and other shale revenues for specific types of expenditure. This could be in the form of a dedicated fund. National Treasury does not endorse ring fencing in principle making this an unlikely outcome. Note that sovereign wealth funds have been used for similar purposes. However, such funds tend to only be considered when countries experience current account surpluses; such surpluses are not predicted as outcomes of the shale production scenarios. In any event, such a fund would require additional political acceptance of the need to defer expenditure into the future in the face of pressing immediate socio-economic needs.

It would be worth exploring the establishment of an offshore sovereign wealth fund or similar should balance of payments risks emerge for the Big Gas scenario. Capital outflows to such a fund could offset the foreign exchange inflows thereby stabilising the exchange rate. This option would face the constraints discussed above. Another option would be to empower existing industry to counter the unintended short term consequences of a currency appreciation. This would be costly, not really address the challenge (i.e. currency appreciation) directly and does not seem realistically achievable given the co-ordination required.

10.2.2 Local and regional impacts from project ownership and spending

10.2.2.1 Description of the impact

SGD would influence local and regional commercial activity depending on its scale and pace both of which would be dictated by market conditions. The key driver in this regard would be the magnitude and distribution of ownership (through, for example, shareholdings) and spending injections associated with these activities that would impact on jobs, incomes and associated business opportunities. Experiences abroad are illuminating in this respect; the following section therefore reviews these. This review, with selected data on the process anticipated for the Karoo, provides the basis for a scientific assessment of SGD scenarios.

10.2.2.1.1 Review of the literature on spending related impacts

Assessments of spending related impacts can be divided into those that attempt to predict impacts (*ex-ante* assessments) using techniques such as Input-Output (I-O) modelling, and those that focus on measuring impacts after the fact (*ex-post* assessments). There are also review studies that critique *ex-ante* assessments. These typically identify inappropriate models and/or overstatements of expected benefits particularly in terms of indirect and induced job creation (assessed using the actual impacts obtained by *ex-post* surveys).

10.2.2.1.2 Predictive or ex-ante assessments

The only South African study which provides a partial quantification of the impact of SGD at a regional scale in the Karoo is Toerien (2015). This study argues that several economic variables are closely related at the town level in the Karoo, namely Gross Value Added (GVA), population size, personal income, total enterprise numbers, and enterprise richness. It uses the premise that these variables have predictive power and if one can anticipate changes in one, the resulting changes to others can be forecast. Using these relationships, and only looking at the impact of worker spending, Toerien (2015) estimates the partial impact of SGD on any given Karoo town. The study assumes that each municipality will have 30 drilling rigs operating, each with 50 workers, for a period of one year. It hypothesises that if each worker spends R300 per day, the resultant injection to the local economy would amount to R 162 million per annum. It infers that this injection would result in a total population increase of approximately 4 300 persons, which should in turn stimulate the creation of between 37 and 41 new enterprises (Toerien, 2015). The number of workers or jobs created among these in-migrants is not estimated.

Industry-sponsored research particularly in the US has relied heavily on the use of multipliers generated from static Input-Output (I-O) models in order to estimate indirect and induced economic impacts. Key results from assessments of this sort include the following:

- In 2008 the Centre for Business and Economic Research (CBER) at the University of Arkansas estimated direct employment was between 4 498 and 4 813 people in the period 2008-2012 for the Fayetteville shale. Regional I-O modelling suggested between 6 769 and 7 722 indirect and induced jobs over the period (an employment multiplier in the region of 1.5 to 1.6).
- Mersich (2013) assessed impacts on Quebec, Canada using two production scenarios (i.e. ~0.18 tcf/yr and ~0.55 tcf/yr). He suggested that $ 7.9 billion to $ 23.8 of direct spending on SGD would yield a total economic impact of $ 37.3 billion to $ 112 billion between 2012 and 2036, implying an expenditure multiplier of 4.7 with 293 000 to 880 000 person years of employment in the same period.
- Considine et al. (2010) assessed the impacts of the Marcellus shale play using the IMPLAN regional I-O model[11]. They predicted that during 2010 (1 743 wells producing 0.37 tcf) and 2011 (2 211 wells producing 0.73 tcf) shale gas would contribute roughly $18.2 billion to Pennsylvania's state GVA.
- Scott (2009) estimated that the seven major shale firms of the Haynesville play spent $ 4.5 billion in 2008 in the economy of Louisiana, 71% of which was on lease and royalty payments. He argued that this spending generated $ 3.9 billion in household earnings and $ 2.4 billion in new business sales within the state. Although the major firms had only 431 direct employees and contract workers, Scott (2009) predicted that they induced 32 742 new jobs in the state (implying an employment multiplier of 76 which is exceeding high particularly in relation to the findings of others).
- Regeneris Consulting (2011) used I-O to assess impacts in Lancashire and the United Kingdom. They concluded that every Pound spent on development, would yield an additional GBP of 0.70 in indirect and induced impacts. Their base case was for 400 wells to be drilled over seven years, leading to peak employment levels of 5 600 full-time equivalent jobs for the UK (of which 1,700 would be in Lancashire) (Regeneris, 2011).
- Wobbekind, et al. (2014) assessed the economic impacts of oil and gas activity in Colorado between 2008 and 2012. They found that the economic contributions of the upstream and midstream oil and gas industry totalled $126.5 billion and that 61 633 direct jobs supported an additional 31 895 indirect and induced jobs, implying a job multiplier of 1.5.

[11] Shale gas is found in shale "plays," which are shale formations containing significant accumulations of natural gas and which share similar geologic and geographic properties (source: http://geology.com/energy/shale-gas/).

- The Perryman Group (2014) used an internally developed I-O model to assess the impacts of oil and gas production in the Barnett Shale on the Texan economy since 2001. According to the authors, the Barnett Shale produced over 15 tcf of natural gas between 2001 and 2014. The average annual gross geographic product they attributed to the Barnett Shale was $ 11.8 billion which they said contributed 107 650 permanent jobs since 2001 (Perryman, 2014). The direct component of this impact, along with multiplier estimates, was not reported.

10.2.2.1.2.1 Critiques of Input-Output based assessments

Critics of I-O based studies have questioned both their appropriateness and their assumptions (e.g., Kinnaman, 2011; Barth, 2013; Christopherson and Rightor, 2011; Kay, 2011; Weinstein, 2014).

I-O models are static in nature and use fixed coefficients and prices to represent links between industries making up the economy. The most serious constraint associated with their static nature is that they explicitly exclude the ability of the economy to adjust through the price mechanism. This implies a highly significant (many would say unacceptable) failure to account for the role of prices as the key dynamic adjustment mechanism in economies.

I-O models are also based on historic economic data (and therefore historic industrial structures). This reliance of historical correlations makes them particularly unsuited to the assessment of an entirely new industry, especially if it is a large one. In this vein, Barth (2013) argues that they are not suited to the assessment of the introduction of SGD as the linkages and flows between it and other industries are likely to change, sometimes substantially (Barth, 2013).

I-O models have also been criticised for double counting, which gives them a built-in tendency to overstate impacts: *"If an economist ran an IMPLAN model on every industry, the direct spending of each industry would be multiplied to estimate the effects on the economy. But as every industry claims responsibility for jobs and revenues in other industries that supply the industry, IMPLAN would estimate more economic activity than actually occurs… Therefore, all impact statements based on input–output models such as IMPLAN are likely overstated"* Kinnaman (2011: 1247).

Much less problematic in the local economy, is Kinnaman's (2011) critique that I-O models are not equipped to predict economic outcomes in situations where the economy is near full employment. They essentially assume that there are no supply constraints within the economy (Barth, 2013), and that a stimulation of a particular industry will bring idle labour and capital into production. There are places where this may be more applicable. In others it is more likely that capital and labour need to be diverted from their current uses or brought in from outside. A further significant weakness of I-O models is that they are unable to adjust for and deal adequately with economies that have underemployed resources. This is a serious issue in South Africa, whose economy currently has much slack capacity. The implication is that little new employment might eventuate through the multiplier process.

Any assessment of economic outcomes will depend on assumptions of gas production, location and timing of expenditure. These can all be problematic. Assuming that patterns of production in one area will follow those in another is almost certain to be incorrect, given variations in the geological, geographical and economic environments (Barth, 2013). Undue optimism is also a concern; Berman (2010 in Kay, 2011) argues that evidence from the Barnett and Haynesville shales shows how the quantity and spatial scale of economically recoverable reserves were overestimated by both advocates and opponents of SGD. Overstatement of local economic impacts is also a risk in underdeveloped areas where few items are locally produced leading to overstated estimates of local spending capture (Kay, 2011; Kinnaman, 2011; Rousu et al., 2015). In the US a significant portion of local benefits has come from spending of lease and royalty incomes by land owners. Critics have pointed out that in many cases land owners in the US do not live in the states or even in the countries where their land is located (Kay, 2011; Hardy and Kelsey, 2015). In these cases, it is not clear that any of the payments that they receive are spent locally and over what period. Indeed, there is also much debate concerning the proportion of such payments that is actually spent on locally produced goods and services, and the proportions that are simply saved or used to pay off historic debts. Note that *land owner royalties would not be paid in South Africa* as mineral rights are state-owned. This does not, however, preclude the payment of compensation to land owners and others, an important issue which is discussed further in Section 10.2.4.

10.2.2.1.3 After the fact or ex – post assessments

Ex-post assessments typically assess positive impacts on employment, income and local taxes, but also such negatives as factor and product price rises leading to crowding out.

10.2.2.1.3.1 Impacts on employment and income

Brown's (2014) *ex-post* panel study for the Federal Reserve Bank of Kansas City investigated the economic effects of a 6.3 tcf increase in production of shale gas in 647 counties across nine states in the central USA between 2001 and 2011. Using two stage least squares regression, it contended that the increase in production was responsible for 49 000 new jobs in the counties concerned. Counties where production increased experienced an average increase in employment of 13%. For every billion cubic feet (BCF) of natural gas production, 12.7 jobs were created in total (12 700 jobs per tcf) with

7.3 of these being direct (indicating a job multiplier of around 1.7). Real average annual wages were found to have increased by $ 43 per BCF of production and population by 18 people per BCF.

Hardy and Kelsey (2015) conducted an *ex-post* analysis in selected Pennsylvania counties between 2007 and 2010, paying particular attention to residents' income. They suggest that SGD has had a substantial impact on residents' income, largely due to the effect of royalty and lease payments, but also to increased profits of locally owned businesses. Counties with 90 or more wells saw a 6% increase in total taxable income compared to an 8.1% average decline (presumably as a result of income being drawn away) in counties without wells and a 5% decrease for the state. These benefits were however relatively concentrated within the 8.8% of the population that are land owners and therefore receive royalties. In this regard the payment of all royalties and lease payments to the central fiscus could be crucial in determining the balance between local and national impacts in South Africa.

Paredes, et al. (2015) conducted an *ex-post* county level assessment of SGD impacts on income and employment in the Marcellus shale play, Pennsylvania. Using statistical matching and panel data techniques, the authors found strong evidence for SGD having a positive impact on employment between 2004 and 2011. Less evidence was found for SGD leading to improvements in direct incomes, and no statistically significant impact on indirect or induced incomes, possibly because in-migrating workers are likely to report their incomes in their home counties. The authors also warn that the employment effects are for the period examined, and do not imply that SGD will provide long term employment benefits.

In a peer reviewed study, Tunstall (2015) looked at the impacts of unconventional oil and gas activity in 14 counties located above the Eagle Ford shale play in South Texas. To isolate the effect of oil and gas production on per-capita income, 56 observations spread over four years were analysed using ordinary least squares. Production was measured in terms of the number of wells drilled in a county during a given year, and was found to have a direct, positive impact on per-capita income.

The Multi-State Research Collaborative is a group of research and policy organisations from around the US that monitor the socio-economic impacts of SGD. In 2014, the group produced case studies of SGD in Tioga County, Pennsylvania (Ward et al., 2014) and in Carrol County, Ohio (Woodrum, 2014). In 2012, Tioga County had 811 shale gas wells, while Carrol County had only 138. In both case studies, the authors conducted a series of interviews with local officials and experts, and also analysed secondary data. For Tioga County, Ward, et al. (2014) concluded that the data demonstrated an overall positive impact of SGD on employment and income, particularly as a result of increased receipts from higher rents, bonuses and royalties. Woodrum (2014) appeared less confident that the overall benefits to Carrol County had been significant, especially citing negative impacts such as strain on services, impacts on roads and increased crime voiced during engagements with stakeholders.

Weber (2012) used difference-in-difference analysis in a peer reviewed study to assess the impacts of SGD on employment and income between 1998/9 and 2007/8 in counties throughout Colorado, Texas and Wyoming. The average boom county saw a $ 757 million increase in the value of gas production over the period, compared to $ 10 million in non-boom counties. This generated modest increases in employment, wages, and median household incomes. Every million dollar increase in gas production appeared to provide 2.35 jobs. These *ex-post* results were five times less than those predicted by the CBER (2008) using I-O multipliers.

Weinstein (2014) conducted a wide ranging analysis of impacts from shale oil and gas development in 3060 US counties over the period 2001 to 2011. She found that, on average, shale boom counties experienced a 1.26% increase in employment while adjacent non-shale counties experienced a 0.43% increase. Furthermore, boom counties saw a 2.56% increase in earnings, while adjacent counties saw a 0.84% increase. The employment multiplier from oil and gas development was estimated at approximately 1.3 at a county level. The study also analysed employment dynamically. Incorporating a simple time trend into the model, it was found that employment in boom counties increases by an initial 3.3%, thereafter dropping off by 0.65% each year. While this may be evidence of crowding out of other sectors, it may simply be due to the life cycle of shale developments.

10.2.2.1.3.2 Risk of crowding out, boom and bust cycles

The natural resource curse is a catch-all phrase describing the negative impacts of expanding exploitation of natural resources. The mechanisms through which it operates has been described in various ways. Often labour costs are the key factor of interest particularly at a local level. By increasing the demand for labour, the growing (booming) extractive sector can put upward pressure on wages to the detriment of other sectors which are then ‘crowded out’.

While crowding out is certainly important a myriad of other processes interact to determine the implications of increased natural resource extraction. These are discussed by Christopherson and Rightor (2011), Weber (2012, 2014), Brown (2014), Weinstein (2014), Allcott and Keniston (2015) and Feyrer et al. (2015), who are unanimous in their view that crowding out is the primary determinant of the natural resource curse at a local and regional level.

Both Weber (2014) and Brown (2014) showed net positive impact on states and counties in which SGD occurred. Weber (2014) concluded that any crowding out was minimal, and that indeed each mining job had created at least one non-mining job. Weinstein (2014), however, argued that merely demonstrating short-term or even medium-term positive net impacts is insufficient to make the natural resource curse implausible; to do so one would need to show that an economy was left in an overall better position following a natural resource extraction cycle than in the counterfactual case without it. Her results from the US, that shale gas based gains in employment and wages become incrementally smaller over time, lead her to question its long term economic implications.

Allcott and Keniston (2015) analysed the employment and wage effects of SGD at a county level in the US and concluded that these effects tended to vary directly with manufacturing rather than crowding it out. They argue that, "… while Dutch Disease is theoretically possible and wages do rise, our results clearly reject the idea of Dutch Disease within the United States, except for within a more narrowly-defined subset of manufacturing plants." (Allcott and Keniston, 2015: 32). However, when they extend their analysis to the oil boom of the 1970s a greater degree of conservatism emerges. The economic distortions induced by an expanding mineral sector can be amplified by conditions in the labour market. Allcott and Keniston (2015) concluded that contractions in tradable sectors are likely to be worsened by inflexible labour markets. Similarly, though focussing specifically on labour migration, Brown (2014) suggests that the natural resource curse is more likely to occur where geographical labour mobility is restricted, while Christopherson and Rightor (2011) note the risks it poses to specific sectors, such as agriculture and tourism, require reliable low cost employees. Fleming and Measham (2015) also found some evidence, although it is statistically not strong, of crowding out of the agricultural sector for coal bed methane development in Australia. So while the literature does not generally appear to support the idea that crowding out is necessarily at work in SGD, there are good reasons for caution.

Previous work on the subject of managing the risk of crowding out advocates a focus on local labour markets and associated skills development (Christopherson and Rightor, 2011). Mitigation can also be closely aligned with measures to smooth boom and bust cycles and discourage gas production patterns driven by the prospect of short-term gains. Christopherson and Rightor (2011) emphasise that the likelihood of sustained gains increases if SGD occurs at a measured pace and at a manageable scale. This allows for better municipal and business planning along with skills development and environmental monitoring of key risks.

10.2.2.2 Assessment of impacts per scenario

10.2.2.2.1 Opportunities

In the absence of detailed information on the extent of shale gas, this analysis will be scenario based. Scenario 0 is the ‘Reference Case’ which simply maintains the local and regional economic status quo. Scenario 1 (Exploration Only) describes shale gas exploration alone. This commences with one year of seismic exploration followed by five to ten years of exploratory drilling. Small scale production (scenario 2, ‘Small Gas’) is based on a total recoverable resource of 5 tcf. This would entail the use of three drilling rigs in the region and the establishment of a 1 000 MW power plant. Large scale production (scenario 3, ‘Big Gas’) assumes a total recoverable resource 20 tcf resource with 20 drilling rigs in the region and the establishment of two 2 000 MW power plants. A GTL plant would also be established but probably at the coast; its impacts on the local and regional economies would therefore be limited.

While estimating the jobs created under each scenario is difficult, predicting the proportion of these accruing to the local unemployed is even more so, requiring a clear understanding of regional worker availability per skill level. The Karoo is an area in which skilled labour is relatively scarce. It is likely that the jobs suiting the average unemployed Karoo resident would be restricted to unskilled and semi-skilled positions such as truck drivers and maintenance workers. However, local participation could increase as the industry matures and local skills levels rise[12]. For the purposes of tentative estimation, we have assumed that initially between 15% and 35% of direct jobs would go to residents of the region[13].

The likely initial direct operational employment opportunities associated with the SGD scenarios are summarised in the Table 10.2 below[14]. Seismic exploration would require between 500 and 750 employees for one year, 20% of whom are likely to be from the region given the highly technical nature of the work. Note that this does not necessarily imply that the remaining jobs would be newly created at a national level. Some would go to foreigners and to those already employed within the firms pursuing SGD. Exploration drilling would then last for five to ten years during which time up to 520 employees may be required, 80 to 120 of whom should come from the region. Small scale production would build to 340 staff for drilling and trucking with an additional ~80 jobs in power plant operations by 2050. Initially between 60 and 145 of all these employees should come from the

[12] A similar pattern applies to, for example, the renewable energy industry.
[13] MSETC (2011) found that 70% - 80% of employees came from outside Pennsylvania in the early stages of the development of the Marcellus shale play with substantially less reliance on outside workers possible over time.
[14] Note that additional temporary jobs would also be created primarily through the construction of (mostly gravel) access roads, wellpads, pipelines and worker camps.

region. Large scale production would build to 2 275 staff for drilling and trucking with an additional 300 people being required to operate the power plants by 2050. Initially between 390 and 900 of all these operational employees could come from the region.

Table 10.2: Preliminary estimate of direct operational employment per SGD scenario.

	Seismic exploration	**Exploration and appraisal drilling**	**Small-scale production ('Small Gas')**	**Large-scale production ('Big Gas')**
Size or recoverable reserve (tcf)	N/A	1	5	20
Use of gas resource	N/A	Potential movable modular power plants (1-2 MW each)	One 1 000 MW combined cycle gas turbine (CCGT) power station in the study area	Two 2 000 MW CCGT power stations in the study area and a 65 000 bpd GTL plant at the coast
Duration of activity (years)	1	5 to 10	35 minimum	35 minimum
Number of rigs/areas	5	5	3	20
Jobs per rig/area	100 to 150	100	100	100
Exploration and drilling jobs*	500 to 750	500	300	2 000
Transport/trucking jobs**	N/A	20	40	275
Power station jobs (by 2050)***	0	0	80	300
Total eventual jobs (regardless of where employees are from)	500 to 750	520	420	2 575
Initial percentage of employees from within the study area	20%	15% to 35%	15% to 35%	15% to 35%
Initial number of employees from within the study area	100 to 150	80 to 180	60 to 145	390 to 900

* Total exploration and drilling jobs were sourced from Burns et al. (2016).

** Transport/trucking jobs based on truck trip numbers in Burns et al. (2016) (these are substantially greater for the Big Gas scenario given the larger number of wells), assuming two drivers per truck and two return trips per eight-hour shift.

*** Power station jobs based on current jobs at larger Eskom power stations which are gas-fired or could be gas-fired such as Ankerlig and Gourikwa.

Table 10.3 below provides a comparison of SGD impacts to those associated with the agriculture and tourism sectors in the study area (where data was available from the relevant specialist assessments on these sectors) and with the 14 renewable energy projects in the study areas that have been awarded preferred bidder status[15]. This provides some broad context for potential impacts and shows that, for example, the Small Gas scenario for SGD should result in roughly half the direct jobs expected from the currently approved renewable energy projects while the Big Gas scenario should exceed these jobs by a factor of at least three.

[15] List of project provided by the CSIR.

Table 10.3: Preliminary estimate of direct operational employment per SGD scenario.

Sector or project	Direct operational jobs for people within the study area	Broad indicators of economic value within the study area
Agriculture*	Not estimated in the Agricultural Specialist Assessment	Total Gross Farm Income (GFI) of R 5.006 billion/yr. Contribution of activities directly related to hunting equalling R 189 million/yr
Tourism*	10 100 to 16 400 jobs	R 2.3 billion/yr to R 2.7 billion/yr contribution to annual study area GVA
SGD	Initially 60 to 145 for the Small Gas scenario or 390 to 900 for the Big Gas scenario	R 3.5 billion/yr to R 7 billion/yr turnover for the Small Gas scenario or R 14 billion/yr to R 28 billion/yr turnover for the Big Gas scenario
Renewable energy projects**	Initially 115 to 270 assuming that the portion of jobs that go to local residents is same as for SGD	R 3.75 billion/yr to R 4.75 billion/yr turnover

* Sourced from respective specialist assessment where available (Oettle et al., 2016 and Toerien et al., 2016).

** Jobs estimates based on capacity (totalling 1 500 MW) of 14 preferred bidders/projects approved for the study area under the REIPPPP multiplied by jobs/MW averages for wind and solar power projects contained in the 'Green Jobs' report (Maia et al.,2011). Turnover estimates based on capacity per project multiplied by capacity factors for wind and solar published by NERSA and by contract prices per bidding round published by DoE.

Indirect and induced impacts would also flow from expenditure by shale gas developers and their employees in the region. Existing firms would benefit from gas sector workers' buying power, and new businesses such as convenience stores would probably be established if demand rose. The modelling options commonly used for their estimation, such as I-O models, are not satisfactory for reasons already outlined. Their modelling and estimation is also beyond the scope of this scientific assessment and not a pre-requisite for the generation of management and mitigation options. Based on *ex-post* job multiplier evidence from the US, it should not become a foregone conclusion that indirect and induced impacts in terms of jobs within the region would reach the same level as direct impacts. Note that the comparative scale and complexity of production is also a key issue here. In the US there is a large and well established oil and gas services sector which tends to support higher multipliers. It stands to reason that similar results should only be expected in South Africa if a viable local industry emerges over time. This would represent a potentially substantial opportunity dependent on factors such as the willingness of industry players to foster local enterprise development, entrepreneurial responses and the formation of clusters that expand value-chains.

The regional economy would also benefit from the diversification associated with the introduction of a new industry. This should increase its overall resilience in the event of external shocks to the existing sectors that drive the economy such as agriculture and tourism. Opportunities in this regard would be more pronounced for the Big Gas scenario relative to the Small Gas scenario.

10.2.2.2.2 Risk of crowding out, boom and bust cycles

Under the Small Gas scenario, the low to moderate level of activity and associated demand for workers and other inputs would limit the risk of localised rises in input prices. Large scale production would result in moderate to high levels of activity and demand which would increase the risk of localised input price rises. It is not, however, possible at this stage to predict confidently whether these would in fact occur and to what degree much less to predict whether they would be severe enough to crowd out other sectors. The evidence from the US indicates relatively limited risks or at least no clear evidence of serious problems in this regard.

At the level of principle, the risks in the Karoo are likely to be similarly low, albeit for different reasons. The first is that local enterprises are unlikely to be ‘crowded out’. That is to say, the prices of inputs including labour, interest rates, fuel prices etc., are unlikely to increase. There is extensive local unemployment of land and labour, and local enterprises use little of the physical capital required by the gas industry. The exception to this is water, a resource in short supply in the Karoo, and one that constrains the operations of farmers in the area. An important proviso is therefore that SGD does not seriously compete with local water users, or pollute local supplies. With regard to water availability in the US, Wang and Krupnick (2013) point out that there has generally been adequate water for SGD, but that in some areas water shortages are a growing concern.

In labour markets, the national agricultural minimum wage is generally above the local Karoo market clearing wage. Exploration or small scale production is therefore unlikely to impact on local workers’ wages. The Big Gas scenario may introduce limited upward pressure on local wages. In capital markets crowding out is precluded by institutional factors. South Africa’s interest rates are set as a policy instrument in Pretoria and are effectively unrelated to local conditions of money demand and supply in the Karoo. It is also worth bearing in mind that gas extraction and associated activity should be spread over a relatively long period of time (e.g. the power stations would only be established by 2050) giving time for other sectors to adjust.

With the exception of water, the points raised above relate to changes in relative prices that might advantage one sector over another. These ‘pecuniary externalities’ are characteristics of a market economy and even if they existed would not necessarily be signs of market failure. Physical externalities, in which an industry imposes technical or physical costs on others, are a more serious problem. Their assessment and recommendations for their mitigation are the responsibility of much of the other specialist studies forming part of this scientific assessment (see assessment of risks on water resources (Hobbs et al., 2016), ecology (Holness et al., 2016), visual quality (Oberholzer et al., 2016), noise (Wade et al., 2016), air pollution (Winkler et al., 2016), agriculture (Oettle et al., 2016), tourism (Toerien et al., 2016), and infrastructure (Van Huyssteen et al., 2016)). Whether these externalities would be sufficient post mitigation to adversely impact the commerce of the central Karoo would clearly depend on their likely severity.

With regard to the potential for boom and bust cycles, the Small Gas scenario would entail minimal risks regionally and locally particularly as this scenario assumes that power generation would be the only use of the gas produced and is likely to be associated with a long term contractual arrangement ensuring a relatively steady demand. The Big Gas scenario may bring slightly higher risks since roughly half of the gas produced would go to a GTL plant (with the rest being used for power generation). Risks are only likely, however, in the absence of longer term contract for local gas to supply the GTL plant, which is considered unlikely, and if local gas prices consistently exceed those for gas that could be shipped to the GTL plant.

10.2.2.3 <u>Options for mitigation or benefit enhancement</u>

An important objective should be the maximisation of the local and regional benefits associated with gas extraction. Procurement processes, hiring and training of staff and local socio-economic development initiatives/projects should act as a departure points in this regard. Key focus areas should include:

1. Targets for use of local labour should be based on the needs of the applicant, the availability of existing skills, and numbers of suitable persons willing to undergo training. Worker training in local communities should be encouraged.
2. Local sub-contractors and suppliers should be used where possible and those from outside the study area that tender for work should also be required to meet targets for how many locals are given employment. Enterprise development at a local level should also be required particularly for less technical service requirements such as catering, laundry, transport, etc. Local supplier databases would be valuable in identifying potential suppliers and service providers to SGD.
3. Mechanisms to facilitate local and regional project ownership or shareholding should be explored whilst also taking the interests of existing shareholders in development companies into account.

4. Applicable empowerment targets should apply to ownership/shareholding, employment and procurement as per national legislation.
5. Developers should be required to enhance local community benefits with a focus on well-conceived socio-economic development projects that are clearly aligned with local needs as outlined in the Integrated Development Plans (IDPs) of local municipalities.

The process of devising specific requirements to govern local and regional benefit enhancement by developers should use existing Department of Mineral Resources (DMR) Social and Labour Plan (SLP) requirements which apply to the mining industry as a starting point. The mandatory requirements which apply to energy project developers under the DoE's IPP Procurement Programme should also be used for guidance as they are arguably superior to SLP requirements in some respects. These requirements set minimum requirements and target levels for such issues as local ownership, employment, procurement, enterprise development, socio-economic development contributions. The process of deciding on appropriate benefit enhancement measures should be as transparent and collaborative as possible involving local communities and municipalities.

There would be limited scope for mitigating the impacts of localised price rises should they arise albeit this is not considered particularly likely. Neither gas developers nor the authorities have the tools to exert much control over the prices of inputs not that such control would necessarily be desirable in a market economy. Among other potentials for distortion, fairness is likely to become an issue. For example, it would be difficult to ensure that wages in the agricultural sector remain low without infringing on the rights of agricultural workers whilst favouring farm owners.

If large scale production were to begin, mitigating the impacts of any potential collapse in gas prices would be particularly challenging. These would be associated with significant withdrawals of spending and employee layoffs. For employees, as in the case of the mining industry, some relief should come from focused programmes to re-skill workers for the time when development activity either decreases substantially or stops altogether. These are, however, likely to only really be effective if contractions in the industry can be anticipated far enough in advance; a difficult task for SGD based on experience in the US. Minimising impacts on suppliers and sub-contractors should focus on notifying them as soon as it is clear that purchases from them are like to decrease or cease altogether. This would not soften the blow of losing an income stream, but would at least allow for some level of planning which could be particularly important for smaller suppliers.

10.2.3 Environmental costs and public finances

10.2.3.1 Description of the impact

SGD has the potential to result in externalities which local and regional authorities and especially municipalities will be expected to deal with. Among others, these include strain on road, water, and other infrastructure. In common with other extractive industries, the eventual finite nature of the resource extraction process and the potential for boom and bust cycles to materialise in sparsely populated areas are key drivers in this regard. Unless carefully managed, externalities have the potential to pose significant budgetary challenges to local authorities and public finance in general. The nature of these challenges along with management solutions worth investigating further are the subject of this section. A more extensive review of the nature of externality risks to local municipalities are being covered in other specialist studies especially the study dealing with Impacts on Land, Infrastructure and Settlement Development (Van Huyssteen et al., 2016).

10.2.3.2 Assessment of impacts per scenario

High intensity localised activities such as SGD often do not necessarily live up to their promise of high levels of local benefits (see Section 10.2.2 for further discussion). There can, however, be substantive local benefits with proper planning based on a thorough understanding of the revenue and income distributional character of the shale gas industry (Christopherson & Rightor, 2011). In the case of South Africa, local areas with no previous oil and gas industry experience could face significant inflows of capital (in its different forms) followed by outflows until infrastructure demands and skills requirements are settled. Some towns are likely to experience booms under the Big Gas scenario which could push up the prices of retail services, housing and rentals (Weinstein, 2014). There is also a risk that locals may leave or be displaced by workers from outside local areas. It is not anticipated that the core towns where most of the SGD could be concentrated will have numerous workers with the high and medium level skills required by the new industry at least initially. These will have to be brought in thereby increasing demands on housing and other services. Since much of this workforce would not be permanent, they could introduce a hollowing out effect on towns during a bust period or once SGD ceases. Some shale workers may well stay but those with highly specialised skills are more likely to leave.

There are essentially three key challenges for municipalities: not to overspend and be burdened with stranded infrastructure, being able to smooth out their revenue streams through a boom and bust cycle and finally, ensuring financially sustainability after SGD. They will have to gain experience and understanding of the industry relatively rapidly to overcome these challenges. Eventual impacts will also depend a great deal on the fiscal framework under which a local authority operates. In South

Africa this framework is constrained for municipalities so localised benefits from shale gas can be limited if most revenues flow back into the national coffers and insufficient allocations are made to the impacted authority that has to bear the costs of the full SGD and production cycle.

Towns can grow rapidly and suddenly find themselves having to make additional allocations for infrastructure and the provision of social services that are hard to anticipate as they are linked to the uncertain pace of SGD. Municipalities in any case cannot raise special taxes and levies without national approval. South Africa's municipal finances have some level of decentralisation but are severely restricted by the provisions of the Municipal Finances Management Act (MFMA). A review of the Auditor General reports on the state of finances in many of the areas in which SGD is to be undertaken does not paint a pretty picture[16]. They describe a situation of limited revenue creation options, persistent lack of clean audits and the general incapacity to account for properly or demonstrate that funds received can be well managed. Municipalities falling under the Northern and Eastern Cape tended to do less well versus those in the Western Cape. Poorly functioning municipalities with little prospect of viable future revenues streams due to demographics and other reasons area likely to struggle to perform the planning, impact management and controls needed for traffic, waste disposal and other stakeholder concerns. The Auditor General reports also shows that even in well-resourced municipalities issues of accountability, discipline and performance management hamper the smooth running of municipal affairs.

The South African situation contrasts with that of the US where local and state authorities have significantly more scope to raise their own revenues from SGD. Additional revenue comes from severance taxes (a form of production/exploitation tax), impact fees and sales tax to cover expanded fiscal demands, they can additionally request companies to raise road haulage bonds and other measures to deal with any damage that may arise due to SGD. Even with revenue raising options in place, fiscal balancing requires astute forecasting as there is usually a lag between costs that need to be incurred and revenues that can be generated once the industry gets off the ground. Predicting peak and decline phases is challenging and something of an art. Potential difficulties in this regard are highlighted by vigorous and ongoing debates in the US regarding the best revenue raising options and their optimal structuring (e.g. linked to production amounts, well numbers or both).

It is likely that municipalities will face significant stress and friction as SGD expands particularly under the Big Gas scenario. The areas where externality effects are particularly likely to stretch their human and financial resources include the following:

[16] See Auditor General report for 2013 and 2014 at:
http://www.agsa.co.za/Documents/Auditreports/MFMA20132014.aspx

- In the early phases of production, municipalities will require additional human and financial resources to accommodate for environmental and other approvals and management needed as exploration and drilling picks up. They may well have to recruit from outside the local workforce to attract the required expertise. Additional capacity needs are likely to emerge in environmental risk management, town planning and zoning and inspectorate. Other additional administrative and staff expansion is also anticipated for policing, public health care, teachers, and emergency services. Furthermore, the attractive salaries generally offered in the oil and gas industry could lead to the loss of municipal staff as they seek more lucrative careers in the shale gas industry. This could increase the wage bill for municipalities if they want to retain or attract the best staff or skills from a very narrow pool of expertise (Christopherson & Rightor, 2011)[17].
- Municipalities are likely to have to face a major challenge from road haulage as trucks and other vehicles are needed to take equipment, gas (if there are no pipelines) and waste water for disposal. Distinctions must be made between drill site access roads which will be built and maintained by developers versus public roads. Experience elsewhere shows that the costs of road infrastructure damage accrue mostly to local and regional authorities and tend to grow as a recurrent expenditure on already tight municipal budgets. For example, Newell and Rhami (2015) found that road damage costs reached around $ 1 million/mile in some US locations. They also refer to studies that show that road management and repair can be the largest expenditure item on the budget of local municipalities in shale areas. Bear in mind that road infrastructure is a non-exclusive good and unrepaired roads or congestion can impact on other economic activity.
- SGD will increase the demand for water and sewerage services. While some of this expansion is for human needs the rest may well be for dealing with waste water from the fracked wells. Since water from shale gas is a specially declared use under South African law, it has to be disposed of properly either permanently, for purposes of treatment or through recycling. Significant uncertainty surrounds the infrastructure required to manage temporary and long-term waste water disposal or storage in the Karoo. A key question is whether the approach that will need to be taken is a centralised infrastructure model or a decentralised system. These details have to be worked out.
- A further area of concern is dealing with the long-term externality problems associated with abandoned or decommissioned wells. These sites need constant monitoring and will require rehabilitation as well casings and ceilings wear and tear over time. In some instances in the US, long after oil and gas production has been completed, the liability of dealing with gas or

[17] Some case studies based on the US experience show staff salary costs going up by 30-40%.

polluted water leakages from abandoned wells has become the responsibility of the local authority (Fakir, 2015). Generally, provisions for rehabilitation and closure tend to be inadequate either because the assessment of how much is needed is not done properly or the funds have not been adequately ring-fenced and securely managed (Ingraffea et al., 2014). It is important that this crucial aspect be investigated more closely including whether a special provisions model should be developed for SGD within the existing legal framework that has been established by the National Department of Environmental Affairs (DEA). A wealth of experience regarding the pitfalls associated with making financial provisions for mine closure is also available to learn from (for example, see Van Zyl et al. (2012) and court actions undertaken by the Centre for Environmental Rights in this regard).

10.2.3.3 Options for mitigation

The growth in SGD will require impacted local authorities to have increased budgets to meet various demands described above. The exact size of budgetary expansion required will have to be determined. In early phases, staff from other municipalities and even secondments from other countries that have extensive shale gas experience should be considered.

Dealing with road damage will require municipalities to consider special policies and measures such as a levy for road haulage. We recommend that the example of road haulage effects of coal transport to Eskom power plants will be a useful starting point if a model of externality costs is to be developed for shale gas impacts. Local authorities could, for example, consider a haulage bond for each operator or a special road haulage levy. The details of such a scheme will need to be investigated further as much depends on the haulage routes chosen and whether it takes place within a specific target municipality or within the jurisdiction of another local authority or province. Such an investigation will have to take into account scale of impact, revenue stream model and damage mitigation options. If road haulage damage impacts a number of jurisdiction, close co-operation between different municipalities and provincial authorities will have to be established to ensure fair and equitable cost and revenue sharing.

It is recommended that the cost of disposal and treatment of waste water be a private cost rather than a public cost as some of this water will have to be treated potentially for re-use in fracking. Municipalities can then focus on residential and commercial water and sewerage needs. In addition, they will have to increase their capacity to deal with the transport, treatment and disposal of hazardous waste water. These will require both onsite and off-site monitoring and assessment by specialists and inspectorate within the municipalities. Early learning and adoption of administrative and management approaches to dealing with waste water from fracking will have to be facilitated by national and provincial government (Rahm et al., 2013).

Well abandonment or decommissioning is likely to create long-term externality challenges as well casings; plugs and valves go through a natural wear and tear process. While there is existing mining-focused legislation that enables financial provisions to be set aside for exactly this eventuality, the South African experience in mining shows that funds are too often insufficient and/or not properly secured. Similar experience can be found in other countries such as the US for mining and fracking. We recommend that this be investigated further and an adequate financing and fund review model for abandoned or decommissioned wells be put in place – possibly done jointly be DEA, DMR, DoE and National Treasury and using the amended regulations for financial provisions in mining as a departure point. It will be particularly important that sound mechanisms are put in place to deal with all potential long-term legacy (i.e. latent and residual) risks including those which may remain beyond the ten year period post-closure for which financial provisions must be made in mining. This could, for example, include considering the potential role for industry-wide financial mechanisms that allow for the pooling of risks among producers in order to protect water resources drawing on lessons from the mining industry. A future SGD industry would have the rare opportunity to learn from mining and put such mechanisms in place from the start thereby enhancing the chances of achieving sustainability goals.

It is likely that the One Environmental System (OES) that has been instituted under new National Environmental Management Act (NEMA), Mineral and Petroleum Resources Development Act (MPRDA) and National Water Act (NWA) amendments, will also be applicable to shale gas although the status of the OES is yet to be finalised. The OES attempts to streamline and fast track the environmental authorisation processes so that companies can simultaneously apply for environmental authorisations, mining rights and water rights. Under the OES, the environmental management function will remain with the DMR but will be governed under NEMA (amended in November 2015) and not the MPRDA. The DMR will therefore assess applications based on NEMA and associated regulation and DEA will be the appeal authority with the power to prospectively prohibit and restrict the granting of environmental authorisations.

With specific reference to the new financial provisioning requirements, they are more onerous on companies who are required to be fully compliant with the new legislation by February 2017. They require companies to submit three closure plans (previously two were needed) as follows: (1) An 'on-going rehabilitation plan' which relates to regular activities during the life of mine; (2) a final rehabilitation plan with rehabilitation details and specifying use of land after closure; and (3) a post closure plan focusing on potentially indefinite post-closure 'latent and residual' environmental impacts recognising that mine liability can continue indefinitely particularly where water treatment is involved.

The new regulations require companies to provide comprehensive itemisation of all the costs associated with annual and final rehabilitation, decommissioning and closure as well as the costs associated with remediating long-term latent or residual impacts (i.e. impacts that may only become visible in the future with a particular emphasis on potential water related threats). A permit or right holder or applicant must calculate and make provision for the availability of sufficient rehabilitation and closure funds, which the DMR Minister must approve. Importantly the regulations specify that, at any point, the funds available for latent and residual effects must be able to cover the actual costs of implementation for at least ten years after closure. Financial provisions can be made through a financial guarantee, a deposit to a specific account administered by the DMR Minister or a combination of both. A trust fund can only be used for the purposes of financial provisions for residual or latent impacts subject to conditions set out in the Act. This marks a change from previous regulation which allowed for a trust to be used for other impacts. The regulations prohibit the deference of "provisioning liability to assets at the mine closure or the mine infrastructure salvage value" and require the verification of registration of a financial institution in the case of a guarantee. In the case of residual or latent impacts, provisions must be ceded to the DMR Minister once a closure certificate has been issued. Companies are further required to review, assess and adjust all financial provisions and the assessment must be audited by an independent auditor. Furthermore, Environmental Management Plans (EMPs) are required to be publically accessible. Companies can be placed under care and maintenance subject to specific requirements and Ministerial approval but cannot operate under care and maintenance for more than five years. Finally, strict liability is imposed for non-compliance. Companies can be fined up to R10 million or their directors can be imprisoned for up to ten years or both.

10.2.4 Impacts on property values

10.2.4.1 <u>Description of the impact</u>

Property values are driven by fundamentals, some of which may be influenced by SGD, typically including both bio-physical and social effects (e.g. visual impacts, increased noise, and water pollution risk). Values can also be influenced by expectations based on incomplete or incorrect information and by stigma especially in the short and medium-term. The latter is defined by the US Appraisal Institute as "an adverse public perception about a property that is intangible or not directly quantifiable". It tends to emerge particularly when new, unknown, land uses or activities are proposed that are perceived to be risky or incompatible with the status quo in some way. In most cases it is not possible or very difficult to determine what proportion of negative market responses should be attributed to stigma and what proportion to the real possibility of adverse externalities. The results of research conducted in other countries on the impacts of SGD on property values is a useful point of departure in understanding likely impacts. This research is reviewed in the following section before proceeding with assessment and identification or mitigation measures.

10.2.4.1.1 Review of the literature on the impacts of fracking on property values

In North America, SGD has often occurred in both sparsely and comparatively densely settled areas with the latter typically experiencing more regular property transactions. Assessments of these sales which tend to be more residential in nature have demonstrated varied outcomes for property values. Wright and Vann (2010) conducted a study using a few different techniques to determine the impact of SGD on residential property values in Flower Mound, Texas. Using the sales comparison method, they found that houses immediately adjacent to well sites with a value greater than $250,000 could experience a drop in value of between 3% and 14%. This drop was not recorded for houses which were separated from the well site by a buffer, such as trees or structures. Applying price-distance relationship, they estimated that the range of property value decline resulting from the presence of nearby well sites was between 2% and 7%, and that this effect dissipated beyond a distance of 300 to 460 m from well sites. When the authors subjected their findings to statistical analysis they were unable to demonstrate whether well site proximity had a significant impact on property values. This does not imply the absence of impacts, but it is noted that if these were “significant and sizeable” then the analysis should have detected them (Wright and Vann, 2010: 9). Finally, residential estate agents were interviewed all of whom mentioned difficulty in marketing houses whilst drilling rigs were in place but not thereafter. Estate agent interviewees also indicated that, on the whole, market participants tended to over-estimate the impacts of gas wells.

Gopalakrishnan and Klaiber (2013) used a hedonic regression model to quantify the impact of SGD on property values in Washington County, Pennsylvania between 2008 and mid-2010. Their focus was expressly on the period between permitting and commencement of drilling (typically six months), since this is the period when both actual impacts from drilling (noise, visual, etc.) and stigma related impacts (such as media coverage) were greatest. Using a sample size of 3 646 residential houses, they found impacts to be negative and significant, particularly where households were reliant on groundwater, close to major highways and where agriculture was the dominant surrounding land-use. The values of houses that relied on groundwater and were located within 0.75 miles of an active well site decreased by 21.7% with discounts dropping rapidly to 5.6% at a 1 mile distance. It was suggested that this was probably because the results included value gains to property owners from potential royalties (Gopalakrishnan and Klaiber, 2013).

Kelsey et al. (2012) analysed changes in the values of properties throughout Pennsylvania between 2007 and 2009, using data from the Pennsylvania State Tax Equalisation Board. The period covers the earliest years of development of the Marcellus shale play. This is important to note for two reasons. The period does not cover the most significant period for Marcellus SGD, but given that it does cover an early period it is likely that changes in value reflect the initially high levels of stigma and impacts associated with permitting and drilling. The study's approach is less nuanced than that of hedonic studies and its units of analysis are the county and the municipality. It found that counties which were host to more than 90 wells saw an increase in average property values of 13.8% between 2007 and 2009. Increases in value thus exceeded any negative localised impacts which might have been felt. The authors advocate considering impacts on a case-by case basis, pointing out that a lack of evidence for significant changes to property values in aggregated datasets should not detract from the fact that for certain individual property owners, SGD has had very real impacts, "with direct implications for their economic well-being" (Kelsey et al., 2012: 2).

In a particularly thorough and wide-ranging hedonic study, Muehlenbachs et al. (2015) measured changes in property values throughout Pennsylvania between 1995 and mid-2012. GIS tools were used to establish the number of wells within view of a house at the time of each sale. This provided the authors with a sample of 229 946 residential properties in the vicinity of at least one of 6 260 wellbores (3 167 wellpads) at some point in time during the 16 year period. Results were similar to the Gopalakrishnan and Klaiber (2013) study in that value reductions were found for groundwater-dependent households within a 1 to 1.5 km distance of wellpads. The authors report this reduction to be large and significant, ranging from 9.9% to 16.5%. They note that "although data are not available to measure the impact of actual groundwater contamination, the perception of these risks is large, causing important, negative impacts on groundwater dependent properties near wells." (Muehlenbachs et al., 2015: 29). On the other hand, properties situated in close proximity to wells enjoyed value increases if the households had access to piped water (as opposed to groundwater). The authors suggest that this was due to the expectation that the value of future royalties from these properties would exceed risks. Note also that increases in property values only occurred for properties which were sold more than a year after adjacent wells had been drilled (i.e. after the most significant impacts, from permitting and drilling, had passed) and in cases where wells were not visible from the property. This suggest the possibility that positive impacts from royalty payments do not outweigh the negative impacts of being located near a well in a number of cases (Muehlenbachs et al., 2015). It also further highlights that impacts and the balance between risks and benefits are most often highly case specific and linked to royalty payments levels.

10.2.4.2 Assessment of impacts per scenario

Impacts on property values should be driven by the real and perceived balance between negative and positive externalities in the presence of any mitigation or compensation measures. The studies reviewed above provide a good basis for understanding the plausible impacts of SGD on property values in the study area. Additional pointers are available in the other specialist studies forming part of the scientific assessment process. Impact findings from most of these studies have potential relevance to property values to the extent that property market participants take them into account in their buying and selling decisions. With this in mind, they have all been broadly considered when assessing risks to property values. Impacts on agricultural potential and, increasingly, the potential for land to remain attractive for those buyers focused on tourism and leisure uses would be key drivers. The following key points from the assessments of visual (Oberholzer et al., 2016) and noise impacts (Wade et al., 2016) also offer examples of findings which assisted in the assessment of overall risks to property values:

- The Visual Chapter (Oberholzer et al., 2016) concludes that SGD activities could affect property values. It notes that wellpads with drilling rigs on them would be dominant in views up to about 1 km during the day-time. It stands to reason that visual risks to property values would be greatest particularly when farmsteads, settlements or other sensitive receptors are located within this distance. Oberholzer et al. (2016) also find that beyond a distance of 2.5 km; rigs would entail a low visual risk to human settlements, private game reserves, game farms and tourist accommodations implying low risks to their property value. Note that at night, the visibility of lights and flares would tend to be visible over greater distances in a dark rural landscape. With respect to the development scenarios, Oberholzer et al. (2016) highlight the risks associated with the Big Gas scenario, which would entail a larger number and higher density of wellpads, infrastructure and related activity and may result in an industrialised landscape. The importance of project-level investigations at Environmental Impact Assessment (EIA) stage to determine specific setbacks and exclusion zones is also emphasised.
- The Noise Chapter (Wade et al., 2016) points out that noise levels in the Karoo are generally far below the typical levels for rural areas in South Africa. This should accentuate the risks to property values from the noise associated with SGD relative to other areas. These risks are likely to be variable and highly dependent on the presence of sensitive receptors especially

nearby wellpads and roads[18]. Wade et al. (2016) allude to the potential for variability and emphasises the importance of project-levels investigations at EIA stage to determine mitigation required in order to meet noise standards including potential setbacks from areas of human habitation.

The issue of stigma is likely to remain complex. Perceptions that SGD in the study area would cause unacceptable changes with limited benefits are arguably widespread. These perceptions have been realised in landowner/community mobilisations against fracking. Perceptions of high risk levels thus seem to be common and pronounced in many cases making it likely that stigma would contribute to property values risks especially for the Big Gas scenario.

Plausible negative externalities in urban areas are more likely to be driven by the increased presence of trucks, the potential for the emergence of social ills and strain on municipal services. Despite these issues, there would remain a strongly likelihood that property values in towns would increase. Such a rise could result from increased commercial activity, higher incomes and in-migration driving up property demand. It would endure to the extent that SGD activity continues and would reverse to the degree that activity reduces or ceases. This would correlate with experiences in other smaller towns in South Africa that have experienced significant increases in commercial activity from major new developments (for example, Kathu near the Sishen iron ore mine, and Lephalale near the Medupi Power Station). It would also be in keeping with what happened in the US. For example, Ward (2014) found that property values went up in the towns within Tioga County, Pennsylvania. This benefited property owners, but comes at the detriment of renters who tend to be from lower income groups.

An important determining factor with respect to property value risks would be the potential for mitigation of impacts on landowners including through compensation. Here the contrast with the situation in the US is instructive where property owners (i.e. holders of surface rights) commonly also own sub-surface mineral rights. This allows them to negotiate often highly significant royalty payments from SGD companies. For example, in 2014, six major US shale plays produced oil and gas valued at $ 213 billion, of which, $ 39 billion was paid out to property owners as royalties. Royalty rates were found to vary substantially across plays, from a low of 13.2% in the Marcellus play to a high of 21.2% in the Permian, and with a countrywide average of 18%. Note also that these amounts accruing to private landowners were more than four times the royalty income received by the Federal government in the same year (Brown, 2015). Since 2002, South African landowners have not been able to extract royalties as they have had no claim to sub-surface mineral rights which were

[18] Assessments of the impacts of road traffic on property values have been reviewed by Bateman et al. (2001), for example, and generally include the estimation of Noise Sensitivity Depreciation Indices (NSDIs) which trace the link between increased noise levels and property value decreases.

transferred to the state. This weakened position means that land owners now have far less to gain if SGD occurs on their land, and may have much to lose if negative externalities eventuate, a situation that is likely to reflect in property values. Compensation to landowners does, however, occur in South Africa for other similar situations discussed below and in the case of SGD in other countries such as Australia where mineral rights are also state owned (for example, see Measham et al,. 2016).

10.2.4.3 Options for mitigation

The key objective of mitigation should be the minimisation of risks to landowners and their property values. Measures should include:

- The application of mitigation measures outlined in the other specialist studies contributing to the scientific assessment such as those focused on impacts on water, visual quality, noise levels, sense of place, ecology, etc. Ideally these measures should reduce risks substantially. There are, however, likely to be externalities that cannot be avoided requiring compensation payments to landowners. This should include compensation for the use of their land and any damages to it that are unavoidable and of a more predictable nature (e.g. loss of productive land, degradation of roads, and disruption of activities).
- Measures aimed at ensuring that financial provisions are made to deal with unexpected negative impacts such as spills which could impact on property owners.

Compensation payments to landowners for the use of their land during SGD would need to be guided by the principle of comfortably compensating landowners for all impacts and losses. They would need to be based on best practice and include elements for loss of land value, future income, assets or infrastructure and have a solatium element[19]. Measham et al. (2016) emphasise the need to establish the appropriateness and legitimacy of compensation through dialog with stakeholders. This dialogue should include agreeing on the compensation principles to be applied and, to the degree possible, fair minimum amounts or conventions/formulas for establishing compensation. They also point out the importance of not relying too heavily on compensation, in a general sense, as a way for local communities to derive benefits given its potential to create and reinforce dependencies.

Compensation levels and associated property value impacts from private sector renewable energy project provide instructive guidance in this regard particularly when compared to seemingly similar types of projects. Renewable energy projects such as wind farms have the potential to impact negatively on the value of land where they are established mainly due to visual impacts. However, anticipation of potential private renewable project developer interest generally results in value

[19] A solatium is essentially a form of broadly defined compensation element for inconvenience and ‘suffering’. It is often referred to as “tranegeld” in Afrikaans (direct translation – money for tears).

increases for land within potential sites. These increases can be linked to anticipation of the payments commonly offered by developers comfortably offsetting any perceived risks. For major powerline development the opposite is often the case. They too imply risks to values for visual impact reasons but they are generally not associated with equally generous payments to landowners and therefore more commonly result in property value decreases[20]. Establishing acceptable compensation payments to landowners for SGD that are guided by processes such as the IPP Procurement Programme is thus recommended. It is important to bear in mind that, aside from ensuring the fair treatment of landowners, compensation which goes beyond what is strictly required by law should also play an important role in facilitating the development of SGD. Interactions with land owners would be less likely to be acrimonious, reaching agreement would take less time and turning to the law to force landowners to grant access to their land is less likely to be necessary[21]. A key caveat is that none of these processes or norms currently offer a clear remedy for adjacent or nearby landowners. Under South African law, those acquiring servitudes or undertaking major developments are not required to compensate neighbouring property owners for potential value losses. This limits the potential for full compensation if neighbouring property values decrease.

With strict implementation, the mitigation measures discussed in Section 10.2.3.3 focused on ensuring adequate financial provisions for well rehabilitation and closure would also offer mitigation for landowners and insulate them from potential risks associated with the financial position of developers such as bankruptcy.

Note that even with careful mitigation and compensation; it is likely that risks associated with stigma would remain. These would be difficult to counter but could be reduced somewhat through communications and media measures that limit the formation of ill-informed perceptions regarding activities and risk levels.

10.3 Risk and opportunity assessment

The key economic risks and opportunities for each SGD scenario have been described and assessed to the degree possible in the preceding sections (given the strategic nature of the assessment). Table 10.4 below provides qualitative ratings for these risks and opportunities guided by the approach and format provided by Scholes et al. (2016). On the whole, economic opportunities at a national and local scale should reach a low or moderate significance with benefit enhancement for the Small and Big Gas

[20] Note that this situation; where renewable energy producers are generally welcomed by land owners while powerline developers are not; also has been observed in the US for similar reasons (Fahey, 2010).
[21] Under the MPRDA, companies with mineral exploration or extraction rights can force land owners (i.e. surface rights holders) to grant them access to their land.

scenarios, respectively. Macro-economic risks and those affecting public finances and property owners should generally remain moderate provided mitigation and compensation mechanisms are well crafted and rigorously implemented.

Table 10.4: Assessment of economic risks and opportunities.

.Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	Likelihood	Risk / Opportunity	Consequence	Likelihood	Risk / Opportunity
Macro-economic opportunities	Reference Case	National	N/A	N/A	N/A	N/A	N/A	N/A
	Exploration only		Slight	Likely	Low	Slight	Likely	Low
	Small Gas		Moderate	Likely	Low	Moderate	Likely	Low
	Big Gas		Substantial	Likely	Moderate	Substantial	Likely	Moderate
Macro-economic risks	Reference Case	National	N/A	N/A	N/A	N/A	N/A	N/A
	Exploration only		Slight	Likely	Low	Slight	Likely	Low
	Small Gas		Moderate	Likely	Low	Moderate	Likely	Low
	Big Gas		Substantial	Likely	Moderate	Moderate	Likely	Low
Local and regional opportunities from project ownership and spending activity	Reference Case	Local and regional	N/A	N/A	N/A	N/A	N/A	N/A
	Exploration only		Slight	Likely	Low	Slight	Likely	Low
	Small Gas		Moderate	Likely	Low	Moderate	Likely	Low
	Big Gas		Substantial	Likely	Moderate	Substantial	Likely	Moderate
Risks to public finances associated with externalities	Reference Case	Local and regional	N/A	N/A	N/A	N/A	N/A	N/A
	Exploration only		Slight	Likely	Low	Slight	Likely	Low
	Small Gas		Moderate	Likely	Moderate	Slight	Likely	Low
	Big Gas		Severe	Likely	High	Moderate	Likely	Moderate
Risks to property values in areas where drilling occurs	Reference Case	Local and regional	N/A	N/A	N/A	N/A	N/A	N/A
	Exploration only		Slight	Likely	Low	Slight	Likely	Low
	Small Gas		Moderate	Likely	Moderate	Slight	Likely	Low
	Big Gas		Severe	Likely	High	Moderate	Likely	Moderate
Opportunities for property value increases in towns within SGD regions	Reference Case	Local and regional	N/A	N/A	N/A	N/A	N/A	N/A
	Exploration only		Slight	Likely	Low	Slight	Likely	Low
	Small Gas		Slight	Likely	Low	Slight	Likely	Low
	Big Gas		Moderate	Likely	Moderate	Moderate	Likely	Moderate

10.3.1 Limits of acceptable change

The concept of limits to acceptable change is generally more applicable to physical measures for which there are established minimum standards that need to be met (e.g. air or water quality). It is a somewhat ‘rule-based’ concept and for this reason is less compatible with the principles of economic assessment which tends to allow for and encourage the consideration of all trade-offs. Nevertheless, at the level of principle, establishing that a given action is economically desirable generally requires that one can show that it is still likely to result in a net benefit to society even when all externalities are taken into account or ‘internalised’. The most effective way to achieve this is through mitigation or compensation to the point when externalities are effectively dealt with. The limit of acceptable change is then up to the point at which externalities cannot be mitigated or compensated for (this would apply equally to SGD as it does to similar extractive industries such as mining). Going beyond this point generally results in significant and pervasive risks to other sectors thereby risking the emergence of an unsustainable, under-diversified and far less robust economy.

Setting limits to change through laws, policies and other guidelines is often more straightforward when compared with implementing them successfully. Past and present environmental and associated socio-economic impacts from mining in South Africa are instructive in this regard. The industry remains a key driver of economic development and yet, if one considers the Mpumalanga coal fields among other examples, it is evident that the benefits of mining could be achieved at a substantially lower cost to the environment and society. This will be the challenge associated with the regulation of SGD and one that is unlikely to be addressed using a business-as-usual approach. An evaluation of the effectiveness of environmental governance in the mining sector commissioned by the Department of Planning Monitoring and Evaluation (DPME) bears this out. It concluded that “…in theory the environmental governance framework is appropriate for promoting good environmental governance in the mining sector. However, in practice, the inadequate implementation and enforcement of the framework seriously compromises its efficacy and ability to ensure environmental sustainability” (Genesis Analytics and Digby Wells Environmental, 2015: vii).

10.4 Best practice guidelines and monitoring requirements

For certain impacts it will be necessary to establish baseline conditions and institute ongoing monitoring in order to either understand impacts better and/or to maximise the efficacy of mitigation. This section provides recommendations in this regard and briefly outlines key best practice guidelines that should be considered most of which have already been mentioned when discussing mitigation measures.

Macro-economic impacts

The DTI along with the DoE and National Treasury should take the lead in policy relating to macro-economic benefit enhancement and risk reduction. The Industrial Policy Action Plan (IPAP) 2015/16 – 2017/18 proposes a Long Term Strategic Framework to leverage the opportunities presented by petroleum and gas resources. The DTI has also recently announced that it will be establishing a unit to manage gas industrialisation that intends replicating the success of the IPP programme unit in the DoE.

The minimisation of long-term risks is highly dependent on political decisions about the use of increased tax and other revenues originating from SGD. Best practice dictates that these need to be directed to maximising the growth potential of the economy.

Local and regional impacts from project ownership and spending

The process of devising specific requirements to govern local and regional benefit enhancement by developers should use existing SLP requirements which apply to the mining industry and requirements under the IPP Procurement Programme as a starting point. The latter have a particularly strong focus on ensuring that a defined share of proceeds flows to socio-economic development in local communities.

Successful and equitable targeting of local beneficiaries would require baseline data on aspect such as:

- The availability of skills in the study area and of people willing to be trained obtainable through the commissioning of skills audit[22].
- The availability of suppliers and sub-contractors in the study area.
- Which socio-economic development projects are viewed as a priority by local municipalities and appear in their Integrated Development Plans (IDPs).

This data for specific local areas can be gathered by developers largely at EIA stage in partnership with the affected local municipalities. There is also likely to be merit in gathering this information at a course level for the entire study area again in partnership with the affected local and district municipalities and preferably with support from the DTI.

[22] This should be informed by an assessment of skills needed such as that contained in the Pennsylvania Marcellus Shale Workforce Needs Assessment (MSETC, 2011).

If the IPP Procurement Programme is used as a departure point, then similar monitoring requirements and processes in terms of the achievement of targets can be used for SGD.

Environmental costs and public finances

The key guideline here would be the amended requirements associated with financial provisions for mine closure under NEMA. These have been designed to tighten regulation and have built on experience in mining that could be used as a departure point for crafting similar regulations for SGD. Determining monitoring needs should be part of the process of generating such regulations. There may also be a need for industry-wide pooling of risks in order to ensure that resources are available for large unforeseen events.

Impacts on property values

If compensation of landowners is to be linked to property values then it would be beneficial to establish a baseline of property values in areas where SGD is proposed. This could be done at the EIA stage using a professional valuer(s). It need not be highly detailed but should ensure that a record of average values in targeted areas is established. Such an exercise could tie in with and be informed by the assessment of tourism baseline data (i.e. an inventory of all private reserves, game farms, guest farms, resorts and tourist accommodation) recommended in Toerien et al. (2016).

10.5 Gaps in knowledge

From an economic perspective the key piece of missing information to allow for further consideration of virtually all of the impacts of SGD is an assessment of the size of the recoverable gas resource. The exploration process, should it go ahead, would be the only way to address this information gap.

The conflicting results from other South African studies on the macro-economic benefits of SGD raise concerns of creating unhelpful confusion and of possible overstatement. A study and/or transparent expert process focused on achieving the highest possible degree of neutrality would probably be needed before clarity emerges on this issue. Such an exercise could be repeated after some degree of activity to either prove or disprove the resource (i.e. through seismic exploration only) and once the size of the resources is known.

Not enough is known about the likely nature and magnitude of financial strain that SGD may impose on local municipalities in particular. This would need to be studied carefully and in detail as a starting point in determining mitigation in this regard. Specific areas that would benefit from further study include:

- Consideration of South African case studies to appreciate the effects of boom and bust cycles associated with the resources sector on municipal economies and fiscal positions (for example, most recently, the platinum industry around Rustenburg and iron ore mining in the Kathu area)[23].
- Identifying other international best practice methodologies for the determination of road haulage damage, pricing it and levy the industry appropriately. A key issue will be determining which road maintenance costs should be an industry cost versus a state cost on public roads. Eskom has provisions set aside in its budget to deal with coal road haulage externality costs which can act as an informant.
- Crafting and implement an effective framework for long-term rehabilitation of abandoned or decommissioned wells will be one of the most significant challenges associated with SGD. Such a framework should be informed by detailed investigations of what has worked elsewhere adapted to the South Africa context. Canada, for example, is reported to have instituted good practice using a Licensee Liability Rating Programme. The Canadian approach is to proactively generate a due diligence measure that tries to match liability creation with the capacity of firms to offset potential liability taking into account their asset bases.

Once the size of the recoverable resource is known and better information is available on risks and other aspects such as the costs associated with internalising externalities, there should be an opportunity to inform further government decision-making through Cost-benefit Analysis (CBA). Subjecting any forms of significant government support for SGD to such analysis would be particularly useful. It could be conducted in terms of the Socio-Economic Impact Assessment System (SEIAS) developed under the DPME which encourages the use of CBA as part of a wider assessment process (DPME, 2015)[24].

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[23] Lessons could also be learnt from the decline of gold mining in the late 1990s around Klerksdorp and Orkney in the Northwest Province.
[24] The SEIAS was approved by Cabinet in 2015 to replace the older Regulatory Impact Assessment (RIA) guidelines.

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CHAPTER 11

Impacts on Social Fabric

CHAPTER 11:
IMPACTS ON SOCIAL FABRIC

Integrating Author:	Doreen Atkinson[1]
Contributing Authors:	Rinie Schenk[2], Zachy Matebesi[1], Karin Badenhorst[3]
Corresponding Authors:	Ikechukwu Umejesi[4], Louwrens Pretorius[5]

[1] University of the Free State, Bloemfontein, 9301

[2] University of the Western Cape, Cape Town, 7535

[3] Independent Consultant, Cape Town

[4] University of Fort Hare, Alice, 5700

[5] University of Pretoria, Hatfield, 0028

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Executive Summary

1. The term "social fabric" embraces numerous complex and interrelated phenomena, including demographic and economic factors, behavioural issues (e.g. investment choices, political dynamics), social institutions (e.g. families), social organisations (e.g. municipalities and churches), and social networks, or relationships amongst people. The social fabric is underpinned by people's beliefs and sentiments, including a sense of *belonging* and identification with a particular social unit.

2. The concept of social fabric is profoundly influenced by different sociological perspectives. This scientific assessment builds on various theoretical overlapping approaches, focusing on local communities as relatively intact social systems, influenced by internal and external variables. South Africa, with its contested political and racial history, poses particular challenges for maintaining the social fabric, as local conflicts may develop along racial or ethnic lines.

3. The study area has significant social and economic variability, particularly from the arid and underpopulated western Karoo zone to the more fertile and populous eastern zone; these zones also have different ethnic, linguistic and social profiles. Consequently, almost all observations in this Chapter would, in practice, need to be refined and adjusted to local contexts.

4. The social fabric interacts with several key themes highlighted in this scientific assessment, notably the natural environment, which enables or hinders sustainability), economic development, tourism, agriculture, health, heritage and the "sense of place".

5. All resource development, including shale gas development (SGD), is particularly prone to creating local booms and busts, with rapid inflows and outflows of investment capital, labour, material and infrastructure. The phenomenon of boomtowns is a constant theme in international studies of mining, including SGD. The fate of boomtowns can vary significantly. Some boomtowns go through subsequent busts; and others level out after a boom. "Busts" can either be rapid and catastrophic declines (for example, when a mine shuts down), or a slow process of downscaling, or simply a transition from a construction phase to a less labour-intensive phase of energy production. The longer-term impacts vary across localities, as well as different kinds of resources being mined. One of the key variables affecting the economic and social future of resource towns is their ability to promote economic diversification.

Consequently, a long term strategic framework should be developed and promoted, during resource development as well as after downscaling and closure.

6. New extractive industries into an area can disrupt and alter the local social fabric in many ways. This can bring benefits in the form of new jobs and increased local revenue, but it can also bring a variety of social and public health harms. There is typically a period of adjustment and eventual stabilisation. Larger towns with diversified economies are more able to absorb rapid investments without social disruption.

7. Cumulative impacts can result from the aggregation (over time or space) and interaction of the impacts of a single activity. Cumulative impacts typically involve multiple actors and causal pathways. The impacts may affect stakeholders in different jurisdictions and involve issues that are legally regulated by multiple institutions; some issues do not fall under any formal regulatory authority at all. The analytical focus now becomes the *receiving entity* (a catchment system, a town, or a housing market), and not simply an impact *per se*. This will require a deeper understanding of the *properties of potentially impacted systems, over time*, even though the required information is often not available, and generalisations from other contexts are of limited use. The practice of 'Cumulative Effects Assessment and Management' (CEAM) within the field of impact assessment analyses complex adaptive systems. South Africa often faces particular challenges regarding the rigidity of government programmes and regulatory frameworks, so that inter-sectoral and cumulative impacts are seldom recognised or addressed.

8. All South African towns and rural areas are characterised by the legacy of racial segregation and *apartheid,* in their spatial form (racially-defined neighbourhoods) and social networks (poor levels of racial integration). This creates a constant backdrop to any other social dynamics and pathologies. It is very easy to exacerbate racial cleavages, and very difficult to overcome established patterns of racial differentiation. However, racial divisions are also intersected by factors such as gender, household income and educational status, so the issue should not be treated simplistically. Very few government programmes have successfully addressed the ongoing challenge of overcoming informal racial segregation patterns. However, some institutions such as schools have had an impact on overcoming racial schisms, among the youth as well as teachers.

9. This Chapter examines risks related to four main pathways: a) human migration; b) safety and security; c) social disruption; and d) governance. These are all interrelated in various ways, so they should not be considered in isolation.

10. For **human migration,** there will be pressure on housing and infrastructure, increases in the cost of living (and subsequent impacts on poverty levels), and the potential squeezing out of other alternative economic options. Almost all towns in the study area already experience housing backlogs, due to inter-town and farm-town migration trends. A key factor is the continued migration of work-seekers, which would start under Scenario 1 (Exploration Only). Once some work-seekers from elsewhere secure jobs and a foothold in the local town, it will encourage other people from their towns of origin to follow suit. Human in-migration to the affected environment often triggers inter-community conflict in competition for scarce resources, such as employment opportunities. The rise in incomes could lead to a property boom, with increased house prices. This, in turn, could increase municipal revenue from the rates base, in the medium term (houses are re-valued every five to ten years for rating purposes). If the exploration phase does *not* move on to the production phase, there will be a sudden and radical reduction in housing demand, and very likely an outflow of population. Mitigation efforts will include housing provision, training programmes and transparent employment practices. Municipal planning processes are typically slow and cumbersome, and therefore unable to respond timeously to these demographic fluxes.

11. As regards **physical security,** there may be impacts on levels of crime, fear of crime, traffic-related risks, pressures on policing agencies, and a sense of insecurity caused by seismic tremors and risks to clean household water supply. Crime could take various forms: By in-migrants, against in-migrants, xenophobia, and various social pathologies such as domestic violence. Increases in crime levels are not a foregone conclusion; they may decline due to increasing employment, but may spike again if SGD production declines or ceases. Various mitigation strategies are possible, depending significantly on the capacity of policing and social support agencies. Small towns in the study area will have to expand their traffic management capability significantly due to much greater traffic pressure caused by SGD trucking.

12. As regards **social institutions**, there may be more jobs and wages in the local community, stimulating new economic multipliers. However, this may be associated with increased competition for resources and xenophobia in a multi-racial society, disruption of local employment patterns, alienation, conflict and greater social inequality (which collectively

amount to a perspective called “the social disruption thesis”). The rapid influx of people tends to loosen social ties, with a constant population churn. New inflow of money, jobs and contracts will strengthen some families and weaken others, depending on people’s spending patterns. New money may be channelled to education, food and housing, but also to alcohol, drugs, prostitution and lead to possible increases in teenage pregnancies and the human immunodeficiency virus (HIV). The social disruption thesis became accepted as ‘conventional wisdom’. Over time, however, an increasing body of work has emerged that has challenged the findings reported in these early studies. Communities may become more resilient and adaptable over time; however it is not clear how much institutional effort will be required by other government agencies, to promote resilience. Furthermore, proactive company initiatives may well strengthen local social institutions. Various international agencies have compiled handbooks and guides to companies on promoting and supporting local social networks, institutions and capabilities.

13. In terms of **governance,** there may be increased pressures on already inadequate municipal governments to meet the growing demand for basic services, and new political tensions. Municipalities will be subjected to a wide range of demands for new or expanded services, and the administrative capacity, staffing levels, equipment, and outside expertise needed to meet those demands may be beyond anything that has been budgeted. In particular, road maintenance, traffic management and disaster management are likely to be heavy burdens. Municipalities are unlikely to benefit financially from SGD, because of their fiscal structure (dependence on property rates and service charges). Energy booms often bring concerns about bribery, corruption and fraud. Municipalities will require a great deal of institutional support and leadership development, to manage these challenges. The mineral leasing process typically involves experienced business people on one side and inexperienced farmers and municipalities on the other. This raises the risk that energy speculators will take advantage of local people, or that such perceptions are created, thereby detracting from municipalities’ legitimacy. Companies’ behaviour is determined by company policies as well as the decision-making style of local mine managers; in particular, their corporate social responsibility (CSR) policies and practices.

14. Various mechanisms are available to bolster local resilience and avoid excessive harm to the social fabric. These include a combination of South African mining approaches (Social and Labour Plans (SLP)), Social Impact Assessments (SIA), Social Impact Management Plans, United Nations Guidelines on Human Rights, and industry standards on community engagement. In addition, various forms of collaborative governance at local level, where local

interest groups can develop shared policies and programmes, will improve social networks as well as government capacity.

15. Municipalities, Provincial Governments and local communities should create local task teams to undertake monitoring of shale gas activities in their areas. This will require significant support by academics and researchers.

16. The risk assessment in this Chapter provides an overview of the possible consequences, the likelihood of them taking place, and the risk to the social fabric which they pose. These include:
    - *Slight but noticeable consequences* refer to small and manageable impacts, or impacts on small sections of the community, or those which can be generally addressed by existing institutions, or can easily be balanced or outweighed by positive impacts. The risks to the social fabric will be minor.
    - *Moderate consequences* refer to impacts which affect the bulk of the local population negatively, require some new institutional capacity, may well produce a net negative impact on the community, and would require some assistance by SGD companies and public authorities to manage. The risks to the social fabric will widespread, but manageable.
    - *Substantial consequences* refer to impacts which place significant strain on the bulk of the local population, require significant new institutional capacity to manage, and would require extensive assistance by SGD companies and governmental authorities to manage. This would require, inter alia, a new approach to regional planning and support. The risks to the social fabric would be extensive and burdensome.
    - *Severe consequences* refer to impacts which would cause significant social strain, would test institutional capacity to their limits, and would require significant SGD involvement to manage effectively. Regional planning and support systems would require extensive funding and skills to address possible impacts. The risks to the social fabric will be far-reaching and very negative.
    - *Extreme consequences* refer to impacts which could result in social or political violence or institutional collapse; mitigation would require a great deal of pre-emptive and far-reaching capacity-building as well as ongoing local partnerships between SGD companies, national government, municipal government, and local leaders. The risks to the social fabric would be profound, long-term and very destructive.

The analysis finds high levels of risk in all four causal pathways (migration, physical security, social relations and governance); however, mitigation measures can significant reduce the level of risk. The critical question will be the political will, on the part of Government and SGD companies, to abide by international guidelines on community engagement.

CHAPTER 11: IMPACTS ON THE SOCIAL FABRIC

11.1 Introduction: What is meant by "the social fabric"?

Social fabric: The term "social fabric" embraces numerous complex and interrelated phenomena, including:

- Demographic and economic factors;
- Behavioural issues (e.g. investment choices, political dynamics);
- Social institutions, such as families;
- Social organisations, such as municipalities and churches; and
- Social networks or relationships amongst people.

The social fabric is underpinned by people's beliefs and sentiments, including:

- A sense of *belonging* and identification with a particular social unit;
- A sense of *social justice* and equity, particularly in government policies;
- A willingness to participate in *shared activities*, and possibly undertake voluntary work;
- Attitudes of *acceptance* towards minorities and newcomers;
- A sense of *life satisfaction*, happiness, and positive future expectations; and
- A sense of *safety and security* (Markus, 2015:12).

The concept of social fabric is profoundly influenced by different sociological perspectives. This scientific assessment builds on various theoretical overlapping approaches, focusing on local communities as relatively intact social systems, influenced by internal and external variables. The work of Manfred Max-Neef (1992:198) broadly informs our approach, as he highlights the role of civil society and the social fabric to "to nurture local spaces, facilitate micro-organisations and support die multiplicity of cultural matrixes comprising civil society".

South Africa, with its contested political and racial history, poses particular challenges for maintaining the social fabric, as local conflicts may develop along racial or ethnic lines.

The study area has significant social and economic variability, particularly from the arid and underpopulated western Karoo zone to the more fertile and populous eastern zone; these zones also have different ethnic, linguistic and social profiles. Consequently, almost all observations in this Chapter would, in practice, need to be refined and adjusted to local contexts.

11.1.1 Interfaces with other scientific assessment chapters

The social fabric is closely interrelated with other Chapters in this scientific assessment, and it is by nature very multi-dimensional. The World Wildlife Fund for Nature (WWF) has identified five fundamental dimensions of well-being: Economics, subsistence, environmental services, cultural and spiritual dimensions, and the political system. The social fabric can be regarded as the totality of these dimensions (Dudley et al., 2008). The phenomenon of the social fabric therefore shares important interfaces with other Chapters:

- Through social networks and social institutions, there are interactions with the *natural environment*, including the use of land, water and vegetation (Jones et al., 2016) (see Hobbs et al., 2016 and Holness et al., 2016). The values, customs and practices of social groups affect the sustainability of natural resource use, which in turn affects the viability of social systems. There is an increasing understanding of the valuable role which the natural environment plays in human well-being.
- The social fabric also underpins the *economic system* (Hayden, 2011) (see Van Zyl et al., 2016). Social values, practices and institutions help to structure systems of production, distribution and consumption. Institutions such as municipalities and businesses play a key role in every link in these economic value chains. This affects manufacturing, tourism (see Toerien et al., 2016), transport (see Van Huyssteen et al., 2016) and agriculture (see Oettle et al., 216).
- The social fabric underpins specialist themes such as *heritage, health and "sense of place"*. Heritage is often a product of the social fabric, as people, families, and cultures create material and non-material products which last for generations (see Orton et al., 2016); heritage in turn affects people's sense of place (see Seeliger et al., 2016), and may strengthen the social fabric when people organise to protect these cultural products. In particular, collective memory is important for the creation of a social fabric.
- The *health sector* is also directly linked to the "social fabric": Where social cohesion is poor, this may be reflected in poor health conditions, such as teenage pregnancies, alcohol abuse, high infant mortality rates, and typical poverty-linked diseases affected by poor nutrition and housing (see Genthe et al., 2016).

TERMINOLOGY

The community: Identifying "the community" in any specific context is not a straightforward matter. Communities can be identified on the basis of any number of shared traits such as geographic territory, religion, culture, history, and kinship. Furthermore, people can have multiple overlapping identities and these identities can change over time. Definitions of community are necessarily open to contestation, both in terms of the limits ("who is included"?) and the structure ("how do members interact with one another?"). In this report, the term *community* is used to refer to people's connection with their home town or district; however, this spatial identity may be affected by racial or ethnic identities. Communities may contain schisms, fault-lines and conflicts.

Social resilience: The ability of communities to respond constructively to disturbances; to maintain themselves, or to recover, adjust, and embark on new development options. Disturbances can be "pulse" events (occurring as discrete events) or "press" events (those that persist for extended periods of time). The term "resilience" is somewhat subjective, as some people may regard a community as resilient, whereas others may feel that it has lost its essential character or functions.

Institutions: The sets of social rules, behaviours, and relationships that last over time. Institutions may be formalised by organisational mandates (such as churches or municipalities), or they may be informal (such as families and kinship groups). Institutions are particularly important in promoting local resilience by reshaping policies and practices in changing circumstances (Wasylycia-Leis et al., 2014).

Boomtowns: All resource development, including shale gas development (SGD), is particularly prone to creating local booms and busts, with rapid inflows and outflows of investment capital, labour, material and infrastructure (Christopherson and Rightor, 2011).

The "social disruption thesis": New extractive industries into an area can disrupt and alter the local social fabric in many ways. This can bring benefits in the form of new jobs and increased local revenue, but it can also bring a variety of social and public health harms (MEDACT, 2015). There is typically a period of adjustment and eventual stabilisation (Chapman, 2015). Larger towns with diversified economies are more able to absorb rapid investments without social disruption (Brasier et al., 2011).

Monitoring and evaluation: Baseline studies should be conducted *before* any mining operations, so that the impacts can be tracked and measured. Some agreement needs to be reached amongst several disciplines on the kinds of indicators, the measurement of those indicators, and appropriate methodologies. In terms of local Integrated Development Planning processes, key local indicators should be identified and tracked according to national policies as well as local developmental priorities. Communities can participate in drafting indicators and conducting monitoring. This would count as best practice regarding planning and measurement.

Cumulative effects: Cumulative impacts can result from the aggregation (over time or space) and interaction of the impacts of a single activity. Cumulative impacts typically involve multiple actors and causal pathways (Franks et al., 2013; Duinker et al., 2013). The impacts may affect stakeholders in different jurisdictions and involve issues that are legally regulated by multiple institutions; some issues do not fall under any formal regulatory authority at all. The analytical focus now becomes the *receiving entity* (a catchment system, a town, or a housing market), and not simply an impact *per se*. This will require a deeper understanding of the *properties of potentially impacted systems, over time*, even though the required information is often not available, and generalisations from other contexts are of limited use. The practice of 'Cumulative Effects Assessment and Management' (CEAM) within the field of impact assessment (Loxton et al., 2013) analyses complex adaptive systems (Duinker et al., 2013).

11.1.2 Key assumptions regarding the social fabric in the study area

Shale gas development (SGD), like other resource mining activities, typically takes place in rural areas, of varying degrees of remoteness. The local settlement forms are usually commercial agriculture, small towns and other rural developments (such as natural parks, game farms, tourist sites, and heritage sites). This narrows the social fabric question to the impact of SGD on *small towns and rural hinterlands*.

The introduction of short-lived, spatially intense extractive industries in and around small, rural communities can profoundly change the social and economic fabric (Hays et al., 2013:39). Such changes can be positive as well as negative, and can affect different groups in the local community in very different ways (Esteves and Vanclay, 2009). Beneficial local effects could include local wage increases, increased purchases of local goods, corporate social responsibility projects, and local economic multipliers.

Rapid, large and novel SGD operations may be welcomed by some segments in the community, because they bring new economic life to underdeveloped rural localities. However, this may also bring developmental challenges and disrupt the social fabric in many ways, including the rapid in-migration of workers (Christopherson and Rightor, 2011; Tonts et al., 2012). Since the 1970s, there has been a growing international literature on the phenomenon of *"boomtowns"*, and more recently, many sociologists have articulated a "social disruption thesis", which emphasises the negative social consequences of boomtowns. The specific components of the "boomtown" concept have been widely debated, so the term should not be applied in a simplistic fashion in South Africa.

Social impacts are often the product of numerous different interventions simultaneously, such as new inflows of money, new technologies, and new people. In turn, social impacts stimulate other causal relationships, creating *cumulative* impacts, involving several time frames, social scales, analytical disciplines and "reverse impacts" (Franks et al., 2008:2-3).

South African towns are in many ways similar to United States (US) and Australian towns, where there is a large literature on boomtowns, resource towns and SGD towns. Jacquet and Kay (2014) suggest four typical assumptions of the "classical" boomtown literature. South Africa meets at least two of these assumptions: a) fairly remote rural towns; and b) non-local ownership of mining operations. But South African towns have their own characteristics, drawn from more African trends (such as indigenous culture and migration patterns). There are, as yet, no African SGD towns. Comparisons between South Africa international case studies should be treated with some caution.

There is a growing appreciation for context-specific development factors, guarding against blanket generalisations about the impact of mining on the local community (Tonts et al., 2012; Deller and Schreiber, 2012). Some communities may experience more positive impacts, while other may be affected more negatively; also, within a single community, different people may have very different experiences (Forsyth et al., 2007). Key determining factors include existing socio-economic and demographic structures of towns, the political economy of the resource itself, the role and behaviour of companies, and regulatory and institutional structures (Chapman et al., 2015). Other key characteristics include climate, terrain, natural amenities, distance from metropolitan areas, local skills, poverty rates, age profiles, educational attainment, population density, culture and lifestyle (Hays et al., 2013; Deller and Schreiber, 2012). Social dynamics are profoundly influenced by human agency (whether that of leaders, followers or institutions). Different towns in the study region have very different trajectories, based on local leadership and institutions, and this will influence the potential impacts of SGD.

The fate of boomtowns can vary significantly. Some boomtowns go through subsequent busts; and others level out after a boom. *"Busts"* can either be rapid and catastrophic declines (for example, when a mine shuts down), or a slow process of down-scaling, or simply a transition from a construction phase to a less labour-intensive phase of energy production (Jacquet, 2009:24). The longer-term impacts vary across localities, as well as different kinds of resources being mined. One of the key variables affecting the economic and social future of resource towns is their ability to promote economic diversification. In the US, gas-related boomtown phenomenon often takes the form of several sequential mini-booms and mini-busts, as work proceeds from one well to another (Jacquet and Kay, 2014).

Communities may be fairly adaptable to large-scale and rapid changes. Over time, communities are likely to experience significant shifts in their sense of contentment and social cohesion. This may initially take the form of declining social cohesion, but later they may evolve a greater sense of acceptance and a restoration of social networks (Brown et al., 2005).

A significant difference between the US shale gas experience and that which is likely to take place in South Africa, is the ownership of mineral rights: In the US, this vests in landowners themselves, whereas in South Africa, it vests in the state. In the US, shale gas companies have therefore expanded their deals with landowners, with two significant consequences: They have offered large bonuses to landowners, and they had to drill within a specified time period, to keep legal access to these land-holdings (Jacquet and Kay, 2014:4). This has contributed to large amounts of money flooding into local communities, and creating local social divisions, economic multipliers and unstable local economies. In South Africa, this scenario is likely to be much more muted.

All South African towns and rural areas are characterised by the legacy of racial segregation and *apartheid*, in their spatial form (racially-defined neighbourhoods) and social networks (poor levels of racial integration). This creates a constant backdrop to any other social dynamics and pathologies. It is very easy to exacerbate racial cleavages, and very difficult to overcome established patterns of racial differentiation. However, racial divisions are also intersected by factors such as gender, household income and educational status, so the issue should not be treated simplistically. Very few government programmes have successfully addressed the ongoing challenge of overcoming informal racial segregation patterns. However, some institutions such as schools have had an impact on overcoming racial schisms, among the youth as well as teachers.

The social fabric also underpins the political system. South Africa is a constitutional democracy, based on universal franchise, democratic representation, devolution of powers, the protection of individual rights through a Bill of Rights, and public participation in development decision-making. Subject to the limitations imposed by Section 36(1) of the Constitution, individuals enjoy protection of their rights to, *inter alia*, to an environment that is not harmful to their health or wellbeing. These rights provide an important framework whereby local communities can address possible challenges to their health and welfare.

However, the practical functioning of the political system at local level is often conflictual and contested, often on racial and linguistic lines. There is inter-party competition (often overlaid by racial identities), as well as ongoing intra-party conflicts within the majority party (the African National Congress (ANC)). Local disputes are often affected by political party dynamics, creating a potentially volatile political environment.

The social fabric is affected by a wide range of sectoral policies, including health, education, social development, policing, economic development, and municipal governance. The potential array of legislation impacting the social fabric is vast. Most significantly, South Africa has a comprehensive public funded social protection programme. The *Social Assistance Act* (2004) creates a broad social protection strategy (Devereux, 2010; Coetzee, 2014; Committee of Inquiry, 2002). Several types of grants are available: Grants for Older people, Disability grants, War veterans' grants, Foster care grants, Child support grants and Grants in Aid. Poor people also have access to other developmental initiatives such as the National Schools Nutrition Programme, the Expanded Public Works Programme (EPWP), the Municipality Infrastructure Grant (MIG), municipal services subsidies, and the Umsobomvu Youth Fund (UYF). These grants have generally positive effects on poor communities (although some abuses may exist) and on sustaining local economic multipliers in rural towns.

11.2 Scope of this Chapter

This Chapter examines risks related to four main causal pathways: a) human migration patterns; b) physical security (and psychological sense of security) in local communities; c) altered social relations and institutions; and d) impact on governance and power dynamics. In each of these pathways, subsidiary causal dynamics are identified, which may impact on the general direction of causality. These are:

1. For human migration, there will be pressure on housing and infrastructure, increases in the cost of living (and subsequent impacts on poverty levels), and the potential squeezing out of other alternative economic options (see Van Zyl., 2016 and Toerien et al., 2016). Human in-migration to the affected environment often triggers inter-community conflict in competition for scarce resources, such as employment opportunities. Mitigation efforts will include training programmes and transparent employment practices.
2. As regards physical security, we consider impacts on levels of crime, fear of crime, traffic-related risks, pressures on policing agencies, and a sense of insecurity caused by seismic tremors and risks to clean household water supply (see Hobbs et al., 2016). Various mitigation strategies are possible.
3. As regards social institutions, there may be increased competition for resources and xenophobia in a multi-racial society, disruption of local employment patterns, alienation, conflict and greater social inequality. New inflow of money, jobs and contracts will strengthen some families and weaken others, depending on people’s spending patterns. New money may be channelled to education, food and housing, but also to alcohol, drugs, prostitution and lead to possible increases in teenage pregnancies and the human immunodeficiency virus (HIV). However, proactive company initiatives may well strengthen local social institutions.
4. In terms of governance, there may be increased pressures on already inadequate municipal governments to meet the growing demand for basic services, new political tensions, and a possible increase in corruption, rent-seeking and gatekeepers. SGD companies may, however, contribute to building municipal capacity in key functions.

There are various ways to analyse and classify possible causal pathways affecting the social fabric. Figure 11.1 below illustrates insights drawn from the international literature on SGD; it is possible that South Africa may, in fact, diverge substantially from these trends:

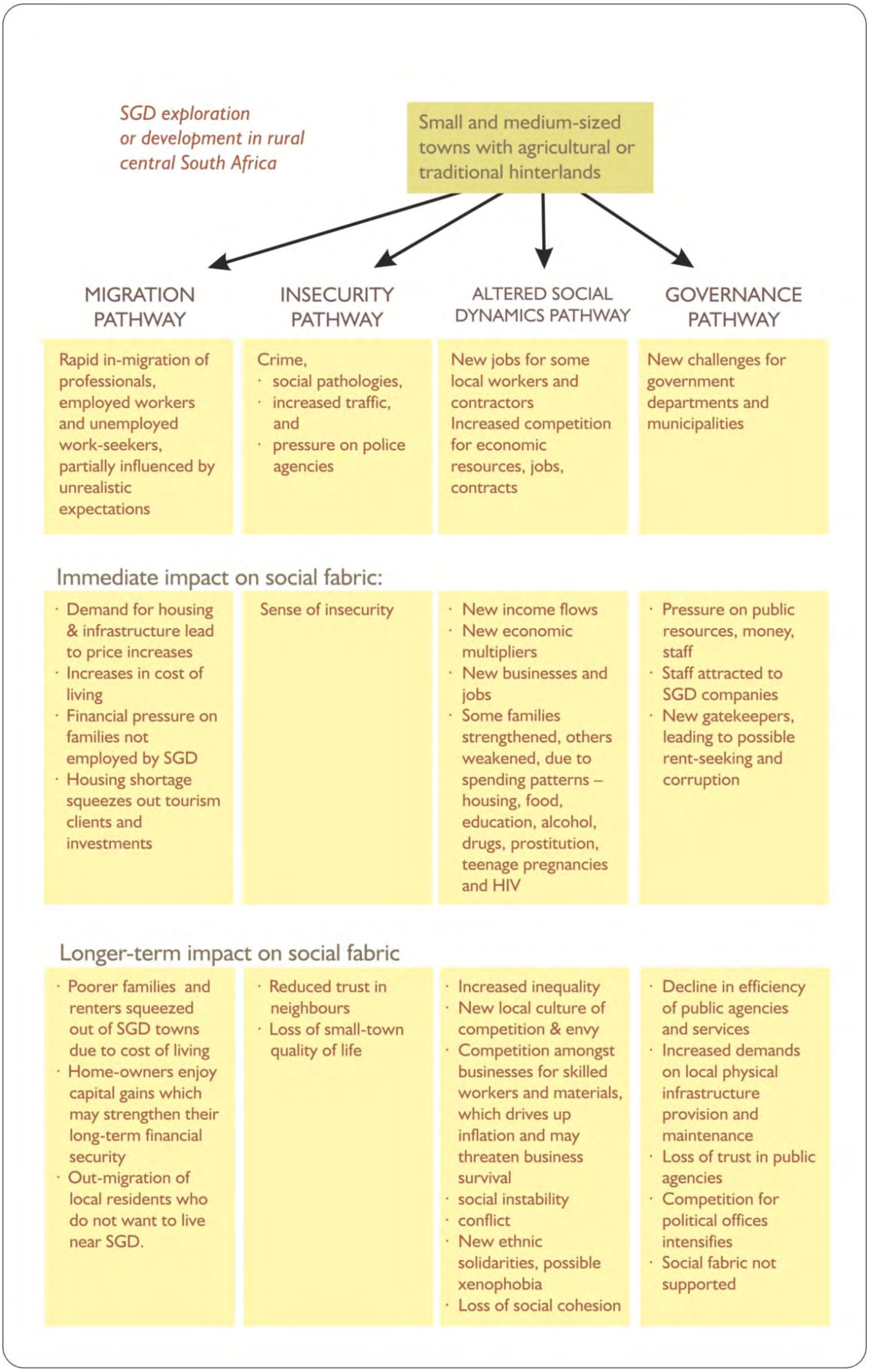

Figure 11.1: Potential causal pathways affecting four dimensions of the social fabric.

11.3 Impact 1: Rapid in-migration

11.3.1 Description

SGD requires more employees and materials than conventional oil and gas drilling (Brundage et al., 2011:20). These processes are much more industrial in nature, labour intensive, and technologically advanced than conventional shallow gas development. They often involve a wide range of subcontractors.

A general factor affecting resource development is the rapid increase in a transient population (Christopherson and Rightor, 2011). The increase in population may take place in the core localities, or in the larger towns nearby. The drilling workers may be specialist teams from elsewhere in the country. Even more basic jobs, such as construction, trucking or services may consist of itinerant teams moving along from one site to another – i.e. they may not be local workers. This usually means an influx of young men – some with families, many without. New work-seekers may arrive, in anticipation of securing jobs (MEDACT, 2015; Deller and Schreiber, 2012; Jacquet, 2009, Chapman et al., 2014). There is an added concern that people throughout the country may have unrealistic expectations about employment possibilities, and may migrate into the regions in large numbers.

This Chapter explores impacts on housing as well as social and psychological dynamics. Project-induced rapid migration has been experienced throughout the world, with a wide range of problematic consequences (IFC, 2009), particularly because it leads to local competition for resources amongst different groups, and places strains on public service delivery.

The immediate impact will be an increase in rental housing demand, depending on four factors:

1. The speed and scale of industry growth in a given community: A fast pace of development, with a high number of wells drilled in a single year, means the drilling activity within a community will be concluded more quickly than if the drilling activity occurs over a longer timeframe. Therefore more workers will be required per year, with more housing, infrastructure and road usage needs, which will be more difficult for local communities to manage. A slower pace of development will be less disruptive and will extend economic benefits over a longer period of time (Kelsey, 2011: 13);
2. The existing housing capacity of a community before drilling begins;
3. Companies' policies on providing their own staff housing; and
4. The availability of local skills relevant to SGD operations (Raimi, 2012).

Housing shortages and high living costs generate significant economic insecurity, especially among already vulnerable populations and those on low or fixed incomes, including the elderly (Ryser and Halseth, 2011; McKenzie, 2015; Williamson and Kolb, 2011), with some poorer people becoming subject to homelessness, overcrowding or being forced out of town (Ennis et al., 2014). As a result of rising housing costs, cheaper housing options such as caravan parks, tents and garages may be sought by long term residents (Chapman, 2014; McKenzie, 2015). The pressure on housing can be alleviated by companies providing temporary housing units (sometimes called “man camps”).

Private investors and Government may be reluctant to initiate housing projects for the new workforce, because of the unpredictable cycle of SGD (Christopherson and Rightor, 2011). Slow Government progress regarding land release for worker housing can create development bottlenecks and delays (Haslam-McKenzie, 2013), due to complex and time-consuming approvals processes. Rapid housing price increases can launch a property construction boom with inflated house prices; however, these entrepreneurs may then face rapid declines in property values once SGD tapers off in that area. When production ceases or declines, it will cause retail to decline, shops may stand empty, and this may lead to foreclosures on people who cannot meet their mortgage payments (Shigley, 2009).

New SGD operations, and an influx of workers, can place great pressure on services and infrastructure maintenance and expansion (Chapman et al., 2014). Levels of service to the local population may therefore decline. Maintenance of new infrastructure is costly for municipalities (Christopherson and Rightor, 2011:365), particularly in the post-boom period, if population levels decline and local tax bases shrink. However, SGD companies may make a contribution to municipal infrastructure revenue, by means of grants or service payments. As local workers in SGD receive improved levels of income, they may well use this income to improve their housing status, thereby adding to the local housing stock.

Because of the rising demand for housing and other goods and services, the cost of living is likely to increase (Raimi, 2012; Chapman et al., 2014). Inflation tends to have a greater impact on the poor than on more wealthy community members.

Rates for hotel rooms and rental units increase in response to greater housing demand (Christopherson and Rightor, 2011; Chapman et al., 2015). Hotels may be booked out for years in advance (Raimi, 2012). This would limit tourism, casual visitors and other business people (Haslam-McKenzie, 2013; Raimi, 2012). However, it would mean an economic windfall to accommodation providers, and may increase levels of local employment.

11.3.2 Scenario 0: Reference Case

All towns in the study area have experienced population growth between 1996 and 2011, at an increasing growth rate (Atkinson, 2015; Nel and Hill, 2008; Groenewald, 2008). This is partially due to in-migration into the region, as well as migration of farm workers into to the towns. Some towns have a strong inflow of seasonal farm workers (Sundays River Local Municipality (LM), 2013; Breede Valley LM2014).

Almost all towns in the study area are already experiencing housing backlogs, with local people waiting for government-built houses. The backlogs are stimulated by migration, as well as "unbundling" of households; replacement of traditional huts by brick houses; and replacing poorly-constructed houses. Therefore, there is generally a pressure on housing provision, as well as providing water, sanitation and electricity infrastructure to residential sites (see Table 1 in Digital Addendum 11A). In many municipalities, land is not available for housing; or if it is available, it will need a long process of land acquisition, subdivision, servicing and title deed registration. Traditional areas are particularly challenged by the informal land tenure system, giving rise to sprawling informal settlements. There is also a growing demand for affordable middle-class housing, mainly due to the growing class of black officials (such as teachers, police, and municipal officials).

Several municipal Integrated Development Plans (IDPs) mention a lack of adequate local construction skills (see Table 2 in Digital Addendum 11A), although there are two construction companies in Cradock. Several IDPs also mention the lack of housing administration capacity within the municipalities, due to inadequate staff or technical training (see Table 3 in Digital Addendum 11A).

Without SGD, it is likely that inflows into rural towns will continue, and the demand for housing for the poor and the middle class will continue to grow. This will require additional land acquisition, service provision, land registration and other tasks associated with housing expansion. The major form of risk is that in-migration outpaces SGD job creation, and/or that in-migration destabilises local communities.

11.3.3 Scenario 1: Exploration Only

Much of the international literature deals with workers from elsewhere; who move to resource towns on a temporary basis. It is not clear whether these workers are seeking jobs, or whether they already have secured jobs when they arrive. The general impression is the latter: These are workers who have some mining experience and some previous work in the gas company, and now arrive to work on a new rig in a new town. Possible employment for the Exploration Only scenario is as follows (Table 11.1):

Table 11.1: Potential employment for the Exploration Only scenario.

Scenario	Specialist staff per year	Local staff per year	Number of years
Exploration Only	800	450	8

A very important question is the likelihood of local employment, compared to in-migration of workers. A study in the Marcellus Shale region showed that most of SGD occupations require no formal post-secondary education; however, nearly all of them require skills and knowledge unique to the SGD industry, which need to be learned through on-the-job experience (Brundage, 2011: 36). Another factor is the hard work ethic, working long hours in difficult conditions, which is required from the workers. Once again, this is typically appropriate for people who have significant previous experience of the industry. These factors will inhibit local people from obtaining and keeping jobs during the Exploration Only scenario, as well as during Scenario 2 (Small Gas) and Scenario 3 (Big Gas).

“General labour” accounted for about 20% of the SGD workforce in Pennsylvania. In addition to SGD staff, there would be indirect employment creation by construction firms (building roads, housing camps and pipelines), as well as businesses providing food and other social services. At the start of SGD, these posts would be suitable for local workers.

In South Africa, there are likely to be five employment scenarios, with different housing requirements:

1. Recruitment of expatriate and South African professionals, who would stay in local hotels or guest houses. During Exploration, the 800 specialist staff (all in-migrants) per annum, for a period of eight years, may not be in the town all the time; they may come and go as their services are needed. Nevertheless, for small Karoo towns to absorb such staff, often staying for weeks or even months, would pose massive challenges for local housing provision. Most Karoo towns have about four to ten guest house or hotel establishments, possibly with an average of 20-50 rooms per town. They are likely to be booked out by the shale gas companies (as has been done by road construction companies and renewable energy companies in the Karoo). This leaves very few rooms, if at all, for tourists or business travellers. These professional employees may be scattered over several towns, which would lessen the impact. The risk is that recreational tourists may be replaced by business tourists, and that this would make businesses more vulnerable in the long term, when SGD declines in the area.

2. Some longer-term national specialists may bring their families and would require rented homes. This may offer a windfall to homeowners. It is likely that existing rental stock will be rented out at premium prices; this in turn may force out families who were already renting houses and apartments. The main risk is that the existing housing shortfall will be exacerbated, with deleterious social consequences for families without adequate accommodation.

3. Locally recruited general workers will either continue to live at home and be transported to work on a daily basis, or will live in the on-site “man-camps”.

4. Unskilled or general workers from further afield would migrate to the local Karoo towns in search of work; if successful, they will either live at the on-site “man-camps” or in back-yard shanties or informal settlements.

5. Unskilled or general workers from further afield, who migrate to the Karoo, but are not successful in securing work, may find temporary backyard accommodation in the local town, waiting for job opportunities to open up, or resorting to the informal sector (such as trading or food sales). The risk is that this may give rise to new or enlarged squatter camps, or backyard shacks, placing more strain on water, electricity and sewerage services.

The factors described in the Reference Case (existing housing constraints, described above) suggest that that a sudden rapid additional inflow of workers or work-seekers will strain the local housing stock, housing waiting lists and municipalities’ ability to acquire suitable serviced land for housing expansion. Renting out shacks will also be a financial windfall for existing house owners or renters, but with several cumulative consequences: It will drive up rentals which may force out existing very poor people who have been barely subsisting in very basic conditions. These people may have to move in with families into overcrowded homes, or may build new shacks on the edge of town (where there may not be services such as water, sewerage or electricity).

The influx of people will certainly put pressure on local water resources (in the arid Karoo), as well as the capacity of sanitation systems. The risk is that it could lead to ongoing service provision and management problems, such as sanitation blockages and spills.

The pressure on rentals as well as other consumer goods will increase the local cost of living, thereby increasing the strain on the local residents who are not benefiting directly or indirectly from SGD (i.e.

employees and housing providers). This creates the risk that local economic inequalities may be exacerbated, as the fortunes of people benefiting from SGD jobs diverge from those who do not. However, with indirect jobs created, there may be more money in circulation, to afford higher rentals. The greater the stimulation of additional economic multipliers in other sectors; the greater the mitigation of the risk of inequality.

Given that the future of SGD would still be fairly uncertain, it is unlikely that Government would invest capital for expanding housing and infrastructure stock. This situation creates the risk that the pressure on existing stock and resources would therefore continue for at least eight to ten years.

The rise in incomes could lead to a property boom, with increased house prices. This, in turn, could increase municipal revenue from the rates base, in the medium term (houses are re-valued every five to ten years for rating purposes). If the Exploration Only scenario does *not* move on to the Small or Big Gas scenario, there is the risk of a sudden and radical reduction in housing demand, and very likely an outflow of population. Many accommodation providers will have a “livelihood shock” in terms of sudden decline of revenue. This will set in motion numerous negative multiplier patterns, affecting particularly the retail and construction industries. It may even lead to a decline in municipal rates, thereby putting pressure on the municipality. These impacts may be mitigated by deliberate attempts to diversify the local economy, during the exploration phase; this would help to stabilise economic fluctuations.

11.3.4 Scenario 2: Small Gas

This scenario builds on the previous one; it assumes that sufficient gas reserves, at appropriate prices, can be extracted to undertake production for local or regional use in the Karoo. Consequently, it follows about eight years of steady in-migration into the local Karoo towns, as illustrated in the Exploration Only scenario.

During this phase, employment declines significantly from exploration levels (Table 11.2):

Table 11.2: Potential employment for the Small Gas scenario.

Scenario	Specialist staff per year	Local staff per year	Number of years
Small Gas	120 (down from 800)	180 (down from 450)	25

Following a decision to undertake limited production, Government may start allocating capital funding (assuming that it has the resources to do so), which can provide new serviced residential sites and housing stock. This will relieve a great deal of the pressure on housing and services. However, it will also mean that guest house establishments and people who rent out accommodation will gradually experience a decline of income (from this sector), and would have to turn back to conventional tourism markets (if possible).

If SGD were to proceed in the region, then some of the Karoo towns may become single industry resource towns (SIRTs), which magnify their exposure and risk to global economic shifts (Argent, 2013), typically dominated by a single firm. The economic future of the towns will depend on whether there is economic diversification or not. SGD impacts on tourism are particularly important. If the towns can re-energise their tourism industry, there will be sufficient accommodation capacity. However, if the town, region or hinterland has been environmentally damaged due to SGD, either in terms of water quality, architecture, landscapes, or reputation, then a shift towards tourism may be difficult. Where the natural or cultural attractions of the local area have been compromised, it will probably reduce or completely eliminate the flow of investment in tourism.

In SGD towns, increasing economic multipliers may lead to a changing profile of local businesses, from family-owned to chain stores. There is the risk that small, locally-owned businesses may be forced out. If SGD activity were to decline at a later stage, chain stores may close or scale down, and local economic resilience may decline.

If other productive sectors, such as tourism or agro-processing, are not able to stimulate housing demand, then towns may start a long-term trend of decline. As jobs and incomes decline, there may be a degree of out-migration, particularly of work-seekers, as well as people who prefer a more rural quality of life. This creates the risk of undermining local social capital and support networks.

When this phase starts, some of the original migrant workers may have become permanently attached to the SGD company and its local operations, and they may have brought their families (either working class or middle class) to settle in the town. This may help to sustain property values.

A key factor is the continued migration of work-seekers, which would start under the Exploration Only scenario. Once some work-seekers from elsewhere secure jobs and a foothold in the local town; it will encourage other people from their towns of origin to follow suit. A “migration path” may be created, whereby work-seekers steadily migrate to Karoo towns; if they do not secure SGD work, they may find informal housing and try to find other jobs or even odd-jobs. Such workers, tied by cultural, location and even kinship links, may use their own “social capital” to access housing and jobs, possibly squeezing out local people. If the Small Gas scenario brings a down-turn as exploration moves to SGD, these people may choose to remain in the area, particularly if their families have accompanied them. This creates a risk of ongoing social tensions between in-migrants and local people

It is not clear whether migrant SGD workers would bring their families with them. If they do, their children would then need to be accommodated in local schools. Many schools in the area (particularly no-fee schools) are already filled to capacity.

11.3.5 Scenario 3: Big Gas

If the limited phase development proves to be profitable, and a phase of large-scale production ensues, then employment will increase again (Table 11.3):

Table 11.3: Potential employment for the Big Gas scenario.

Scenario	Specialist staff per year	Local staff per year	Number of years
Big Gas	800 (increase from 120)	1200 (increase from 180)	30

This may well give rise to new rounds of in-migration, either of people already working for SGD companies, or of new work-seekers. Pressure on housing, infrastructure provision and schools is likely to increase. The main pressure on housing is likely to take place during the drilling phase of each well, calculated at about 98% of jobs in the Marcellus shale region (Brundage et al., 2011:5). This is usually regarded as the “boom” period. During the production phase, only very few workers remain, and they are likely to be situated at company offices further away. However, future scenarios are not at all clear; in the Marcellus region, scenarios varied from: a) a relatively quick flurry of activity that subsides when drilling moves to another location; b) high intensity drilling that jumps from hotspot to hotspot; and c) moderate and sustained drilling across an entire basin (Brundage et al., 2011:21).

A significant factor is that SGD is highly responsive to international energy prices. Experience in the US has shown that price volatility may lead to companies putting their local operations on hold, if prices are low, and then re-start operations after price recovery (Jacquet and Kay, 2014). This creates the risk of a series of mini-booms and mini-busts in local economies, with staff moving in and out of the locality, in sequential waves, and destabilising local social networks and planning processes. During the later stage of development, when the industry has matured, a greater number of local people are likely to be employed, as they would have developed the required skills and experience (Brundage et al., 2011:20).

11.3.6 Options for mitigation of risks

In-migrants bring revenue, at least to certain service providers (e.g. accommodation). This revenue flow can create local jobs and multipliers, stimulating new rounds of wealth-creation – at least for some people. The most effective mitigation of "boom and bust" cycles is economic diversification. However, this will require pro-active steps by municipalities and SGD companies.

The organisation called *Equitable Origin* has devised standards for the shale gas industry. They recommend that companies pre-emptively assess potential negative economic impacts on local communities of a large and sudden influx of labour. Companies should devise mitigation measures in collaboration with authorised representatives of the affected community and local governments. They can also take measures such as the design of temporary worker camps, community programs and cultural safeguards to reduce potential negative impacts and augment positive impacts (Equitable Origin Standards LLC, 2015:17).

In the discussion below, we differentiate mitigation efforts that have implications for: i) policy; ii) spatial development frameworks; and iii) project specific Environmental Impact Assessments (EIAs). We also differentiate between the primary agencies responsible for mitigation: i) national government; ii) provincial government; iii) LMs; and iv) private developers.

Measures for mitigation could include:

1. *Companies:*
    - Promote local employment: Companies need to create transparent methods for job applications and criteria for hiring staff, possibly indicating that preference will be given to local applicants, if sufficiently skilled. SGD companies themselves may offer training courses to assist local people, or family members of in-migrants, to improve their schooling and/or technical training. Oil and Gas Industry Associations have provided guidance for reporting on local recruitment and training (IPIECA et al., 2015). These measures will be the responsibility of SGD companies; however, it will require policy guidelines set by national government departments, notably the Department of Mineral Resources (DMR).
    - Create sufficient man-camps to house migrant workers, and out-source catering and services to local residents, thereby stimulating local wealth creation without adding pressure to municipal services. This will be the responsibility of SGD companies, acting within local and district municipal development frameworks (such as IDPs).
    - Sign long-term leases and contracts with local guest houses, so that they can be assured of a steady flow of income over several years, and possibly use this income to add to their accommodation facilities in order to maintain the tourism market. This will be the

responsibility of SGD companies, as a private arrangement between them and tourism providers.

2. *Public authorities:*
   - Pro-actively release land for housing, and install infrastructure, so that in-migrants can build informal housing if required (in the short-term), or provide public housing (in the longer-term). Upgrade water, electricity and sewerage infrastructure, as well as local streets and stormwater drainage, to cope with the additional demand. This will be the responsibility of LMs, as part of their spatial planning responsibility; however, it will also require financial and technical support by provincial authorities.
   - Assist the local business sector, particularly through Business Chambers, to understand and respond to new opportunities posed by SGD. Where such chambers do not exist, they need to be established by municipalities and the business community working together. National and provincial guidelines by Departments such as Co-operative Governance and Traditional Affairs will be required to assist municipalities.

11.4 Impact 2: Safety and security

11.4.1 Description

SGD may reduce physical security in Karoo towns, due to an influx of outsiders in a context of fragile local households and networks. This follows extensive evidence of social disruptions in resource towns generally, and SGD towns more specifically, elsewhere in the world.

“Physical security” is here defined as a range of issues which can affect people’s sense of stability and safety. This involves a combination of empirical facts (e.g. crime rates) and people’s subjective sense of quality of life, including environmental impacts, heavy truck traffic, noise and light pollution, traffic accidents, perceived declines in liveability, loss of property values, social stress, fear of crime, and anxiety (Krannich et al., 1989; Hays et al., 2015: 39). For people in small towns where crime and social disruption has always been very limited, sudden social changes and risks will be felt particularly severely.

In several studies of mining resource towns, there appears to be a strong link between crime and resource booms, due to an influx of young single men (Ruddell et al., 2014; Deller and Schreiber, 2012; Negi, 2014; Chapman et al., 2015). In particular, there is a risk that alcohol-related offences may increase, illicit drugs become more prevalent (Pershee, 2011, Christopherson and Rightor, 2011), and property crimes and domestic violence may increase. A Pennsylvania study found increasing alcohol and traffic offences, but unclear correlations regarding SGD and other forms of crime (Centre for Rural Pennsylvania (CRP), n.d.). There may also be an increase in sexually transmitted diseases, due to more risky sexual behaviour by young men (Raimi, 2012).

There are at least five kinds of crime-related risks to physical safety which may ensue:

1. Crimes against property and people committed *by in-migrants* who cannot secure work – this could be against SGD staff as well as local people;
2. Crimes against the property of in-migrants (professional and unskilled workers) *committed by local people* who are unsuccessful in finding work, particularly if they are extremely unskilled or cannot hold down a job, particularly if they believe that in-migrants are "stealing their jobs";
3. *Domestic violence* caused by the disruption of sudden new household revenue streams, and poor spending habits of family members (e.g. excessive alcohol consumption);
4. *Increased social pathologie*s such as prostitution, in the context of many young men in the locality with income at their disposal. This, in turn, can lead to an increase in unwanted and teenage pregnancies. Anecdotal evidence of solar projects in the Karoo shows that "sun babies" have become a typical phenomenon in these towns; and
5. Crimes committed against in-migrants *by locals* as a form of xenophobia.

Nevertheless, one should not jump to conclusions. In some US shale gas counties, crime rates had increased *before* the advent of SGD; in other cases, they had increased in shale and non-shale counties. Even where crime increased in SGD counties, this may have happened because of other causal factors (CRP, n.d). In fact, other studies have pointed to falling rates of crime, unemployment and welfare dependence in a number of large resource towns (Lawrie et al., 2011, Chapman et al., 2015; Raimi, 2012), possibly due to new opportunities for local employment. "Any generic argument associating boomtowns with rising levels of reported crime needs to be treated with caution" (Chapman et al., 2015, also see Deller and Schreiber, 2012). Much of the evidence about the impact of resource towns on crime rates is anecdotal. The issue depends significantly on the level of statistical collection – e.g. by region, county or locality (Raimi, 2012). Many rural police forces have inadequate data gathering systems (Ruddell et al., 2014), so it is difficult to determine baseline conditions with subsequent trends.

In South Africa, a study of violent crime near mines showed that an increase in mining activity tends to lead to a *decrease* in crime; however, as mining activity slows down, there follows an *increase* in violent crime (Axbard et al., 2015). A potentially important link in this causal chain is migration of workers; when economic or mining activity declines, there is a risk that these workers would be left unemployed with few links to other local labour markets. A real concern is the risk of an increase in crime in farming areas, particularly where new access roads have been built, and effective access control has been dissipated.

Other variables also affect the possible impact on crime levels: Police professionalism and tactics; where workers live (locally in single-male hostels, or further afield, with their families); and whether companies hire locally or not. People from out of town may play a greater role in crime rates, but we should not assume that an increase in crime is caused by gas workers as perpetrators - in some cases they are the victims (Raimi, 2012).

Resource-based boom communities tend to experience increased traffic incidents, including accidents, collisions, “driving under the influence”, and hit-and-run offences (Pershee, 2011; Ruddell et al., 2014). It also included higher levels of traffic, number of emergency room visits, and the demand for emergency response services (Christopherson and Rightor, 2011). The large increase in heavy trucks will damage the local roads which were not designed for such traffic. This will require a clear model of co-funding by the SGD companies, to maintain the roads; if this is not in place, a significant amount of public investment will be required for reconstructing and maintaining these roads.

Increased crime and traffic tend to leave police forces overworked and stretched thin (Archbold 2013 and Ruddell et al., 2014). Additional policing will be required in SGD towns, requiring more government expenditure (Raimi, 2012). This, in turn, will place greater financial and manpower strain on other policing regions.

Increasing earth tremors and damage to buildings may also create local feelings of fear and distrust (Van der Voort and Vanclay, 2015). The process of assessing damage may be lengthy, leaving people dissatisfied and frustrated. The costs can be far-reaching, with homes needing structural reinforcement. House prices may decline, and compensation and payment mechanisms are complex.

11.4.2 Reference Case

Generally, rural areas in South Africa are characterised by lower crime levels than the large cities. In the study region, crime levels vary: IDPs in four municipalities mention that property crimes are low or decreasing, and increasing in four other municipalities (Table 4 in Digital Addendum 11A). Crimes of physical violence (murder and assault) are decreasing or are not very serious in five municipalities, but increasing in four others. The most prevalent forms of crime are alcohol and drug-related crimes (mentioned in 12 IDPs as serious and/or increasing), and sex-related crimes (mentioned in 11 IDPs). Five of the IDPs noted grave concern about the levels of crime. Six IDPs mentioned insufficient police stations, or inaccessibility of police stations, as a problem.

Traffic management is a municipal function, in terms of Schedule 5 of the Constitution. Four municipalities mentioned traffic accidents in their IDPs as a significant problem (see Table 5 in Digital Addendum 11A). Four municipalities mentioned that they have recently strengthened their traffic management capability, while three others mentioned that they have none, or insufficient, traffic management capability.

Disaster management is a provincial function, while fire-fighting is a municipal function. In practice, there is a lack of clarity regarding roles, responsibilities and funding sources. Typically, district municipalities (DMs) take some responsibility for disaster management in their jurisdictions, and some of them assist LMs to build fire-fighting capability (see Table 7 in Digital Addendum 11A). The general impression is that both these functions are poorly developed at municipal level, although some planning has been done in some cases. Typical problems include: insufficient budget, staff, skills, buildings and equipment, and slow response times, particularly in rural areas.

In the 34 municipalities included in the study, there were a total of 799[1] public safety posts on their organograms; of these, 143 posts were vacant. In six municipalities, no public safety posts have been created. In 13 municipalities, ten posts or fewer have been created. This suggests that some municipalities are either incapable of dealing with traffic or public safety issues, or their manpower is stretched very thinly. In the absence of SGD, it is likely that this profile will continue, due to municipal financial constraints.

Mitigation efforts by SGD companies would need to focus on building or providing disaster management capability. SGD-related disaster management is likely to be highly specialised, including dealing with blow-outs, fires and spills. SGD companies typically have their own disaster management teams. However, municipalities will need to liaise with these companies well in advance of actual drilling, to clarify roles and responsibilities.

Two additional factors may have an impact on local people's sense of security: the possibility of seismic tremors (which may lead to poorly-built houses collapsing), and threats to the supply of clean drinking water.

[1] Note that this is a misrepresentative figure, since five of the District Municipalities listed in the Table 6 in Digital Addendum 11A contain large areas falling outside the study area.

11.4.3 Exploration Only

In this scenario, there is likely to be a significant influx of workers, or of people seeking work. A major factor will be the degree to which local people can secure jobs, and hold down those jobs; also how many in-migrants will secure jobs, and how many will arrive and be left stranded and frustrated.

The best-case scenario will be a large level of employment of local people – either the unemployed, or people who are currently employed and can secure better skills and incomes through working for the SGD companies. This may cause a decrease in crime. The worst-case scenario will be an influx of many outsiders, seeking work, and many not being successful in finding work. Some of those people (typically single men) may remain, in the hope of finding work (either with the SGD companies or other local jobs). During the period that they are living in the local town, with few networks or resources, they may resort to crime. The most realistic scenario will probably be roughly midway-between these extreme cases.

Most Karoo towns have a very limited police force, geared to rather low levels of crime and rare cases of serious crime. The additional crimes and social pathologies brought in the wake of SGD may greatly add to the workload of police services. The South African Police Service (SAPS) will need to plan for this, in terms of larger allocations of staff, vehicles and other resources.

The exploration phase will be accompanied by traffic pressure on local roads, either by official SGD vehicles, or by workers moving in or around the town. This is likely to cause an increase in traffic violations, accidents, injuries and even deaths. In towns which are not accustomed to heavy traffic, children and the elderly may be particularly vulnerable. Local people will have increased anxiety caused by increased traffic hazards, accidents and loss of life on the roads; as well as stress due to roadworks.

A particular challenge will be disaster management. SGD will require new kinds of hazardous materials. Where spills happen, either on roads or on-site, rapid response teams will be required. Many smaller Karoo towns do not have a fire service at all, let alone any more sophisticated forms of disaster management. This will place pressure on provincial disaster management services, in terms of funding, staffing, equipment and training.

Many small Karoo towns have very limited health provision, depending either on a small local clinic or a local private doctor. Typically, injured or ill people have to be transferred to public or private hospitals elsewhere. In cases of serious injury, this could be a life-threatening situation. Government clinics may need to increase their local medical staff.

If seismic testing is done in the vicinity of towns and farm houses, people may experience damage to their structures. This is particularly likely for very old buildings (pre-World War I) as well as township houses. Not a single IDP in the study area mentioned seismic tremors as a risk. This suggests that seismic activity will be a new form of hazard for municipalities to deal with. Several municipal IDPs mention poorly constructed public housing in black townships; these houses may be prone to damage from seismic tremors, causing threats to property and physical safety. This will bring added maintenance burdens to house-owners, accompanied by a sense of infringement and resentment.

At the end of the exploration phase, there may be a decision *not* to continue with production. This will mean a sudden loss of jobs and livelihoods. A crime wave may well ensue, which could include crimes against property, people, social pathologies, domestic violence and xenophobia.

11.4.4 Small Gas

During this scenario, a steady level of employment is maintained for 20 to 25 years, providing a reliable income stream to the community. However, the loss of jobs from the Exploration Only phase may bring a higher level of crime and insecurity, which may well continue into the long-term, particularly if the local economy remains weak and undiversified.

Significantly, crime and lawlessness, even of trivial kinds (such as littering and begging), are likely to be a major disincentive for future tourism investors, and may encourage them to leave this region. This may create ripple effects in the ecotourism industry, as there may be an increase in animal poaching and attacks on tourists in isolated rural areas.

SGD will intensify the level of traffic, both of staff, heavy equipment and hazardous materials. This will add to the workload of local police forces and disaster management teams. With low-level production, seismic disturbances may continue to damage properties, placing additional financial burdens on the shoulders of home-owners.

At the end of the Small Gas scenario, SGD may be terminated, causing new rounds of retrenchments and "shocks" to livelihoods, with a new wave of criminality.

11.4.5 Big Gas

During full production, employment is likely to be increased, which may again reduce local crime. However, much depends on the level of in-migration which had taken place in the previous two decades. Where there are a vast number of in-migrants expecting jobs, and not being successful in securing employment, a significant level of crime may continue. There have been informal reports of people seeking work in the Karoo, and being too poor to afford the travel costs to return home. They then stay on in the Karoo towns, eking out a living from odd jobs in the informal sector. This will continue to add pressure to the public safety authorities.

Under the Big Gas scenario, traffic pressure is likely to be very heavy, due to the transport of equipment and materials, as well as staff circulating to and from work. This is likely to intensify the work of the police service as well as disaster management teams. On the other hand, road construction is one of the most accessible opportunities for employment for local unskilled workers.

Seismic damage is likely to intensify, with potential dangers to properties (particularly poorly-built township houses) and human injury. Furthermore, if SGD results in contamination to drinking water (and many towns rely on boreholes located several kilometres outside the built-up area), this will cause local consternation, and it may even result in political agitation.

11.4.6 Options for mitigation of risks

Mitigation will require:

1. Proactively increasing staff at police stations, with varied specialisations, such as domestic violence, alcohol management, traffic management, disaster management, theft and murder. Steps need to be taken that new police officers are adequately trained, managed and integrated into the community. This will have budgetary implications for the SAPS. Mitigation efforts will be the responsibility of national and provincial departments of Safety and Security, at the level of strategic planning.
2. Proactively strengthening Provincial Departments of Social Development, to provide more social workers to deal with household problems, at the level of strategic planning.
3. Creating effective local labour bureaux so that employment processes can take place in a transparent, fair and professional, to prevent xenophobia, conflict and violence. This will be the responsibility of the Department of Labour, at the level of strategic planning.
4. Workforce development programs for those who might seek jobs in the oil and gas sector and related industries, such as construction, machinery maintenance, pipeline construction. This will be the responsibility of the Department of Higher Education, in partnership with SGD companies.
5. Companies can insist on high standards of behaviour by employees.
6. Strengthening traffic management systems, and constantly improve road maintenance, possibly with the support of SGD companies. This will be the responsibility of local and

DMs, with the assistance of provincial road and traffic departments. It will be required at the level of strategic planning.

7. Providing traffic training to school learners. This should be a national intervention by the Department of Basic Education, with priority given to SGD regions.
8. Rapidly up-scaling fire-fighting and disaster management capabilities at provincial and municipal level, in partnership with SGD companies.
9. Regular measurement of seismic tremors (see Durrheim et al., 2016).
10. Regular water testing and rapid response when any evidence of water contamination is detected (see Hobbs et al., 2016).

11.5 Impact 3: Altered local economic dynamics, social relations, and institutions

11.5.1 Description

This Chapter does not provide an adequate overview of local economic multipliers (this topic is discussed in Van Zyl et al., 2016). However, some consideration of local economic impacts is necessary, to prevent an impression that all impacts on the social fabric are negative or disruptive.

Local communities can benefit from several types of beneficial economic impacts:

- *Direct* impacts represent the direct increase in the number of jobs due to the spending by SGD companies, including on-site workers, geologists, technicians and other company employees;
- *Indirect* impacts measure the additional jobs and output gained in those sectors from whom the natural gas industry contracts or purchases, such as seismic and well completion companies, trucking and construction companies, and gas processing; and
- *Induced* impacts measure the additional jobs due to an increase in household and government expenditures.

The *total economic impact* is the combination of these direct, indirect, and induced effects (Kelsey, 2011:30).

A key factor affecting economic multipliers is the size and spending patterns related to land leasing and royalties (Kelsey, 2011:37). Recipients of these funding streams may or may not spend their money immediately, and may spend it outside the locality. In South Africa, this important impact will be significantly smaller, since royalties will not be payable (only land leasing will be relevant).

As boomtown conditions set in, communities are likely to experience different stages in their reactions (Jacquet, 2009:12). Initially, officials and residents may be *enthusiastic***,** as they look forward to the economic impacts of job growth and retail spending, while the possible negative impacts are either unknown or are dismissed as unlikely in their specific area. When the new workers arrive in noticeable numbers, the town may experience some *uncertainty,* and people begin to become aware of negative impacts. Divisions may emerge within the community as to whether the growth is detrimental or beneficial. As the changes speed up, the community may experience *near panic,* with people becoming confused and angry with one another. Government services are overwhelmed and quality of services declines; any prospects of increasing revenues look uncertain or remote. Finally, as the core problems are identified and planning or mitigation strategies are developed, the community *adapts* and accepts the reality of the situation. Sometimes these phases can be experienced almost simultaneously, in different sectors of the community.

The 'social disruption' thesis (England and Albrecht, 1984; Lawrie et al., 2013) argues that rapid economic and demographic changes associated with large-scale resource development lead inevitably to social and psychological dislocation and a breakdown of established community social structures. The rapid pace of development stretches services and infrastructure, can undermine a sense of community and belonging, and can contribute to problems such as drug use, crime, alcohol abuse, domestic violence and suicide (Chapman et al., 2015; Deller and Schreiber, 2012). Socio-psychological impacts can be pervasive and diffuse, and can include an increased sense of insecurity, uncertainty, injustice, anger and family stress (Loxton et al., 2013; Shandro et al., 2011), either during the start-up phase or during a later down-turn. These, in turn, can affect the motivations, goals and decisions of community members.

An influx of temporary workers (often predominantly composed of young men) can negatively affect community cohesion, increase the cost of living, and be associated with higher levels of alcohol and drug use, mental illness and violence. Such negative effects typically fall disproportionately on community members least able to bear them (MEDACT, 2015:18.) An extensive literature (cited in Jacquet, 2009) shows that boomtowns are often associated with higher mental health caseloads, crime, divorce, suicide and alcoholism, as compared to non-boomtowns. Rapid social change, uncertainty, the isolation of migrants' families, inadequate housing and poor services are typically regarded as the causes of such dysfunctions, and this increases the demand for mental health services (Raimi, 2012). Currently, health clinics are very inexperienced in dealing with mental health issues.

The threat to social stability is a wide-ranging phenomenon, which can take different forms in different situations. It can also affect various groups in very different ways. Social disruption affects in-migrants as well as the local community members.

Employees who are long distance commuters may remain on the worksite ("man-camps"), where all accommodation, meals, entertainment and other amenities are provided. They may work for the SGD companies, or for non-SGD services such as catering, transport, or drilling. Very often (but not always), these migrants are male. For the commuters themselves, the system of single worker migration can be positive (e.g. extended leave, no interruption to family's residence, it does not affect their children's education, high incomes, camaraderie, interesting work, career opportunities), but also negative consequences (loneliness, marital strain, anxiety and possible alcohol abuse). Facilities may be better during the operational phase of a SGD operation, but rather primitive during the construction phase (Misan and Rudnick, 2015).

Local communities would experience a rapid influx of newcomers, with different values, habits and needs. Social change takes place rapidly: A relentless increase in traffic may worsen their sense of physical insecurity, and face-to-face relationships become more distant (Jacquet, 2009). Towns are suddenly flooded with strangers. Inflationary pressures may affect the poor, including the elderly (Jacquet, 2009). Young people may face mixed impacts, with greater job opportunities, but also increased crime and overcrowding of schools. Marginalisation of local people can take place, on account of their lack of experience in mining activities (Negi, 2014).

In boomtown conditions, tensions can arise between new in-migrants and old-timers, and a sense of bifurcation between the two groups can develop. Newcomers often bear social hardships, including substandard living conditions, stress from moving to a strange and isolated community, and social isolation from hostile old-timers (Jacquet, 2009:20; Pershee, 2011; Filteau, 2015).

An important aspect of increasing inequality is raising prices of local commodities, notably food, housing, services and strategic items (such as car parts). This affects all local residents, including those who do not earn the higher wages paid by the shale gas companies (Christopherson and Rightor, 2011:359). Over time, those people involved in the wealth boom can ride out these price increases, or can even benefit from them; other community members tend to experience an erosion of their incomes. Landowners who lease their properties to shale gas companies would gain financial rewards; their neighbours may only experience the inconveniences (Raimi, 2010). Those landowners who signed leases in the earlier stages may have weaker deals than those who held out until later (Brasier et al., 2011). Property owners who rent out accommodation are likely to have a rapid increase in revenue. Uneven distribution of benefits and costs from drilling activity has the potential to create divisions within communities (Raimi, 2010; Chapman et al., 2014).

In some cases, SGD pits neighbour against neighbour, as people disagree about whether or not to drill in a local community. These divisions have the potential to sour friendships and divide the community (Raimi, 2012). In some cases, disputes over drilling have led to lengthy and costly lawsuits, hardening local social divisions. These lawsuits are sometimes between neighbours; in other cases, lawsuits arise between local communities and drilling companies. Divisions may develop between farmers who intend to collaborate with SGD companies (e.g. selling or leasing their land), and those who do not intend to do so (Brasier et al., 2011). All farmers, including those who have not sold or leased their land, may experience inflationary pressures.

The rapid influx of people tends to loosen social ties, with a constant population churn. Most workers, and particularly families, tend to stay in the region for only as long as a job lasts and then move away because housing costs erode the high wages. Community leaders complain that there is limited sense of community commitment, thus contributing to a sense of transition and 'shallowness' (Chapman et al., 2014). In rural communities, farmers may also perceive a threat to their social status as the most culturally and economically significant sector of the community (Jacquet, 2009).

The social disruption thesis became accepted as 'conventional wisdom'. Over time, however, an increasing body of work has emerged that has challenged the findings reported in these early studies, pointing to weak empirical evidence and an over-reliance on single-town case studies (Lawrie, 2011). As reiterated above, local circumstances can vary dramatically. The sense of social disruption may not be shared by all local people, and it may not remain at the same level over time (Brasier et al., 2011). Boom and bust periods may be followed by a recovery. As development evolves, many community members may adapt, leading to new phases of economic development. Indicators of wellbeing, such as community satisfaction, trust in other community residents, and social ties, may rebound to pre-boom levels. Communities may develop a new sense of identity, based on an acceptance of new local conditions.

Curiously, SGD has also united communities in some areas (Raimi, 2012). In communities where leasing activity has begun, neighbours have joined together in land owner coalitions. Some of these coalitions negotiate lease terms on behalf of their members, resulting in better monetary outcomes, improved property rights protection and stronger environmental safeguards. But while this is beneficial from the point of social cohesion (at least for land owners), it also increases the level of inequality between those who benefit from SGD (e.g. employees or landowners) and those who do not benefit (Jacquet and Stedman, 2011:84).

Where interaction amongst local community leaders is inadequate or minimal, or local institutions work in silos, then it is much more difficult for communities to adapt to rapid changes or shocks (Wasylycia-Leis, 2014). The in-migration of workers on shale gas projects may contribute to new forms of social cohesion, in terms of local friendships and intermarriages, between workers themselves (and their families), and between workers and local people (the “melting pot syndrome”) (Onoh, 1997).

11.5.2 Reference Case

Small towns in the study area vary greatly in terms of their “social fabric”. However, there are some similarities. Typically, the towns consist of a small middle class, including white entrepreneurs or retired people, as well as black or coloured government officials and a few emerging black entrepreneurs (typically in sectors such as retail and transport).

Figure 11.2: Central business districts in Karoo towns.

Race relations in many rural towns are fairly settled, with racial social status differences still remaining, but some degree of practical co-operation across racial lines within government departments or private work places. There are still very few cases of spontaneous friendships across the colour line, and even fewer cases of intermarriage between white people and black or coloured people. Commercial agriculture is still largely constituted by white farmers, and local Agricultural Unions are almost exclusively white. “Emergent” or aspiring small-scale black or coloured farmers tend to have their own agricultural associations, based on their common interest as commonage farmers.

The working class is largely black, but there are also white employees who generally earn fairly low salaries, which do not compare with urban salaries. Some white people are beginning to experience poverty and even destitution. All race groups have significant numbers of elderly living in these towns, drawing state pensions, which are often used to support children and grandchildren. The government "grant system" is a critical factor supporting local livelihoods.

Due to the amalgamation of municipalities in 2000, the erstwhile local leadership structure in each town (Mayor and Council) has fallen away. Although local towns are represented on the Municipal Councils by means of Ward or proportional representation (PR) Councillors, many Councillors' performance has been poor, so that townsfolk have very little effective representation in municipalities and there is little municipal responsiveness to local needs: "Many challenges have been identified with respect to governance. These include a lack of political leadership, political interference and patronage. There is also a demanding policy agenda, complex reporting demands and a weakening of institutional abilities in many municipalities" (Van der Byl, 2014:30). Municipalities are not geared for dealing with sudden, rapid or large-scale investments or social upheavals. Municipal projects are typically infrastructure-driven, funded by national government (such as water or sewerage projects).

Party-political structures are typically weak, and are only activated at election-time. At such times, there is often a great deal of mutual suspicion and animosity between contending political parties. To some extent, this is influenced by racial divisions, with the ANC being largely black, and the Democratic Alliance (DA) being largely white and coloured. Party-political competition therefore has the likelihood of enhancing racial cleavages.

Towns in the eastern part of the study area have traditionally been predominantly isiXhosa- and English- speaking; those in the west were predominantly Afrikaans speaking. There has been a growing influx of isiXhosa-speakers into the western regions, with the erstwhile dominance of the Afrikaans language gradually becoming undermined. In this situation, English is becoming an increasingly important *lingua franca*, particularly where government institutions are involved.

Almost every town has foreign traders, whether from China, northern Africa, India or other Asian countries. Generally, they are well tolerated because of their hard work and business acumen. However, there may be underlying resentment that these traders have undercut, and often squeezed out, the local African informal “spaza” traders (Figure 11.3). In South Africa, there have been severe cases of xenophobic violence; however, this has not taken place in the study region.

Figure 11.3: Informal traders

The growing class of tourism providers, often undertaken by investors from the cities (typically white South Africans) has added a degree of sophistication and even cosmopolitanism to South African small towns. They have also created employment, often of a higher status and with higher wages than traditional small-town occupations. The slow but steady influx of “semi-grants” (people who move from cities to rural areas) has been stimulated by various factors, such as the architectural charm of many towns, as well as the opportunities offered by the hospitality, arts and crafts, and cuisine trades (Figure 11.4).

Figure 11.4: Tourism investment in the Karoo

In towns where middle-class schools have closed down, many white and black middle-class children are sent to larger centres to better schools. The rural towns which host such schools do conspicuously better, both economically and socially, than the towns without such schools. Many parents do a great deal of their own shopping and business in the larger towns when they transport their children to boarding schools; this undermines the local economies of the smaller towns. This has led to a class-based bifurcation between middle-class schools (for black, white and coloured children) and working-class schools (typically black or coloured).

As in almost all rural towns in South Africa, poverty rates are high. Poverty rates range from highs in the 40 - 60% range (seven municipalities) to those in the 30% range (six municipalities) (see Table 8 in Digital Addendum 11A)[2]. The Human Development Index (HDI) ranges from 0.46 in the Ngqushwa LM (Peddie area) to 0.67 in the Makana LM (Grahamstown). Most HDI rates are within the 0.5 and 0.6 ranges. Dependency ratios (non-working age population dependent on working age population) range from 44.1% in Makana LM to 81.8% in Emalahleni LM (Dordrecht/Lady Grey). All these indicators suggest that the public authorities already have a major challenge of dealing with poverty. However, many areas have seen an improvement in poverty rates; this is generally understood to be a result of the roll-out of social grants.

There are high levels of inequality in the study area, ranging from Gini 0.54 in Breede River Valley LM (Worcester area) to 0.63 in Inkwanca LM[3]. More significant is the racial profile of HDI levels. In the Cape Winelands District, for example, the general HDI of 0.65 is a composite of 0.52 for black people, 0.66 for coloured people and 0.86 for white people (Cape Winelands, 2014). There are also locational inequalities: in Tsolwana LM, for example, the HDI for Tarkastad is 0.51 while that of Hofmeyr is 0.44 (see Table 8 in Digital Addendum 11A). South African towns are highly unequal, within their communities as well as in comparison with one another.

Social services are typically very constrained; for example, only four out of 15 social worker posts were filled in 2010 in the Camdeboo LM (Graaff-Reinet area; Camdeboo, 2015). Social capital is fairly weak. Rural towns typically have numerous church denominations, although many congregations in small towns are weak and without permanent clergy living in the town. Non-governmental organisations (NGOs) tend to be few and far between, although some Karoo towns have remarkably innovative and successful NGOs. Typically, their work is limited to one or two towns. Schools and clinics are fairly well developed in the study area, although the quality of these institutions may vary from town to town.

The general impression of rural towns is that much of apartheid South Africa still exists here, although it has been slowly altered by the rise of black and coloured officialdom, a new “emergent”

[2] Information not available for all municipalities.
[3] Information not available for all municipalities.

black bourgeoisie, the influx of more liberal values associated with tourism providers, and the recent arrival of renewable energy companies in many small towns.

11.5.3 Exploration Only

The rapid influx of professionals will strengthen the local hospitality industry by providing a regular cash flow to accommodation enterprises – an issue dealt with more fully in Toerien et al. (2016). This will stimulate businesses and job creation, because of their spending on food, housing, recreation and other household needs. These multiplier effects are profoundly affected by where workers live, and particularly, where their primary household is located, as this would determine the level of household remittances (Kelsey, 2011:17). The economic impacts of employment of locals differ significantly from employing migrant workers, due to different levels of local multipliers.

The percentage of people with post-matric qualifications ranges from 4% in Sundays River LM (Kirkwood/Paterson) to 12% in Makana LM (Grahamstown). These people may have good access to SGD jobs; however, the numbers are small, and this would give rise to greater levels of inequality. It would also require an inflow of additional professionals to fill all the required SGD posts.

The international phenomenon of growing divisions amongst land owners is likely to take place in the Karoo. Those landowners who host SGD companies, and secure attractive lease incomes, may well favour SGD, but they may be challenged by those farmers who do not benefit in this way. There are also likely to be ideological contestations about the desirability of SGD, based on intense debates which have already started (Ingle and Atkinson, 2015). Small towns in South Africa are often deeply divided about the desirability of infrastructural and other developments (Ingle, 2012), with some tourism entrepreneurs preferring to keep the rural ambience of their towns. Also, the influx of professional employees may cause recreational tourism to decline, and may also lead to a decline in accommodation quality and standards.

While exploration will attract a significant corps of highly trained professional staff, the most dramatic social upheaval is likely to be caused by in-migrant work-seekers. In the South African context, this may be called a “balloon-town” phenomenon (work-seekers who do *not* manage to secure work, but remain in the vicinity), in contrast to conventional analyses of “boomtowns” where in-migrants do indeed secure jobs on the new projects. Where such in-migrants do not secure work, this may well contribute to local problems of prostitution, teenage pregnancy, HIV and alcohol abuse. This will place added burdens on social services.

A growing degree of xenophobia is very likely, if people from other cultural areas migrate to the SGD towns to take advantage of jobs. Educational levels in the study area are generally low: Matriculation levels range from 11% of the adult population in Emalahleni LM (Dordrecht/Lady Grey) to a high of 25% in the Breede River Valley LM (Worcester area). It is not clear that these matric-holders will be able to compete with incoming job-seekers (see Table 8 in Digital Addendum 11A).

11.5.4 Small Gas

A key factor will be the likely growth in employment, for locals as well as outsiders. A US study found that approximately 75% of the natural gas industry's direct workforce is comprised of occupations that require little formal post-secondary education and relatively few trade certifications. However, these jobs depend heavily on the experience and acquired skills and knowledge unique to the natural gas industry. Finding workers with the unique skill sets, knowledge, and work ethic gained from experience in the gas industry remains a significant barrier to finding adequate local workforces. Initially, a large portion of natural gas industry jobs will be filled by non-local workers; however, over time nearly all of these jobs could potentially be filled by local workers (Brundage et al., 2011).

In the US, blue collar and white collar skills within local communities are often inadequate for SGD, and this required a strong focus on expanding local training options. In one Marcellus Shale study, 40% of workers needed a trade or industrial certificate, while 27% needed a technical college degree. Only 15% needed no previous training (Brundage et al., 2011). Over 150 different occupations were needed. In the rural Karoo regions, training opportunities are currently highly inadequate, and would have to be expanded rapidly in order to enable local people to benefit from job opportunities.

In US shale gas operations, the inherent uncertainty of SGD means that many workers remain only transient residents of a development location (Brundage et al., 2011). This constant churn of outsiders may generate or exacerbate racial schisms (within the local community) or xenophobia (towards in-migrants).

Some local people may develop good relationships with SGD companies, either as landowners, or as employees or service providers, and will continue to strengthen their economic position. SGD will bring a financial windfall to hospitality providers. Accommodation providers will have revenue to expand and upgrade their facilities. It could also stimulate more local property owners, in towns and on nearby farms, to make available rooms for rent and they will also share in the windfall. With the lucrative market for rental housing, there may be an increase in property values as local residents expand their accommodation services, or people from elsewhere move to the town to purchase or establish guest houses. This may stimulate a further round of investment in the construction industry, as more housing stock is built. Other local industries will benefit as well, notably retail, food, transport and recreation.

In the South African case, it is not clear what benefits will accrue to land owners, in terms of rentals. In the USA, rentals and royalties have been a major income flow to local communities (although it exacerbated inequalities, and was not necessarily spent within the local area) (Kelsey et al., 2011:11). In South Africa, mineral rights are owned by the state, and therefore landowners are likely to benefit from leases, but not from royalties. However, given that most commercial farmers are white; this may arouse local racial resentment amongst nearby black communities. The benefits accruing to some community members may give rise to envy and resentment on the part of local community members who are not as privileged. This may take the form of racial tensions, if white people are more fortunate in securing SGD jobs, tenders or contracts.

11.5.5 Big Gas

As in the Small Gas scenario, the problems associated with the inflow of employees (typically men), will continue; social and economic inequality will intensify, and local tensions may take the form of racial schisms (within the local community) or xenophobia (towards in-migrants).

Some local people will develop good relationships with SGD companies, either as landowners, or as employees or service providers, and will continue to strengthen their economic position. This may give rise to envy and resentment on the part of local community members who are not as privileged.

Given several decades of experience with SGD, these towns may develop a new identity and forms of social cohesion which provide stability, as well as a platform for future growth. These towns will lose their original character, but will become consolidated economically and socially based on a new sense of place.

11.5.6 Options for mitigation of risks

Mitigation will depend profoundly on building local leadership, governance and NGOs to identify and address potential social challenges. It is critically important that we learn from the renewable energy towns about the unintended social consequences of “boomtown” experiences. This will require:

1. Companies to proactively adopt policies and report measures to curb corruption or bribery, and promote financial transparency (IPIECA et al., 2015).
2. Departments of Social Development should provide guidance to municipalities and NGOs to manage new challenges. There should be a much greater degree of collaboration

between NGOs, churches, government departments and municipalities, to address issues such as prostitution, teenage pregnancy and alcohol abuse. The creation of local committees consisting of SGD companies, municipalities and other stakeholders will be required. This would be a region-wide intervention, and require strategic planning by the relevant Department, NGOs and municipalities.

3. Different languages will need to be utilised in community engagement processes, to match South Africa's multi-cultural social contexts. At a minimum, Afrikaans and isiXhosa will be required to complement English. It would be the responsibility of SGD companies to promote effective communication.
4. Due to the significant diversity amongst towns, in the quality and nature of their social fabric, town-based monitoring and community engagement will be required. Regional engagement processes will not be sufficient. This would be the responsibility of municipalities, under the guidance of provincial Cooperative Governance and Traditional Affairs (COGTA) departments.

These issues are addressed more fully in the section on Best Practice below.

11.6 Impact 4: Governance, power-holders and gate-keepers

Rapid SGD can increase the nature and level of risks faced by municipalities (Jacquet, 2009). Municipalities are subjected to a wide range of demands for new or expanded services, and the administrative capacity, staffing levels, equipment, and outside expertise needed to meet those demands may be beyond anything that has been budgeted (Christopherson and Rightor, 2011). In particular, road maintenance is likely to be a heavy burden (Kelsey, 2011:28).

There are two dimensions of government capacity which will be critical to management of SGD: Engagement with the SGD process itself, and management of the social consequences of SGD. While the SGD technical issues are analysed elsewhere in this scientific assessment, they are important for the social fabric because of the demands they would place on already overburdened municipal and government officials – which may lead to poorer service delivery in other sectors.

One of the major problems facing policymakers is that once an SGD project is approved, development often proceeds at a pace that exceeds the ability of governments to keep up with necessary service and infrastructure needs. This can contribute to social dislocation and, at least in the short term, a decrease in the local standard of living. Government agencies are often unwilling to commit to the upgrade or provision of new infrastructure and services until the company involved has full regulatory approval and financial certainty. As regards housing and land provision, there is also a difficulty of synchronising development phases: if the local government releases large areas of land prior to the project being approved they could over-supply the market and contribute to a crash in local property prices. In boomtown conditions, municipalities tend to have insufficient control of land use, due to central government regulations. The provision of social, economic and cultural services and infrastructure is complex, and often hindered by governmental agency structures, project complexity, competing demands and priorities, and remoteness. Very often, municipalities will not engage in preventive planning, so that their funding will almost exclusively be used for reactive programming – i.e. in response to problems that have already occurred. Also, municipalities often have to bear the brunt of new service demand immediately after mining development, but the expected revenue does not arrive until much later, either from local taxation or government grants (Jacquet, 2009; Chapman et al., 2014).

Municipal and government planners are additionally disadvantaged because rapid mining developments are often accompanied by an unequal distribution of information. The SGD companies will exert tremendous power over the pace of development and the amount of information that is available to planners; sometimes, an incentive to misinform exists (Jacquet, 2009).

It is also not clear that municipal revenue will increase from SGD. In countries with SGD experience, the municipal fiscal system may differ significantly from South Africa. Even in Pennsylvania, only 18% of 131 municipalities (i.e. 23 municipalities) reported higher revenues, either from Income Tax, Property Rates, local services taxes, or permit fees) (Kelsey, 2011:27). Given that South African municipalities only derive income from property taxes, service fees (mainly water, sanitation and electricity) and national subsidies, the municipalities may benefit little from the sudden economic windfall, at least in the short term. Significantly, income tax is not payable to the local government level in South Africa.

Even when municipal revenue increases, in the wake of boomtown conditions, municipalities may be hampered by laws restricting the use of the funding, staff shortages or inexperience, lag-times involved in large capital facility construction, and the public unwillingness to change long-standing local policy. Many rural areas historically have had little need for a highly educated and experienced planning staff, and quickly acquiring such a staff can be difficult and even controversial (Jacquet, 2009). Administrative costs for a range of planning, permitting, monitoring, and enforcement activities rise, as do the demands on the police, courts, jails, health services, fire and emergency services, and social services. All these services may require new equipment and training (Christopherson and Rightor, 2011). Community health nurses often have to engage with a range of new issues, such as water and air quality, water testing, and new kinds of diagnoses and referrals.

Municipalities must learn to plan, zone, negotiate with industry, evaluate different people's needs for compensation, figure out new laws, and revamp their infrastructure and services. They must learn to work with new types of people. Over time, municipalities may become more sophisticated, providing new services and facilities, and bureaucratise government systems (Jacquet, 2009).

SGD companies may contribute to municipal services, such as road maintenance and disaster management. However, a significant factor will be the length of time spent on constructing and operating a wellpad; if the impacts are short-term, then symbiotic relationships with LMs are less likely.

Impacts do not only occur at a locality level. Towns which do not have drilling operations, or where such operations have ended, may still be affected by neighbouring truck traffic, gas storage facilities or pipelines. These more widely distributed impacts need to be taken into account when anticipating what impacts SGD will have on communities (Christopherson and Rightor, 2011; Jacquet, 2009). This creates jurisdictional challenges.

In some cases, municipalities lose some of their skilled and experienced employees to private-sector jobs in the gas industry. That adds to the cost of recruiting and training new staff, and the need to increase salaries to attract or retain them (Christopherson and Rightor, 2011), at a time when the municipal revenue has not increased significantly.

The new SGD companies need careful supervision and monitoring (such as water quality and environmental health), which creates more pressures on public agencies (Pershee, 2011). If adequate monitoring is unavailable, it may create the risk that a breach at the waste sites could go unnoticed for months, increasing dramatically the risk and scope of potential harm. Even with funding for additional positions, it takes time to find, hire, and train new officials. New kinds of disaster management may be required. Dealing with abandoned wells poses additional problems for public authorities, and the costs may eventually be borne by local taxpayers (Sovacool, 2014). At issue are the kinds of public regulations, as well as their enforcement.

Not only do boomtown conditions impact on municipalities' administrative challenges, but they may also heighten political tensions. Local communities may well be divided about the merits of SGD. Typically; they may trust different sources of information on what is occurring. In the mining sector, the intensified awareness of resource depletion and the environmental and climatic impacts associated with mining activities have prompted debates on social negligence on the part of mining companies

(Gyapong, 2013). This creates a fractious political environment for local officials (Christopherson and Rightor, 2011). Local disagreements about SGD can lead to new schisms and conflicts, with politicians, businesspeople, economists, geologists, engineers, environmentalists, opinion-makers and local residents taking sides (Kenarov, 2013; Jones et al., 2013; Van der Voort and Vanclay, 2015; Vesalon and Creatan, 2015). Local protests about SGD may meet with strong or even excessive police force, giving rise to social anger, frustration and demoralisation (Short, 2015).

Energy booms often bring concerns about bribery, corruption and fraud. The mineral leasing process typically involves experienced business people on one side and inexperienced farmers and municipalities on the other. This raises the risk that energy speculators will take advantage of local people (Pershee, 2011), or that such perceptions are created, thereby detracting from municipalities' legitimacy. There has also been a surge in the prevalence of community protests in mining-affected communities across the world (Murombo, 2013; World Bank, 2010).

Corruption (or bureaucratic rent-seeking) has various negative impacts on local or national economies, including a greater development of bureaucratic regulations, and a tendency for poor project selection (Leite and Weidmann, 1996). Some theorists argue that there is a proven link between resource abundance and corruption (Papyrakis and Gerlach, 2007; Agbese, 2015). Natural resources provide an easy way of receiving "rents" (payments, kickbacks or bribes), and increase the returns to bribing the administration in order to gain access to these resource rents (Mauro, 1998; Gray and Kaufman, 1998). Politically powerful interest groups, linked to natural resource development, may attempt to influence politicians prone to corruption in order to adopt policies that may favour particular interests as opposed to the general public interest. Since abnormal profits are available to those who extract natural resources, officials who allocate extraction rights may be offered bribes. Corruption also tends to be self-enforcing: once a corrupt system is in place, individuals have no incentive to try to change it (Mauro, 1998). Because of their sizeable local investments, mining companies can exert a great deal of local power and influence (Tonts et al., 2012; McDonald, 2012). Sudden and unannounced operations closures can have a major impact on local multiplier effects and viability of enterprises.

The way in which SGD companies engage with local communities can have a significant impact on the local social fabric. At one extreme, companies can keep themselves isolated; at the other extreme, they can join and share decision-making processes and community projects in good faith. They may also become involved in rent-seeking arrangements with public officials (Garvie and Shaw, 2015). SGD companies may well have networks at national and provincial government levels that would effectively override local leaders and interests. Companies' behaviour is determined by company policies as well as the decision-making style of local mine managers; in particular, their CSR policies and practices have a direct effect on local communities (Wasylycia-Leis et al., 2014; Garvie and Shaw, 2015). In practice, CSR is influenced by numerous factors, including local situations, company culture, the strength of stakeholder demand, local leadership, the scope of environmental and social concerns, and past environmental incidents related to the mining sector in the region (Kotilainen et al., 2015). It is therefore difficult to generalise about company-community relationships.

Typically, mining companies attempt to secure a "social license to operate" (SLO) through various community initiatives, including charity, infrastructure improvement, health programs, support to local businesses through procurement policies, and sustainable livelihood projects (Kotilainen et al., 2015). Some mining companies employ a range of professionals, including anthropologists, health professionals, and development workers (Kapelus, 2002). The "machinery of CSR" now often includes divisions for community affairs, public relations, SIAs, and public involvement programmes (Kapelus, 2002). Companies' interactions and support for local community groups may create dependency relations (Kotilainen et al., 2015), or relationships of patronage and clientelism in the local community (Rajak, 2012). This may reduce local leaders' willingness to monitor companies' local activities or enforce regulations. Where communities feel powerless, they may develop a sense of lethargy and fatalism (Garvie and Shaw, 2015). Power relations between companies and local communities may remain highly unequal (Garvie and Shaw, 2015:2).

A potentially significant countervailing power may resort in coalitions of land owners, who negotiate jointly with gas companies to secure good leases. They may also be public-spirited: In New York State, these coalitions have insisted that shale gas companies improve their environmental monitoring and management, and that infrastructure is planned to promote local benefit. They have also taken gas companies to court when regulations or agreements have been violated (Jacquet and Stedman, 2011).

11.6.1 Reference Case

Municipalities in South Africa have been frequently characterised as weak institutions. In fact, they vary significantly, from fairly competent and professional agencies to poor and chaotic administrators. There are 34 municipalities in the study area, of which seven are DMs. Typically DMs contain, in their jurisdictions, several LMs. Their functions vary: most LMs are responsible for water, sanitation, electricity, streets, sidewalks, and other basic services, with DMs responsible for regional-level planning, regional roads, environmental management and disaster management. Often, the allocation of powers and functions is unclear, and municipalities tend to rely on a range of *ad hoc* service agreements amongst DMs and LMs to implement their functions (See Digital Addendum 11B for provincial and municipal powers and functions).

The pressures and strains on municipal government have been frequently asserted and analysed (for example, Van der Byl, 2014). Over the last twenty years, local governments have had to extend infrastructural and social services; at the same time, there have been two major structural transformations (1996 and 2000). They have had to develop a new generation of local government managers and professionals, while at the same time losing the institutional memory and skills of the apartheid generation (Solomon, 2008:41). They have had to deal with new legislation, policy and programmes in numerous sectors. An added difficulty is that municipal boundaries are set to be changed yet again after the 2016 municipal elections. These changes will require a great deal of organisational adjustments, causing significant confusion in the short-term, and possibly dysfunctions in the medium-term. In the study area, all the relevant changes are in the Eastern Cape, where ten municipalities will be consolidated into five.

Typical problems faced by municipalities include very limited revenue (small tax bases), a dependency on government grants for operational and capital expenses, understaffed administrations (sometimes combined with bloating in certain departments), inexperienced and insufficiently qualified officials, conflicts between municipal officials and councillors, and sometimes, suspected or proven corrupt practices. However, one must be wary of generalisations, as there are municipalities which have consolidated their performance over time.

Figure 11.5: Some municipalities have vibrant participatory processes.

Audit opinions (by the Auditor-General’s Office) provide a useful indication of municipal capacity (see Table 9 and Table 10 in Digital Addendum 11A). Audit reports do not only concern financial management. The 2012 Auditor-General's report noted that, in South Africa, "At least 73 percent of the auditees showed signs of a general lack of consequences for poor performance … modified audit opinions remained the norm. When officials and political leaders are not held accountable for their actions, the perception could be created that such behaviour and its results are acceptable and tolerated. More than half of the auditees can attribute their poor audit outcomes to mayors and councillors that are not responsive to the issues identified by the audits and do not take our recommendations seriously" (Van der Byl, 2014:34).

A total of 20 municipalities are rated as Excellent or Good; of these, 14 have improved in the last three years, while six have retained a constant course. Of the 16 poorly rated municipalities, four have improved (from extremely poor), ten have remained constantly poor, and two have deteriorated. In 2014, about one-twelfth of municipal posts were vacant (see Table 11 in Digital Addendum 11A).

For all the municipalities combined, in this vast region, there were only 142 environmental protection posts available in 2014, with 26 vacancies. For health management, there were 221 posts available, with 36 vacancies. For public safety, there were 799 posts available, with 143 vacancies (see Table 12 in Digital Addendum 11A for the municipal comparisons). Of course, it is not clear that the posts that are indeed filled will have the requisite skills, funding or equipment to function optimally.

Without SGD, a slow process of municipal capacity-building is likely to ensue, although there may be municipalities where deterioration may set in again, due to a lack of political leadership or a culture of corruption.

11.6.2 Exploration Only

Additional traffic will place significant pressure on rural and inter-town roads. Already, municipalities are facing severe road maintenance backlogs (see Table 12 in Digital Addendum 11A). A lack of finance, staff, skills and equipment already creates an almost universal problem of road maintenance. SGD will also place an additional load on environmental and waste management and environmental health staff, which is already thinly stretched (see Table 13, Digital Addendum 11A).

The dynamics between SGD companies and LMs are difficult to predict, and may vary from collegial co-operation to side-lining, manipulation or undue influence. Given the intense rivalry between political parties at municipal level, it is possible that SGD companies may – deliberately or not – become involved in these loyalties and rivalries.

11.6.3 Small Gas

These scenarios are likely to continue and intensify, and could vary greatly between one municipality/company and another. SGD taxation revenue will not contribute to the municipal revenue coffers, since they will not be ratepayers. Companies may need to purchase water from municipalities, which could result in increased municipal revenue, if water is priced suitably. This may place municipal water supplies under great strain. Dealing with possible environmental problems associated with SGD will also place strain on the limited resources of municipalities. In South Africa, SGD may gradually benefit municipal revenues if it stimulates new housing construction (for SGD staff and people attracted to support industries), as it would contribute to property rates.

11.6.4 Big Gas

By now, there could be ongoing support by national and provincial governments for municipalities, in their planning and management systems, and in dealing with SGD challenges. However, this positive scenario could be undermined by undue influence of SGD companies at national level, which could filter down to municipal level as well, possibly through party-political channels.

Some municipalities will build the capacity to manage SGD environmental health and road management challenges, but these are likely to be in a minority.

11.6.5 Options for mitigation of risks

There are already significant Community Investment guidelines drafted by international development agencies (e.g. IFC, 2010), which will need to be read and understood by local SGD companies as well as other stakeholders (such as municipalities and provincial government departments).

The ability of local governments and economic development organisations to build on the presence of the mine while it is in operation, by introducing long-term development strategies, can dramatically alter the short-and long-term impacts of the mine (Deller and Schreiber, 2012). SGD companies will need to take special efforts to engage municipalities and offer to assist them in crucial functions, particularly to prevent growing backlogs in approvals and infrastructure maintenance. Key steps have been proposed to empower municipalities to deal with the SGD challenge (Christopherson and Rightor, 2011):

1. The need for baseline data on roads, water treatment, rents, traffic, use of government equipment, water quality, and so forth, to hold companies and contractors accountable for the increased cost to local services that their activities generate. Without this, they

cannot make a good case for relief from the companies or the state. This would be the responsibility of municipalities, at a region-wide level; they, in turn, would require the assistance of provincial departments such as COGTA, Transport and Water Services.

2. The need for a dedicated revenue stream from gas production. This may be unlikely in the South African context, since our municipalities do not receive income taxes. They depend on property rates and service charges, which tend to be fairly inflexible and slow to adjust to local changes; and municipal expenditure growth may exceed revenue growth. However, it would be possible for SGD companies to establish their own local Trusts, from which municipalities and civil society organisations can draw down grants. Ideally, the DMR should provide guidelines on this; in addition, departments such as COGTA and Social Development should provide inputs in the design of these guidelines.

3. The need to budget for future costs: the effects of SGD may last far longer than the boom in drilling activity in any given locality. A variety of budgeting instruments; fiscal impact fees, trust funds, capital reserve funds and a healthy fund balance, should be set aside to defray future costs. This would require guidance by National Treasury and COGTA.

Some traditional communities in British Columbia are now insisting on multi-year pre-development plans from industry and government, cumulative environmental assessments, the protection of culturally significant areas and resources, and third-party or independent monitoring and enforcement (Garvie and Shaw, 2015). First Nations have signed agreements directly with companies whereby the latter agreed to abide by community conditions, including extensive baseline studies, rigorous monitoring, and local participation in monitoring processes. The challenge is to get the provincial government departments to implement these requirements.

In towns experiencing booms (and busts), leadership qualities can make a significant difference in managing the impacts of rapid investments, and to plan appropriate urban expansion (Shigley, 2009). It is therefore critical that provincial governments realise the potential strain which municipalities will face, and assist municipal councillors and senior officials to identify and address new challenges.

Diversification of local economies is an important way of reducing dependence on natural resource extraction. This can happen in two ways: 1) by extending the extracted resource based value chain (both forward and backward); and 2) by building value chains across multiple industries for other extracted, cultivated and/or grown resources (such as agriculture, retail or tourism). This could counter any fluctuations in commodity prices, as these would be different for the different products, especially where value adding happens along the respective value chains.

11.7 Risk assessment

11.7.1 Measuring risks

Impacts on the social fabric can be measured by means of several indicators. However, in many cases, an underlying *"theory of change"* needs to be clearly enunciated, to link proxy indicators with social outcomes, in purported cause-effect relationships. It is possible, for example, that the same indicator (such as jobs for in-migrants) may be linked to positive as well as negative impacts on the social fabric. It is also possible that several indicators may have contrasting impacts on a single dimension of the social fabric (for example, in-migration of professionals may support local accommodation enterprises, but at the same time, they may squeeze out recreational tourists, which may undermine tourism in the longer-term).

1. *In-migration:*
   - 1.1 Population figures, e.g. census figures;
   - 1.2 House prices, rentals, housing backlog lists (compiled by municipalities), backyard shacks, and ratio of people to houses (i.e. overcrowding);
   - 1.3 Temporary accommodation: hotel and guest house rooms, beds and occupancy rates, number of tourist-nights vs number of SGD staff-nights (this will require data collection systems launched at the beginning of the exploration process);
   - 1.4 Jobs for locals, jobs for in-migrants (this will require data collection by SGD companies);
   - 1.5 Local petrol sales as a proxy for financial inflows;
   - 1.6 School enrolment figures; and
   - 1.7 Amounts of water used locally.

2. *Public safety:*
   - 2.1 Crime levels, in various categories;
   - 2.2 Traffic accidents and rule-breaking, in various categories; and
   - 2.3 Number of cases of damaged houses.

3. *Altered social relations and institutions:*
   - 3.1 Teenage pregnancies;
   - 3.2 Clinic visits;

3.3 HIV and AIDS infection rates;

3.4 Farmers unions experiencing internal conflicts and disputes related to SGD; and

3.5 Incidents related to xenophobia.

4. *Governance:*

4.1 Staffing levels in key municipal departments: public safety, environmental management and environmental health;

4.2 Municipal budgets allocated to key municipal departments;

4.3 Municipal audit reports, in various categories;

4.4 Newspaper reports of collaborative or problematic interactions between municipalities and SGD companies;

4.5 Newspaper reports of positive or conflictual interactions between municipalities and communities/NGOs;

4.6 Road maintenance as a proxy for municipal infrastructure management capacity;

4.7 Municipal involvement in dealing with environmental health challenges related to SGD;

4.8 Annual rates and taxes as revenue stream in LM;

4.9 Number of indigent households in municipality;

4.10 Number of taxpayers in municipality; this is based on property ownership; and

4.11 Incidents of public protest (Hanna et al., 2016).

11.7.2 Limits of acceptable change

The question of the social fabric is a profoundly normative one, based on every person’s underlying assumptions regarding social systems, values and practices. Consequently, there is likely to be a great degree of controversy about the limits of acceptable change. At one extreme, a conservative view will regard any changes to the inherited social fabric in these rural towns as unacceptable; at the other extreme, people may be willing to contemplate a large degree of change, in the expectation that such changes will be constructively managed to secure beneficial outcomes.

This assessment attempts to pose limits which are roughly midway between these extremes:

1. Some degree of in-migration is acceptable, as long as it does not place the local housing market under severe strain. If there is some strain, it may kick-start private investors to expand their housing stock, which may benefit these towns in the long run. However, such housing expansion will need to be phased in a careful way, to prevent extreme pressure on the

existing infrastructural systems – which are already under strain. The most beneficial scenario is that in-migrants are accommodated in accommodation establishments (e.g. hotels, guest houses), or in man-camps. New building construction may also undermine local architectural heritage.

2. Local employment can be boosted by creating labour exchange offices. A fair and transparent hiring system will reduce social tensions and possible xenophobia. Proactive training opportunities will also help to balance supply and demand for labour.

3. Improved levels of policing, disaster management and traffic management must be achieved in order to cope with waves of in-migrants and local social pathologies.

4. Farmers associations and churches are likely to be much divided in their response to SGD, particularly where some land owners or service providers can benefit from deals with SGD companies. Given that these institutions are almost the only real forms of civil society in these rural areas, such divisions may sour local relationships for years to come, and thereby reduce the resilience of communities to deal with SGD or other problems. A limit of acceptable change may be described as preparedness for increasing conflicts, by creating or supporting local consultative institutions.

5. Racial tensions still exist under the surface of rural communities. Where some racial groups feel that they have been systematically disadvantaged by SGD, it is likely to increase these divisions, and this may lead to physical conflict or violence. This is clearly beyond an acceptable limit of change, and proactive steps will be required to illustrate fairness in employment and benefits.

6. The poorer sectors of the local communities are already facing problems of family violence, alcohol and drug abuse, and sexual crimes. Many families are very vulnerable, with young women particularly prone to abuse by single men. An influx of male workers is likely to exacerbate this situation quite quickly, as the experience of the solar and wind energy projects have shown (a phenomenon of “solar babies” born to unwed young mothers). These problems are likely to show themselves quite quickly after SGD operations begin. There are no clear pre-emptive measures that can be taken to prevent these problems. Hence the limit of acceptable change will be reached very quickly, unless vigorous pre-emptive steps are taken to support households in distress.

7. The poor condition of roads, combined with poor maintenance practices by municipalities, is likely to create severe traffic risks quite quickly after SGD operations begin. Hence the limit of acceptable change will be reached very quickly, unless road maintenance programmes are launched early in the exploration phase.

8. Some municipalities will cope with the exploration phase fairly well; others will struggle to manage even this level of SGD operations. Once limited production is reached, many municipalities and public services will face difficulties in planning and administering services related to SGD, including infrastructure management, environmental health, social development services, and policing. At higher levels of SGD operations, even the stronger municipalities will soon reach the limits of their capability. The key risk is that municipalities may be overwhelmed by too many new demands.

9. Many municipal officials and Councillors are prone to corrupt and nepotistic practices, as regular newspaper reports have shown. Different municipalities vary in their abilities to manage potentially lucrative contracts, with different levels of transparency and oversight. Many councillors and officials are also hampered by their lack of experience in dealing with mining issues generally, or SGD in particular. There is a risk that such individuals may find themselves in compromising deals with SGD companies, either knowingly or inadvertently. This may further reduce the legitimacy of municipalities, and promote party-political tensions. Once again, the limit to acceptable change is likely to be reached rather soon. One or two contentious situations are likely to set in motion a great deal of popular suspicion and hostility, particularly since the SGD issue is already a highly contested one in the Karoo. Proactive steps would require clear and sustained company measures to implement international guidelines on community engagement.

11.7.3 Best practice guidelines and monitoring

Best practices can be drawn from South African sources, as well as international agencies. South African practices have not been developed in relation to SGD and focus instead on general mining operations.

For mines, the drafting of SLPs is required, by South African law. The SLPs have several limitations, compared to the other approaches:

- The Plans are not made available to the public, although annual reports are;
- public involvement is not required in compiling them;

- there are no specified timeframes for reviews and updates;
- there are no explicit requirements for co-ordination with other initiatives;
- there is no explicit requirement for partnerships; and
- impact monitoring is not required (Franks and Vanclay, 2013).

Despite their shortcomings, SLPs would be an important strategy to examine companies' intentions with regards to local employment and social development. These Plans can be supplemented by other mechanisms to identify possible impacts and interventions timeously. In addition to the South African version of SLPs, there are several other formats for Social Impact Management Plans (SIMPS) (Franks and Vanclay, 2013). These include the International Finance Corporation (IFC) Performance Standards; Anglo American's Socio-Economic Assessment Toolbox and associated corporate management systems; and the SIMPS which were developed as part of an Environmental Impact Statement in the State of Queensland, Australia. These would be worth investigating.

SIAs attempt to encourage the commitment of resources for engagement with communities and other external stakeholders, and for the development of processes for regularly reporting on social performance (Franks and Vanclay, 2013). This also offers a valuable institutional mechanism to pin down company intentions and contributions to local development. Various methodologies for SIAs have been proposed, including the addition of local social needs assessments (Vanclay et al., 2015; Esteves and Vanclay, 2009).

SIMPs are a management tool for addressing social impacts during the implementation of planned interventions (projects, plans, policies and programs). SIMPs have the potential to operationalise the findings of dedicated phases of predictive assessment, outline the priorities, resources, strategies, processes, activities, commitments and staffing employed to avoid and mitigate negative impacts, and enhance the positive impacts of development (Franks and Vanclay, 2013). They can also build multilateral partnerships.

Internationally, communities have increasingly come to demand a greater share of benefits from local mining projects, more involvement in decision-making, and assurances that mining will be conducted safely and responsibly (Prno, 2013). This has resulted in the concept of a *SLO,* whereby communities broadly provide their approval of a mining project. Where the SLO is strong, local groups can participate in various activities of the mine, including reviewing reports, approving plans, monitoring agreement implementation, and guide training and hiring practices (Prno, 2013).

The success of SLOs depends on a variety of contextual factors, such as trust in government, local leadership and local values (Prno, 2013). Relationship-building is critical: companies need to be part of the fabric of the community, the company must keep its promises, and dialogues must be effective. Local benefits are important, including business opportunities, employment, and training; however, unequal benefits may cause further rounds of conflict. However, there is always the potential of local schisms, where part of a community is in favour of a mine (and participate in its structures), and another part remains suspicious. SLOs require some kind of joint management and decision-making.

SLOs have their own challenges. They are informal and unstructured (Owen & Kemp, 2013). They are open to interpretation, i.e. companies may claim that a SLO exists, or disaffected community members may claim that it does not even exist, or is not legitimate. SLOs may exclude marginalised local voices, which may lead to conflict at a later stage.

Important guidelines for social engagement are provided by the European Commission's *Oil and Gas Sector Guide on Implementing the UN Guiding Principles on Business and Human Rights* (n.d.). This document advises companies regarding their interactions with employees and affected communities. Key themes are: that human rights need to be included in companies' behaviour from the start of their activities in an area (including the exploration phase); that they need to engage in stakeholder mapping; that companies need to invest in appropriate skills to undertake such engagement; that these skills may differ from their normal operational technical skills; and that "root cause analysis" needs to be undertaken during situations of conflict.

Another set of standards for shale gas companies (*Equitable Origin,* 2015) includes recommendations on community engagement, dealing with grievances, monitoring impacts on water quality, land management and waste management. Furthermore, the International Council on Minerals and Mining has provided guidelines on obtaining Free, Prior and Informed Consent (FPIC) from local communities living in a mining region (see International Council on Mining and Minerals (ICMM), n.d.).

In addition to these company-driven mechanisms, capacity needs to be built at municipal and community level. A key question is the financing of municipalities; in order to fund additional or expanded functions, municipalities will need a larger funding flow. This could be provided by means of national subsidies, possibly drawn from SGD-related taxation revenue. SGD companies may be willing to fund local municipal functions, which would be a welcome adjunct to existing municipal revenue; however, this may also open the way to undue influence for these companies.

Municipalities and communities are often overwhelmed by rapid new activities, and suffer from a lack of clear information. Creating a community "task force" is a useful approach. It can serve as a clearing-house of information on the SGD and socio-economic issues. It can also conduct a baseline study of a locality before SGD starts, so that changes and impacts can be noticed quickly. Such profiles can identify the capacity required for local government and private services (ranging from ambulances to accommodation). Municipal staff or volunteers can work for this task force. The involvement of several LMs can help to promote inter-jurisdictional communication. Information such as drilling rig numbers and locations, well locations, permits, production trends, and real estate trends should be monitored. Such a task force can also reach out to energy companies who may be able to mitigate problems in some areas (Jacquet, 2009). Task forces can also plan for new growth, identifying new opportunities and resources. Local monitoring groups can build significant social cohesion and local empowerment (Haggerty and McBride, 2014). However, these processes may take years of sustained effort to establish and consolidate.

Planning and inter-sectoral collaboration are increasingly considered important for deriving long-term benefits for local communities from resource industry activities (Ennis et al., 2014). One suggestion that appears to have some merit is the notion of implementing a 'development authority' for SGD regions. These co-ordinating statutory bodies would have responsibilities cutting across portfolios in order to ensure projects move quickly and in an integrated way. In remote resource towns, this approach has the potential to manage the entire development/expansion phase, cutting across portfolios such as planning, land administration, regional development, environment, and even some of the essential service providers (Chapman et al., 2014).

Collaborative governance is becoming a popular means for addressing cumulative impacts in the resources sector; however, these often take a long time (up to two years) to establish. For example, in 2011, the Onslow Community Reference Group (CRG) in the Pilbara region in Western Australia comprises municipal, community and company representatives with members co-opted from state government agencies and contractors (Haslam-McKenzie, 2013). Typical issues include "buying local" and deciding where to house temporary employees. The company pledged financial support for local infrastructure. The complexity of SGD operations typically involves mixtures of government regulation, industry self-regulation, and regulation by new institutions evolving from ad hoc multi-stakeholder collaborations (Boutilier and Black, 2013; Figure 11.6).

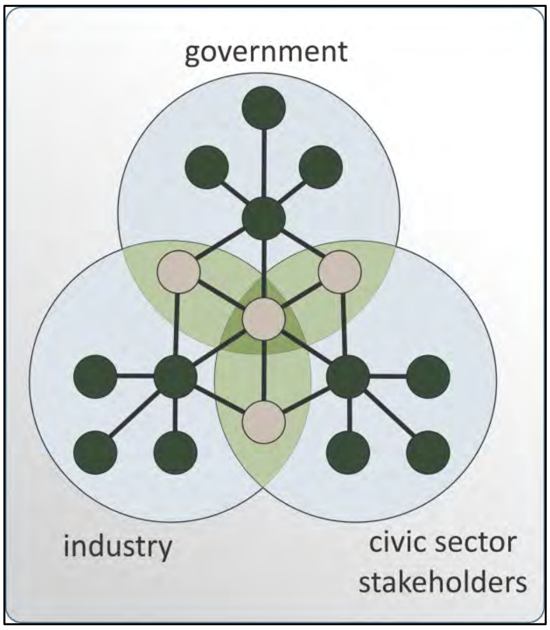

Figure 11.6: Interface between Government, Industry and Civil Society.
Source: Boutilier and Black 2013:697.

However, collaborative governance is not a panacea. A case study in Western Australia showed that, as the construction phase gathered pace, cracks emerged in process, as the community, local and state government and the corporate partners had different understandings of agreements. The state government was slow to honour its key leadership and partner role, and international market imperatives and government/corporate manoeuvring left the community with escalating housing costs, business closures and power and water shortages (Haslam-McKenzie, 2013).

The risk assessment table below (Table 11.4) provides an overview of the possible consequences, the likelihood of them taking place, and the risk to the social fabric which they pose. Clearly, in this topic, many of these assessments are normative, subjective and open to debate. For the purpose of the risk analysis:

- *Slight but noticeable consequences* refer to small and manageable impacts, or impacts on small sections of the community, or those which can be generally addressed by existing institutions, or can easily be balanced or outweighed by positive impacts.
- *Moderate consequences* refer to impacts which affect the bulk of the local population negatively, require some new institutional capacity, may well produce a net negative impact on the community, and would require some assistance by SGD companies and public authorities to manage.
- *Substantial consequences* refer to impacts which place significant strain on the bulk of the local population, require significant new institutional capacity to manage, and would require

extensive assistance by SGD companies and governmental authorities to manage. This would require, *inter alia*, a new approach to regional planning and support.

- *Severe consequences* refer to impacts which would cause significant social strain, would test institutional capacity to their limits, and would require a far-reaching SGD involvement to manage effectively. Regional planning and support systems would require extensive funding and skills to address possible impacts.
- *Extreme consequences* refer to impacts which could result in social or political violence or institutional collapse; mitigation would require a great deal of pre-emptive and far-reaching capacity-building as well as ongoing local partnerships between SGD companies, national government, municipal government, and local leaders.

The social fabric can benefit greatly from well-designed mitigation efforts. To achieve maximum impact, such efforts would have to be planned and co-ordinated by an inclusive regional strategic planning and management team. The classical "mitigation hierarchy" would be a useful guideline: What negative impacts can be avoided, and how? What impacts can be reduced, and how? Where are negative impacts unavoidable (e.g. in-migration). How can social problems be identified and pre-emptive measures taken? How can local people be compensated for unavoidable losses or harms? These solutions are not self-evident at this early stage; they would have to be negotiated by a well-designed and resourced management structure.

Table 11.4: Risk assessment matrix for social fabric.

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Human migration	Reference Case	All towns involving SGD	Moderate	Likely	Low	Moderate	Likely	None
	Exploration Only		Severe	Very likely	Moderate	Severe	Very likely	Low
	Small Gas		Severe	Very likely	High	severe	Very likely	High
	Big Gas		Severe	Very likely	Very high	Severe	Very likely	High
Physical security	Reference Case	All towns involving SGD	Moderate	Likely	Low	Slight	Likely	Very low
	Exploration Only		Severe	Very likely	High	Substantial	Likely	Moderate
	Small Gas		Extreme	Very likely	Very high	Substantial	Very likely	High
	Big Gas		Substantial	Very likely	High	Substantial	Likely	High
Altered local social dynamics	Reference Case	All towns involving SGD	Slight but noticeable	Very likely	Very low	Slight but noticeable	Likely	Very low
	Exploration Only		Substantial	Very likely	High	Moderate	Very likely	Moderate
	Small Gas		Severe	Very likely	High	Substantial	Very likely	Moderate
	Big Gas		Substantial	Very likely	High	Moderate	Very likely	Moderate
New power dynamics	Reference Case	All municipali ties involved with SGD	Moderate	Very likely	Low	Slight	Very likely	Very low
	Exploration Only		Severe	Very likely	High	Substantial	Very likely	High
	Small Gas		Severe	Very likely	High	Substantial	Very likely	High
	Big Gas		Substantial	Very likely	High	Moderate	Very likely	Moderate

The analysis finds high levels of risk in all four causal pathways (migration, physical security, social relations and governance); however, mitigation measures can significant reduce the level of risk. The critical question will be the political will, on the part of Government and SGD companies, to abide by international guidelines on community engagement.

11.8 Gaps in knowledge

The analysis of the impacts of rapid large investments in South African towns would benefit by drawing on the experience of the renewable energy projects being rolled out in various towns in central South Africa. There is, as yet, no monitoring and evaluation study of these projects, and this is urgently required. The findings from such studies would be very valuable in anticipating some of the risks to the social fabric which we can expect from SGD projects in this area.

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11.10 Digital Addenda 11A – 11B

SEPARATE DIGITAL DOCUMENT

Digital Addendum 11A: Municipal information

Digital Addendum 11B: Provincial and municipal powers and functions

DIGITAL ADDENDA 11A – 11B

Digital Addendum 11A: Municipal information

Table 1: Housing demand, drawn from recent Integrated Development Plans (IDPs).

Municipality	Housing waiting lists	Middle class housing needs
Beaufort West LM (2014)	3000	
Gariep LM (Burgersdorp, Venterstad, Steynsburg) (2013)	4570	
Ngqushwa LM (Peddie) (2013)	10320	
Umsobomvu LM (Colesberg, Noupoort, Norvalspont) (2014)	2000	
Hantam LM (Calvinia) (2014)	1000	
Karoo-Hoogland LM (Sutherland, Fraserburg, Williston) (2014)	880	
Nxuba LM (Bedford, Adelaide (2013)	1923	
Makana LM (Grahamstown) (2014)	16582	
Inxuba Yethemba LM (Cradock, Middelburg) (2014)		Shortage of affordable middle-class housing
Gariep LM (Burgersdorp, Venterstad) (2011)		Shortage of affordable middle-class housing, particularly for government officials
Sarah Baartman DM (Grahamstown, Graaff-Reinet) (2015)		Increasing housing demand due to unbundling of households; rapid influx of people creating shortage of housing
Ikwezi LM (Jansenville) (2014)		Demand for housing due to growing squatter areas
Ubuntu LM (Victoria West, Richmond, Loxton)	820	Need to upgrade old township houses

Table 2: Construction industry in various localities, drawn from recent Integrated Development Plans (IDPs).

Municipality	Local housing & construction conditions
Inxuba Yethemba LM (Cradock, Middelburg) (2014)	High construction sector growth; two large companies and several smaller ones; up to 1000 workers available; constraints in water and electricity prevent additional construction in Cradock and Middelburg
Joe Gqabi DM (HQ Lady Grey) (2014)	Lack of available land for housing expansion; lack of serviced sites; poor local skills
Tsolwana LM (Tarkastad, Hofmeyr (2014)	Contractors poorly skilled, leading to poor quality housing
Gariep LM (Burgersdorp, Venterstad) (2013)	Suitable land available. Poor local skills and workmanship. Need infrastructure upgrades for housing expansion
Maletswai LM (Aliwal North,	Inadequate construction skills in localities; inadequate management skills.

Municipality	Local housing & construction conditions
Jamestown) (2014)	Contractors suffer from late payments by public authorities
Sarah Baartman DM (Grahamstown, Graaff-Reinet)	Insufficient land available
Pixley ka Seme DM (HQ De Aar) (2014)	Lack of public funding for housing
Camdeboo LM (Graaff-Reinet) (2015)	Delays in housing expansion due to EIAs, title deeds, delays in release of public funding; hence growing backlog
Makana LM (Grahamstown) (2014)	Rapid growth in informal settlements, hence demand for formal housing
Karoo-Hoogland LM (Sutherland, Fraserburg, williston) (2014)	Delays in securing land, providing services and doing transfers of titles
Chris Hani DM (2014)	In traditional areas, land is available, but informal land tenure is problematic
Emalahleni LM (Lady Frere, Dordrecht) (2014)	Informal land tenure is problematic, so no development possible. Urbanisation causes sprawling informal settlement with slums, traffic congestion and illegal developments

Table 3: Municipal housing management capacity, drawn from recent Integrated Municipal Plans.

Municipality	Housing and construction capacity
Tsolwana LM (Tarkastad, Hofmeyr) (2014)	No housing department at municipality; housing managed by Community Services Directorate. Depends on province and private sector. No in-house capacity.
Pixley ka Seme DM (HQ De Aar)	Lack of housing skills in eight local municipalities
Karoo-Hoogland LM (Sutherland, Williston, Fraserburg) (2014)	No housing administration capacity
Emalahleni LM (Dordrecht, Lady Frere) (2014)	Very little town planning capacity; the single town planner is overworked and processes are slow

Table 4: Crime trends in the study area, based on information in recent Integrated Development Plans (IDPs).

Municipality	Drug- and alcohol-related crimes	Sex-related crimes	Property crimes	Murder and assault	Sense of security	Policing capability
Ngqushwa LM (Peddie) (2013)	Highest category of crimes in the area; Murder, assault, fights and stabbing result from people near taverns	Increasing slightly; increase in child rape	Declining slightly	Declining slightly	Community expressed concern	
Nkonkobe LM (Fort Beaufort)		Steady increase	Slight decline	Slight decline		

Municipality	Drug- and alcohol-related crimes	Sex-related crimes	Property crimes	Murder and assault	Sense of security	Policing capability
(2015)						
Maletswai LM (Aliwal North, Jamestown) (2014)	Increased levels				Grave concern	Insufficient police stations
Pixley ka Seme DM (De Aar) (2014)	High levels	High levels	Not very high	Not very high	Communities are concerned	Insufficient police stations
Central Karoo DM (Beaufort West) (2015)	Significant increase	Significant increase	Increasing	Increasing		
Laingsburg LM (2013)	All increasing, but this may be due to better reporting					
Prince Albert LM (2014)	Significant increase				Communities concerned	
Breede Valley LM (Worcester) (2014)	Significant increase	Varying rate		Decreasing		
Witzenberg LM (Tulbagh)	Significant increase	Significant increase	Decreasing	Decreasing		
Nxuba LM (Adelaide, Bedford) (2013)		Prevalent	Prevalent			
Amathole DM (2014)	Serious levels, linked to illegal taverns					Lack of capacity in local municipalities to pass alcohol bylaws
Chris Hani DM (2014)		Serious levels	Serious levels			Insufficient jails
Tsolwana LM (Tarkastad, Steynsburg) (2014)	Serious levels					
Camdeboo LM (Graaff-Reinet) (2015)	Increasing	Increasing	Increasing	Increasing	Very concerned	Ineffective policing
Ikwezi LM (Jansenville) (2014)	Increasing	Prevalent		Significant levels		
Umsobomvu LM (Colesberg) (2014)						Insufficient police stations

Table 5: Traffic concerns in selected localities, drawn from recent Integrated Development Plans (IDPs).

Municipality	Traffic concerns	Traffic enforcement capability
Chris Hani DM	High traffic volumes; Limited traffic calming measures in areas with high accidents	Low visibility of traffic police and law enforcement
Emalahleni LM (Dordrecht and Lady Grey) (2014)	Heavy traffic flow and accidents on gravel roads	Have recently appointed two traffic officers for the first time
Tsolwana LM (Tarkastad, Steynsburg) (2014)	R61 notorious for serious accidents	Four traffic officers recently qualified
Gariep LM (Burgersdorp) (2013)		Three traffic officers now employed; vehicle testing station not functional
Sarah Baartman DM (2015)		Has created a road accident GIS to devise traffic programmes
Sundays River LM (Kirkwood) (2013)	Fairly high levels of accidents	By-laws regarding stray animals not enforced
Kareeberg LM (Carnarvon) (2014)		No traffic capability – relies on provincial department

Table 6: Public safety posts and public safety vacancies, 2014.
(*Source***:** www.localgovernment.co.za**)**

	Public safety positions 2014	Public safety vacancies 2014
Inkwanca LM (Molteno)	0	0
Nxuba LM (Bedford)	0	0
Pixley ka Seme DM	**0**	**0**
Emthanjeni LM	0	0
Kareeberg LM	0	0
Karoo Hoogland LM	0	0
Baviaans LM	2	0
Sundays River (Kirkwood)	2	0
Namakwa DM	**2**	**0**
Ikwezi LM (Jansenville)	4	0
Laingsburg LM	5	0
Cacadu DM	**5**	**0**
Tsolwana (Hofmeyr)	5	0
Hantam	6	0
Chris Hani DM	**8**	**0**
Gariep (Burgersdorp)	8	0
Prince Albert LM	8	1
Umsobomvu	9	0

	Public safety positions 2014	Public safety vacancies 2014
Inxuba Yethemba (Cradock)	10	0
Emalahleni LM (Lady Frere)	13	11
Ubuntu LM	14	0
Maletswai (Jamestown)	15	0
Camdeboo LM	15	3
Nqushwa (Peddie)	22	0
Joe Gqabi DM 14	**29**	**0**
Nkonkobe (Fort Beaufort)	32	17
Witzenberg (Tulbach)	41	2
Beaufort West LM	48	7
Blue Crane	63	52
Makana (Grahamstown)	64	0
Cape Winelands DM	**81**	**14**
Amathole DM	**85**	**3**
Breede Valley (Worcester)	97	21
Lukanji (Queenstown)	106	12
TOTAL	**799**	**143**

Table 7: Disaster management and fire-fighting, drawn from recent Integrated Development Plans (IDPs).

Municipality	Disaster management concerns	Disaster management capability
Nxuba LM (Bedford, Adelaide) (2013)	Storms, fire, drought, accidents	One officer, reporting to Disaster Management office in East London; four volunteer fire fighters, very limited equipment
Amathole DM (2014)	Fire risks, particularly in informal shacks; veld fires; severe weather conditions and floods; drought; road transport hazards; disease outbreaks; water pollution. Hilly topography makes response difficult	No Disaster Management system, long response times, capability is in breach of legislation. Runs six fire stations, of which one (Peddie) is in the study area. Staff shortages; inadequate finance; poor levels of training; inadequate buildings; poor communication systems. Lack of co-operation by sectoral departments.
Nkonkobe LM (Fort Beaufort) (2015)		Two permanent staff plus nine volunteers; lack of buildings; lack of skills; lack of vehicles
Chris Hani DM		Well-established office. Six satellite centres, three staff each. Inadequate equipment. Supports LMs in fire-fighting function.
Emalahleni (Lady Frere) (2014)		Disaster Management Plan to be written
Tsolwana LM (Hofmeyr, Tarkastad)	Fire and other emergencies	No service in rural areas; need a satellite office with equipment

Municipality	Disaster management concerns	Disaster management capability
(2014)		
Gariep LM (Burgersdorp) (2013)	Veld and forest fires; floods	One disaster officer; two fire fighters; some volunteers have been trained. One fire-fighting vehicle. Two tankers. Response time slow during floods, due to insufficient vehicles. Only one ambulance. Need clarification of roles of Local and District Municipality.
Maletswai LM (Aliwal North, Jamestown) (2014)	Fire, floods, oil spillages	One Disaster Management Centre for the LM; chief fire officer at District level. Fire services bylaws at District level.
Camdeboo LM (Graaff-Reinet, Aberdeen, Nieu Bethesda)		Functional Protection Services Department, expanding staff of fire station. New equipment being acquired. Drafted a disaster management plan.
Ikwezi LM (Jansenville, Klipplaat) (2014)		Fire-fighting unit, which also deals with road rescue. Four officers. Need new fire station building and satellite at Klipplaat. Need more vehicles. Adopted a disaster management plan.
Karoo-Hoogland LM (Sutherland, Fraserburg, Williston) (2014)		Disaster management plan compiled.
Prince Albert LM (2014)		Disaster management centre and plan.
Namakwa DM (2011)	Drought, flood, wind, storm, dam failure, hazmat, airstrips, fire, veld fire, snow, stormwater	Working on disaster management plan
Cape Winelands DM (2014)	Fire, floods, transport of hazardous materials, poor water management, road and rail, extreme weather	

Table 8: Social indicators per municipality.
(*Source: StatsSA: 2001 and 2011 censuses, www.statssa.gov.za; municipal IDPs*)

Municipality	Depen-dency ratio 2001 %	Depen-dency ratio 2011 %	No schooling 2011 %	% of adult pop with Matric 2011	% of adult pop with post-school education 2011	Poverty rate 2011 % of pop	HDI 2011	Gini co-efficient 2011
Laingsburg LM (2013)	58.7	50.9	11.7	16.7	8.7	38	0.59	
Prince Albert LM (2014)	67.8	56.2	9.1	16.9	8.5		0.58	
Beaufort West LM (2014)	62.4	59.7	10.1	23.6	6.5		0.60	0.57
Breede Valley (Worcester) (2014)	52.7	49.5	4.9	24.9	8.3			0.54

Municipality	Dependency ratio 2001 %	Dependency ratio 2011 %	No schooling 2011 %	% of adult pop with Matric 2011	% of adult pop with post-school education 2011	Poverty rate 2011 % of pop	HDI 2011	Gini co-efficient 2011
Witzenberg (Tulbagh)	50.6	42.0	6.6	18.2	5.8			0.55
Baviaans LM (Willowmore)	62.5	60.2	8.0	16.4	4.7	43	0.62	
Camdeboo LM (2015)	67.0	58.0	9.0	19.6	9.5	34	0.65	
Blue Crane	55.7	56.8	10.5	18.9	6.3	34	0.62	
Ikwezi (Jansenville)	64.3	61.4	12.6	15.4	5.4	43	0.61	
Makana (Grahamstown)	47.6	44.1	6.3	22.7	11.9	31	0.67	
Sundays River (Kirkwood)	51.9	47.0	8.8	15.2	3.8	35	0.62	
Emalahleni LM (Lady Frere)	95.5	81.8	18.8	11.0	3.8	45	0.54	0.55
Inkwanca LM (Molteno)	68.6	59.9	13.4	15.2	7.2	58	0.58	0.63
Inxuba Yethemba (Cradock)	56.1	54.7	10.7	20.0	8.8	35	0.63	0.6
Lukanji (Queenstown)	65.4	59.8	7.8	22.1	11.4	41	0.64	0.6
Tsolwana (Hofmeyr)	75.3	70.5	16.0	13.9	5.0	49	0.57	0.55
Gariep (Burgersdorp)	67.4	61.8	14.9	16.2	7.4		0.47	
Maletswai (Jamestown)	64.2	61.1	11.0	21.8	10.1			
Ngqushwa (Peddie)	75.2	72.1	13.7	15.0	3.9	66	0.46	
Nkonkobe (Fort Beaufort)	67.0	61.3	7.2	17.0	7.1	32		
Nxuba (Bedford)	61.8	62.4	6.3	15.1	6.2			
Emthanjeni LM	60.2	60.1	11.0	24.7	6.6			
Kareeberg LM	69.5	59.9	18.0	17.5	5.7			
Ubuntu LM	63.8	63.5	16.4	18.7	6.0			
Umsobomvu	63.8	59.3	16.3	23.1	6.3			
Hantam	65.5	55.6	14.4	18.8	8.1			
Karoo Hoogland	63.6	60.5	18.4	16.9	8.7			

Table 9: Municipal audits in the 34 municipalities in the study area, 2014.
(Source: www.localgovernment.co.za)

Type of audit opinion	Explanation of audit opinion	No of municipalities	Type of municipalities	Municipalities
Clean audit	Financial statements are free from material misstatements, and there are no material findings on the quality of the annual performance report or non-compliance with legislation.	4	2 DM 2 LM	Cape Winelands DM Sarah Baartman DM Breede Valley LM Witzenberg LM
Financially unqualified with findings	The financial statements contain no material misstatements. Findings have been raised on either the annual performance report or non-compliance with legislation, or both these aspects.	15	5 DM 10 LM	Joe Gqabi DM Amathole DM Pixley ka Seme DM Namakwa DM Laingsburg LM Prince Albert LM Beaufort West LM Baviaans LM Camdeboo LM Tsolwana LM Maletswai LM Kareeberg LM Umsobomvu LM Hantam LM
Qualified audit opinion	Financial statements contain material misstatements in specific amounts, or there is insufficient evidence for the Auditor-General to conclude that specific amounts included in the financial statements are not materially misstated.	8	1 DM 7 LM	Chris Hani DM Emalahleni LM Gariep LM Nkonkobe LM Nxuba LM Emthanjeni LM Ubuntu LM Blue Crane LM
Disclaimer of audit opinion	The auditee provided insufficient evidence in the form of documentation on which to base an audit opinion. The lack of sufficient evidence is not confined to specific amounts, or represents a substantial portion of the information contained in the financial statements.	7	7 LM	Ikwezi LM Makana LM Sundays River LM Inkwanca LM Inxuba Yethemba LM Lukanji LM Nqushwa LM
Audit not completed		1	LM	Karoo Hoogland LM

Table 10: Changes in municipalities' audit status, 2012-2014.
(Source: www.localgovernment.co.za)

2014 status	Number	2011-2014 trend	Number	Municipalities
Excellent (Clean)	5	Improved slightly	1	Cape Winelands DM
		Improved	4	Sarah Baartman DM Witzenberg LM Breede Valley LM
Good (unqualified)	15	Improved significantly	2	Baviaans LM Camdeboo LM
		Improved	7	Pixley ka Seme DM Namakwa DM Tsolwana LM Maletswai LM Kareeberg LM Hantam LM
		Constant	6	Joe Gqabi DM Amathole DM Laingsburg LM Prince Albert LM Beaufort West LM Umsobomvu LM
Compromised (Qualified)	8	Improved significantly	2	Emalahleni LM Nxuba LM
		Improved	2	Chris Hani DM Gariep LM Emthanjeni LM
		Constant	2	Blue Crane LM Nkonkobe LM
		Deteriorated	2	Ubuntu LM
Very Poor (Disclaimer)	7	Constant	7	Ikwezi LM Makana LM Inxuba Yethemba LM Lukanji LM Nqushwa LM
Audit not complete (very poor)	1	Constant	1	Karoo-Hoogland LM

Table 11: Municipal posts and vacancies.

% of posts vacant, 2014	**Number of municipalities**	**Municipalities** **Municipalities in *italics*: Clean and Unqualified audits**
0 posts	6	Laingsburg LM Sundays River LM Maletswai LM Emthanjeni LM Kareeberg LM Namakwa DM
1-5% of posts	11	Sarah Baartman DM Makana LM Tsolwana LM Nqushwa LM Umsobomvu LM Amathole DM Karoo Hoogland LM Witzenberg LM Ikwezi LM Nxuba LM Chris Hani DM
6-10% of posts	5	Joe Gqabi DM Hantam LM Camdeboo LM Inkwanca LM Lukanji LM
11-20% of posts	6	Baviaans LM Cape Winelands DM Beaufort West LM Breede Valley LM Ubuntu LM Blue Crane LM
21-29% of posts	4	Pixley ka Seme DM Inxuba Yethemba LM Prince Albert LM Emalahleni LM
30-35% of posts	2	Gariep LM Nkonkombe LM

Table 12: Municipal posts and vacancies in environmental management, health, and public safety. *(Source: www.localgovernment.co.za)*

	EP positions 2014	EP Vacancies 2014	Health positions 2014	Health vacancies 2014	Public safety positions 2014	Public safety vacancies 2014
Laingsburg LM	0	0	0	0	5	0
Prince Albert LM	0	0	0	0	8	1
Beaufort West LM	0	0	0	0	48	7
Witzenberg (Tulbach)	0	0	0	0	41	2
Baviaans	0	0	0	0	2	0
Ikwezi (Jansenville)	0	0	0	0	4	0
Sundays River (Kirkwood)	0	0	0	0	2	0
Chris Hani DM	**0**	**0**	**0**	**0**	**8**	**0**
Inkwanca LM (Molteno)	0	0	0	0	0	0
Inxuba Yethemba (Cradock)	0	0	0	0	10	0
Lukanji (Queenstown)	0	0	70	10	106	12
Tsolwana (Hofmeyr)	0	0	0	0	5	0
Maletswai (Jamestown)	0	0	0	0	15	0
Nqushwa (Peddie)	0	0	0	0	22	0
Nkonkobe (Fort Beaufort)	0	0	0	0	32	17
Nxuba (Bedford)	0	0	0	0	0	0
Pixley ka Sme DM	**0**	**0**	**0**	**0**	**0**	**0**
Emthanjeni LM	0	0	0	0	0	0
Kareeberg LM	0	0	0	0	0	0
Ubuntu LM	0	0	0	0	14	0
Umsobomvu	0	0	0	0	9	0
Namakwa DM	**0**	**0**	**10**	**0**	**2**	**0**
Hantam	0	0	0	0	6	0
Karoo Hoogland	0	0	0	0	0	0
Sarah Baartman DM	**2**	**0**	**0**	**0**	**5**	**0**
Emalahleni LM (Lady Frere)	2	1	0	0	13	11
Blue Crane	3	1	0	0	63	52
Makana (Grahamstown)	4	0	61	0	64	0
Camdeboo LM	6	1	55	1	15	3
Gariep (Burgersdorp)	15	15	25	25	8	0
Breede Valley (Worcester)	16	1	0	0	97	21
Joe Gqabi DM 14	**22**	**0**	**0**	**0**	**29**	**0**
Amathole DM	**26**	**7**	**0**	**0**	**85**	**3**
Cape Winelands DM	**46**	**0**	**0**	**0**	**81**	**14**

	EP positions 2014	EP Vacancies 2014	Health positions 2014	Health vacancies 2014	Public safety positions 2014	Public safety vacancies 2014
TOTALS	**142**	**26**	**221**	**36**	**799**	**143**

Table 13: Municipal infrastructure management challenges.
(Source: Municipal Integrated Development Plans)

Municipality	Infrastructure management challenges	Environmental management challenges	Environmental health challenges
Amathole DM (2014)	Water quality hampered due to: Lack of reservoir and pipeline maintenance due to cleaning schedule not being adhered to. Post-chlorination not being done effectively. Low chlorine levels. Delay in the repair of equipment.	Poor management of landfill sites. Sewerage spills	Waste management: poor service delivery due to insufficient resources, inadequate policy guidelines, inadequate planning, inadequate management and lack of technical expertise and capacity.
Ngqushwa LM (Peddie) (2013)	Difficulties in extending water and electricity infrastructure to rural areas. Lack of infrastructure maintenance skills and budget. No building control bylaws. Poor road maintenance. Low salaries, hence poorly skilled staff. Non-adherence to contractual obligations.	Soil erosion, overgrazing, deforestation. Pollution from pit latrines.	
Nxuba LM (Bedford, Adelaide) (2013)	Roads in poor condition.	Overgrazing of commonage. No environmental management officer.	Waste site poorly managed.
Nkonkobe LM (Fort Beaufort) (2015)	94% of unpaved roads in poor condition.		
Chris Hani DM	Rural roads in poor condition, no maintenance.		
Emalahleni LM (Dordrecht) (2014)	Rural roads and tarred roads in critical condition due to lack of maintenance – need total overhaul.	No environmental management officer.	No air pollution officer.
Lukanji LM (Queenstown) (2014)			No air pollution officer Waste removal equipment in poor condition

Municipality	Infrastructure management challenges	Environmental management challenges	Environmental health challenges
Tsolwana LM (Tarkastad) (2014)	Roads, bridges in poor condition – some have collapsed.		No air pollution officer. Landfill site poorly managed.
Gariep LM (Burgersdorp) (2013)	Electricity network under strain. Need staff and budget. Urban streets in critical condition. Major backlog in road maintenance.	Illegal mines, no rehabilitation. Contaminated rivers and streams. Sewerage spills. No environmental management officer.	Leaching from landfills. Air pollution from burning waste. Lack of skilled staff.
Maletswai LM (Aliwal North, Jamestown) (2014)	Need upgrading of water systems and sewerage systems. Some roads rapidly deteriorating. Upgrading of electrical network underway.	Working for wetlands programme.	Uncontrolled waste sites. Sewerage spills.
Sarah Baartman DM (Port Elizabeth hinterland) (2015)	More than 20% of gravel roads in poor condition. Water shortages in several towns.		
Camdeboo LM (Graaff-Reinet) (2015)	Severe bulk water shortage.		
Ikwezi LM (Jansenville) (2014)	Bulk water is insufficient.		
Makana LM (Grahamstown) (2014)	Poor maintenance of roads and streets.		No air quality officer
Sundays River LM (Kirkwood) (2013)	Insufficient bulk water. Poor maintenance of roads and streets. Lack of stormwater infrastructure damages roads.		Poor water quality. Water management system insufficient and does not comply to regulations.
Pixley ka Seme DM (De Aar) (2014)	Rural roads in poor condition. Equipment very old; not refurbished or replaced.	No environmental management officer.	
Kareeberg LM (Carnarvon) (2014)	Streets and rural roads in poor condition. Lack of stormwater management destroys roads.		

Municipality	Infrastructure management challenges	Environmental management challenges	Environmental health challenges
Ubuntu LM (Victoria West) (2014)	Inadequate bulk water supply. Water quality poor. Water infrastructure old. Telecommunications network insufficient; vandalism. Gravel roads in poor condition.		Poor management of waste sites.
Umsobomvu LM (Colesberg) (2014)	Road upgrades required. Water infrastructure old, need replacing. Lack of funding and skilled staff.		Landfill site poorly managed.
Karoo-Hoogland LM (Fraserburg) (2014)	Roads and streets in poor condition. Insufficient staff and budget. Shortage of bulk water.		
Prince Albert LM (2014)	Electricity blackouts – network is old. Need to manage water demand – need more water storage facilities. Lack of bulk water at Klaarstroom.		Problem of dust along all rural roads and untarred streets. Burning of refuse at municipal landfill site. No capacity for air quality control.
Witzenberg LM (Tulbagh)	Excellent water quality, but bulk water shortages. Rural roads in poor condition.	Industrial and agricultural effluent into rivers. No environmental management programme.	
Breede River LM (Worcester) (2014)			Air pollution problems due to agriculture and industry. Powers and functions poorly defined.

Digital Addendum 11B: Provincial and municipal powers and functions

Schedule 4 of the Constitution: Functional areas of concurrent national and provincial legislative competence

Functions which may have an impact on SGD, or may be impacted by SGD, are underlined.

- Administration of indigenous forests
- Agriculture
- Airports other than international and national airports
- Animal control and diseases
- Casinos, racing, gambling and wagering, excluding lotteries and sports pools
- Consumer protection
- Cultural matters
- Disaster management
- Education at all levels, excluding tertiary education
- Environment
- Health services
- Housing
- Indigenous law and customary law, subject to Chapter 12 of the Constitution
- Industrial promotion
- Language policy and the regulation of official languages to the extent that the provisions of Section 6 of the Constitution expressly confer upon the provincial legislatures legislative competence
- Media services directly controlled or provided by the provincial government, subject to Section 192
- Nature conservation, excluding national parks, national botanical gardens and marine resources
- Police to the extent that the provisions of Chapter 11 of the Constitution confer upon the provincial legislatures legislative competence
- Pollution control
- Population development
- Property transfer fees
- Provincial public enterprises in respect of the functional areas in this Schedule and Schedule 5
- Public transport
- Public works only in respect of the needs of provincial government departments in the discharge of their responsibilities to administer functions specifically assigned to them in terms of the Constitution or any other law
- Regional planning and development
- Road traffic regulation
- Soil conservation
- Tourism
- Trade
- Traditional leadership, subject to Chapter 12 of the Constitution

- Urban and rural development
- Vehicle licensing
- Welfare services

Part B: Municipalities

The following local government matters to the extent set out in Section 155(6)(a) and (7):

- Air pollution
- Building regulations
- Child care facilities
- Electricity and gas reticulation
- Firefighting services
- Local tourism
- Municipal airports
- Municipal planning
- Municipal health services
- Municipal public transport
- Municipal public works only in respect of the needs of municipalities in the discharge of their responsibilities to administer functions specifically assigned to them under this Constitution or any other law
- Pontoons, ferries, jetties, piers and harbours, excluding the regulation of international and national shipping and matters related thereto
- Stormwater management systems in built-up areas
- Trading regulations
- Water and sanitation services limited to potable water supply systems and domestic waste-water and sewage disposal systems

Schedule 5 of the Constitution: Functional areas of exclusive provincial legislative competence

Part A: Provincial functions

- Abattoirs
- Ambulance services
- Archives other than national archives
- Libraries other than national libraries
- Liquor licences
- Museums other than national museums
- Provincial planning
- Provincial cultural matters
- Provincial recreation and amenities
- Provincial sport
- Provincial roads and traffic
- Veterinary services, excluding regulation of the profession

Part B: Municipal functions

The following local government matters to the extent set out for provinces in Section 155(6)(a) and (7):

- Beaches and amusement facilities
- Billboards and the display of advertisements in public places
- Cemeteries, funeral parlours and crematoria
- Cleansing
- Control of public nuisances
- Control of undertakings that sell liquor to the public
- Facilities for the accommodation, care and burial of animals
- Fencing and fences
- Licensing of dogs
- Licensing and control of undertakings that sell food to the public
- Local amenities
- Local sport facilities
- Markets
- Municipal abattoirs
- Municipal parks and recreation
- Municipal roads
- Noise pollution
- Pounds
- Public places
- Refuse removal, refuse dumps and solid waste disposal
- Street trading
- Street lighting
- Traffic and parking

CHAPTER 12

Impacts on Human Health

CHAPTER 12:
IMPACTS ON HUMAN HEALTH

Integrating Author:	Bettina Genthe[1]
Contributing Authors:	Ashton Maherry[1], Maronel Steyn[1], Andrea Rother[2], Leslie London[2], Mieke Willems[3]

1 Natural Resources and the Environment (NRE), Council for Scientific and Industrial Research (CSIR), Stellenbosch, 7900

2 School of Public Health and Family Medicine, University of Cape Town, Observatory, 7925

3 Program Impact Evaluation, Department of Health, Western Cape, Cape Town, 8000

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Executive Summary

This Chapter of the scientific assessment focused on potential health impacts of four different shale gas development (SGD) scenarios. The status quo represents Scenario 0 (Reference Case), exploratory drilling representing Scenario 1 (Exploration Only), moderate drilling representing Scenario 2 (Small Gas), and lastly high gas production representing Scenario 3 (Big Gas). The scope of the study is to assess potential human health risks in the study area. International experience and scientific evidence was used to predict the potential health impacts. The following had to be done for the impact assessment: identify potential chemicals to be used, assess the potential health impacts of these chemicals, assess the potential population that could be exposed, and consider the potential pathways through which the population might be exposed.

Chemical information was obtained using international databases of most used, most detected, most toxic to human health and most likely to be transported in the environment. This Chapter presents the South African data illustrating the extent of the area that may be affected, the current size of the study population and the current health status of the study population, with a description of possible pathways through which the community might be exposed.

Different pathways for potential exposure, with air, water, noise, direct contact resulting from traffic or machine injuries, and dermal contact were considered. These were considered separately for workers and community members. The four scenarios were found to yield health risks as ranging from none, to moderate risk for the Reference Case as the current health status of the study area population faces serious challenges with infant, maternal and under-five mortality rates double that of the provincial rate. For Exploration Only, community health is expected to range between a very low risk to a moderate risk (with water as the exposure pathway) and worker health ranging from high risk (via the air pathway) to low risk, depending on the exposure pathway. For the Small Gas scenario, worker health risks range from low risks to high risks (multiple pathways). Community health risks range from low to high (where water is the exposure pathway). The Big Gas scenario results in high risks for workers from air, noise and direct contact pathways, and high risks for the community via air and water pathways, to low risks for the other pathways.

Uncertainties in the scientific evidence of chemicals to be used and health impacts that might be expected are the major restriction in the health impact section of this assessment. Chemicals included in assessing potential health impacts is based on international data and experience with regards to time for long-term health effects to be measurable is limited. Many of the chemicals used in SGD do not have sufficient health data, as chronic health effects data are available for only 8.4% of the 1173 reportedly used chemicals in the United States Environmental Protection Agency (US EPA) database. Each drilling and hydraulic fracturing (“fracking”) event is unique depending on the geology, depth

and resources available, with the chemicals and products used and the amounts or volumes used differing from well to well.

Since the activity of fracking is relatively new in relation to the time needed to assess long-term health effects as well as trans-generational effects, scientific evidence that can be used with certainty is lacking. However, information on individual chemicals used has been shown to cause long-term and transgenerational effects.

Any potential health impacts resulting from SGD will require that baseline monitoring for air and water quality. Baseline health monitoring, including additional health symptoms associated with SGD will need to be carried out prior to initiating the exploration activity to enable ascribing any future health effects to a specific cause. The additional health symptoms implies that standard health monitoring done at hospitals and clinics will not be sufficient and that additional health symptoms associated with SGD such as nose, eye and throat irritation, dermal or skin lesions, upper respiratory impacts, etc. (see Figure 12.5) be noted prior to, throughout as well as for a long time after exploration or mining has seized. Transgenerational effects as well as endocrine disrupting chemical (EDC)-related health impacts (e.g. thyroid, reproductive) as well as cancer will require long term monitoring.

The current Regulations for Petroleum Exploration and Production (Government Gazette, 2015) do not consider health in any way, and this should be recommended for inclusion.

CHAPTER 12: IMPACT ON HUMAN HEALTH

12.1 Introduction

According to the World Health Organisation (WHO), environmental health deals with the physical, chemical, and biological factors that can potentially affect human health through the environment (WHO, 2016).

Health impacts are often expressed as reductions in human life expectancy or as increases in adverse health effects. The World Health Organisation (WHO) uses the Disability Adjusted Life Year (DALY), as a health gap measure that accounts for potential years of life lost (YLL) due to premature death, plus equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability (Prüss-Üstün et al., 2003). DALYs are typically calculated for a disease or health condition. These measures are often used to describe the current health of a population to compare different diseases and their impacts.

Health risk assessments are used to predict the potential health impacts on a population based on known or modelled chemical concentrations. According to the United States Environmental Protection Agency (US EPA) (2004, 2005), a human health risk assessment estimates the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future.

The scope of this study is to predict possible health impacts due to environmental contamination as a result of unconventional oil and gas exploration and development, making use of a combination of WHO measures and health risk assessment methods.

12.2 Does hydraulic fracturing pose health risks to the people living near drilling sites?

In the USA, a financial settlement of $1.6M was reached in 2012 to compensate three families for contaminated drinking water wells. This is thought to have been the first case publicly disclosing the settlement terms as others were sealed (Associated press, Pittsburgh). Prior to this, the non-disclosures limited access to public health information.

The short answer is that do we do not know yet. Although there have been reported cases internationally and research is underway, few studies to date could provide conclusive evidence about how unconventional natural gas development affects nearby communities (Adgate et al., 2014; National Institute of Environmental Health Sciences (NIEHS), 2014). It is however the aim of this Chapter to assess possible health risks. Further, the Chapter will present what is known internationally, describe the knowledge of the health status and unique vulnerabilities of nearby communities, give an overview of the vast majority of chemicals declared for use elsewhere during such development and describe best practices within the regulatory framework of South Africa. Further, the Chapter seeks to summarise within the current uncertainties, a qualitative health risk assessment for each of the four likely SGD scenarios and conclude with some recommendations on future monitoring requirements and the current uncertainties hampering decision-making.

Concerns have been expressed that some of the many chemicals used in SGD may constitute a health impact; this section will therefore consider and describe what is known regarding potential health impacts of hydraulic fracturing ("fracking") for oil and gas as a result of potential contamination of water resources in particular. Separate chapters dealing with water (Hobbs et al., 2016), air (Winkler et al., 2016) and noise pollution (Wade et al., 2016) and waste disposal (Oelofse et al., 2016) are presented amongst the other 15 issues considered in the scientific assessment.

Occupational health is an important component regarding potential health impacts of fracking. Most of what is currently known in terms of human health impacts have been derived from studies of workers and the health risks posed to them at unconventional natural gas development sites (NIEHS, 2014). While such studies are still limited globally, ongoing efforts are made to gather more in depth details on worker health at these sites. Apart from risks associated with accidents, the NIEHS (2014) highlighted the following three risks that have been associated with occupational health risks during fracking:

- Silica sand inhalation – Silica sand (which can cause lung cancer) is used in the fracking process where workers may inhale fine silica sand particles even if they are wearing the correct personal protective equipment (PPE) (Esswein et al., 2013).
- Exposure to chemical spills – Workers may be exposed to compounds used in the fracking process during accidental spills. Depending on the chemical compounds used, it may present a variety of health risks (Newton, 2015).
- Exposure from flowback[1] operations (Esswein et al., 2014) – Field studies found that workers are exposed to high levels of volatile hydrocarbons which can be acutely toxic. According to Snawder et al. (2014), at least four workers have died as a result of exposures during flowback operations since 2010. Since then the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) reported nine worker fatalities associated with manually gauging and sampling fluids on production and flowback tanks (NIOSH, 2016).

In addition to these health and safety issues related to the hydraulic fracturing processes, most worker fatalities in the industry are as a result of motor vehicle accidents, with 7.6 deaths per 100,000 workers recorded by Retzer et al. (2013). The Occupational Health and Safety Amendment Act (Act 181 of 1993) regulated by the Department of Labour (DoL) is available to protect the health and safety of workers in South Africa. This however does not guarantee worker safety. The DoL, together with each employer (defined in the act), are responsible according to Section 8 of the Act to provide

[1]Flowback is defined as a "water based solution that flows back to the surface during and after the completion of hydraulic fracturing" (Schramm, 2011).

workers with a safe working environment and protect workers from exposures, and to provide them with the correct PPE and equipment in order to prevent adverse health impacts as a result of accidents and operations.

12.3 Overview of international experience

In relation to health impacts of SGD, few studies have focused on long term health outcomes to include health impacts such as cancer or developmental outcomes (McDermott-Levy et al., 2013; Werner et al., 2015). Werner et al. (2015) conducted a review of the current state of the evidence of environmental health impacts of unconventional natural gas development. They noted that health outcomes reported to be in some way associated to these environmental impacts are symptoms of upper respiratory tract ailments, burning eyes, headaches, vomiting, diarrhoea, rashes, and nosebleeds. Most reported symptoms are acute, with short-term impacts, while there may be the potential for chronic, long-term impacts which have not been assessed.

Communities living near natural gas extraction sites may experience exposure to volatile organic compounds (VOCs), silica and other compounds arising both from the well completion and fracking processes as well as leaks from pipes and valves (Public Health UK, 2013; Adgate et al., 2014). Although Bunch et al. (2014) found measured VOC concentrations in the Barnett Shale production site in Texas to fall below federal and state health-based air comparison values, Macey et al. (2014) found that at sites in four of the five states (Wyoming, Arkansas, Pennsylvania, and Colorado excluding Ohio) in proximity to shale gas production analysed for 75 volatile organics, levels of eight volatile chemicals exceeded federal guidelines. These exceedances could be linked in space and time to oil and gas production sites. Goetz et al. (2015) investigated emissions from criteria pollutants and their precursors, as well as natural gas constituents, from Marcellus SGD activities. They found elevated levels of methane and ethane, with other VOCs generally not observed at elevated levels at the investigated sites. The literature provides evidence for increased air pollution impacts at a population level involving methane, VOCs and other hydrocarbons arising from the complete continuum of SGD production processes.

As stated in the US EPA report (2015), health effects include the potential for carcinogenesis, immune system effects, changes in body weight, changes in blood chemistry, pulmonary toxicity, neurotoxicity, liver and kidney toxicity, and reproductive and developmental toxicity. Evaluating potential risk to human populations would require knowledge of the specific chemicals that are present at a particular site, whether or not humans are exposed to those chemicals and, if so, at what levels and for what duration, together with the specific toxicity of the chemicals being used.

Burton et al. (2016) found that gas-well density and formation pressures best correlated with changes in water quality and not the proximity to gas-wells solely. However, Hill (2013) reported an increase in low birth weight and small for gestational age and reduced APGAR[2] scores in infants born to mothers living near SGD in Pennsylvania. McKenzie et al. (2014) found positive associations between density and proximity of natural gas wells within a 10 mile radius of maternal residence and birth prevalence of congenital heart defects and possibly neural tube defects. It is unclear if these positive associations could be due to other confounding factors and more research is required. Casey et al. (2016) found prenatal exposure to unconventional natural gas extraction activity was associated with two pregnancy outcomes. The changes associated with building and having a drilling site can have numerous impacts on community well-being. Some of these impacts may be positive. For example, a drilling operation can increase local employment rates, and result in greater access to health care. Drilling-associated activities, and a sudden influx of a large transient workforce, can also have negative impacts on a community. These may include increased noise, light, and traffic; heavier burdens on local infrastructure and resources, such as roads and hospitals; higher rates of crime and substance abuse; and changes to community character (National Institutes of Health, US Department of Health and Human Services, 2014).

Possible health impacts occur through many different pathways and are discussed in this Chapter. However many issues that impact on human health are discussed in more detail in other Chapters of this scientific assessment. Table 12.1 summarises the issues and the Chapters that deal with them.

Table 12.1: Description of potential health hazards discussed in other Chapters of the scientific assessment.

Topic	Description of potential health hazards addressed in chapters	Chapter
Social fabric	- Known social and health problems in the study area. - 'Boomtown' effect with boom-bust cycle. - *Influx of workers raises the demand for housing thus negatively impacting those not working in the industry*. - Influx of people may increase crime and thus health problems. - Raised incidence of HIV/AIDS is a possibility as a result of influx of workers to the study area, increased truck traffic (water needs). - Lack of Health System responsiveness at current capacity. - Poor implementation of disaster management strategies. - Traffic resulting in raised noise pollution. - *Moving target: the communities affected by changes all the time.*	Atkinson et al. (2016)
Occupational Health	Occupational exposure to chemicals in the SGD industry poses direct health risks such as dermal and respiratory problems; however the emphasis of the Human Health Chapter is community health. Although general exposure to SGD related chemicals is covered in this Chapter, occupational exposure raises critical concerns in industries such as SGD and mining where exposure duration, concentrations and chemical combinations have different implications than	Current Chapter

[2] Apgar scale refers to a newborn baby's clinical status within the following categories: Appearance (skin colour); Pulse (heart rate); Grimace response (reflexes); Activity (muscle tone); Respiration (breathing rate and effort) (Committee on Obstetric Practice and American Academy of Pediatrics, 2015).

Topic	Description of potential health hazards addressed in chapters	Chapter
	exposures of the general public not involved in the industry. The industry is legally responsible for protecting staff against work related exposures such as staff responsible for mixing chemical cocktails and handling equipment. Exposed workers using public transport, and having direct contact with family members or infants when returning from work, and storage of exposed protective equipment remains a concern seldom addressed effectively in low income countries such as in the study site. Furthermore, security guards and other non-chemical handling staff might not undergo the same training as those at risk of direct chemical exposure; however might help out in case of an emergency or have extended exposure periods at a low concentration without risk awareness. There is limited knowledge on the health effects of long term compounded exposure to chemicals at high concentrations.	
Human health	The health status of a population affects the resilience of that population to tolerate the introduction of new chemicals and other environmental health hazards. Communities with a negligible disease burden and sufficient access to amenities are likely to tolerate the introduction of environmental health hazards better than those who are competing for resources, have a high disease burden and have difficulty accessing basic health care such as the community in the study site. This Chapter presents the South African data of the challenges and the potential benefit of SGD in the Karoo, in light of the known challenges the Karoo population faces, including high disease burden, limited access to preventative and curative health services, arid landscape and underground water dependence, high unemployment - and poverty rates.	Current Chapter
Noise exposure	Exposure to noise through increased truck traffic for those living in the proximity to SGD. Exposure to noise from the industry for industry workers.	Toerien et al. (2016)
Air pollution	Fugitive gas emissions like methane leaking into the atmosphere exposes community to short term and long term health risks. Exposure to vehicle emissions as a result of SGD.	Winkler et al. (2016)
Waste	Exposure to hazardous waste created during the SGD process could result in health problems. In addition, the additional on-site sanitation as well as additional waste water created by the community could result in unhygienic conditions and possible health impacts if not managed properly.	Oelofse et al. (2016)
Agriculture	Health effects as a result of loss of income, financial strain.	Oettle et al. (2016)
Planning	Increased gravel roads– negative impact on farming, increased dust/air pollution. Road building requires large amounts of water thus threatening water resources in this already semi-arid area.	Van Huyssteen et al. (2016)
Water	Exposure to SGD waste water through a number of pathways could cause short and long term health effects. Pathways include contamination from surface spills, from flowback and produced water. Water shortage and threats to the current supply in the study area could have long term health implications. Contamination of current community water sources through SGD.	Hobbs et al. (2016)

12.4 Special features of the Karoo environment from an environmental health perspective

The study area under review within this scientific assessment is illustrated in Figure 12.1 below. It shows the areas within the water catchments where water resources are expected to be in shortage or are already in deficit. The possibility of water resource contamination is described in the section below, together with background information describing water supplies served to the population within the study area.

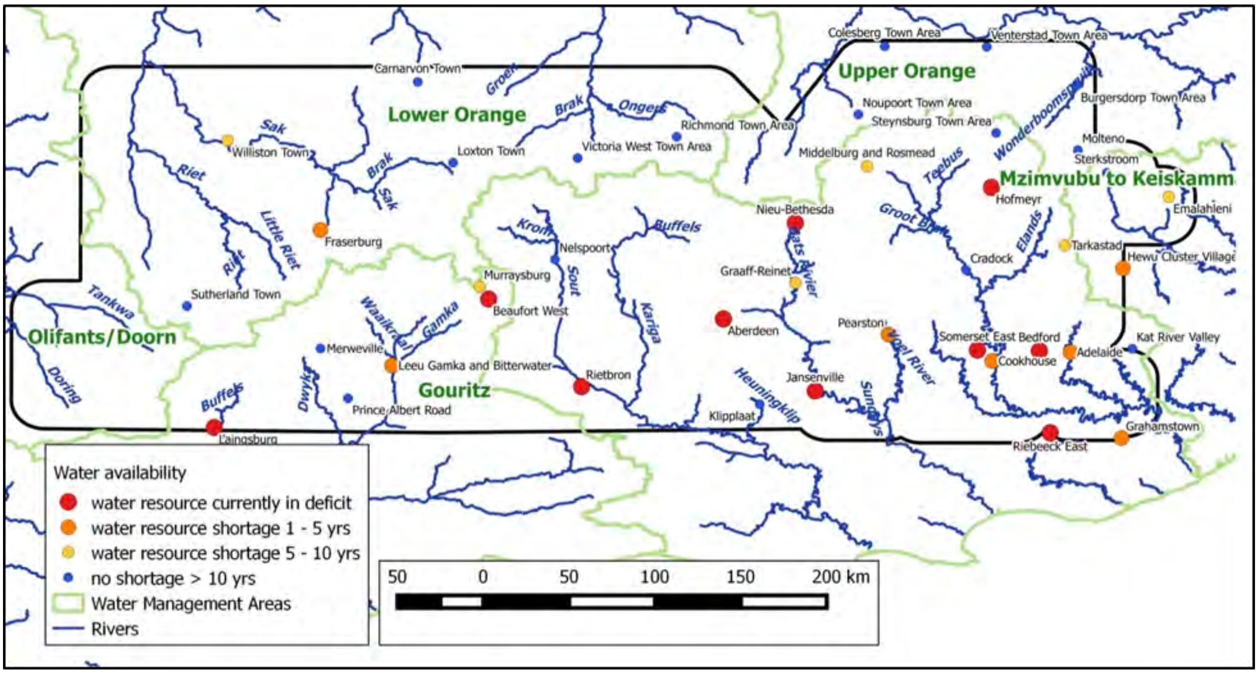
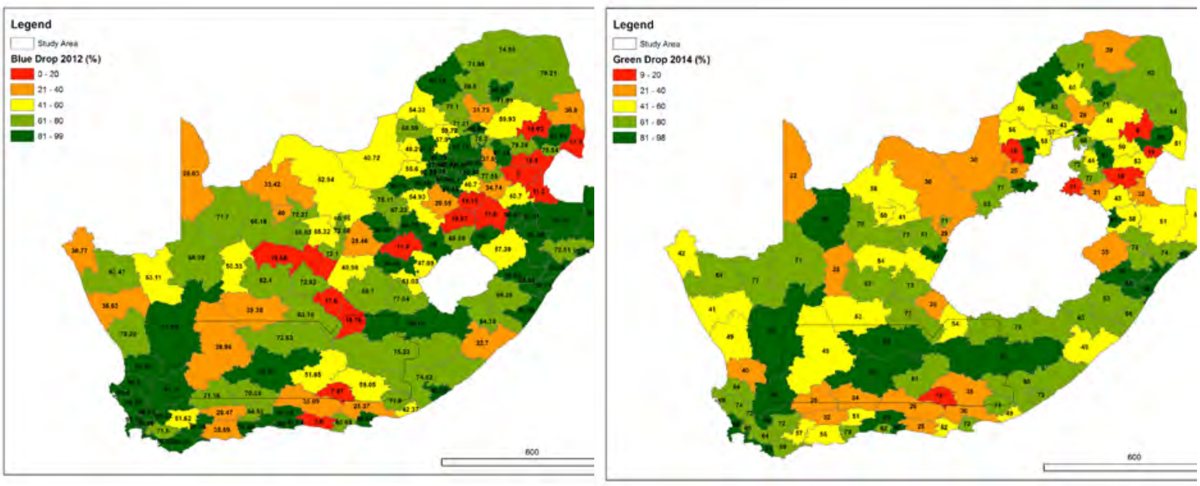


Figure 12.1: Water supply within the study area.



Blue drop status (DWS, 2012) Green drop status (DWS, 2014)

Figure 12.2: Blue Drop status (Department of Water and Sanitation (DWS), 2012) and Green Drop status (DWS, 2014) across South Africa

Blue Drop and Green Drop Programme (DWS, 2009)

The Department of Water and Sanitation (DWS) initiated the Blue and Green Drop Certification Programme, introducing incentive-based regulation for the drinking water quality management functions, respectively. The key purpose was to ensure effective management of drinking water and waste water quality and making the information public for transparency (DWS, 2009). For Blue Drop requirements, drinking water service providers must provide evidence of the following:

- adequate process control, maintenance and management;
- efficient monitoring compliance with the South African National Standard (SANS 241);
- have a failure response management programme; and
- report results to the DWS

Green Drop status for waste water treatment management is achieved if the water service authority complies with waste water legislative requirements and other best practice requirements are shown to be implemented. Similar requirements must be shown as for the Blue Drop requirements. A risk based approach is used to determine priority areas and ensure that a strategic approach is adopted to scientifically calculate priority waste water facilities for urgent regulatory intervention and tangible targets for municipalities to reduce risk.

Water use data, together with the population numbers is summarised in Digital Addendum 12A, based on the Water Authorisation Registration and Management System (WARMS) which is a national register of water users. Beaufort West, Camdeboo and to a lesser extent Ubuntu District; and head waters of two river systems: the Groot River (the Sout River and the Kariega River) and the Sundays River. The Kariega joins with the Sout River to form the Groot River at Beervlei Dam, which is a flood control dam (not a storage dam). There are two towns located on the tributaries of the Groot River and in the Beaufort West Local Municipality which are at risk to surface water contamination during the exploratory phase, namely, Murraysburg and Nelspoort. Estimates from 2011 state that Murraysburg has a population of 5 069, but its drinking water, is derived from two boreholes. In 2011, Nelspoort has an estimated population of 1 699 and derived 65% of its water from a weir on the Sout River. The remainder of Nelspoort’s water is obtained from two boreholes. Blue Drop and Green Drop scores (Figure 12.2 and text box) assessing the management of drinking water and waste water treatment facilities, respectively, demonstrated fairly good management and maintenance of the facilities. Nelspoort water treatment works (WTW) received a Blue Drop Score of 74.45% in 2012, and a Green Drop Score of 87.9% in 2011. Rietbron is located downstream of Nelspoort and, as at 2011, had a population of 1 184, with only a single borehole to supply the town with water. Steytlerville, with an estimated population of 4 017 in 2011, is located on the Groot River but 100% of the towns water supply is from two boreholes. The Groot River joins with the Kouga River downstream of Kouga Dam to form the Gamtoos River, and enters the ocean at the Gamtoos estuary.

Graaff-Reinet is located downstream of Nieu-Bethesda within the "Prospectively - high probability" zone and has a population of 35 672 (as at 2011). The population is estimated to increase by 2 000 people during the holidays. Graaff-Reinet receives surface water from the Nqweba Dam and groundwater from two wellfields: the northern wellfield located approximately 3 km north of Graaff-Reinet consisting of 13 boreholes. Graaff-Reinet received a blue drop score of 53.49% in 2012 and a green drop score of 6% in 2011. Aberdeen, as at 2011, had a population of 7 162, with the population increasing by 2 000 people during the holidays. Aberdeen is supplied by boreholes. Aberdeen had a blue drop score of 42.11% in 2012 and a green drop score of 5.3%. As at 2011 Jansenville, known as the centre of mohair sheep farming and mohair production, is located on the Sundays River, has a population of 5 612 and receives its water from 9 boreholes with a demand of 0.21 million cubic meters per annum (mcm/a). Downstream is Darlington Dam, which receives water from Gariep Dam on the Orange River via the Orange-Fish Tunnel, the Fish River, the Fish Sundays Canal and Skoenmakers River.

12.5 Baseline health status of the population in the study area

The areas earmarked for SGD in South Africa include some of the most sparsely populated, but socio-economically deprived, districts in the country. Of the four Health Districts which comprise the localities where SGD has been proposed, all are districts with health indicators suggesting serious challenges for health care coverage (London and Willems, 2016). For example, in 2012/13, the Central Karoo district reported the highest rates of stillbirths in the country and the highest rates of early neonatal death rates in the Western Cape Province (Massyn et al., 2013). Also, under-five mortality, infant mortality and maternal mortality in the Central Karoo were reported as double the rates for the Western Cape as a whole. The nearest specialist centres are located in George and Port Elizabeth, and the distances from sites where SGD is proposed exceed 400 km for some areas. The Central Karoo had only five ambulance stations and four district hospitals in 2013 which are expected to provide emergency services for this large area.

The study area is perceived as a healthy environment, but there are many impoverished and health-compromised communities. Consideration of the potential health impacts of SGD requires recognition that the districts where SGD has been proposed are characterised both by higher levels of illness and a socio-economically deprived population. In addition, the health system is stretched by a higher burden of disease and substantial logistical challenges posed by the rural nature and geographical dispersion. In rural Pennsylvania, where SGD has taken place, health parameters have improved as a result of increased employment. Current use of fossil-fuel causes substantial ill-health from air pollution and occupational hazards. Nevertheless, health challenges still exist (lower health scores) dealing with rural conditions such as distance from medical facilities. According to Colborn et al. (2011), given the human resource constraints faced by health services in these districts and the need for high-level epidemiological and toxicological skills to detect early perturbations in health status of local populations, it is unlikely that such rural districts would have the public health capacity to track, monitor, and act upon evidence of risks (London and Willems, 2016).

The District Health Barometer (2013/14) (Massyn et al., 2014), reports that the Amathole District Municipality (DM) and the Chris Hani DM have the highest number of clinics, 153 and 147 clinics respectively, the Central Karoo DM has the least amount of clinics in the country with only eight clinics. The Central Karoo DM has a total of four District Hospitals, of which two, the Beaufort West and the Murraysburg Hospital, are located in the study area. The Central Karoo DM also has one specialised tuberculosis (TB) and psychiatric hospital located in Nelspoort. The South African Hospitals Survey 2011-12 (Code4SA 2016) states that Beaufort West Hospital received an overall performance of 60% and Murraysburg Hospital of 51%. The overall performance of the clinics was however not available in the dataset. South Africa has a total of 3 401 clinics, which is roughly equivalent to one clinic per 15 200 people.

DALYs were calculated in the study area at the ward level making use of the WHO Burden of Disease calculations (WHO, 2003) and the 2013/14 District Health Barometer Burden of Disease data (Massyn et al., 2014). These estimates are presented in Figure 12.3 and Figure 12.4 below.

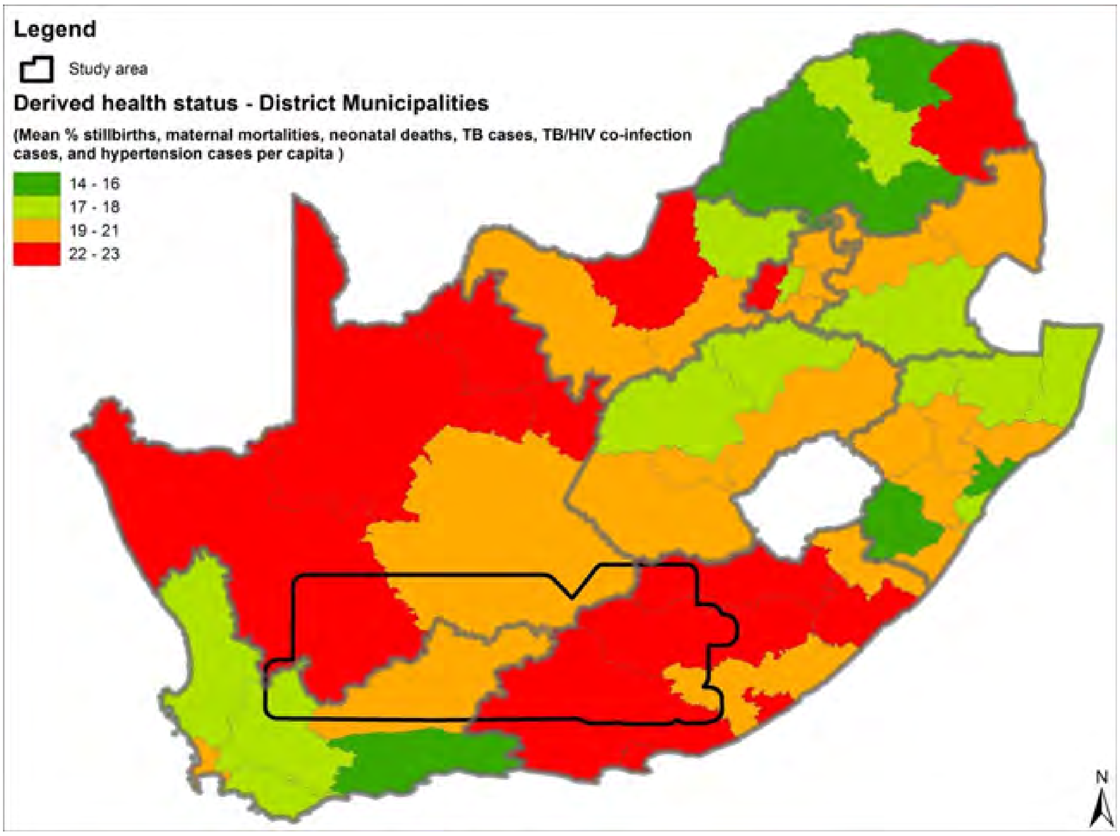


Figure 12.3: Health status of the study area relative to country.

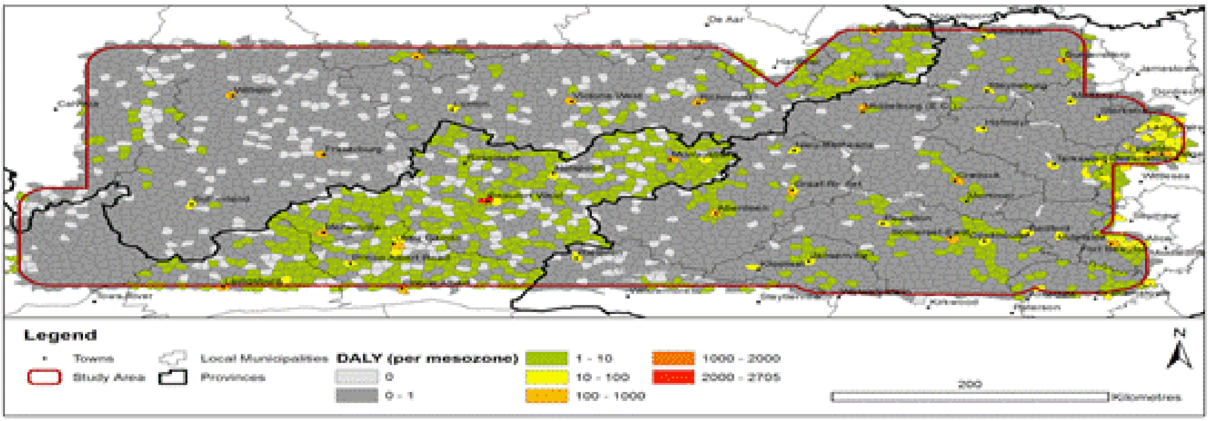


Figure 12.4: Baseline Disability Adjusted Life Years (DALYs) for the study area with low DALYs shown in most areas and the highest DALYs shown in the towns with the largest population size.

Data used to calculate DALYs included Years of Life Lost (YLL) (maps illustrating this dataset is in the Digital Addendum 12A) resulting from HIV, TB, communicable diseases, maternal deaths, perinatal deaths, nutrition causes, injuries and non-communicable diseases. Years Lived with a Disability (YLD) was calculated based on limited data that were available and accounted for HIV, TB, hypertension and mental health, along with WHO disability weights. Maps of YLL and YLD showing the differences between the municipalities, differences between YLL and YLD and how this compares to the rest of the country are shown in Digital Addendum 12B, where the data is also provided.

Figure 12.5 provides the individual DALYs per local municipality within the study area, showing that Beaufort West has the highest DALYs.

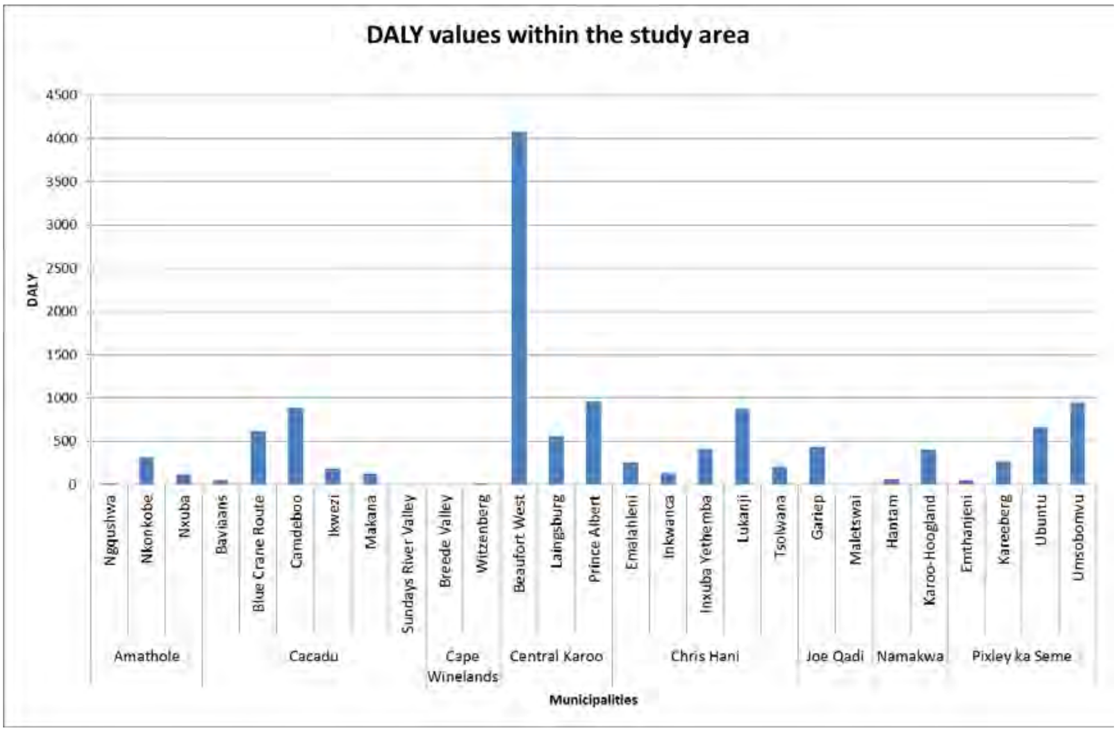


Figure 12.5: Disability Adjusted Life Years (DALYs) per local municipality within the study area.

12.6 Relevant legislation, regulation and best practice

The existing South African legislation and regulations relevant for water and health are presented in Table 12.2. SGD and its impact are covered by various legislations and regulations, governed by multiple government departments. With multiple departments tasked with overseeing compliance and monitoring, the potential for gaps exist particularly in relation to residents and worker health, financing the monitoring of health impacts and sustainable risk mitigation measures. To protect water and health in South Africa, petroleum exploration and production regulation needs to reflect the relevant principles in South Africa’s Constitution. Health is indirectly implied and needs to be more explicit with sustainable approaches and financing of monitoring systems by the industry. Capacity constraints (financial resources, additional man power, and technical know-how) might be a limiting factor in many areas. The onus for financing of a formal monitoring plan and analysis costs lies with the unconventional oil and gas industry. This should entail the development of a formal sampling and analysis plan with the execution of sampling and analysis conducted by independent, credible and certified laboratories and service providers.

Table 12.2: Existing legislation and new regulations relevant for water and health.

Existing SA Legislation	Department	Relevant Principles and Sections for Water and Health
Constitution of the Republic of South Africa, 1996	Department of Justice	**Relevant Bill of Rights:** - right to an environment not harmful to health and wellbeing (Section 24) - right to sufficient food & water (Section 27(1)(b)) - right to just administrative action (Section 33) - - right to access to information (Section 32)
National Environmental Management Act, Act 107 of 1998 (NEMA)	Department of Environmental Affairs	**Relevant components:** - Responsibility for the environmental health and safety consequences of a policy, programme, project, product, process, service or activity exists throughout its life cycle. - DWA is a member of multi-stakeholder committee for environmental coordination under NEMA - Chapter 1: National Environmental Principles: Section 2 Principles are all relevant - NEMA Principles including: o Public participation o Polluter pays o Precautionary principle o Cradle to Grave o Environmental justice o Integrated and holistic approaches
National Water Act, Act 36 of 1998 (NWA)	Department of Water Affairs	**Chapter 1: Interpretation and Fundamental Principle of the Act:** - Sustainability and equity are identified as central guiding principles in the protection, use, development, conservation, management and control of water resources. These guiding principles recognise the basic human needs of present and future generations, the need to protect water resources, the need to share some water resources with other countries, the need to promote social and economic development through the use of water and the need to establish suitable institutions in order to a thieve the purpose of the Act.
Mineral and Petroleum Resources Development Act, Act 28 of 2002 (MPRDA)	Department of Mineral Resources	**References to Water Management:** - ‘‘(1) The holder[3] of a prospecting right, mining right, retention permit**, [or]** mining permit, or previous holder of an old order right or previous owner of works that has ceased to exist, remains responsible for any environmental liability, pollution, **[or]** ecological degradation, the pumping and treatment of extraneous **water**, compliance to the conditions of the environmental authorisation and the management and sustainable closure thereof, until the Minister has issued **[an]** a closure certificate in terms of this Act to the holder or owner concerned.’’; and - ‘‘(5) No closure certificate may be issued unless the Chief Inspector and **[the Department of Water Affairs and Forestry]** each government department charged with the administration of any law which relates to any matter affecting the environment have confirmed in writing that the provisions pertaining to health and

3 "Holder" means a holder of an exploration or production right granted in terms of Sections 80 and 84 of the Act, respectively (MPRDA).

Existing SA Legislation	Department	Relevant Principles and Sections for Water and Health
		safety and management pollution to **water** resources, the pumping and treatment of extraneous **water** and compliance to the conditions of the environmental authorisation have been addressed.''
Regulations for Petroleum Exploration and Production 2015		**Relevant sections for water include:** 1) "**well examination schemes**" are required to by competent and independent persons to assess "risks to the health and safety of persons from the well or anything in it, or from strata, to which the well is connected, have been assessed and are within acceptable levels." - Holder[2] must prevent **well design** risks to health and safety of persons from the well or anything in the well, or in strata to which the well is connected. - Holder must address **fracking fluids management** to ensure assessment of potential environmental and health risks of fracking fluids and additives in both diluted and concentrated form. - During **fracking**, a holder must conduct operations in a manner that does not pose a risk to public health, life, property and the environment. 2. **Water Resource Monitoring;** (described under Best Practices) 3. **Management of Water** – provides detail on: - water balance; - protection of water resources; and - water use. 4. **Management of Spillage** (described under Best Practices)
National Environmental Management: Waste Amendment Act , Act 26 of 2014 (NEMWA)	Department of Environmental Affairs	**Relevant principle:** - Schedule 3 Category A: Hazardous waste (four wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal: (c) wastes from natural gas purification and transportation)
Health Act (Act No. 61 of 2003)	Department of Health	**General, non-specific, relevant principles:** - supports the constitution in terms of everyone having a right to an environment not harmful to health and well-being (Section 24). - water quality monitoring is referenced in terms of municipal health services provisions – no other mention of water.

12.7 Best practice guidelines, mitigation and monitoring requirements

The safety and health of employees, contractors and the general public, as well as the environment, is critical throughout every stage of SGD. Regulation, monitoring, prevention and control strategies are crucial to minimise public health impacts associated with SGD. Globally, legislation is used to regulate various types of pollution as well as to mitigate the adverse effects of pollution. In order to protect public health, the emissions and effluents from SGD into the air, water and land or soil have to be prevented, minimised, or at least controlled. In other words public health protection involves the regulation, prevention and control of human exposure via environmental impact pathways (e.g. air, water, soil, land). Pollution can be minimised by adopting practices that involves (i) recycling, (ii) reusing, (iii) waste minimisation, (iv) mitigation, (v) prevention, and (vi) composting (Owa, 2013). Apart from the abovementioned practices, pollution control devices such as a dust collection system e.g. bag houses, cyclones, etc. could be used to minimise air pollution. According to Roy et al. (2014), SGD-related emissions of nitrogen oxide (NOX) and VOC to the air could be reduced up to 85% and 88% respectively with the correct mitigation measures. Pollution control can also include waste water treatment e.g. sedimentation (primary treatment); activated sludge bio filters (secondary treatment, also used for industrial waste water); aerated lagoons; constructed wetlands (also used in urban runoff); and industrial waste water treatment e.g. ultra-filtration, to minimise water pollution (Owa, 2013).

To protect the environment and prevent negative health impacts, SGD in South Africa will need to comply with best international practices and best international regulatory requirements. To protect health, there needs to be a holistic best practice approach incorporating health, environment and social-economic factors. In this section we highlight some of the key best practices linked to water and health that should be incorporated into this holistic approach.

From an occupational health and safety perspective, there is a hierarchy of measures to be taken to mitigate worker exposure and subsequent health impacts (International Association of Oil and Gas Producers- International Petroleum Industry Environmental Conservation Association (OGP-IPIECA), 2009; 2013). These are summarised in Figure 12.6.

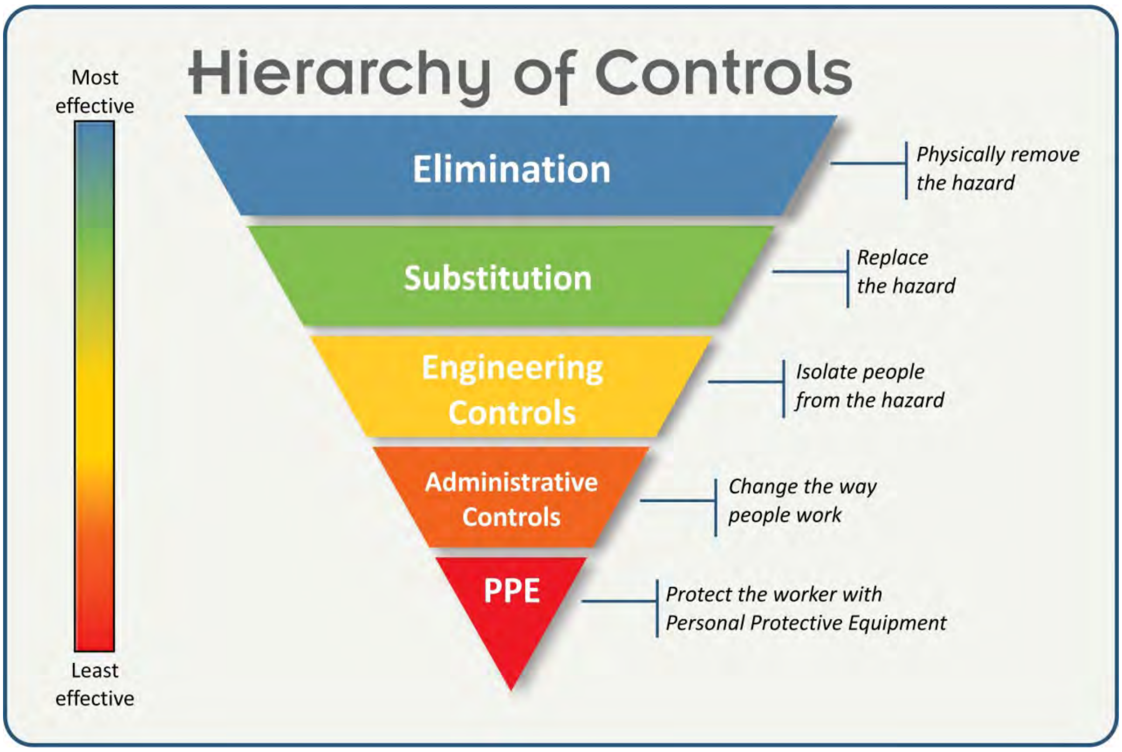


Figure 12.6: Hierarchy of Pollution Controls for SGD (Source NIOSH, 2015).

Over-reliance on industry self-regulation is limited particularly in the event of non-compliance with safety standards and best practice, therefore approaches South Africa considers, should not only include the American Petroleum Institute (API, 2011) industry standards, but those recently published internationally by the European Union (EU), United States (US) and United Kingdom (UK). These include:

- the **International Energy Agency's (IEA)** 2012 report Golden Rules for an Age of Gas: World Energy Outlook Special Report on Unconventional Gas (Golden Rules Report; http://www.lea.org/publications/freepublications/publication/WEO2012_GoldenRulesReport.pdf);
- the **European Commission's** 2012 Report on Potential Risks from Fracking entitled Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe;
- the current and developing standards of the **United States of America's Federal Environmental Protection Agency** (US EPA) relevant for water including oil and gas extraction guidelines (https://www.epa.gov/eg/oil-and-gas-extraction-effluent-guidelines) and oil and gas water stormwater permitting (https://www.epa.gov/npdes/oil-and-gas-stormwater -permitting#undefined); and
- the **United Kingdom's Department of Energy and Climate Change's (UK DECC)** July 2013 Guidance about shale gas and hydraulic Fracturing (fracking; https://www.gove.uk/government/uploads/system/uploads/attachment_data/file/225826/About_Shale_gas_and_and_hydraulic_fracking.pdf.

Best practices and standards for environmental and health protection (social-economic factors are addressed in other Chapters) need to address the following areas:

1. **Appropriate Regulatory Framework and Compliance Structures**

A key best practice is to ensure the regulatory framework protects water from fracking activities in the short and long run that will protect the health of workers, children, residents, and tourists. Currently, as highlighted in Table 12.1, the legislation is fragmented particularly in relation to protection of health from fracking related issues. For example, health – with particular reference to the Health Act (Act No. 61 of 2003) - is missing from the South African Government Gazette No. 38855 (2015) on MPRDA (28/2002): Regulations for Petroleum Exploration and Production which specifies the requirements for petroleum exploration and production.

2. **Baseline Data, Public Access to Information and Disclosure**

Detailed information needs to be provided to the public before SGD begins and during the extraction process. This includes access to baseline information on ground and surface water quality, water supply and characteristics (i.e. that is compliance with the 2015 Regulations for Petroleum

Exploration and Production "baseline water quality assessment" requirement). Best practice is that this information is conducted two to five years prior to drilling. This information then allows for adequate monitoring and compliance with standards and regulations. Transparency and impartial monitoring are essential. For example, SGD companies in the US are able to publically disclose the chemical additives in their fracking fluid for each well on the Chemical Disclosure Registry - *FracFocus*[4] - managed by Ground Water Protection Council and Interstate Oil and Gas Compact Commission.

Furthermore, the OGP- IPIECA Good practice guidelines for the SGD (2013) and their drilling fluids and health risk management - A guide for drilling personnel, managers and health professionals in the oil and gas industry (2009) provide recommendations for worker health monitoring which would need to be extended to monitoring community health symptoms. Monitoring should be financed by the unconventional oil and gas industry but sampling and analysis should be carried out by independent certified and credible service providers. Where possible, capacity building and improved health care could form part of the social responsibility plan of the unconventional oil and gas industry.

3. **Site Characterisation and Location**

Best practices for well site location are required to prevent contamination of underground drinking water from fracking fluid and contamination of surface waters. The Regulations for Petroleum Exploration and Production (Government Gazette, 2015) include specifications for:

Site preparation: The area in respect of which an exploration or production right is granted must be prepared in accordance with the Environmental Authorisation- and the approved Environmental Impact Assessment Regulations; and

Site contamination: A holder must at all times, prevent the contamination of the environment by providing a suitably designed impermeable site underlay system and making site drainage arrangements.

Further measures include:

- Geologic and hydrologic mapping and risk analysis to demonstrate geologic suitability and the presence of an appropriate confining zone to inhibit vertical migration of contaminants.
- Identification of existing wellbores, determination of the integrity of those wellbores (i.e. casing, cement, plugs, etc.), and mitigation where necessary.
- Estimation of full life cycle fresh water use.
- Estimation of full life cycle waste water volumes and assessment of the ability of the various disposal options to safely handle these volumes without adverse effects on the environment or human health.

[4] FracFocus website: http://fracfocus.org/

- Comprehensive assessment of potential impacts to water resources used to supply fracking base fluid.
- Baseline water testing.
- Ongoing monitoring of potentially affected ground and surface waters (API, 2011).

4. **Isolating Wells, Preventing Leaks, Preventing Spillage, and Preventing Worker Risks**

Planning and prevention are key and need to be clearly supported by legislation. For instance, the US EPA (2015) explored spill containment and mitigation measures in an analysis of spills related to fracking activities and a section of the document is dedicated to this subject. They also mention that the API has a guidance document *Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing* (API, 2011). The document describes practices currently used in the oil and natural gas industry to minimise potential surface environmental impacts. New Brunswick in Canada has rules for industry on responsible environmental management of oil and natural gas activities (Government of New Brunswick (GNB), 2013).

Drilling practices health risk management: A guide for drilling personnel, managers and health professionals in the oil and gas industry (IPIECA, OGP Report Number 396).

Further measures for preventing surface water contamination are outlined in the Australian 2013 best practices from the Camden Health Impact Assessment (HIA) document (Environmental Risk Sciences (EnRiskS), 2013[5]). These include:

- Construction of silt fences and other erosion control measures that would be implemented to minimise surface erosion.
- A water management system, including water gathering lines where necessary, will be employed to enable collection, management and appropriate reuse of water produced as a result of the drilling, fracture stimulation and production operations including the storage of saline production water in storage tanks.
- Infrastructure will be inspected and audited following a flood event to ensure that all elements are operating effectively, and necessary rehabilitation works are carried out immediately.
- Gas wells will be located at a minimum distance of 100 m from creeks or other water bodies (not located uphill from the well).
- Appropriate crossing locations will be selected on dry creek beds for the installation of gathering lines and the area rehabilitated suitably following any earthworks.

[5] EnRiskS (2013) has these references: DTIRIS, 2012a. Code of Practice for Coal Seam Gas. Fracture Stimulation Activities. NSW Department of Trade and Investment, Regional Infrastructure and Services. Available at: http://www.resources.nsw.gov.au/ community-information/coal-seam-gas/cop;
DTIRIS, 2012b. Code of Practice for Coal Seam Gas. Well Integrity. NSW Department of Trade and Investment, Regional Infrastructure and Services. Available at: http://www.resources.nsw.gov.au /communityinformation/ coal-seam-gas/cop).

- Under-boring would be used for the installation of gas gathering lines where permanent water flows occur and for crossings of watercourses in the vicinity of the Mount Annan Botanic Gardens.
- Rehabilitation of areas where earthworks have taken place to a surface profile similar to the original profile, particularly where gathering lines have been installed by either trenching or under-boring. Rehabilitation works would be in accordance with AGL Energy Ltd.'s established and proven Landscape and Rehabilitation Management Sub Plan (LRMSP) as detailed in the existing Environmental Management Plan (EMP).
- Saline water produced from the wells will be stored either in lined drill pits or water storage tanks (majority). Bunding will be in place around lined pits to reduce the potential for saline waters contained within the pits to be liberated during a flood. The water level and quality of water stored within the lined drill pits will be monitored regularly to ensure sufficient space is available for rainfall contribution and to ensure that the quality of the water is acceptable for proposed future uses.

Management of spillage:

The Regulations for Petroleum Exploration and Production (Government Gazette, 2015) indicates that:

(1) A spillage of fracking fluids or flowback in excess of 50 litres must be reported to the designated agency within 24 hours of occurrence.
(2) A spillage of fracking fluids, additives, or flowback, used or generated during or after fracking operations must be cleaned up immediately.
(3) An incident involving the spilling of a harmful substance that flows or may flow into a water resource must be dealt with in accordance with Sections 19 and 20 of the NWA (1998), and Sections 28 and 30 of the NEMA (1998).

5. **Responsible Water Use, Storage Treatment and Disposal**

The Regulations for Petroleum Exploration and Production (Government Gazette, 2015) cover water use requirements as well as storage, treatment and disposal.

Jordaan (2014) highlights several best practices for avoiding water contamination and pollution that strengthen the current regulations. For example:

Implement minimum depth limitations on fracking. An appropriate minimum depth limitation prevents fracking above a certain depth and is based on local geology and the risk of communication with fresh water aquifers. In the Karoo such a limitation must account for the complex hydrogeology and *the prior experience of groundwater travelling long distances. In this context, the limitations of the proposed fracking regulations are insufficient (Jordaan, 2014: 24).*

Store and dispose of produced and waste water lawfully and safely. To the extent that this is not already regulated under the NWA and NEMWA, regulations must set and enforce appropriate standards for safe water storage, extending to the use of storage tanks instead of open pits, and appropriate technology for waste water treatment. Regulations must consider the availability and proximity of fresh water supplies and disposal options, implement control measures for volatile organic compound (VOC) emissions from flowback and produced water and enforce the operator's responsibility in accordance with developing best practice standards (Jordaan, 214:29).

6. **Compliance Monitoring and Enforcement**

The South African Regulations for Petroleum Exploration and Production (Government Gazette, 2015) specify what needs to be carried out with regards to water resource monitoring:

Water resource monitoring

(1) An applicant or holder must appoint an independent specialist to conduct a hydro-census fulfilling the standard requirements of the department responsible for water affairs which indicates potentially affected water resources, on at least, a 3 kilometres radius from the furthest point of potential horizontal drilling, as well as identify priority water source areas and domestic groundwater supplies indicated on relevant geo-hydrological maps.

(2) An applicant or holder must prepare and submit, together with the water use licence application, to the department responsible for water affairs, a proposed water resource monitoring plan, for approval. The plan must at least identify-

(a) the sampling methodology;
(b) the monitoring points;
(c) the monitoring parameters;
(d) the monitoring frequency; and
(e) the reporting frequency.

(3) The monitoring plan contemplated in sub -regulation (2) must be submitted to the competent authority for consideration, as part of the application for Environmental Authorisation.

(4) Water samples collected as part of the monitoring plan contemplated in sub-regulation (2) must be analysed by an accredited laboratory and the holder must submit the results and their interpretation to the designated agency and the department responsible for water affairs within 7 days after receipt thereof.

(5) The results must at least include a detailed description of the sampling and testing conducted, including duplicate samples, the chain of custody of the samples and quality control of the testing.

(6) A full water monitoring report must be included in the EMPr required in terms of the Environmental Impact Assessment Regulations, 2014.

(7) A holder must, after conducting a baseline water quality assessment, continue with monitoring in accordance with the approved plan and must-

(a) have the water resources subjected to sampling, analysis and interpretation of water quality and changes in water levels by an independent specialist approved by the designated agency in accordance with the approved plan contemplated in sub –regulation (2);

(b) submit the results of the analysis and interpretation to the designated agency and the department responsible for water affairs within 7 days of receipt of the analysis and interpretation; and

(c) submit the monitoring assessment reports in accordance with the approved monitoring plan contemplated in sub -regulation (2).

(8) (a) The designated agency, Council for Geoscience, Council for Scientific and Industrial Research, designated local authorities or the department responsible for water affairs, may collect samples of fluids encountered in the exploration or production area (water or hydrocarbons, at depth or at the surface) for their own analysis and interpretation.

(b) The holder must allow site access to the authorities mentioned in paragraph (a) for the purpose of collecting the samples.

(9) Data collected as contemplated in this regulation must be published except where it may be shown to directly relate to the availability of petroleum and commercial value of the holder's acreage.

(10) Groundwater aspects must be recorded and reported according to the department responsible for water affairs' Standard Descriptors for Geosites.

(11) The holder must capture the water resource data generated.

Additional sections dealing with well construction (Chapter 8) and operational maintenance (Chapter 9) are provided in detail in the Gazette, with relevant monitoring requirements including the following points:

Management of Operations

- *Hydraulic Fracturing Equipment*

- *Mechanical Integrity Tests and Monitoring*
- *Hydraulic Fracturing Fluid Disclosure*
- *Fracture and Fracturing Fluid Containment*
- *Fracturing Fluids Management*
- *Management of Flowback and Produced Fluids*
- *Transportation of Fluids*
- *Fluids Storage*
- *Hydraulic Fracturing Operations*
- *Post Hydraulic Fracturing Report*
- ***Management of Water***
- *Water Balances*
- *Protection of Water Resources*
- *Water Use*
- ***Management of Waste***
- *General*
- *Waste Management*
- ***Management of Pollution Incidents***
- *Management of Spillage*
- ***Management of Air Quality***
- *Fugitive Emissions*
- *Fugitive Dust*
- *Noise Control*

Although management of environmental quality which includes air and water quality as well as waste disposal and spills, the health of community members and workers in the SGD industry are not specifically mentioned in the regulations. This is a shortcoming which should be addressed where health symptoms should be monitored for both workers (as part of occupational health responsibilities of the employer) and community members. The type of health symptoms that are associated with exposure to contaminants of SGD and the extra vehicle traffic should also be monitored by local clinics/health facilities and fed back into national monitoring systems.

Health monitoring systems, as well as regulatory processes, requires a system of linking to current evidence-based research and findings which would mean having a system in place for overseeing this with perhaps national research institutions. Again financing of such initiatives should be through the unconventional oil and gas industry. Additionally, capacity building and improved health care facilities could form part of the social responsibility plan of the unconventional oil and gas industry.

12.8 Key potential impacts and associated chemical risks

Chemicals found in association with fracking includes over 1100 chemicals, although only an average of 14 are reported to be used in a single well (US EPA, 2015). A comprehensive list of chemicals found in fracking waters and their corresponding toxicity, cancer and endocrine disrupting chemical (EDC) data are presented in Digital Addendum 12C. Digital Addendum 12F provides links to additional electronic peer reviewed literature and databases on various aspects associated with SGD.

The list of chemicals was developed based on US (US EPA, 2015) and Australian (EnRiskS, 2013) environmental knowledge including reported usage, percentage of times detected, persistence in the environment and toxicity of health impacts. Subsequently, removing the close to 50 chemicals that are specified in the regulations to be prohibited for use in South Africa (Government Gazette, 2015) from the most toxic and frequently found chemicals, the list was shortened to 74 chemicals that were considered. These chemicals together with the EDCs (total 132) are shown in Digital Addendum 12D.

Produced water is naturally occurring water that is found in the source rock and can contain inorganic chemicals not found in fracking fluid. These chemicals were not included in Digital Addendum 12D, but are of potential concern and include: arsenic, strontium, barium, nickel, lead, iron, bromine, iodine, fluoride, uranium and other radioactive chemicals.

The Endocrine Disruption Exchange (TED-X) created a database where health effect data were organised into several categories, focusing on the main organs and systems that have been identified as being potentially impacted by chemicals used in fracking. A total of 12 categories were used to describe the health effects associated with these chemicals. Of the 650 chemicals detected in fracking fluids presented in the multistate TED-X database (2013), the majority (375) were able to cause skin and eye irritations, with 366 causing respiratory symptoms. Table 12.3 summarises the health effects and the number of chemicals known to contribute to those symptoms.

Table 12.3: Specific health effects associated with 650 chemicals known to be used in hydraulic fracturing process (Summarised from TED-X, 2013).

Symptoms or effects	Number of chemicals
Skin and eye	375
Respiratory	366
Gastric and liver	308
Brain and neurological	202
Immunological	151
Kidney	154

Cardiac	173
Cancer	85
Developmental	83
Reproductive	91
Other (e.g. weight changes, death)	177

Over 78% of the chemicals are associated with skin, eye or sensory organ effects, respiratory effects and gastrointestinal or liver effects. The brain and nervous system can be harmed by 55% of the chemicals. These health effect categories are likely to appear immediately or soon after exposure. They include symptoms such as burning eyes, rashes, coughs, sore throats, asthma-like effects, nausea, vomiting, headaches, dizziness, tremors, and convulsions. Other affects, including cancer, organ damage, and harm to the endocrine system, may not appear for months or years later. Between 22% and 47% of the chemicals were associated with these possibly longer-term health effects. Forty-eight percent of the chemicals have health effects in the category labelled ‘Other’. The ‘Other’ category includes such effects as changes in weight, or effects on teeth or bones, for example, but the most often cited effect in this category is the ability of the chemical to cause death.

12.9 Potential sources or pathways for environmental pollution from SDG

For the purposes of the risk assessment matrix, six impact pathways were assessed and two receiving human environments were identified. The two receiving human environments are workers who often have direct exposure on the wellpad through SGD activities and often have a higher risk, and ultimately the indirectly exposed community, often located further away from the SGD activities.

12.10 Air pathway exposures

Methane and VOC emissions are the main contaminants from SGD processes (US EPA, 2014), whereby people may be exposed via the air pathway. Natural gas leakage can occur throughout the entire unconventional oil and gas development and production process (Chimowitz et al., 2015), Crystalline silica sand delivered by trucks to the drilling site releases silica dust into the air, where workers can be exposed (Esswein et al., 2013). Workers experience the most direct exposure; however, silica dust may also be an air contaminant of concern to nearby residents.

12.10.1 Worker

Air pollution is thought to be one of main routes of exposure for workers involved in unconventional oil and gas development to a range of potentially hazardous chemicals. There is a proven association between respiratory exposure to silica dust and the development of silicosis, a progressive lung disease (Shonkoff et al., 2014) and other diseases such as chronic obstructive pulmonary disease, tuberculosis, kidney disease, autoimmune conditions, and lung cancer (Centers for Disease Control and Prevention (CDC), 2002). Emissions of methane and other hydrocarbons have been noted in relation to SGD operations, both from the wells and related infrastructure such as production tanks, valves, pipelines and collection facilities (Adgate et al., 2014). Methane emissions may be a marker for the release of other potentially toxic volatile hydrocarbons, such as benzene, toluene, ethylbenzene and xylenes, collectively referred to as BTEX, released during well development and production (Korfmacher et al., 2013). As is discussed in Winkler et al. (2016), occupational exposure to air pollutants is very likely and the consequences are substantial. The use of heavy diesel trucks, stationary engines and associated rig equipment for SGD will lead to occupational health risks at the well site due to emissions of diesel exhaust, nitrogen dioxide (NO_2), particulate matter (PM), VOCs, hydrogen sulphide (H_2S) and silica.

12.10.2 Community

There is evidence of potential environmental exposure to chemical contaminants associated with SGD. Many studies highlight the risk of contaminants being transported in ambient air at concentrations of pollutants known to be associated with increased risk of morbidity and mortality (Shonkoff et al., 2014). The study presents air pathways either from emissions on site from drilling, processing, well completions, servicing, and other gas production activities or emissions off-site from transportation of water, sand, chemicals, and equipment to and from the wellpad (Shonkoff et al., 2014).

12.11 Water pathway exposures

12.11.1 Worker

Figure 12.7 provides a schematic representation of the fate and transport associated with SGD and possible contamination of drinking water sources. Water contamination with chemicals used in SGD is not the most likely exposure pathway for workers involved in SGD, but chemicals such as H_2S gas may contaminate water samples. According to the IPIECA (2009) guide for drilling fluids and health risk management, these gases must be closely monitored and treated to eliminate hazardous exposure to personnel.

12.11.2 Community

An increasing body of studies suggest that water contamination risks exist through a variety of environmental pathways (Table 12.4), most notably during waste water transport and disposal, and via poor zonal isolation of gases and fluids due to structural integrity impairment of cement in gas wells (Shonkoff et al., 2014). The main potential pathways of water and land pollution during SGD as identified by Shonkoff et al. (2014) are:

- Accidental spillages during the mixing and transport of drilling and SGD chemicals before being injected into the well;
- Leaks from failure or inadequacy of well casings in the upper part of the well. With cement failures reported to occur in 2–50% of all wells (Shankoff et al., 2014), a large number of pollution incidents in the US have been due to this sort of failure. This has allowed methane and fracking chemicals to migrate into groundwater, drinking water or nearby properties, sometimes causing explosions, evacuations necessitating the replacement of water supplies,
- Fissures in rock, potentially accentuated by the SGD process, leading to contamination of important groundwater reserves, potentially contaminating drinking water, springs etc.,
- Leaks from storage and treatment of the large volumes of flowback water produced,
- Leaks from transport of flowback water, and
- Inadequate treatment of flowback prior to discharge, and leaks from reinjection of flowback into the ground (where permitted). Flowback contains the substances added to facilitate SGD, combined with salts, hydrocarbons, heavy metals and naturally occurring radioactive materials present in the rock. Flowback waters should be treated before any release into the environment.

Waste water from fracking operations contains toxic elements originating in the shale and from chemicals used in the fracking treatment including total dissolved solids, volatile substances, arsenic, bromide, naturally occurring radioactive materials, and heavy metals such as arsenic, barium, beryllium, uranium, and zinc (Chermak and Schreiber, 2013; Burton et al., 2016). Harkness et al. (2015) attributed the high bromide and chloride content in the waste water to the brine from the shale reservoir. Rowan et al. (2011) demonstrated that high salinity mobilises radionuclides, increasing exposure to radioactive isotopes such as radium 226. This study also demonstrated that, while the quality of groundwater may not be directly associated with proximity to gas wells, it is impacted by the high density of gas wells in an area. In the Barnett Shale region, the highest density of gas wells is located in the highest pressure gradient region. A high density of gas wells treated in a small area may cause an intersection of pressure cones in the subsurface, possibly increasing the reservoir pressure and/or fracture treatment pressure and affecting the integrity of the vertical wellbore.

In addition to the oil and shale gas related waste water, on-site sanitation and additional sewage loads to waste water treatment facilities from a growing community (as a result of job creation and opportunities), will present an additional load to the already overloaded waste water treatment systems. This in turn could cause untreated sewage to join the rivers and streams or enter the groundwater system, possibly polluting already scarce water sources and causing possible human health impacts or unhygienic conditions, with subsequent human health impacts.

Table 12.4: Four steps in SGD processes where water resources may become contaminated (Source: US EPA, 2015).

Chemical mixing	Spills of fracking fluids
Well injection	Subsurface migration of fracking fluids or formation fluids
Flowback and produced water	Spills of flowback or produced water
Waste water treatment and waste disposal	Discharge of untreated or inadequately treated waste water and inappropriate disposal of waste solids

Flowback and produced water are recognised as likely to contain many potentially hazardous chemicals (including fracking chemicals, petroleum condensates, metals, and naturally occurring radioactive material (NORM) and must be safely stored in open ponds prior to removal for treatment or discharge. Typically, formation water is highly mineralised at such pressure/temperature conditions (>20 g/L total salinity) and should be termed “brine”. In addition, produced water can contain a number of dissolved and trace substances, such as heavy metals, aromatic hydrocarbons, dissolved gases and NORM. In SGD, produced water is extracted along with natural gas, as "flowback", and must be disposed of.

Inorganic chemicals not included in the fracking fluid need to be considered as they can result from SGD due to the geology and presence of aerated water i.e. arsenic, boron, barium, and beryllium, for example.

Studies assessed surface and groundwater samples using reporter gene assays in human cell line were conducted in Colorado. Water samples collected from the more intensive areas of SGD exhibited statistically significantly more estrogenic, anti-estrogenic, or anti-androgenic activity than references sites with either no operations or fewer operations (Kassotis et al., 2014). The concentrations of chemicals detected were in high enough concentrations to interfere with the response of human cells to male sex hormones and oestrogen. This study indicated that EDCs are a potential health concern in SGD operations, and supports the screening for EDC activity.

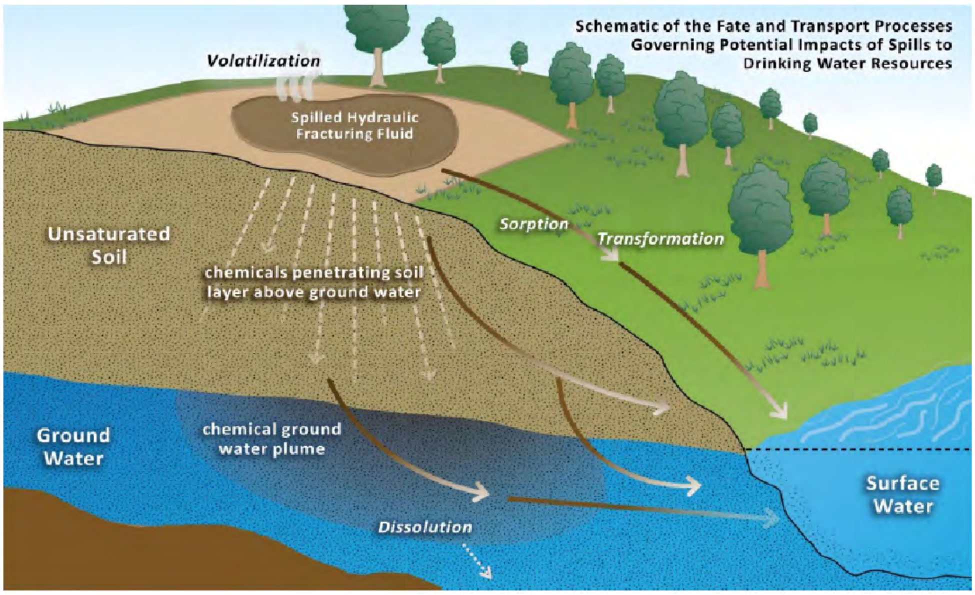


Figure 12.7: Fate and transport schematic for a spilled fracking fluid showing the potential pathways that spilled chemicals can impact water resources. Source: US EPA 2015.

The potential for fracking to result in contaminated groundwater is not well understood. Recent studies have shown that groundwater contamination may be caused by poor well construction with leaks caused by ruptured wellbore casings (Burton et al., 2016). Results showed that higher concentrations of certain groundwater constituents are probably related to SGD in the study area and that beryllium, in the specific study area formation, could be used as an indicator variable for evaluating fracking impacts on regional groundwater quality. The study also showed that well density and formation pressures correlate to change in regional water quality whereas proximity to gas wells, by itself, does not.

12.11.3 Exposure to fracking chemicals via spills

As reported in the review by Kassotis et al. (2015); in 2013, spills were reported at 1% of Colorado wells (550 spills at 51 000 active wells) and it has been estimated that 50% of surface spills contaminate groundwater (Gross et al., 2013). An analysis of permitted Pennsylvania wells suggests a similar total spill rate of 2% (103/5 580 active wells) (Souther et al., 2014).

Based on primary catchments, Figure 12.8 illustrates the area of extent of possible impact on the water supply outside the study area (indicated by the blue arrows) if a spill were to occur within the study area.

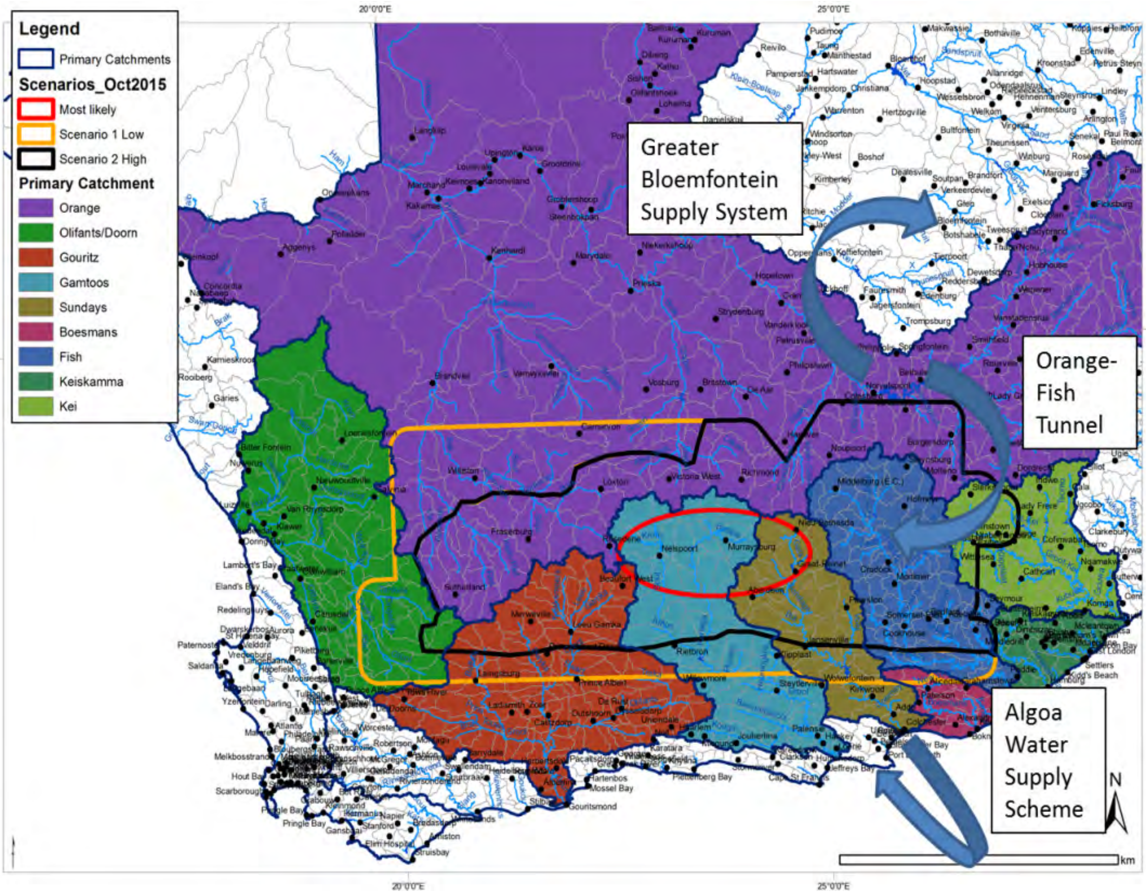


Figure 12.8: Water catchment areas possibly impacted in total study area

12.12 Noise pathway exposures

As discussed in Wade et al. (2016), the most significant noise sources during SGD are the increased traffic flow and plant noise. Traffic noise disturbs rural communities due to constant traffic flow to and from site (Weigle, 2010). Each single wellpad requires approximately 1000 truck trips, with the process usually running day and night for approximately one to two months (–Xiphu, 2012; Weigle 2010).

12.12.1 Worker

According to the WHO (2011) the health end-points of environmental noise include cardiovascular disease, cognitive impairment, sleep disturbance, tinnitus and annoyance. There is evidence for associations between noise exposure and adverse reproductive outcomes such as low birth rates (Ristovska et al., 2014). Workers are exposed directly to unsafe levels of noise (above 80db - see Wade et al., 2016) through drilling operations and exposure to generators, however through mitigation these levels can be reduced to acceptable levels with the use of sound damping boxes and PPE.

12.12.2 Community

Noise nuisance from SGD activities from the wellpad and from road traffic can affect the community even at low levels around 45db (Fahy and Walker, 1998), which can result in sleep disturbances.

12.13 Direct physical contact (traffic or machine injury)

12.13.1 Worker

As stated earlier in the occupational health section, the majority of worker fatalities in the industry are as a result of motor vehicle accidents accounting for nearly 40% of all work-related fatalities, with 7.6 deaths per 100 000 workers, which is equivalent to one death per 13 157 workers (Mason et al., 2015; Retzer et al., 2013). An overall fatality rate of 27.5 deaths per 100 000 workers was recorded by NIOSH (2012) in the US industry, a total that is more than seven times the death rate for all other industries (3.9 for all US workers). After vehicle accidents, the next most common fatal events were explosions (8%), workers caught or compressed in moving machinery or tools (7%), and falls (6%) (NIOSH, 2012). In South Africa, the occupational injury and fatality rates are considerably higher than developed countries with five times the fatality rate and four and a half times the accident rates of the developed countries. According to the DoL data, South Africa had a fatality rate of 19.2 per 100 000 workers and an accident rate of 14 626 per 100 000 workers (Haupt et al., 2008).

12.13.2 Community

It is expected that an increase in traffic on the roads will result in an increase in car accidents in the study area. In the US, vehicle accidents measurably increased in conjunction with SGD (Graham et al., 2015). According to surveys carried out in a SGD area in Texas (Rahm et al., 2015), vehicular accidents increased 26% from 2009 to 2013 when SGD began. In Pennsylvania the increase in vehicular traffic accidents attributed to SGD ranged from 7 - 49% (Food & Water Watch, 2013).

12.14 Dermal exposure to chemicals

12.14.1 Worker

Worker exposures to hydrocarbons and chemicals used in the fracking processes can occur during SGD, resulting in dermatitis and skin irritations. This could take place during accidental spills or improper waste disposal.

12.14.2 Community

Although unlikely, dermal exposure to chemicals from SGD may occur through bathing in water contaminated with chemicals.

12.15 Light pollution

Light pollution was listed as a possible health impact pathway; however it was not covered in this Chapter.

12.16 Risk Ranking

Different methods of risk ranking or prioritisation have been described in the literature with summaries provided below. This human health risk assessment takes into account community and worker health via different environmental impact pathways including, water, air, noise, direct and dermal.

Different ranking systems were used internationally to assess the potential health risks. The US EPA (2015) used a Multiple Criteria Decision Analysis (MCDA) by means of a database of 1 173 chemicals associated with fracking, the frequency of use data (692 chemicals) or the measured concentrations found in flowback or produced water (75 chemicals) and toxicology data (421 chemicals) together with physicochemical data (515 chemicals). Chemicals not included in the analysis were those considered to be proprietary or identified as business confidential information.

The MCDA resulted in 37 chemicals used in fracking fluid ranked from high to low with propargyl alcohol scoring the highest overall hazard potential score. This chemical was used in 33% of wells and had one of the lowest reference doses (representing the most toxic), being hydrophilic, it would likely be transported in water. Twenty-three chemicals were detected in flowback and produced water of which ten were also used in fracking fluid. Benzene, pyridine and naphthalene scored the highest total hazard potential scores, all with low reference doses (which indicates high toxicity), detected frequently and moderate physicochemical properties for their transport to water.

The Australian Ranking System used in the Camden HIA (EnRiskS, 2013) looked at where concentrations of chemicals found in produced water exceeded drinking water quality guidelines. As drinking water quality guidelines are derived to allow for a lifetime exposure with no adverse health effects expected they were used as surrogate reference doses and compared to the measured concentrations. If a ratio is greater than one, it indicates the potential for adverse health effects. A limited number of chemicals were predicted to be at concentrations higher than drinking water guidelines. These include Tetrakis(hydroxymethyl)phosphonium sulphate (THPS), benzoalkonium chloride, citric acid, (which are drilling chemicals) and medium length total petroleum hydrocarbons (TPHs) C15-C28.

Boyle et al. (2016) describe a hazard ranking methodology used for the Maryland Marcellus Shale Public Health Study to assess the potential public health impacts for eight hazards associated with the SGD process. The system is based on a modified ranking process described by Witter et al. (2010).

This process allows for systematic evaluation of identified hazards to allow for recommendations to minimise the hazards.

12.17 How health risks were assessed for the scientific assessment

Potential health risks were ranked according to the *likelihood of exposure* and *likelihood of a consequence* as a result of such exposure, and provide a qualitative assessment of the potential health risks in the study area as a result of SGD. It was used to rank both occupational related risks to workers, as well as the communities in the study area.

Figure 12.9 shows the risk ranking matrix in which aspects such as fate and transport of chemicals contributed to the likelihood of exposure for the different scenarios. Table 12.5 gives an explanation of the likelihood of consequence to community health when exposed. Likely exposures of moderate consequences to worker health may result in transient effects that may require medical treatment such as respiratory effects. Similarly, a very likely exposure to a severe consequence will result in death or significant injury.

Likelihood of exposure	*Likelihood of consequence*						
			None	**Slight**	**Moderate**	**Substantial**	**Severe**
			1	***2***	***3***	***4***	***5***
	Highly likely	5	VL	L	M	H	E
	Very likely	4	VL	L	M	H	E
	Likely	3	VL	L	M	M	M
	Not likely	2	VL	L	L	L	L
	Extremely unlikely	1	VL	VL	VL	VL	VL

VL – Very Low Risk	L – Low Risk	M – Moderate Risk	H – High Risk	E – Extreme Risk

Figure 12.9: Risk ranking matrix.

Table 12.5: Description of consequences used for ranking risks.

Consequence					
	None	**Slight**	**Moderate**	**Substantial**	**Severe**
	1	2	3	4	5
Off-site human health issues (Chronic)	No adverse long term health effects associated with low level environmental exposures	Minor transient health effects	Transient effects that may require medical treatment such as respiratory effects, more significant irritation	Permanent health effects that require extended medical treatment and or permanent disability	Death or significant injury likely to result in death

12.18 Limits of acceptable change

According to the WHO (2001) and US EPA the limits of acceptable change are often prescribed depending on the type of health impact. For instance a long-term impact such as developing cancer will have a lower level of acceptable change than an infection from a pathogen.

The WHO (2001) presents the following with regards to acceptable change:

"The US Environmental Protection Agency (EPA) typically uses a target reference risk range of 10^{-4} to 10^{-6} for carcinogens in drinking water (Cotruvo, 1988), which is in line with World Health Organization (WHO) guidelines for drinking water quality which, where practical, base guideline values for genotoxic carcinogens on the upper bound estimate of an excess lifetime cancer risk of 10^{-5} (WHO, 1993). In the UK, for example, the Health and Safety Executive (HSE) adopted the following levels of risk, in terms of the probability of an individual dying in any one year: 1 in 1000 as the 'just about tolerable risk' for any substantial category of workers for any large part of a working life. • 1 in 10,000 as the 'maximum tolerable risk' for members of the public from any single non-nuclear plant. • 1 in 100,000 as the 'maximum tolerable risk' for members of the public from any new nuclear power station. • 1 in 1,000,000 as the level of 'acceptable risk' at which no further improvements in safety need to be made."

The South African Water Quality Guidelines developed by the DWS (1996) are divided into different volumes according to the various water uses, namely, domestic recreational, industrial, agricultural water used for irrigation, agricultural water used for livestock watering and agricultural water used for aquaculture. These guidelines make use of the "fitness for use" concept which is a judgment of how suitable the quality of water is for its intended use. These guidelines are currently being revised to be more aligned with international best practices and the NWA (1998). The revised guidelines will be specifically risk based and site specific making them appropriate for future water quality assessments in areas should fracking take place. Currently the South African water quality guidelines do not make allowance for the type of chemicals that are used in fracking practices.

The domestic water use or drinking water quality guidelines are relevant to human health in this chapter as water quality for the environment is dealt with in Hobbs et al. (2016). The South African National Standards (SANS) for drinking water is the regulatory standard, or guideline, that the Water Law specifies for compliance monitoring purposes. The SANS-241(2015) drinking water limits are risk based with the standard for each determinand derived to safeguard the health of the consumer over a life-time consumption and to be protective of susceptible subpopulations. Table 12.6 lists the determinands included in the standards with the frequency of monitoring specified. These standards also do not specify the chemicals associated with fracking. This would need to be considered in monitoring programmes should SGD take place.

Table 12.6: SANS- 241 (2015a; b).

Table 2 — Physical, aesthetic, operational and chemical determinands

1	2	3	4
Determinand	**Risk**	**Unit**	**Standard limits**
Physical and aesthetic determinands			
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Total dissolved solids	Aesthetic	mg/L	≤ 1 200
Turbidity	Operational [a]	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 °C [b]	Operational	pH units	≥ 5 to ≤ 9,7
Chemical determinands — macro-determinands			
Free chlorine as Cl_2 [c]	Chronic health	mg/L	≤ 5
Monochloramine [cd]	Chronic health	mg/L	≤ 3
Nitrate as N [ef]	Acute health	mg/L	≤ 11
Nitrite as N [efg]	Acute health	mg/L	≤ 0,9
Combined nitrate plus nitrite [efg]	Acute health		≤1
Sulfate as SO_4^{2-}	Acute health	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F^-	Chronic health	mg/L	≤ 1,5
Ammonia as N	Aesthetic	mg/L	≤ 1,5
Chloride as Cl^-	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical determinands — micro-determinands			
Antimony as Sb	Chronic health	µg/L	≤ 20
Arsenic as As	Chronic health	µg/L	≤ 10
Barium as Ba	Chronic health	µg/L	≤ 700
Boron as B	Chronic health	µg/L	≤ 2 400
Cadmium as Cd	Chronic health	µg/L	≤ 3
Total chromium as Cr	Chronic health	µg/L	≤ 50
Copper as Cu	Chronic health	µg/L	≤ 2 000
Cyanide (recoverable) as CN^-	Acute health	µg/L	≤ 200
Iron as Fe	Chronic health	µg/L	≤ 2 000
	Aesthetic	µg/L	≤ 300
Lead as Pb	Chronic health	µg/L	≤ 10
Manganese as Mn	Chronic health	µg/L	≤ 400
	Aesthetic	µg/L	≤ 100
Mercury as Hg	Chronic health	µg/L	≤ 6
Nickel as Ni	Chronic health	µg/L	≤ 70
Selenium Se	Chronic health	µg/L	≤ 40
Uranium as U	Chronic health	µg/L	≤ 30
Aluminium as Al	Operational	µg/L	≤ 300
Chemical determinands — organic determinands			
Total organic carbon as C	Chronic health	mg/L	≤ 10
Trihalomethanes [h]			
Chloroform	Chronic health	µg/L	≤ 300
Bromoform	Chronic health	µg/L	≤ 100
Dibromochloromethane	Chronic health	µg/L	≤ 100
Bromodichloromethane	Chronic health	µg/L	≤ 60
Combined trihalomethane [h]	Chronic health		≤ 1
Total microcystin [i]	Chronic health	µg/L	≤ 1
Phenols	Aesthetic	µg/L	≤ 10

Table 3 — Frequency of analyses for determinands identified during the risk assessment exceeding the numerical limits in SANS 241-1

1	2	3	4
Risk	Frequency	Infrastructure optimization	Infrastructure change
Acute health – 1	Weekly	Ensure optimized functioning of infrastructure	If problem is not resolved, obtain necessary infrastructure
Acute health – 2	Monthly		
Chronic health	Monthly		
Aesthetic	Monthly		
Operational	Weekly		

12.19 Risk assessment

Four SGD scenarios were assessed as per the scope of the scientific assessment. These include:

Scenario 0: Reference Case (health status with no drilling)

Scenario 1: Exploration Only

Scenario 2: Small Gas

Scenario 3: Big Gas

The risks were ranked according to the likelihood of exposure for each of the scenarios and the severity of the consequence. The risk ranking results are shown in Table 12.7, followed by Table 12.8 describing the selection of ranking.

Different pathways for potential exposure, with air, water, noise, direct contact resulting from traffic or machine injuries, and dermal contact were considered. These were considered separately for workers and community members. Without mitigation, the four scenarios were found to yield health risks as ranging from none, to moderate risk for the Reference Case as the current health status of the study area population faces serious challenges with infant, maternal and under-five mortality rates double that of the provincial rate. For Exploration Only, community health is expected to range between a very low risk to a moderate risk (with water as the exposure pathway) and worker health ranging from high risk (via the air pathway) to low risk, depending on the exposure pathway. For the Small Gas scenario, worker health risks range from low risks to high risks (multiple pathways). Community health risks range from low to high (where water is the exposure pathway). The Big Gas scenario results in high risks for workers from air, noise and direct contact pathways, and high risks for the community via air and water pathways, to low risks for the other pathways. Mitigation measures involve engineering based interventions, PPE, or the containment of spills and will have a reduction in the likelihood of exposure, thereby reducing the risk ranking in each scenario.

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Table 12.7: Health risk assessment of four SGD scenarios for different exposure routes.

Impact	Receiving Environment	Scenario	Location	*Without mitigation*			*With mitigation*		
				Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Air pathway exposure	Worker	Reference Case	On the wellpad	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
		Exploration Only		Severe	Very likely	High	Substantial	Unlikely	Moderate
		Small Gas		Severe	Very likely	High	Substantial	Unlikely	Moderate
		Big Gas		Severe	Very likely	High	Substantial	Likely	Moderate
	Community	Reference Case	10 km from a town	Slight	Likely	Very low	Slight	Likely	Very low
		Exploration Only		Moderate	Likely	Low	Slight	Likely	Very low
		Small Gas		Substantial	Likely	Moderate	Moderate	Likely	Low
		Big Gas		Substantial	Likely	Moderate	Moderate	Likely	Low
Water pathway exposure	Worker	Reference Case	On the wellpad	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
		Exploration Only		Moderate	Likely	Low	Moderate	Very unlikely	Low
		Small Gas		Moderate	Likely	Low	Moderate	Not Likely	Low
		Big Gas		Moderate	Very likely	Low	Moderate	Likely	Low
	Community	Reference Case	From a formal and informal water source and supply	Substantial	Not likely	Moderate	Moderate	Not Likely	Low
		Exploration Only		Substantial	Not likely	Moderate	Moderate	Not Likely	Low
		Small Gas		Severe	Likely	High	Substantial	Not Likely	Moderate
		Big Gas		Severe	Highly likely	High	Substantial	Likely	Moderate
Noise pathway exposure	Worker	Reference Case	On the wellpad	None	Extremely unlikely	None	None	Extremely unlikely	None
		Exploration Only		Severe	Very likely	High	Substantial	Likely	Moderate

Impact	Receiving Environment	Scenario	Location	*Without mitigation*			*With mitigation*		
				Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
		Small Gas		Severe	Very likely	High	Substantial	Likely	Moderate
		Big Gas		Severe	Very likely	High	Substantial	Likely	Moderate
	Community	Reference Case	5 km from a residential area	None	Extremely unlikely	None	None	Extremely unlikely	None
		Exploration Only		Moderate	Unlikely	Low	Moderate	Unlikely	Low
		Small Gas		Moderate	Likely	Low	Moderate	Unlikely	Low
		Big Gas		Moderate	Very likely	Low	Moderate	Likely	Low
Direct physical contact (traffic/ machine injury)	Worker	Reference Case	On the wellpad or road	Extreme	Very unlikely	Low	Severe	Very unlikely	Low
		Exploration Only		Extreme	Not likely	Low	Severe	Very unlikely	Low
		Small Gas		Extreme	Likely	High	Severe	Not Likely	Moderate
		Big Gas		Extreme	Likely	High	Severe	Not Likely	Moderate
	Community	Reference Case	Road network	Extreme	Very unlikely	Low	Severe	Very unlikely	Low
		Exploration Only		Extreme	Very unlikely	Low	Severe	Very unlikely	Low
		Small Gas		Extreme	Unlikely	Low	Severe	Unlikely	Low
		Big Gas		Extreme	Unlikely	Low	Severe	Unlikely	Low
Dermal through chemical exposure	Worker	Reference Case	On the wellpad or road	None	Extremely unlikely	None	None	Extremely unlikely	None
		Exploration Only		Moderate	Likely	Low	Moderate	Not Likely	Low
		Small Gas		Moderate	Very likely	Low	Moderate	Likely	Low
		Big Gas		Moderate	Very likely	Low	Moderate	Likely	Low
	Community	Reference Case	From a formal and informal water source	None	Extremely unlikely	None	None	Extremely unlikely	None

Impact	Receiving Environment	Scenario	Location	*Without mitigation*			*With mitigation*		
				Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
		Exploration Only	and supply	Moderate	Extremely unlikely	Very low	Moderate	Extremely unlikely	Very low
		Small Gas		Moderate	Very unlikely	Low	Moderate	Extremely unlikely	Very low
		Big Gas		Moderate	Not likely	Low	Moderate	Very unlikely	Low

Table 12.8: Summary health risk assessment of four SGD scenarios.

Scenario	Description on selection of ranking
Reference Case	Health risks ranged from **none to moderate** risk as the current health status of the study area population faces serious challenges with infant, maternal and under-five mortality rates double that of the provincial rate. Greater TB and HIV rates and lower life expectancies are found, however drilling related health risks are considered as negligible.
Exploration Only	Community health is expected to range between a **very low to moderate** risk (with water as the exposure pathway). As ten vertical wells will be drilled with 100Ml drilling and fracking fluid produced. Reported spillage in international literature varied between 1-4%. Assuming similar spillage rates, the consequence is considered to be high but the likelihood of exposure is considered unlikely. Worker health ranges from **high risk** (via the air pathway) **to low risk**, depending on the exposure pathway. *With mitigation the likelihood of exposure is reduced in each scenario*[6].
Small Gas	Worker health risks range from **low to high** (multiple pathways). Community health risks range from **low to high** (where water is the exposure pathway). Around 60 vertical wells will be drilled, six times as much production water and chemicals and is therefore considered to have a high consequence, with a possible likelihood, and is therefore classified as a **moderate** risk.
Big Gas	Workers health risks resulted in **high risks** from air, noise and direct contact pathways, and **high risks** for the community via air and water pathways, to low risks for the other pathways. Five hundred and fifty vertical wells will be drilled – assuming a 1-4% spillage, the likelihood of exposure is considered to be very likely.

12.20 Limitations, recommendations and conclusion

Many of the chemicals used in SGD do not have sufficient health data to make decisions - in the extensive US EPA assessment chronic health data was only available for 8.4% of the 1 173 reportedly used chemicals. Each drilling and fracturing event is custom-designed depending on the geology, depth and resources available. The chemicals and products used and the amounts or volumes used can differ from well to well.

As the activity of fracking is relatively new in relation to the time needed to assess long-term health effects as well as trans-generational effects, scientific evidence that can be used with certainty is severely lacking.

Any potential health impacts resulting from SGD will require that baseline monitoring for air and water quality. Baseline health monitoring, including additional health symptoms and blood or urine tests associated with SGD will need to be carried out prior to initiating the exploration activity to enable ascribing any future health effects to a specific cause. The additional health symptoms implies

[6] Note that mitigation is expected to reduce the likelihood of exposure assuming any spillage to be contained to a certain degree.

that standard health monitoring done at hospitals and clinics will not be sufficient and that additional health symptoms associated with SGD such as nose, eye and throat irritation, dermal or skin lesions, upper respiratory impacts, etc. (see Table 12.4) be noted prior to, throughout as well as for a long time after exploration or mining has seized. Transgenerational effects as well as EDC -related health impacts (e.g. thyroid, and reproductive effects) as well as cancer will require long term monitoring.

As mentioned earlier in the Chapter, health protection is not sufficiently and explicitly covered in the legislation where SGD is concerned and will need to be addressed.

12.21 References

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12.22 Digital Addenda 12A – 12F

SEPARATE DIGITAL DOCUMENT

Digital Addenda 12A – 12F

DIGITAL ADDENDA 12A – 12F

Digital Addendum 12A

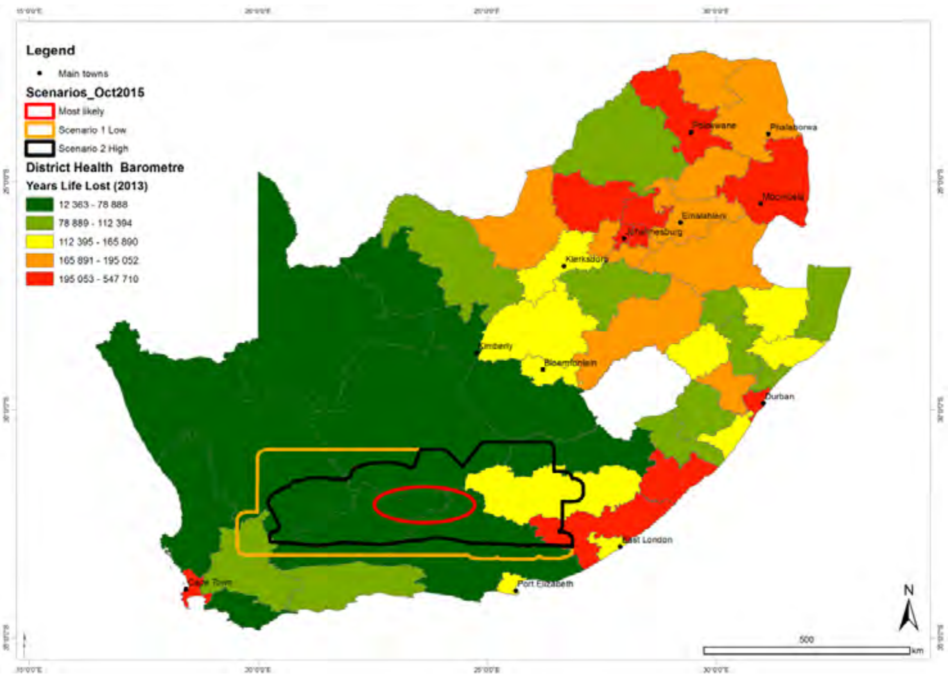

Figure 12A(i): Map of Years Life Lost (YLL) within the study area compared to the rest of the country.

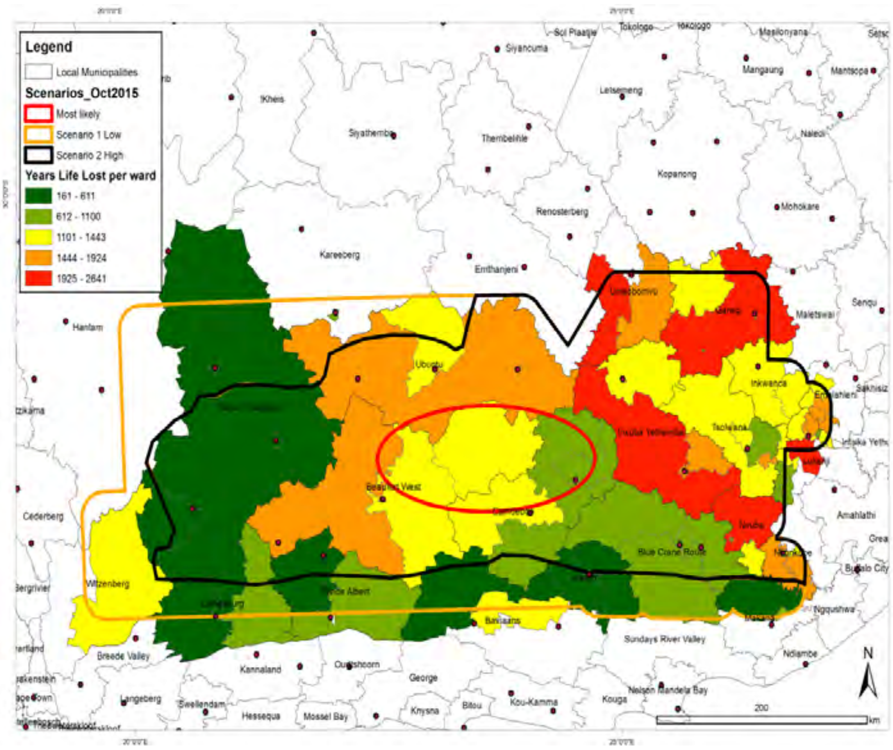

Figure 12A(ii): Map of Years Life Lost (YLL), showing differences between the municipalities within the study area.

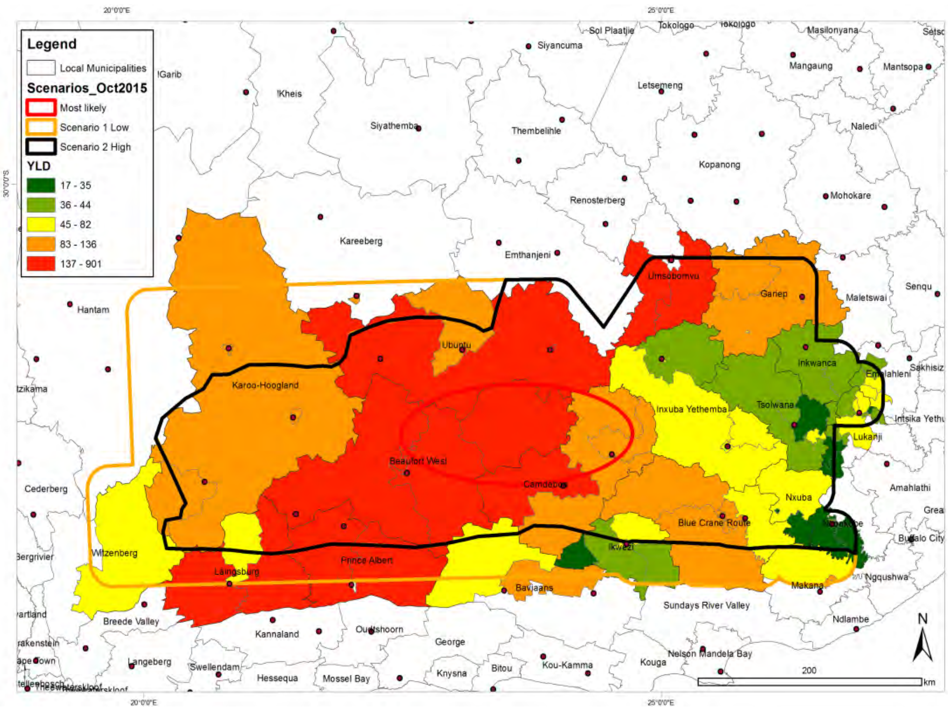

Figure 12A(iii): Map of Years Living with Disability (YLD) within the study area, and compared to YLL.

Digital Addendum 12B

Table 12B(i): Years Life Lost (YLL), Years Lived with Disability (YLD) and Disability Adjusted Life Years (DALY) per District and Local Municipality in the study area, based on DHB 2014/15 2013 values and the Census 2011 ward population data.

Municipality	Years Life Lost (YLL)	Years Lived with Disability (YLD)	Disability Adjusted Life Years (DALY)
Amathole District Municipality	17393	369	17762
Nkonkobe	11693	248	11941
Nxuba	5700	121	5821
Cacadu District Municipality	17431	2040	19471
Baviaans	1581	185	1766
Blue Crane Route	5313	622	5935
Camdeboo	7525	881	8406
Ikwezi	1555	182	1737
Makana	1456	170	1627
Cape Winelands District Municipality	1159	65	1224
Witzenberg	1159	65	1224
Central Karoo District Municipality	11345	5375	16721
Beaufort West	8606	4077	12684
Laingsburg	1376	652	2028
Prince Albert	1363	646	2008
Chris Hani District Municipality	58315	1871	60186
Emalahleni	7101	228	7329
Inkwanca	4260	137	4397
Inxuba Yethemba	12713	408	13121
Lukanji	27786	892	28678
Tsolwana	6454	207	6661
Joe Qadi District Municipality	7527	451	7978
Gariep	7527	451	7978
Namakwa District Municipality	1785	422	2207
Karoo-Hoogland	1785	422	2207
Pixley ka Seme District Municipality	16821	1670	18492
Kareeberg	2378	236	2614
Ubuntu	6690	664	7354
Umsobomvu	7754	770	8524
Grand Total	131777	12264	144041

Digital Addendum 12C

12.1.1.1 List of chemicals and health effects

This is in an excel spreadsheet by TED-X called the Multistate chemicals database which can be accessed at http://endocrinedisruption.org/chemicals-in-natural-gas-operations/health

Digital Addendum 12D

Table 12D(i): Chemicals remaining in consideration for prioritisation after removing prohibited chemicals in South Africa including some endocrine disruptors.

Chemicals remaining in consideration for prioritisation after removing prohibited chemicals in South Africa	
Hydrotreated light petroleum distillates	Ethylenediamine
Isopropanol	Bisphenol A
Peroxydisulfuric acid, diammonium salt	2-(Thiocyanomethylthio)benzothiazole
Sodium hydroxide / Caustic soda	Dodecylbenzenesulfonic acid
Guar gum	Benzoic acid
Quartz / Silica	1,3-Dichloropropene / Telone II
Glutaraldehyde	Ethyl acetate
Proparagyl alcohol / Propargyl alcohol (Prop-2-YN-1-OL)	Pyridine
Potassium hydroxide	2,4-Dimethylphenol
Ethanol / (Acetylenic alcohol) / Ethyl alcohol	Chloroform / Trichloromethane
Acetic acid / Ammonium acetate (dif cas nr)	Benzyl alcohol
Citric acid	Carbon disulfide
2-Butoxyethanol / (2-BE) Ethylene glycol monobutyl ether / EGBE	Pyrene
Sodium chloride	Di-n-butyl Phthalate
Solvent naphta, petroleum, heavy arom	Fluoranthene
2,2-Dibromo-3-nitrilopropionamide	Diphenylamine
Phenolic resin / (Phenoformaldehyde resin) - similar to formaldehyde CASRN: 50-00-0	Fluorene
Choline chloride	Sodium carbonate (Soda ash)
Methenamine / Hexamethylenetetramine	Xanthan gum
Carbonic acid, dipotassium salt / Potassium carbonate	Starch/ Modified polysaccharide or Pregelatinised cornstarch or starch
1,2,4-Trimethylbenzene	Benzoalkonium chloride
quaternary ammonium compounds, benzyl-C12-16-alkyldimethyl,chlorides / Alkyl dimethyl benzyl ammonium chloride / Benzalkonium chloride / Barquat	Potassium chloride
Poly(oxy-1,2-ethanediyl)-nonylphenyl-hydroxy (mixture)	Cellulose fibre
Formic acid	Barite sulfate / (BaSO4)
Sodium chlorite / (Chlorous acid, sodium salt) / Chlorite	Hemicellulose enzyme concentrate
Nonyl phenol ethoxylate / Polyethylene Glycol Nonylphenyl Ether	Sodium hypchlorite
Tetrakis (hydroxymethyl)phosphonium sulfate	Monoethanolamine borate
Polyethylene glycol	Methane
Ammonium chloride	Benzo(a)pyrene
Sodium persulfate	Benzo(b)fluoranthene
1-Butanol/ n-Butyl alcohol	Benzo(g,h,i)perylene
Epichlorohydrin / Chloromethyloxirane (Propene Polymere)	TPH C10 - C14
Didecyldimethylammonium chloride	TPH C15-C20
1,4,Dioxane / Diethylene oxide	TPH C29 - C36
(E)-Crotonaldehyde / 2-Butenal	2-Ethylhexanol
Furfural (2-Furaldehyde)	Diethanolamine
1,2-Propylene glycol / Propane-1,2-diol	NaHCO3

Hexnedioic acid /Adipic acid	Boric acid
2-Methyl-1-propanol (Isobutanol)	2-(2-Methoxyethoxy)ethanol
Dichloromethane / Methylene Chloride)	2,2',2"-Nitrilotriethanol
Humic acid (Leonardite)	5-Chloro-2-methyl-4-isothiazolin-3-one
Iron	Acetic anhydride
Kerosene	Ammonium nitrate
Sodium metasilicate	Chlorine dioxide
Sodium nitrate	Coal
Sodium nitrite	Diethylene glycol
Urea	Ethylene oxide
1,2-Bromo-2-nitropropane-1,3-Diol (2-Bromo-2-nitro-1,3-propanediol or Bronopol)	Glyoxal
Hydrogen sulfide	Aliphatic hydrocarbon
Mercaptoacidic acid	Ammonium sulfate
Nickel sulfate	Ammonium thiocyanate
N-methyldiethanolamine	Cadmium
Polyvinyl alcohol [AlcoteX 17F-H]	Calcium sulfate
Zinc	Cottonseed flour
1,6-Hexanediamine	Dibromoacetonitrile
1-Methoxy-2-propanol	Diethylenetriamine
9-Octadecenoic acid (9Z)	Dodecanoid acid
Acrolein	Ethoxylated octylphenol
Hexacanoic acid	Sodium tetraborate decahydrate (Borax)
Hydrodesulfurized kerosene	Styrene
Methyl salicylate	Sulfur dioxide
Octadecanoic acid	Thiourea
Petroleum distillate/ naphtha	Tributyl phosphate
Silane, dichlorodimethyl-, reaction products with silica	Zinc chloride fume
Sodium bromate	Zirconium sulfate
Sodium bromide	Sucrose

Digital Addendum 12E

Table 12E(i): Towns, population, sources of water, location and Blue- and Green Drop Scores (Source: DWS WARMS, 2016).

Town	Population (2011)	Source of Water	Location	Blue drop score 2012	Green drop score 2011
Murraysburg	5 069	Boreholes (0.268 mcm/a)	Prospectivity – high probability	n/a	n/a
Nelspoort	1 699	Sout River weir (0.1 mcm/a) and boreholes (0.043 mcm/a)	Prospectivity – high probability	74.45%	87.9%
Rietbron	1 184	Boreholes (0.0344 mcm/a)	Border of Prospectivity – medium probability	n/a	n/a
Steytlerville	4 017	Boreholes (0.268 mcm/a)	Outside study area	33.04%	18.65%
Nieu-Bethesda	1 540	Boreholes(0.012 mcm/a)	Border of Prospectivity – high probability	42.86%	6.8%
Graaff-Reinet	35 672	Nqweba dam (2.4 mcm/a) and boreholes (0.84 mcm/a).	Prospectivity – high probability	53.49%	6%
Aberdeen	7 162	Boreholes (0.3 mcm/a)	Prospectivity – medium probability	42.11%	5.3%
Jansenville	5 612	Boreholes (0.21 mcm/a)	Border of Prospectivity – medium probability	n/a	n/a
Kirkwood	5 371	Sundays River (2.025 mcm/a)	Outside study area	28.33%	3.21%
n/a = Not Applicable					

Digital Addendum 12F

US EPA 2015 documents can be accessed at
http://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651

CHAPTER 13

Impacts on Sense of Place Values

CHAPTER 13:
IMPACTS ON SENSE OF PLACE VALUES

Integrating Author:	Leanne Seeliger[1]
Contributing Authors:	Mike de Jongh[2], David Morris[3,4]
Corresponding Authors:	Doreen Atkinson[5], Katie du Toit[6], Jolynn Minnaar[7]

1 University of Stellenbosch, Stellenbosch, 7600

2 University of South Africa (UNISA), 0003

3 McGregor Museum, Kimberley, 8300

4 Sol Plaatje University, Kimberley, 8301

5 University of the Free State, Bloemfontein, 9301

6 Karoo Tertiary Enrolment &Access Centre, Kimberley, 8300

7 Filmmaker, Cape Town

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Executive Summary

1. **It is more meaningful to speak of senses of place in the Karoo rather than to attempt to define a single sense of place for the Karoo.** This does not mean that all senses of place are equally valid or that any sense of place is justifiable within all contexts. Senses of place are often shared by people who either live in a place, or those who value it as a destination for work or holidays or who view it from an outsider's perspective. Some senses of place may have greater legitimacy than others. They may be regarded to have more value because they are shared by a greater number of people or potentially create value for a larger number of people. Others have more impact because it is the majority view of the people who own land and/or pay taxes and still others carry more weight because they are compatible with a diversity of certain perspectives.
2. **The different senses of place in the Karoo can be placed on a spectrum, ranging from strong anthropocentrism (transformed sense of place) to intrinsic value theories (more static senses of place).** The strong anthropocentric sense of place values (like shale gas development (SGD)) allow for significant transformation of the natural world. It is argued that it is permissible to substitute the current rural sense of place with an industrial sense of place because of the economic benefit it could unlock for the South African population as a whole in the form of energy self-sufficiency. Some people argue that this denotes a weak sense of place. More intrinsic sense of place value theories that appreciate the Karoo for its different inherent cultural, botanical, historical, astrological, palaeontological and archaeological significance, are largely against significant physical transformation of the Karoo. They argue that these different forms of heritage are of both national and international significance. They believe that something as invasive as SGD will cause an irrecoverable loss of sense of place.
3. **All stakeholders in the scientific assessment, including shale gas developers, have an explicit or implicit sense of place.** Some authors argue that a sense of place of the Karoo that is based on the shale gas energy that can be extracted is not a sense of place at all but merely an appreciation of certain utilitarian values present there. This Chapter argues differently. It proposes that there is no one way of valuing a place that can claim a priori more legitimacy than another, except by persuasion of others to that particular point of view. Valuing the Karoo for a job that is linked to SGD is as much a sense of place/or placelessness as valuing it as a tourism destination.
4. **Some senses of place are in conflict with one another whereas others are more compatible.** It could be argued, for example, that shale gas developers employ a sense of place that is in conflict with the average Karoo tourist's sense of place that usually involves a sense of nothing or remoteness. Should SGD occur, a significant measure of this remoteness

or "Niks" of the Karoo could be lost forever. However, for example, the tourism industry's sense of place and the farming community's sense of place are far more compatible and even supportive of each other. They both encourage low levels of noise, open space and limited numbers of people.

5. **Sense of place is not adequately protected in Environmental Impact Assessment (EIA) and development planning processes.** The principles of the National Environmental Management Act (NEMA) call for the consideration of all people's values and the investigation of any potential impacts on it. However, the processes and additional legislation required to achieve this are inadequate. The National Heritage Resources Act (NHRA), for example, does not define or consider sense of place directly but allows for its protection under the definition of National Estate which discusses the concept of cultural landscapes. The timeframes for EIA or other regulatory processes are too short to allow for communities to reach agreements on levels of acceptable change insofar as it is related to sense of place. While debates on acceptable change on senses of place can be more appropriately addressed in strategic planning frameworks such as Spatial Development Frameworks (SDFs) and Environmental Management Frameworks (EMFs), the quality of participation and the resultant frameworks are not up to standard.
6. **SGD in the United States (US) has led to a loss of sense of place.** In Pennsylvania, East Ohio, West Virginia and Colorado, where significant SGD has taken place, citizens have complained of significant negative impacts on sense of place. Over time many citizens have experienced a loss of social identity and a feeling of alienation. The main drivers of these negative impacts have been increased population numbers, visual changes to landscapes, pollution caused by shale gas, higher volumes of traffic and the cultural diversity of people that now reside in these places. While it is anticipated, based on earlier research of similar projects, that a new sense of place will emerge along with another form of social cohesion, this might not compensate for the loss of a particular way of life that cannot be reinstated.
7. **It is not always possible to compensate for loss of sense of place.** Karretjie People, who are itinerant shearers, have historically lived a nomadic existence moving from one farm and town to another. While they could potentially be compensated by shale gas developers for loss of place due to the industrialisation of the parts of the Karoo, they cannot be compensated for the loss of lifestyle or identity that will accompany this transition. This is true for farmers too but it is especially a concern for Karretjie People and other marginalised communities given their vulnerable economic status and their ephemeral, intangible and almost subliminal connection with the Karoo. However, it could also be argued that even if SGD doesn't proceed it is not a given that their current lifestyles would continue unaltered e.g. due to changes in the farming practices.

8. **This scientific assessment is not able to provide detailed senses of place, but can currently draw limits of acceptable change based on the existing landscape and its land use**. It is recommended that all natural and built heritage sites in the Karoo be regarded as no-go areas and protected by a negotiated buffer from SGD to protect the tourism and heritage potential of these areas. This is insufficient, so in future Strategic Environmental Assessments (SEAs), it is recommended that indicators for sense of place values be included for proposed development projects.
9. **Detailed empirical research of specific sense of place values in a particular context are recommended to be developed in EIAs, SDFs and EMFs**. It is recommended that both quantitative (Likert type surveys) and qualitative (ethnographic type interviews) research should be mandatory in EIAs, SDFs and EMFs to gauge sense of place values. Orton et al. (2016) regards interviews as a mitigation measure for living heritage when people are removed from the land. This Chapter attempts to prevent this loss of sense of place values in the first place by including the m in development processes. The research data gathered would enable communities to develop sense of place indicators within the public participation processes of SEAs, EIAs, SDFs and EMFs that could monitor the limits of acceptable change to their communal sense place.

CHAPTER 13: IMPACTS ON SENSE OF PLACE VALUES

13.1 Introduction and scope

> Sense of place is a complex concept that explores the range of factors which define the local distinctiveness of a specific place and the ways in which people experience, use and understand that place. It comprises an attachment that is created from an emotional connection to a place; an identification that makes it part of the person or community and lastly a functional dependence because it is needed for economic or recreational activities (Zia et al., 2014).

What is meant by this topic? "Sense of place" is emerging as one of the key factors that affects how people respond to energy developments that cause large scale land use changes (Jacquet and Stedman, 2014). As technology advances and populations grow so companies and governments worldwide are looking for new ways to extract energy. Many of these new projects create widespread social and environmental change in the communities where they are being introduced. Shale gas development (SGD), because of the industrial nature of the activity and its location in remote areas, is a form of energy extraction that particularly affects collective and individual "senses of place". Communities in the United States (US) have begun to oppose SGD with specific reference to an anticipated change to their "sense of place".

The recognition of "sense of place" within scientific assessments reminds us that natural resources are inextricably linked to a social and political context. The concept of sense of place creates a powerful medium for framing the relationship between people, place and events. By recognising that people are part of the ecosystem, and vice-versa, sense of place has the potential to bridge the gap between the science of ecosystems and their management (Larson, 2013). If environmental managers hence understand the meanings and social relations that people attach to an area they will better able to respond and manage these bonds in a way that promotes sustainability (Williams and Stewart, 1998).

Different senses of place depict different ways of valuing a particular physical context, some based on use values to human beings like farming or SGD and others based on the intrinsic value of physical or social environments. Sense of place meaning takes on a variety of forms. Often the community itself is what gives the place its uniqueness. The people of the Karoo town of Nieu Bethesda where the famous owl house stands, for example, are an attraction in themselves. The town is described as "one big family" with "strong-minded, intelligent" people living there (Shenton, 2012). Other times sense of place is found in objects. Culinary artist Rachel Botes locates the Karoo's unique sense of place in its food and its soil. Botes (2015) associates it with ostrich eggs, springbok, figs, olives and the blue sky. This is all called living heritage.

For others it is a deep-seated emotional connection. “For most of my life the Karoo has just been a dusty old place that I was ready to leave as soon as I could. It was a vast, dry landscape that blurred on my way to boarding school in a nearby town….I have learned that the silence is not a stifled one but the sense of a deeply rooted peace that transcends your and my lifetime. Its vast landscape is not one of abandonment or emptiness but of space that holds” (Minnaar, 2015).

For tourists, like Ronell Engelbrecht it is an aesthetic adventure. “… when the city life gets too much for my weary soul, the first place that I long for, is Calitzdorp. I can only close my eyes, and whisk myself away to the Huis River Pass, or the Rooiberg Pass or Groenfontein Road … and let the silence flow through your body; have you ever experienced a thunder storm while driving through Huis River Pass at dusk with the rock formations changing colour that is unbelievable; have you ever watched the sun rise while sitting under the tree in Gamkasberg Nature Reserve, with no living soul in sight” (Engelbrecht, 2016).

For the landless, Karretjie People who move from one town to the next on donkey carts as itinerant shearers, it is a place of hardship but belonging and of space with relative freedom of movement (De Jongh, 2004). This theme of hardship is also emphasised by some groups like the Karoo Shale Gas Community Forum which is promoting SGD as a form of economic upliftment for the area. “The Karoo is beautiful, but it is also a very sad place. In winter, you see children walking to school barefoot without shoes, through the frost,” says Chairman Chris Nissen (Du Venage, 2013).

For emerging farmworkers and dwellers represented by the Southern Cape Land Committee (SCLC) the Karoo is a source of work. “We are extremely worried because farmworkers will lose their jobs and they will lose their homes on the farms and they don’t have the financial means to move anywhere else,” says organiser Chriszanne Janse van Rensburg (Karoospace, 2012).

The Karoo for the farming community is a multi-billion Rand industry that directly or indirectly supports nearly 100 towns, thousands of schools, hundreds of banks and retailers, and about a million people. Similarly, for retirees and creatives it has become a place to reinvent yourself. “Stockbrokers become rose growers. Company mavens become cheese-heads. Former coal miners now make forest fairies for a living. Old journos become wine-makers” (Marais and du Toit, 2016).

For the national government, the Karoo and its shale gas possibilities is a place of great potential wealth generation for the country. The Department of Mineral Resources (DMR) reports on the possibilities: “It is expected that the contribution of SGD to the growth of the economy and Gross Domestic Product (GDP) would be enhanced by the necessary creation of service industries with all the attendant implications for sales of goods and services… The potential long-term direct employment opportunities are likely to number in the tens of thousands, with similar numbers in the industries consuming the gas" (DMR, 2012). The number of jobs opportunities for locals is, however, estimated to be much less by some economists. (See Van Zyl et al. (2016) for a more detailed discussion of the impacts on the economy).

A sense of place is a dynamic concept that changes over time. This is illustrated within the travel and tourism industry. In the past, the Karoo was a stop-over as a holiday destination and depicted as a grim, monotonous landscape in travel logs. In the last three decades, the emerging interest in adventure tourism and stargazing in remote places has seen renewed interest in the Karoo as a tourist destination (Atkinson, 2016).

Sense of place values are also political and socially constructs. Each effort to create a place becomes an expression of the values and beliefs of a collection of people in a historical context. Something of this historical dimension of sense of place is expressed in the latest archaeological excavations in Biesje Poort in the Southern Kalahari where, because of the many different layers of objects and interpretations, archaeologists struggle to find a definitive understanding of the meaning of the history of the site. Some archaeologists are calling for the conversation to be kept open so the full range of interpretations can be heard (Morris, 2014). Morris (2014) writes "Narrating Biesje Poort has been about acknowledging the strain of representation, indeed announcing the 'creaking', the gaps, the vagueness, the not-always-coherent multi-strandedness of the available accounts".

Given the diverse, changing, subjective nature of sense of place described above, some argue that it is not meaningful to include it in a Strategic Environmental Assessment (SEA) process. However, others argue that sense of place contains both subjective and objective aspects and that it can be measured (Zia et al., 2014). Landscape architects argue this from a visual perspective. They say there are certain features of a landscape that are more objectively pleasing to a greater number of cultures and people than others. They have found that these features evoke the same positive or negative feelings across a cross section of people (Newtown Landscape Architects, 2011).

Social scientists are beginning to argue that sense of place should be taken more seriously in risk analysis too (Jacquet and Stedman, 2014) because it often indicates strong opposition to land use change and the likelihood of social disruption if the development proceeds. This is because it disturbs not only the economic dependence of people on a place but also their emotional attachment and identity. This is especially the case in small remote communities where the roles of people and the identity of communities are not subject to much change.

One example of a group like this are the Karretjie People whose primary resource base lies in the clientele (the farmers) beyond their own community, and their capital is largely verted and maintained through their specialised skill and the service that they render shearing. They are both integral and peripheral to the wider community and hence they occupy and exploit a distinct social and economic niche. And herein lies their vulnerability – a high premium is placed on spatial mobility and the value they attach and accessibility and variability of place.

The concept of sense of place is also referred to in several other Chapters, each differently and each in a more narrow sense. Atkinson et al. (2016) links the concept to that of collective memory. The connection here is between “history and place”. Umejesi (2015) writes that histories are attached to places and the environmental value we attach to a place comes largely through the memories and historical associations we have with it. Toerien et al. (2016) links sense of place to “Die Niks” or the remoteness, silence and solitude that attract people to the place. Within Orton et al. (2016) it is referred to as the meaning, identity and intrinsic character of a place, as provided by its natural and cultural features and one’s experience thereof. The visual aspect of sense of place within heritage is particularly well researched with a visual impact methodology devised to rate a place’s sense of place value.

This Chapter adopts the broadest interpretation of the concept in an effort to compare all the different claims made with regard to sense of place. Judgement is deliberately not made on whether an industrial sense of place for the Karoo has more value than a remote, untouched sense of place (sometimes referred to as a “wilderness”). It is not the brief or responsibility of this scientific assessment to do this, but rather to identify the full range of sense of place values that are expressed by the people/communities. We therefore acknowledge how all expressions of sense of place demonstrate a form of environmental value ranging from very anthropocentric values that allow for an extensive transformation of the physical environment of a place (and could be labelled a more transient sense of place) to more intrinsic values that limit human interference in a landscape (representing more static senses of place).

It should be noted that by deliberately not making a judgement in a scientific assessment does not imply that a judgement cannot or should not be made or that all claims to sense of place are equally valid. It is the responsibility of the communities involved in an Environmental Impact Assessment (EIA) to make this judgement. There will be interpretations of sense of place that may directly conflict with each other and others that are more compatible in a particular context. It is the responsibility of the government and communities involved to engage with these, and justify why they prioritise a certain sense of place over others. By doing this they are creating new senses of place or sustaining a particular sense of place. This reinforces the importance of individuals and communities registering as interested and affected parties (I&AP) in EIAs.

13.2 Overview of international experience

SGD in the US has brought the issue of "sense of place" to the fore, with specific or implied mention in the literature in Pennsylvania (Perry, 2012), Eastern Ohio (Willow et al., 2014), West Virginia (Sangaramoorthy et al., 2016) and Colorado (Jacquet and Stedman, 2014). While some of the changes to sense of place have been positively encountered, many have been considered negative with some being found to have caused widespread social disruption. The key drivers to a disrupted sense of place have been the rapid change in population diversity and numbers, increased traffic, speedy industrial land development, pressure to submit to gas industry demands, the violation of environmental and administrative laws, land erosion, mudslides, chemical run off and changes in air and water quality. Another key driver of loss of sense of place has been an anticipated, rather than an actual loss of community cohesion and identity as well as uncertainty about potential health impacts.

In Bradford County, Pennsylvania, shale gas was initially perceived positively. It was seen as a way of boosting the local economy and providing jobs for US troops returning from the Middle East. Residents were confident that all environmental concerns would be adequately addressed by the government's environmental protection agency. However, by 2012, researchers described the community as having experienced "acute social disruption and stress ranging from altered connections with place and ruptures in sense of belonging and identity". Residents complained of a feeling of loss or fear of loss (Perry, 2012). Key drivers of loss of sense of place in Bradford County were the rapid change in the county's population, the rapid pace of industrial land development and pressure to submit to gas industry wants and the failure of gas companies and governments to adhere to administrative and environmental legislation and listen to community concerns.

In Eastern Ohio local residents complained of feeling vulnerable, disempowered and insecure in their hometowns. While sense of place is not specifically mentioned it is implied (Willow et al., 2014). These feelings of vulnerability were closely associated with human health concerns. Many were anxious about their own health and that of their families. They were concerned that hydraulic fracturing ("fracking") would contaminate the water and air, resulting in short- and long-term adverse physical health effects. Some additionally discussed stress and mental health consequences. "Several people who have experienced energy development near their homes spoke of the nearly constant worry that began when wells were drilled and may not ever end. Interviewees talked about being afraid to go to sleep with drilling and fracturing underway, about feeling the need to endlessly rehearse evacuation procedures, about knowing there is danger out there but being unable to pin it down, and about having to decide on a daily basis whether their home is safe to inhabit. In addition to fears related to accidents and direct effects, not knowing if—and how much—contamination is present has also been highly stressful" (Willow et al., 2014).

In Doddridge County, West Virginia, fracking was found to have contributed to a disruption of residents' sense of place and social identity, causing widespread social distress. It influenced how they perceived the environmental and health impacts of fracking (Sangaramoorthy et al., 2016). They were affected by the environmental changes brought about by SGD operations such as increased traffic, land erosion, mudslides, chemical run off and changes in air and water quality. The general change in landscape from rural to industrial was upsetting. On a more concrete level, the separation of surface and mineral rights with regard to land use, with the latter taking precedence, meant they did not always consent to what was being done on their land.

A health impact study of natural gas drilling in Colorado made an indirect mention of a disrupted sense of place when it found that a major source of stress was fear of future changes to community relations and social cohesion that drilling would bring (Jacquet and Stedman, 2014). It was this anticipated loss that caused stress rather than any actual loss as yet being experienced.

13.3 Special features of the Karoo as an iconic place

The Karoo does not have a single way in which it is valued as a place; there is rather a multiplicity of ways in which people value it, thereby creating many senses of place. Some senses of place may clash in a given geographical area. There may, for example, be conflict between the desire to exploit shale gas in some areas and the need to preserve endemic plant or animal species in others. Furthermore, SGD might threaten a vulnerable population group's spiritual connection to the Karoo. The itinerant Karretjie People, for example, who attach strong symbolic value to parts of the Karoo may suffer a significant loss of identity as parts of the area industrialise for SGD and no longer resemble anything they understand or have access to.

On the other hand, however, nature tourists' appreciation for wide open spaces may converge with conservationists' need to protect endemic species. It could also merge with the desire of astronomers to keep the bright lights of towns away from their stargazing spots. Moreover, farmers who wish to diversify their sheep farming to include other revenue generating forms of income like agri-tourism, would also welcome keeping the Karoo as free of industrial activity as possible to attract tourists for farm stays.

In the section that follows, we provide a broad categorisation of the different senses of place as they have emerged in the public domain around the possibility of shale gas being exploited in the Karoo. These senses of place are, for the sake of convenience, provisionally organised into the occupational or economic interest groups that are found in the Karoo. We have used these interest groups because this is how they appear in the public domain and are recognised by people. However, it should be noted that one cannot generalise, for example, and say that all farmers always value the Karoo as a natural resource only. There are likely to be some that value it as a place of heritage. Similarly, shale gas developers might both value the Karoo both as a resource for SGD and in their personal capacity see it as a tourist destination.

Senses of place are constructed by human beings and collectively by communities and are therefore not static but shift as people and their experiences shift and change. Some farmers, for example, having experienced too many drought seasons might find the selling of their farms to developers a relief. Moreover, Karretjie People, for example, with the diminishing of opportunities to earn an income from seasonal sheep shearing might welcome the possibility of low-skilled part time jobs offered by SGD (except that they might not be first in line when these jobs become available). In the absence of doing detailed ethnographic research among the Karretjie People (who for the purposes of this Chapter are used as representative of marginalised people in the Karoo) there is no way of ascertaining this. It should be noted that we have not focused directly on the Border-Kei region that has Xhosa settlement and subsistence farming however; we include the farmers in this area under the more general heading of emerging farmers.

The material was selected from a wide variety of resources including electronic and hard copy material provided by other participants in the scientific assessment who represent a wide spectrum of the diverse opinions on SGD in the Karoo (i.e. both gas companies and anti-shale gas Karoo activists), by web searches that included both pro- and anti-shale gas opinions, by material suggested by reviewers of the first draft and by a literature search on the international electronic academic literature on the impacts of shale gas on sense of place values. In the case of vulnerable communities like the Karretjie People, the advice of a co-author was sought. Works of art, poetry and film material that was available online and related to sense of place was also used where available to develop as diverse an understanding of the different perceptions of sense of place as possible.

13.3.1 Established Commercial Farmers

- The Karoo is valued as a resource that should be farmed sustainably.

Karoo farming is a multi-billion Rand industry with some of its products like mohair and Karoo Lamb having achieved worldwide recognition. Farming in the Karoo supports about a million people (Du Toit, 2016a).

13.3.2 Emerging farmers

- The Karoo is valued as a place of economic and social upliftment.

Several emerging farmers are being helped by the national Department of Agriculture, Forestry and Fisheries (DAFF) and other farmers to establish themselves in the Karoo. One example of this is found about 120 km from Carnarvon in the Hantam district where four farmers are being mentored and given stock to begin their own sheep farms (Van Rijswijk, 2011).

- Farming the Karoo is our only source of livelihood.

"Shell must stay away from here," said 59-year-old Molly Nikelo, an unemployed grandmother who supplements her meagre monthly state grant by cultivating a small plot of rare purple garlic for sale in expensive eateries in Durban. "What about the water? It supplies everybody and only comes from one place. People drink it, wash in it and grow vegetables with it. I've drunk this water every day of my life and I've never been to hospital" (Reuters, 2013).

13.3.3 Farm labourers

- The Karoo is valued as a resource that provides jobs.

Each farm, on average, supports between two and 20 people. A total of 100 000 people are employed full-time or part-time on Karoo farms. Many of these workers are also provided with housing and services like water, electricity and sanitation (Du Toit, 2016a).

- The Karoo is valued as a source of family heritage.

Like the farmers who own the farms, many of the labourers have been on the farms for several generations. They have a historical relationship with the land and the farmer and consider the place as part of their own identity. Many of the labourers and farmers have relatives buried on the land.

13.3.4 Karretjie People

- The Karoo is their primary source of symbolic meaning.

“Although the itinerant Karretjie people own no land or do not even have free access to land, their attachment to the region is no less real or authentic than the owners of the extensive tracts of land over which they roam. For the Karretjie People space is an orientation---physically, socially, and cosmologically. It is much more than just a physical place for them---it encodes social meanings and values as well" (De Jongh, 2012). For example, their names for "farms" do not always in fact refer to farms but to topographical features or other places of significance as chronicled in the oral history of the people.

- The Karoo is their link to their ancestors.

As opposed to the more western-inclined emphasis on individual ownership, economic value and productivity of land, the significance for them and other rural communities is often still also vested in the perception that the soil serves to link them to their ancestors. The land itself as socially constituted plays a fundamental role in the ordering of cultural relations. Both the perceived threats to identity, place and landscape have nudged communities-to re-entrench and defend a specific place -this spawns nostalgic imaginings of such places, and the, sometimes, romanticised community and identity (De Jongh, 2008).

13.3.5 Botanists

- The Karoo is valued as a biodiversity heritage site.

There are well over 6 000 plant species in the Karoo, about 40% of which are found nowhere else. The Succulent Karoo is recognised by Conservation International as one of only two arid zone biodiversity hotspots in the world (Du Toit, 2016b), and is now on the tentative world heritage site list (United Nations Educational, Scientific and Cultural Organisation (UNESCO), 2016). For more detail on the biodiversity and ecological impacts of SGD, see Holness et al. (2016).

13.3.6 Astronomers

- The Karoo is valued for its open skies and lack of pollution.

The open skies, lack of radio interference, absence of light and other pollution in the Karoo make it a valued place for studying the stars. It is to be the new home of the Square Kilometre Array (SKA) telescope. Since the early 1970s, the major telescopes of the South African Astronomical Observatory (SAAO) have operated on a hilltop 1 800 metres above sea level, near the Karoo village of Sutherland, about 370 km inland (SAAO, 2016).

13.3.7 Palaeontologists

- The Karoo is valued for its unique fossils.

The South African Karoo Basin contains the best therapsid fossil record in the world giving us the exciting opportunity of being able to study the intricate details of the transition into mammals. These animals, that span a period of more than 80 million years from the Middle Permian to the Middle Jurassic, show the gradual acquisition of mammal-like characteristics until it is almost impossible to distinguish the latest most mammal-like therapsids from the earliest true mammals (Bloemfontein National Museum, 2016).

13.3.8 Archaeologists

- The Karoo is valued for its wealth of archaeology and rock art.

Many important archaeological sites are located in the study area. These include rock shelters with deep sequence deposits as at Blydefontein, the pastoralist landscape of the Seacow Valley and many rock paintings and engravings left by both hunter-gatherers and herders. At Nelspoort, the impressive array of engravings is said to be of national significance (see Orton et al. (2016) where all these sites are described and referenced). The Great Karoo is integral to the work of the world's scientists, botanists, archaeologists, geologists, palaeontologists and ecologists (Cape Town Heritage Trust, 2016).

13.3.9 Lifestyle farmers

- Karoo is valued as a place of peace and tranquillity.

Top executives leave their jobs and buy farms in the Karoo to experiment with a new, more relaxed way of life. "I'm loving being in nature. I love the dog walks, I love the quiet. I used to define myself through my business and now I wonder why" says Renee Silverstone. "I feel more whole here than I've ever done before" (Du Toit, 2012).

13.3.10 Creatives and Retirees

- The Karoo is valued as a place to reinvent yourself.

The concept of the 'creative class' refers to those people who make a living from creative pursuits, including artists, designers and knowledge-based professionals. These people, coming from all walks of life, seek refuge from the city, its crime and fast pace and migrate to small towns of the Karoo. Their investment in property and cultural life and their entrepreneurial spirit has a significant impact on the sense of place of these small towns (Ingle, 2013).

- The Karoo is a source of creative inspiration.

The Karoo has been the inspiration for many poets, visuals artists, sculptors, playwrights and other creatives. A recent art exhibition organised by artist Katie du Toit, titled Fear and Loss, is response to their concern that the SGD could destroy "their" Karoo. It represented prominent South African artists' concern about the endangered ecology of the Karoo landscape (Du Toit, 2015).

- The Karoo is a place to retire.

The relatively low cost of land and houses in the Karoo has seen an increase in the number of people wanting to buy property as an investment here. In towns like Colesberg and Hopetown, for instance, you can buy a two-bedroomed house from R380 000. By the time one reaches retirement age, the house could be paid off while in the meantime it could be used as a weekend break or a way to earn extra income (Badenhorst, 2013).

13.3.11 The Land Claimants

- Karoo is a place for restitution and restorative justice.

The SCLC is a non-governmental organisation established in 1987 that promotes equitable land redistribution and supports farm dwellers and emerging farmers in the Eastern Cape and central Karoo. The SCLC has taken an anti-fracking stance. "South Africa is not for sale" said erstwhile SCLC chairwoman, Angela Conway. "We call on all peaceful loving South Africans to urge our government not to fall for the empty promises of multinational companies and promises of creating jobs, at the expense of future generations of our beautiful country" (Oelofse, 2012).

13.3.12 SGD Companies

- A location for cleaner energy generation.

In South Africa we need to limit our carbon dioxide (CO_2) emissions, but also end power shortages and keep electricity prices affordable for everyone. Natural gas could be instrumental both in meeting growing energy demands and contributing to the country's emission reduction targets (Eggink, 2011a).

- A location for wealth generation, economic upliftment and job creation.

The shale gas opportunity in the Karoo could significantly boost South Africa's economy and create hundreds of thousands of jobs (Econometrix, 2012). This scientific assessment has been criticised by some economists as overstating the potential job creation benefits of SGD. See Van Zyl et al. (2016) for more details on the economic impact of SGD.

- The Karoo is valued for its potential to make South Africa more energy self-sufficient.

The growth in the exploitation of shale gas reserves in the US, has transformed the country from being short on gas some ten years ago to being self-sufficient or even over-supplied in gas today. South Africa could follow a similar path should it be demonstrated that shale gas is available and can be developed while protecting the environment and character of the country (Eggink, 2011b).

13.3.13 Low skilled workers, the unemployed and the youth

- The Karoo is a place of limited opportunity.

The Karoo Hoogland Local Municipality has an unemployment rate of 23.1%. More than half (55.5%) of employed individuals in Karoo Hoogland are classified as semi- and unskilled. The 2008/2009 Growth Rate was -5.2% (Karoo Hoogland Municipality Draft Revised Integrated Development Plan, 2015/2016).

For the unemployed, such as Petrus Kabaliso from Colesberg, it's a place of marginal existence. "We find old metal, and sometimes the trucks that stop here leave bottles in the rubbish" he says. "We can change this for money, and buy pap [maize meal porridge] and sugar" (Du Venage, 2013).

- The Karoo is a place of loss.

Some workers complain that a lack of jobs means the youth; friends and family have to leave home to find work. They are in favour of fracking in the Karoo. "Creating new jobs will mean my friends and family can come home. Everybody here is losing people who move to Cape Town or Johannesburg looking for work. Our people are all over and they don't come back" says Ricardo Josephs, a petrol pump attendant in Graaff-Reinet. "It will be better for all of us" (Du Venage, 2013).

13.3.14 Tourists

- The Karoo is a valued tourism destination for its remoteness, silence, solitude and clean air (see Winkler et al., 2016).

The Karoo has shifted profoundly from being hostile, dangerous and boring to being attractive, enticing and spiritual. At the same time, tourists are increasingly expressing favourable opinions of the Karoo as a destination, while accommodation facilities are growing apace (Atkinson, 2016).

It has been suggested that the sense of place refers to all those feelings left over once you have accounted for specific worries about water, roads, biodiversity, heritage and social fabric. This, however, is to confuse the concept with something separate from the land uses currently in operation or those envisioned in the future in the Karoo. Embedded in all the ways in which the land is being used and proposed to be used are inherent senses of place. The way in which land is utilised creates a sense of place. Industrial activities, like SGD, create an industrialised sense of place that, when in close proximity to other activities like farming and tourism, could destroy the latter.

13.4 Relevant legislation, regulation and practice

Sense of place is not directly addressed in South Africa. However, the National Environmental Management Act (NEMA) (Act 107 of 1998, as amended), along with the National Heritage Resources Act (NHRA) (Act 25 of 1999), does create a framework which allows sense of place to be addressed:

- Section 2 (principles) of NEMA, *inter alia*, states that "sustainable development requires the consideration of all relevant factors including … that the disturbance of landscapes and sites that constitute the nation's cultural heritage is avoided, or where it cannot be altogether avoided, is minimised and remedied".
- Section 2 (principles) of NEMA, inter alia, states that "sustainable development requires the consideration of all relevant factors including…that decisions must take into account the interests, needs and values of all interested and affected parties, and this includes recognising all forms of knowledge, including traditional and ordinary knowledge".
- Section 24(4) of NEMA, inter alia, states that "procedures for the investigation, assessment and communication of the potential consequences or impacts of activities on the environment … must include, with respect to every application for an environmental authorisation and where applicable … investigation, assessment and evaluation of the impact of any proposed listed or specified activity on any National Estate referred to in Section 3(2) of the National Heritage Resources Act (NHRA), 1999 (Act No. 25 of 1999)".

Landscapes with cultural significance do not have a dedicated section in the NHRA but they are protected under the definition of the National Estate (Section 3). Section 3 (2)(c) and (d) list "historical settlements and townscapes and landscapes and natural features of cultural significance" as part of the National Estate. Furthermore, Section 3(3) of the NHRA describes the reasons a place or object may have cultural heritage values; some of these speak directly to the cultural landscapes. In terms of Section 2(vi) of the NHRA, "cultural significance" means aesthetic, architectural, historical, scientific, social, spiritual, linguistic or technological value or significance.

It could therefore be argued that current (EIA and development planning) practices, rather than the regulatory framework, are inadequate in addressing sense of place issues. Moreover, the timeframes for EIA or other regulatory processes are often too short to allow for communities to reach agreements on levels of acceptable change insofar as it related to sense of place and quality of life. Stakeholders complain that consultants complete desktop Environmental Management Plans (EMPs), consult only a few people and do not give feedback about the community's comments on their EMPs. Moreover, the SGD public meeting sometimes degenerate into political meetings (Jansenville Agricultural Society, 2016). These debates on limits of acceptable change of senses of place can more appropriately be addressed in strategic planning frameworks such as SEAs, Spatial Development Frameworks (SDFs) and Environmental Management Frameworks (EMFs). Unfortunately the quality of participation and the resultant frameworks (especially SDFs) are generally falling short. This results in regulatory assessments taking place in a strategic void (i.e. not giving guidance to contextualise development proposals) and not being able to address impacts related to sense of place, cumulative impacts etc.

Section 24 of the 1996 Constitution also provides some form of indirect protection to sense of place in that it stipulates that everyone has the right to an environment that is not harmful to their health or wellbeing. The State is required to respect, protect, promote and fulfil this right. One could argue in terms of this that a disruption to one's sense of place causes social disruption and thus is harmful to one's health.

However, despite the lack of direct protection, sense of place has been used to legally block developments locally and internationally. For example, the development of a shopping mall was blocked at Princess Vlei, in Cape Town in 2009, and the development of mining was blocked at St Lucia in KwaZulu-Natal in 2002 (Nicolson, 2014). Internationally, in New South Wales, Australia, the court recognised a new term solastalgia as "the pain or sickness caused by the loss or lack of solace and the sense of desolation connected to the present state of one's home and territory. It is the 'lived experience' of negative environmental change. It is the homesickness you have when you are still at home." This phrase was coined by an Australian environmental philosopher Glenn Albrecht in 2003.

13.5 Key potential impacts and their mitigation

Two of the key dimensions of the variation in sense of place in the study area (Figure 13.1) are whether the economic activities that take place in the Karoo allow for extensive transformation of the physical environment or whether they advocate minimal disturbance of the natural world. Another dimension is the measure of priority which human needs are given, over and above the existence of rights or needs of the Karoo ecosystem and/or individual plant and animal species in the area. The shift from disconnected (strong) anthropocentrism to integrated (weak) anthropocentrism moves in parallel to choices for human activities or lifestyles (Karretjie People) that are less exploitative or invasive towards other species or ecosystems.

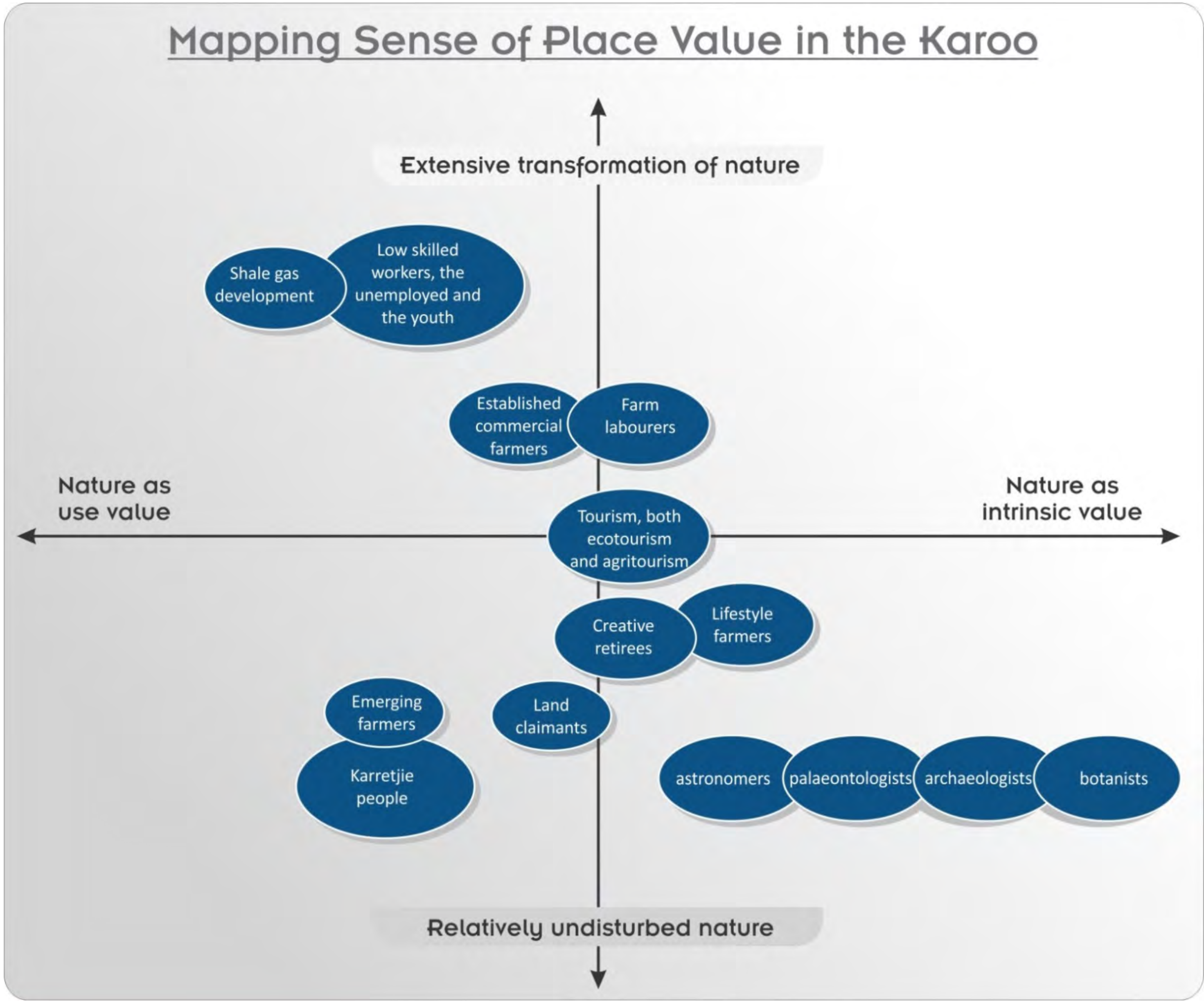

Figure 13.1: Key dimensions of the variation in sense of place in the study area.

Large-scale SGD runs the risk of severe disruption of place-based identities without mitigation because of the scale of physical transformation that occurs. These industrial activities in remote places can create psycho-social shocks for individuals and communities, sometimes far greater than the actual pollution produced by these operations. Risk assessment, that has only recently started incorporating social impact data in its analyses, is now also endeavouring to include sense of place values. This is challenging given that social impacts in risk analysis are currently largely limited to measurable data like employment and poverty rates (Jacquet and Stedman, 2014).

The concept of sense of place is difficult to define and measure and can have several different components. It could include an emotional attachment to a place, a dependence on that place for some form of livelihood or entertainment and/or the incorporation of that place into the identity of a person or community or into their traditions and mythology. These components may or may not be present in an individual or collective expression of sense of place. A local South African tourist's sense of place of the Karoo that they visited while on a once-off holiday on the way to the Garden Route, is unlikely to be as strong an identity and emotional attachment as a sheep farmer whose farm has been in the family for five generations, or a Karretjie person who has never left the Karoo. The question arises as to how to measure these different senses of place and weigh them appropriately in order to include them in a decision-making process that seeks to provide benefit to society at large.

Despite the difficulty of doing this; some brave attempts have been made. Jacquet and Stedman (2014) explain a potential methodology:

Using a Likert scale of 'extremely unlikely' to- 'extremely likely', researchers have delved to ask respondents questions like: 'if SGD occurs in the study area, how likely is it that the area will no longer be a good place to raise children?' or 'if SGD occurs in the study area, how likely is it that the area will still have wilderness qualities?' To measure magnitude of impact, respondents could be asked 'Using a scale from 'very happy' to 'very unhappy', how happy or unhappy would you be if your community was no longer a good place to raise children?' or 'how happy or unhappy would you be if your area no longer contained wilderness qualities?' Further, respondents can be asked whether and how their strength of local attachment might change due to changes in these place meanings. As with other risk perception questionnaires, these questions can be situated under certain hypothetical circumstances, including economic compensation.

If accompanied by more qualitative ethnographic work that has traditionally been used to explore sense of place, there is great value in this. This would be most valuable at a local, EIA level, possibly through the inclusion of sense of place indicators that had been arrived at in SDFs and EMFs. At a

SEA level, sense of place indicators could provide some red-flags as to where significant social disruption and loss is likely to occur. This scientific assessment has attempted to do this by examining the values underpinning the different senses of place as they have been expressed in the public domain, in the media and various other internet sources. By comparing different senses of place according to how people value the environment in a particular context we have created a meaningful scale of comparison between more industrial senses of place in the Karoo and essentially conservationist, preservationist and spiritual senses of place. It has enabled us to reduce the 14 different groups that were identified in Section 13.3 to four general categories: a broad spectrum of farmers who would like to continue farming in the Karoo and increase productivity; the creatives and researchers who would like to preserve the Karoo in its wilderness format; the marginalised communities of the Karoo like the Karretjie People; and the SGD developers and unemployed who are in favour of significant physical transformation of the Karoo.

Established commercial farmers, emerging farmers and farm labourers are largely anti-SGD because it competes with their current source of livelihood in the Karoo. This grouping could be described as adopting a conservationist approach to valuing the natural world. They are of the opinion that small-scale and gradual transformation of the natural environment, that is sustainable for future generations and that does not threaten the existing water resources in the Karoo, is a better way of uplifting the community and providing jobs for locals. Commercial farmers especially are arguing that their industry is centuries old and has proved itself to be sustainable, whereas the benefits of SGD are uncertain and have proven to have very negative consequences in the US, where SGD has been underway for some time. Provided farming remains within the limits of the water and grazing resources of the land and does not overexploit them and leaves them intact for future generations, farmers' and farm workers' sense of place will be sustained. SGD runs the risk of tipping this fine balance, especially with regard to its use of considerable water resources.

A subgroup of this group, the land claimants, are unique in that their sense of place embraces the idea of transformation of existing ownership of land in the Karoo to include formerly displaced people and so are making an argument for broader socio-economic upliftment, but they are not in support of the physical transformation of the land. They are instead asking for a transformation of social and economic relations in the area. They too, like large-scale farmers, farm labourers and emerging farmers, fear the loss of farming land. They do not see SGD as a way of improving their social and economic standing. They too are a vulnerable group but because of the land they might be able to lay claim to, and be compensated for, are perhaps not as vulnerable as farm labourers who might not have this option. Like commercial farmers, they too are concerned that their identity as Karoo families might be at stake should SGD go ahead.

Moreover, this farming grouping is also threatened by the heritage value that SGD runs the risk of losing. They see themselves as losing part of themselves when the Karoo is exploited for shale gas as their families have lived in the area for generations and have identified themselves with farming as part of their livelihood. A threat to farming could also result in a threat to their identity and way of life. The most vulnerable components of this grouping are the emerging farmers and the farm labourers who do not have access to financial resources or skills should farming no longer be able to continue unhindered.

The second broad group: lifestyle farmers, tourists, creatives, retirees, property developers, botanists, astronomers, palaeontologists, archaeologists and tourists have largely adopted a resource preservationist approach to their understanding of the Karoo as a place. They would like the Karoo to remain as rustic, quiet, blue sky and untouched as possible. The Karoo is of great value to them in its most pristine state. They are accommodated in the preservationist approach because they sanction minimum disruption to the environment. They have come to the Karoo for “Die Niks”, for a simple and for a less hurried way of life. Progress in the form of more vehicles, more business and more pollution is precisely what they want to avoid. They have relocated to this quiet, creative, simple life or they come regularly to visit it for academic research interests or tourist/adventure pursuits. While SGD might not cripple them financially it will certainly affect their sense of place and possibly could force them to move to another place of solitude or recreational or research interest. They are not as vulnerable as emerging farmers and labourers because of their social networks and possible access to other resources or investments but nevertheless a part of their identity could be at risk.

A third group, the Karretjie People (and other marginalised individuals or communities that are mostly landless), are difficult to place on the spectrum of sense of place values because their views are not easily available in the public domain and also because it is not clear whether their symbolic and/ or spiritual/emotional connection with the Karoo is sustainable regardless of whether SGD takes place or not. They currently live a marginal existence in the Karoo that is largely linked to seasonal shearing on sheep farms and ad hoc jobs that they obtain in and around towns. Their low-skill base and minimum level of schooling makes them the most likely to be unable to access the socio-economic transformation and job opportunities that shale gas is expected to bring to the Karoo. Moreover, already on the interstices of society, their identities could also be at risk as increased numbers of people, vehicles and livelihood sources might further alienate them from their fragile connection to existing towns and farms. It is not possible in SEAs, without detailed research, to ascertain what their viewpoint would be on the SGD in the Karoo. However, it is also not clear that if SGD did not go ahead whether their present connection with the Karoo would continue unchanged because their existence is already precarious given changes in the agricultural economy in the region.

Finally, there are shale gas developers, the unemployed and the low-skilled workers that are calling for full-scale SGD. They are valuing the environment in a strong anthropocentric way that advocates extensive transformation of the environment for the benefit of society at large. Their argument is that by tapping into this resource the country will provide jobs, energy security and general socio-economic upliftment not only to people living in the Karoo, but also to South Africa in general. They justify the radical transformation of parts of the physical environment and loss of sense of place for several Karoo inhabitants on the grounds that it will ultimately be better for more South Africans. Their argument is that it is acceptable to trade the loss of a few people's sense of place when it will so greatly benefit so many more people. The extent of this benefit to the greater South Africa is disputed with some economists arguing that it is overstated (see Van Zyl et al. (2016) on the Economic Impacts of SGD).

The grouping of the above-mentioned stakeholders in the shale gas debate, on the basis of their environmental values expressed in their sense of place, gives one a broad sense of potential conflict areas. There is conflict between SGD's strong anthropocentric approach to resource use in the Karoo, and the farming communities, creatives and tourists desire to ensure sustainable utilisation and conservation of Karoo resource in a way that does not put the existing livelihoods at risk. If SGD goes ahead then one runs the risk of water resource contamination and this could affect farming in some areas. As discussed above some sub-groupings within this conservation orientated cluster would be more vulnerable than others should SGD go ahead and threaten farming. All members of this conservation grouping are likely to suffer a sense of loss of identity and increased anxiety as their social roles in the small towns and community are altered by experts and skilled work-forces from outside.

The mitigation of such losses should SGD go ahead is challenging. In theory, farmland that is affected by SGD could be compensated for in a monetary sense. However, this is difficult in practice because available and suitable alternative land needs to be bought by the farmers (Jansenville Agricultural Society, 2016). Moreover, the loss of identity and community among farmers, farm labourers, landless claimants and the lifestyle farmers, retirees, Karretjie People and creatives is difficult to compensate for within a generation. It can lead to a significant loss of self. It could be argued that this closely guarded identity and heritage is hampering the progress of South Africans at large who will benefit greatly from the energy security of shale gas and jobs that it will generate. Unemployed Karoo residents, low-skilled workers and youth are suffering because the Karoo is not being exploited to its full economic potential. The counter argument is that the risk associated with SGD is too high and there is no guarantee that it will result in the projected socio-economic gain proposed.

In Scenario 0: Reference Case; where SGD does not go ahead and the status quo remains, one could argue that the low-skilled, unemployed and the youth might be forced to leave the Karoo if new employment opportunities are not created for them by the existing farming sector, tourism industries and renewable energy sector. They might suffer a loss of identity and socio-economic status on account of this that they might not have had to if SGD had been allowed to proceed. They would then continue to experience the Karoo as a place of hardship. It could be argued, however, that if the tourism and farming industry grew and renewable energy was pursued in the Karoo, then new opportunities might arise for the previously unemployed. Moreover, if skills' training is intensified in renewable energies, more land claims are processed and the tourism industry continues to grow, this could further boost socio-economic development in the area. The only mitigation required in such a scenario is a concerted attempt to lower unemployment rates, increase skills training and improve the marketing of farming and tourism products.

In Scenario 1: Exploration Only; compensation would have to be paid in the areas where wellpads were drilled and where local tourism and farming businesses were affected. The extent of this mitigation would need to be researched by means of an EIA process where both quantitative and qualitative evaluations of community responses to the particular area of activity were completed. As the operation would be small in scale and only exploratory, mitigation could arguably take the form of monetary compensation to those directly affected by the exploration/exploitation activity. Very limited identity loss or social disruption due to loss of sense of place is likely to occur. Very little impact on the tourism and farming industries is expected.

In Scenarios 2 (Small Gas) and 3 (Big Gas), it is likely that the tourism industry and the farming community would find reduced operational profits in the areas that are close to SGD activity. Visual screening might be able to mitigate some of the risks to sense of place values here. Moreover, the branding of the Karoo as a region and its farming and tourism products as environmentally friendly and pristine could be tainted with perceptions that water was contaminated even if this in reality this was not the case. The increased industrial activity, trucks and new arrivals from elsewhere are likely to affect the tourism industry hardest in areas close to SGD as people lose "Die Niks" that the Karoo is known for. While guest houses might initially benefit from the new arrivals for the industrial activity, they run the risk of losing longer-term customers that visited the area for the peace and quiet.

The Small and Big Gas scenarios are likely to still allow the farming industry to continue as a viable form of livelihood, provided water tables are not affected. Similarly, tourism is likely to continue successfully in areas that are not major routes for trucks. The market-related monetary compensation of farmers is theoretically possible in both scenarios where they are directly affected by SGD operations. However, this process is likely to be challenging for farmers who wish to continue farming. They will need to find and purchase both available and suitable alternative farmland. At risk, should full-scale SGD occur, is the "Die Niks" of the Karoo especially in areas in sight and sound of drilling. Scientific tourists, however, might still visit the area despite the lack of peace and quiet for the remaining botanical, astrological, paleontological and archaeological finds.

13.6 Limits of acceptable change

It has been suggested that the limits of acceptable change to sense of place values in the Karoo be set for the purposes of the scientific assessment by existing land uses, biophysical limitations (like water availability) and cultural and natural heritage sites. It is proposed that all these sites and land uses be red-flagged and a negotiated buffer placed around them to prevent the risk of their being affected by SGD. SGD would therefore theoretically only take place in underutilised areas that did not pose a threat to any existing sense of place values.

It is recommended, however, that in future SEAs and especially EIAs that sense of place indicators be developed through existing development processes like EMFs and SDFs and used as limits of acceptable change to sense of place. It is important to distinguish sense of place indicators as different from biophysical, cultural and natural indicators. This is because sense of place indicators are essentially relational indicators that are about the significance a particular community places on a natural or cultural artefact or space at a point in time.

Sense of place values are not static but influenced by new technologies, alternative forms of energy generation, political opportunism, social movements and changes in small and multi-national business interests. The constructed nature of sense of place values means they are dynamic and open to change. They shift as individuals and communities needs and interests change. Exactly what is understood as acceptable change is in theory open to negotiation with the stakeholders involved. For example, some farmers may be willing to sell their farms to shale gas developers for the right price and relocate to other parts of the country. Other farmers on the other hand, might regard this as an irrevocable loss of cultural heritage and identity.

This brings one to the point of trying to ascertain the limits of acceptable change in sense of place values in an area. Proponents of the latest SGD technology might argue that there is a very low risk of water contamination in the industry. The South African government could argue that the tax revenue and energy security that shale gas promises could radically alter the country's sense of place in the world economy and is therefore strongly justifiable in most cases. For the purposes of the hypothetical risk analysis in **this** scientific assessment with regard to sense of place values, we will argue that limits to acceptable change are determined by existing land uses, biophysical limitations and natural and cultural heritage sites (sense of place indicators have not yet been developed).

13.7 Risk assessment

13.7.1 How the risks are measured?

In the absence of any baseline data on sense of place values in the Karoo it is impossible to discuss a risk assessment in a meaningful way, except conceptually. If any actual risk assessment was to be completed and be regarded as empirically or scientifically valid, it would have to make use of both quantitative and qualitative methods conducted by independent researchers with people actually living in particular areas of the Karoo that have specific natural and cultural attributes, land uses and biophysical limitations. The definition of very low risk, low risk, moderate risk, high risk and very high risk would in this case be best defined by the participants of the surveys, comprising local inhabitants as well as ‘outsiders’ such as international tourists and scientists who had an interest in the area.

Conceptually, this scientific assessment has inferred sense of place values from various occupational groups by virtue of the kind of activities they are currently involved in, or plan to do in the Karoo and that they would hope to continue to do in the future. The justification for this rests on the fact that land use or symbolic association creates and sustains a sense of place. In most cases, these sense of place values have been inferred from actual opinions that have been quoted from texts or from art works, poetry, photographic material and documentaries made available in the public domain or from conversations with these interest groups at scientific assessment workshops. Where these have not been available in the public domain, like for example in the case of the Karretjie People, they have been inferred from anthropological expert opinion.

Theoretically, a slight consequence to sense of place values in the Karoo could therefore be defined as a consequence that would not significantly alter the livelihood activities, community spirit, cultural/spiritual practices or appreciation of a particular area. For example, it is unlikely that sense of place values of Beaufort West residents living near the industrial area of the town would be negatively altered if shale gas developers decided to build a trucking depot there. Noise risks could typically be mitigated in this area by merely making some kind of logistical or technical change to their operation to it within acceptable limits of the existing industries in the area.

A moderate consequence to sense of place values in the Karoo would be where an existing form of livelihood, community spirit, cultural practice, identity or appreciation would be slightly altered by SGD. For example, if shale gas trucks made use of Graaff-Reinet's main street to access a drill site about 20 km from this heritage town, they would only slightly alter the sense of place of the Graaff-Reinet town centre. Moreover, the truck route might be welcomed by overnight accommodation venues and petrol garages even though it might make the town centre more vibrant than it has been before.

A substantial consequence would be where SGD led to a significant loss of a livelihood, community spirit, cultural or spiritual practice, group identity or appreciation of the Karoo. For example, if a SGD was located within 10 km of cultural heritage site in the Karoo. This might destroy the business of a single sector of tourism establishments, i.e. bed and breakfast businesses in that area, requiring these venues to relocate. Farming, however, would continue unabated and water resources would remain pristine.

A severe consequence would be if SGD destroyed most forms of nature tourism in the area with only a few research scientists visiting the area. Farming would be significantly affected with a loss in productivity and subsequent job losses. The area might encounter increased air, noise and water pollution with the rural character of the Karoo transformed into an increasingly industrial zone.

An extreme consequence would be if SGD resulted in the all forms of tourism, farming and alternative lifestyles and creative occupations being irrevocably destroyed. The livelihoods, community identities and cultural practices of the people of the Karoo would be completely changed. The identities of the Karretjie People and other marginal groups would no longer be distinguishable and a new industrial centre would have been created with new identities emerging.

13.7.2 Risk assessment table

As discussed earlier, this table represents a conceptual or hypothetical risk analysis. It cannot do otherwise because no baseline data exist for sense of place values for the whole of the study area. Moreover, even if these baseline data did exist it would only be a temporary risk analysis for sense of place values at a point in time because as social contexts and opportunities change, so would individuals and a community's senses of place. However, this does not mean that including sense of place values in risk analysis is without value. It does add a great deal of value. As discussed previously in the section on SGD in the US, ignoring sense of place can result in social disruption within a community.

While any form of development can affect any individuals or groups sense of place, this does not mean that all senses of place are equally valid. It merely implies that a community's sense of place needs to be negotiated and adjusted continuously as new individuals and groups emerge and as new challenges arise. By making use of desktop expressions of sense of place values in the public domain and grouping them in the four categories below we illustrate the sense of place sensitivities that SGD could unlock in the Karoo. This attempt to represent sense of place values is a first step towards getting it recognised as an important factor to be considered by communities, shale gas developers and governments.

The first category of people addressed in the risk assessment table is the farming community (Table 13.1). The Reference Case scenario where no SGD occurs means that no threat to sense of place will occur for this group. In the Exploration Only scenario where widespread seismic surveys and stratigraphic drilling take place, but no further development, there might be a slight risk to sense of place of the farming community, even though it is temporary, because perceptions of water contamination and noise levels will play a role. Mitigatory measures that involve regular feedback to the community on the quality of water sources are likely to be adequate.

In the Small Gas scenario where exploration and limited development occurs, SGD is expected to pose moderate risk without mitigation, especially in areas less than 10 km away from the site, and a low risk with mitigation. Mitigation in the form of substantial monetary compensation for farmland is likely to be necessary to encourage farmers to continue farming. This is because those who receive the monetary compensation would still have to purchase another farm and finding suitable land takes time, as does building up knowledge of the new area. Moreover, the farmer might have built significant infrastructure on their current farm that would take time to replace elsewhere. It is also however, not clear how farm labourers, would be compensated if a farm was sold, this would need to be part of any mitigation plan. Regular feedback to farmers by SGD developers regarding water contamination threats and air pollution would be also be necessary if they chose to stay on in the area and relinquish only a part of their farm.

The Big Gas scenario, where extensive SGD occurs, poses a high risk to sense of place values if no mitigation is offered and a moderate risk if substantial mitigation in the form of monetary compensation and regularly feedback on water and air pollution is offered.

The second group of people whose sense of place values are assessed are the Karretjie People (Table 13.1). We have assumed that in the Reference Case, where no SGD occurs, their sense of place will largely continue unaltered. Without actual investigation it is difficult to ascertain if this is true but it is a conservative assumption that their precarious livelihoods will continue. The Exploration Only scenario, where widespread seismic surveys and stratigraphic drilling takes place, but no further development; they are likely to have an altered sense of place but with mitigation in the form of alternative roads for trucks so as not to disturb their migrations; risk could be removed. However, in the Small- and Big Gas scenarios, where there is limited and then extensive SGD that affects farming; their sense of place is expected to be moderately at risk and then highly at risk, respectively, if no compensation is offered. If substantial monetary compensation as well as jobs are offered; their identities and sense of place would remain at risk but they might not find this a negative option, given their current marginal existence. It is for this reason that risk to sense of place is considered low to moderate when mitigation is offered.

Lifestyle farmers, creatives, retirees, tourists and scientists are, by and large, (Table 13.1) the most likely to have their sense of place offended by SGD. They are interested in the Karoo because of its remoteness and uniqueness and the value they place on the Karoo in its pristine state. The Reference Case, where nothing changes, is first prize to them. In the Exploration Only scenario where exploration occurs but no development takes place, they will experience moderate risk, if they are not compensated. Mitigation in this instance would require continual SGD developer feedback on water contamination, noise and air pollution. Moreover, mitigation would need to address the visual aspects of SGD so that it had very limited visibility. Monetary compensation might satisfy some of the people in this category who are in need of supplementary income; others might simply decide to relocate because they can afford to move away.

Shale gas developers, low-skilled workers, and unemployed youth value the Karoo in its transformed state (Table 13.1). They are in favour of an industrial sense of place in the Karoo because it has the potential to bring about the most jobs or revenue. The unemployed and low-skilled workers do not necessarily see the Karoo positively if they cannot find employment. While they may see the area as their historical home, their future existence here is at risk without access to work. The current existing land uses as well as natural and cultural sites do not provide this group with sufficient access to jobs. The Reference Case scenario, where it is business as usual in the Karoo and no SGD takes place, is unacceptable to them. Mitigation in this instance is a job or an alternative cost effective site to conduct SGD. If they are not compensated for this wasted opportunity for revenue and/or jobs; their sense of place will be negatively affected.

However, with mitigation in the form of other jobs or other possible areas to prospect for shale gas they are likely to be easily satisfied. In the Exploration Only scenario they would be satisfied if other opportunities were made available in the form of jobs or other sites. The Small and Big Gas scenarios would be second and first prize to them, respectively.

Table 13.1: Risk assessment table

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	Likelihood	Risk	Consequence	Likelihood	Risk
Loss of sense of place to farmers, farm labourers, emerging farmers and land claimants	Reference Case	The Karoo as a Region	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Slight	Likely	Very low	Slight	Very unlikely	Very Low
	Small Gas		Moderate	Very likely	Moderate	Moderate	Not likely	Low
	Big Gas		Severe	Very likely	High	Severe	Not Likely	Moderate
Loss of sense of place to Karretjie People	Reference Case	The Karoo as a Region	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Moderate	Likely	Low	Moderate	Not Likely	Low
	Small Gas		Substantial	Likely	Moderate	Substantial	Very Unlikely	Low
	Big Gas		Severe	Likely	High	Substantial	Not Likely	Moderate
Loss of sense of place to lifestyle farmers, creatives, retirees, tourists and scientists	Reference Case	The Karoo as a Region	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Substantial	Likely	Moderate	Moderate	Likely	Low
	Small Gas		Severe	Likely	High	Substantial	Likely	Moderate
	Big Gas		Extreme	Very likely	Very high	Severe	Likely	High
Loss of sense of place to SGD, low-skilled workers, unemployed youth	Reference Case	Places within sight or sound of wellfields or other facilities	Extreme	Very Likely	Very High	Substantial	Likely	Moderate
	Exploration Only		Substantial	Likely	Moderate	Moderate	Likely	Low
	Small Gas		Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Big Gas		Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low

13.8 Best practice guidelines and monitoring requirements

No best practice guidelines exist to measure or monitor the full range of sense of place values. As mentioned earlier; sense of place values are only beginning to be introduced into risk analysis. It is also true that South Africa's EIA and development planning practices inadequately address sense of place issues. More research is required into how these processes can be better informed by sense of place values.

It is suggested that Likert scale quantitative research surveys where sense of place values of affected communities are empirically researched and made public should be mandatory in public participation processes - as should further ethnographic research and other qualitative methods, where individuals were found to be at moderate and extreme risk. Cases of potential extreme displacement of people and communities where no compensation would suffice should be highlighted and addressed in these public meetings.

Moreover, it is proposed in cases where no acceptable compensation is feasible with regard to loss of sense of place, that the prevention of any form of development be considered.

13.9 Gaps in knowledge

Sense of place values within SGD are only beginning to be researched. There is therefore inadequate literature and research on how it can be meaningfully included in risk analysis. Moreover, the information on sense of place values provided for this scientific assessment cannot be regarded as conclusive. Without empirical research into sense of place values at specific sites with specific communities and individuals, it is impossible to be definitive and can only be really conceptual and hypothetical. By conducting a value analysis of sense of place values of groups whose views were available on the internet, we were, however, able to provide red flags of possible areas of conflict. For a more definitive risk analysis to inform decision-making an empirical baseline study of sense of place values would need to be done in the affected regions of the Karoo.

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CHAPTER 14

Visual, Aesthetic and Scenic Resources

CHAPTER 14: VISUAL, AESTHETIC AND SCENIC RESOURCES

Integrating Author:	Bernard Oberholzer[1]
Contributing Authors:	Quinton Lawson[2], Menno Klapwijk[3], Graham Young[4]
Corresponding Authors:	Megan Anderson[5], Jayson Orton[6]

1 Bernard Oberholzer Landscape Architect (BOLA) Landscape and Environmental Planning, Stanford, 7210

2 MLB Architects, Gardens, 8001

3 Bapela Cave Kalpwijk (BCK) Land Planning & Design, Hatfield, 0028

4 Newton Landscape Architects, Pretoria, 0027

5 Megan Anderson Landscape Architects, Bredasdorp, 7280

6 Archaeological Services & Heritage Assessment (ASHA) Consulting, Muizenberg, 7945

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Executive Summary

Concern has been expressed by many about the possible visual effect of shale gas development (SGD) on the character of the Karoo landscape, its sense of place and on tourism in the area. Further reference to these concerns is covered in Chapter 9 on tourism (Toerien et al., 2016), Chapter 11 on social fabric (Atkinson, *et al.*, 2016) and Chapter 13 on sense of place values (Seeliger et al., 2016) of this scientific assessment report. SGD activities could affect scenic resources, the amenity value of recreation and resort areas, property values and subsequently the economy of the region, an aspect covered in Chapter 10 on economics (Van Zyl et al., 2016). Taking these concerns into account, the importance of visual, aesthetic and scenic considerations is stressed in Section 14.1.

This visual study focuses on spatial aspects relating to the distribution of scenic resources and sensitive receptors and the possible effects and risks that would arise as a result of SGD. Being a strategic visual assessment at a regional scale, the desktop study did not involve fieldwork, but instead relies on available information and the knowledge of the study area by the authors. It is important therefore that a more detailed visual assessment is carried out during the Environmental Impact Assessment (EIA)/project phase at the local scale. In the context of the Karoo study area, landforms tend to play a major role in the mapping of scenic resources at the regional scale as outlined in Section 14.2. For example, the escarpment, which roughly traverses the middle of the study area, is a major feature of visual significance.

Four scenarios are assessed, ranging from Scenario 0) the Reference Case, with no further exploration, Scenario 1) Exploration Only, Scenario 2) Small Gas and Scenario 3) Big Gas. It is anticipated that the greatest visual impacts would occur during the construction and drilling phases, which although short-term, will re-occur as new wells are opened up. With eventual decommissioning, the study area could be restored to a partly natural state over time, with reduced visual effects, taking into account the challenge of landscape rehabilitation in arid environments.

The geology of the Karoo has a profound influence on landscape characteristics within the study area, with seven landscape types being identified, ranging from the arid Ceres-Tankwa Karoo in the west to the more watered grasslands of the Eastern Plateau area, as outlined in Section 14.3. Scenic resources, such as important topographic features and cultural landscapes, as well as sensitive receptors, such as those relating to National Parks, nature reserves, human settlements and major routes have been identified. Visual buffers for each of these were determined in order to prepare a combined visual sensitivity map with *high*, *moderate* and *low* visual sensitivity zones. Zones of high scenic value seem to correlate with those of high biodiversity and heritage value.

Potential visual impacts resulting from the proposed SGD can be managed to a limited degree through a range of avoidance, mitigation and offset measures. Avoidance measures involve the protection of valuable scenic resources, including the use of visual buffers. Mitigation measures are mainly project-related, such as the control of construction activities and minimising the visual intrusion of structures in the landscape. Finally, offset measures involve compensation in one form or another for the visual intrusion caused by SGD and possible loss of scenic resources. A possible offset is the creation within the study area of a scenic wilderness corridor forming a linked system of protected landscapes. A risk assessment matrix in Section 14.4, both *without* and *with* visual mitigation, for the four scenarios, would be combined with risks identified in other Chapters, to inform possible future SGD.

National, Provincial and Local Government need to prepare for future possible SGD in South Africa in order to conserve scenic resources and protect visually sensitive receptors. Best management practices to minimise potential visual impacts have been gleaned from similar activities in South Africa and from overseas studies on SGD. These are outlined in Section 14.5 for the exploratory, development, rehabilitation and monitoring stages.

The level of information relating to scenic resources needs to be addressed; there being no comprehensive or standardised baseline or grading system currently in South Africa, nor fine-scale mapping for the study area. Additional information is required in particular for cultural landscapes and for private reserves, game farms and resort or tourism-related amenities that could be affected, as indicated in Section 14.6. An assessment of cumulative impacts would require information on the location and density of proposed SGD in relation to other existing and proposed activities, such as wind and solar energy developments, as well as uranium mining.

CHAPTER 14: VISUAL, AESTHETIC AND SCENIC RESOURCES

14.1 Introduction

14.1.1 Relevance of the visual study

Much of the current opposition to shale gas development (SGD) in the Karoo can be attributed to the perception that the character of the landscape will be significantly altered, particularly the Karoo’s unique sense of place. This includes its sense of expansiveness, emptiness, silence and dark starlit skies at night (see Toerien et al., 2016; Atkinson et al., 2016; and Seeliger et al., 2016).

SGD activities, and their related infrastructure, tend to have an industrial connotation and could potentially compromise the iconic scenic characteristics of the Karoo, the subject of this Chapter, and the more abstract sense of place characteristics, the subject of Chapter 13 (Seeliger et al., 2016) of this report. These effects on scenic resources would be particularly felt in pristine or protected landscapes, while they may be less of an issue in previously disturbed areas. Wind and solar energy projects, along with electrical infrastructure, have already transformed some parts of the Karoo.

SGD could in addition detract from the amenity value of recreation or resort areas, and affect property values in some cases, all of which could affect the economy of the region (Van Zyl et al., 2016). Scenic resources, particularly in relation to national parks, game farms and other visitor destinations, have important economic value in the form of tourism for the Western, Northern and Eastern Cape Provinces.

The siting of the SGD activities therefore has implications for not only the scenic resource base (the receiving environment), but also for the community and the tourism industry (the receptors). The purpose of this strategic level visual assessment is to identify scenic resources at the regional scale, as well as potential sensitive receptors that could be affected, and to recommend measures to avoid, mitigate or offset possible adverse effects.

14.1.2 International and national context

SGD have been in progress in North America for some time, where a great deal of experience and precedent can therefore be derived. Europe, Australia and China on the other hand still appear to be in the early stages of developing regulatory frameworks for their respective shale gas industries (see Scottish Government, 2014). One of the challenges for the current study is that there is no precedent for SGD in South Africa as yet, which means that the potential effects are largely unknown, particularly with regard to changes in landscape character, and therefore many of the inhabitants are understandably nervous.

A notable difference between SGD in the forested biomes of the Northern Hemisphere and South Africa, from a visual perspective, is that the forested landscapes tend to be more visually absorptive than the arid Karoo landscape, which is more visually exposed and where the vegetation does not recover easily. Even though it is a harsh environment in which to live and farm, there is a great deal of romanticism surrounding the Karoo's serene, uncluttered '*vlaktes*', brilliant starlit skies and fresh air on which local eco-tourism is founded. This is partly in contrast to say Texas, in the United States (US), where oil wells and shale gas production have been in existence for some time, and the local population have become more used to the visual effects of these activities.

The proposed SGD would take place in a partly rural or wilderness type Karoo landscape, which except for centuries of grazing and widely spaced settlements, is largely unaltered and still retains its pastoral character. SGD could

GLOSSARY

Cultural landscapes	Human-modified landscapes, particularly those of aesthetic, historical or archaeological significance.
Cumulative impacts	The combined or incremental effects resulting from changes caused by a proposed development in conjunction with other existing or proposed activities.
Geomorphological features	Landforms derived from geological formations resulting in particular topographical characteristics.
Landscape typology	The classification of the landscape into units, each unit having typical physiographic or scenic characteristics.
Offsets	Measures to compensate or provide restitution as a result of adverse impacts.
Sense of place	The unique or special qualities found in a particular location, including the combined natural, cultural, aesthetic, symbolic and spiritual qualities.
Receptors	Viewers who would be affected by a proposed development, the viewers usually being residents, commuters, visitors or tourists.
View corridor	A linear geographic zone, usually along movement routes such as trails, roads and railways, visible to users of the routes.
Viewshed	A geographic zone encompassing a view catchment area, usually defined by ridgelines, similar to a watershed.
View shadow	A zone within the view catchment area that is visually obscured from the proposed development by the topography, trees or structures.
Visual buffer	A geographic zone of varying distance, indicating visual sensitivity or visual constraints for proposed development or activities.

potentially compete in places with grazing and game farm related tourism within the study area. The cumulative visual impacts of SGD activities in combination with wind and solar energy projects, is a possible concern.

14.2 Scope of the visual strategic issue and its links to other strategic issues

14.2.1 Visual Parameters

Visual-aesthetic issues are concerned with the scenic integrity of natural landscapes (environmental health) on the one hand and the psychological sense of wellbeing or 'quality of life' (human health) on the other. Visual assessments by their nature encompass both tangible and more abstract qualities of the landscape, resulting in a degree of subjectivity, with cultural undertones. This visual study focuses on spatial aspects relating to the distribution of scenic resources and sensitive receptors, while 'sense of place' is the subject of the Chapter 13 (Seeliger et al., 2016) of this report.

Visual and scenic qualities are determined by both landscape and cultural characteristics within the study area including, but not restricted to, topographical and geological features, vegetation patterns, land use activities and settlement forms (Oberholzer, 2005).

A definition of visual:
The term 'visual' broadly includes visual, scenic, aesthetic and amenity values, which contribute to an area's overall 'sense of place', and which encompass both natural and cultural landscapes.

The Visual Chapter, being part of a scientific assessment, is a desktop study and did not involve field work to ground-truth scenic resources, but instead relies on the knowledge and experience of the authors, and on available literature. Furthermore the study area is regional in scale, involving scenic resources at a broad spatial level. During the Environmental Impact Assessment (EIA) or project phase, a more detailed visual assessment would be required at the local scale involving, amongst others, viewshed analyses.

At the regional scale of the study area, landforms such as mountain ridges, escarpments and dolerite '*koppies*' play a dominant role in the mapping of scenic resources. Vegetational differences and land uses tend to only become meaningful at the local scale and have therefore not been considered in the current visual sensitivity mapping. Although vegetation, in combination with topography, provides a visual backdrop, the generally stunted nature of Karoo vegetation provides little visual screening.

14.2.2 Visual Assessment Considerations

No standardised approach to visual quality or even scenic resource mapping exists for the country as a whole at present, or for the rating of scenic resources in terms of their sensitivity or significance. Some work on this has been done for the Western Cape Province (Winter and Oberholzer, 2013). Furthermore, there is no specific legislation relating to the protection of scenic resources in South Africa at present, except for the NEMA and National Heritage Resources Act (see Box below).

Instrument	Key objective
National Instrument	
National Environmental Management: Protected Areas Act, 2003 (NEMA)	The Minister/MEC may restrict or regulate development in a 'protected environment' that may be inappropriate for the area given the purpose for which the area was declared (Section 5).
National Heritage Resources Act (Act 25 of 1999) NHRA)	Includes protection of national and provincial heritage sites, as well as areas of environmental or cultural value, and proclaimed scenic routes.
Provincial Instrument	
Protected Areas Act (PAA) (Act 57 of 2003, Section 17)	Local authority zoning schemes can be used to protect natural and cultural heritage resources through 'Conservation Areas', 'Heritage Overlay Zones' and 'Scenic Overlay Zones' including scenic routes.

In the assessment of scenic value, aspects such as landscape complexity and topographical diversity of the landscape are often considered. This is not to say that the open plains of the Karoo are without scenic value, but that they tend to be enhanced through contrast with surrounding landforms. Visual variety and scale tend to be important ingredients, particularly at the interface between landforms. Aesthetic perception is an elusive science, but coherence, legibility, complexity and mystery are some of the universal factors considered (Bell, 2012).

Another consideration in determining scenic value is the level of 'landscape integrity' or intactness, as opposed to disturbed or degraded natural and cultural landscapes. However, this is difficult to determine in a desktop study at the regional scale, and would instead be mapped at the local project scale, usually as part of a Visual Impact Assessment (VIA).

In determining 'visual sensitivity' for SGD, the authors adopted a similar approach to that used in other regional-scale scenic studies (Lawson and Oberholzer 2014, 2015). This allowed a common database and sensitivity analysis to be used covering fairly similar geographical areas. The advantage of this approach is that it provides consistency in assessing competing land uses.

14.2.3 Links to other strategic issues

The Chapter on visual issues is closely linked to that of Chapter 15 on heritage (Orton et al., 2016), taking in both natural and cultural landscapes. These include protected landscapes and heritage resources, which because of their legal status; tend to have increased visual significance.

Similarly, a close connection between the Chapters on visual impacts and sense of place values (Seeliger et al., 2016) exists, adding the dimension of 'landscape meaning', with particular reference to the Karoo. Because of the relationship to human perception and values, there is a connection to the social fabric Chapter (Atkinson et al., 2016). The Noise Chapter (Wade et al., 2016) has relevance in that noise resulting from SGD activities can adversely affect sense of place. The combination of these factors, seen together, all have potential implications for the Tourism Chapter (Toerien et al., 2016). Interestingly, the zones of high scenic value correlate fairly closely with those of high biodiversity (Holness et al., 2016) and heritage value (Orton et al., 2016).

14.2.4 Assumptions and Limitations

Being strategic in nature, the current visual aesthetic study makes use of broad baseline information, resulting in a number of assumptions and limitations listed in the Box Below.

Limitation	Included in the scope of this study	Excluded from the scope of this study	Assumption
Level of mapping detail	1: 500 000 topographical maps and 1:1 000 000 geological survey maps.	1:250 000 and 1:50 000 topographical maps.	More detailed 1:50 000 maps and aerial imagery would be used for local or project scale assessments.
Information on cultural landscapes	Included where known from previous studies.	Cultural and heritage sites.	Heritage information and mapping provided in Chapter 15 (Orton et al., 2016).
Information on private reserves, game/guest farms and resorts.	Information was included where these facilities were known.	Detailed survey of private reserves / game farms.	Detailed information would be needed at the project scale.
Viewsheds of National Parks and nature reserves	Viewsheds of SKA and SALT astronomical sites.	No viewsheds for individual features or visual receptors.	Viewshed mapping would be needed at the project scale.

14.2.5 Description of Shale Gas Development

Visually significant components of the proposed SGD are listed below for each of the scenarios, as described in Chapter 1 (Burns et al., 2016). Only those components that could have a visual effect on scenic resources or receptors within the study area are indicated in Table 14.1, 14.2 and 14.3, below. The four scenarios that are being considered are as follows:

Scenario 0: Reference Case
Scenario 1: Exploration Only
Scenario 2: Small Gas
Scenario 3: Big Gas

Table 14.1: Components associated with the Exploration Only scenario that could have a visual effect on scenic resources or receptors within the study area.

Activity / facility	Footprint	Height	Visual implications
Seismic exploration:			
Clearing of seismic lines 0.25 to 10 km spacing	Up to 2 000 km. ± 5 m width	n/a	Short-term vegetation clearing for pedestrian and light vehicular access. Limited visual effect.
Seismic equipment	4x vibreosis trucks 1x auger drilling truck Plus other trucks	± 3m	Short-term at each site (2-3 years total). Also has noise emissions; especially shot point method (90 dB). Limited visual effect. 12 - 24 hour operation.
Drilling exploration:			
5 drilling rigs (1 rig per campaign)	Part of wellpad	40m	Medium-term 5-10 years. Significant visual effect because of height. Also noise emissions (90 dB) 24hrs.
30 wellpads (6 wellpads per campaign)	2 ha/wellpad total: up to 120 ha	n/a	Includes drilling rig, prefabricated offices, storage tanks, parking, laydown area, stockpiles.
5 crew accomm. Camps (1 camp per campaign)	1 ha/camp total: 5ha	± 3m	Footprint could be slightly less. Probably prefabricated units.
Access roads	1 km/wellpad total: 30 km	n/a	Probably gravel surface. Limited visual effect of roads, but potentially significant effect of dust from truck traffic.
Wellpad lighting	For 30 wellpads	unknown	24 hour operational/security lighting. Directed to wellpad footprint. Visual effect at night, especially in the dark Karoo sky.
Flaring during flow-testing	For 30 wells		Approximately 30 days per well.
Total exploration area within the study area	Notional 30 x 30 km target area. Total: 5 target areas		Actual footprint of exploration area < 5% of target area. Target areas not known. Potentially scattered effect. 5 drilling campaigns assumed.

Table 14.2: Components associated with the Small Gas scenario that could have a visual effect on scenic resources or receptors within the study area.

Activity / facility	Footprint	Height	Visual implications
3 drilling rigs	Part of wellpad	40 m	Increased visual effect because of height, but short-term. Noise emissions (90 dB) 24 hours.
55 wellpads	2 ha/wellpad total: up to 220ha		Wellpad includes drilling rig, prefab offices, storage, parking, laydown area, stockpiles. Construction period 5-10 years.
550 production wells	10 wells per wellpad		Drilling short-term, with ongoing production long term, 10-30 years.
1 crew accommodation camp	1 ha	± 3 m	Refurbished exploration camp. Probably prefabricated units. Moderate visual effect.
Access roads	0.5 km - 1 km/wellpad total: 27.5+ km	n/a	Probably gravel surface. Moderate visual effect of roads. Significant effect of dust and noise from truck traffic.
Wellpad lighting	For 55 wellpads.	unknown	24hour operational/security lighting. Visual effect at night in dark Karoo sky.
Flares during drilling and well-flow testing	For 55 wellpads	unknown	Installed for safe shutdown or routine maintenance. Short-term visual effect.
Gathering and export pipeline network	Length unknown	n/a	Some visual effect during excavation, (short-term), if below ground. Mainly located in road reserves.
Gas processing plant, incl. compressor station	Number and footprint unknown	unknown	Long-term. Significant visual effect depending on scale and height. Visual effect of flares at night on dark Karoo sky.
1 CCGT power station 1000 MW. (within 100km of production block)	total: 15 ha	unknown	Long-term. Significant visual effect depending on scale and height. Connecting substation and powerline would be needed.
Initially 1 production block assumed.	Notional 30 x 30 km production block.		Potential scattered effect of wellpads and access roads. Target areas not known.

Table 14.3: Components associated with the Big Gas scenario that could have a visual effect on scenic resources or receptors within the study area.

Activity / facility	Footprint	Height	Visual implications
20 drilling rigs	Part of wellpad	40 m	Short-term at each wellpad. Longer-term in the production blocks. Increased visual effect because of height. Noise emissions (90 dB) 24 hours.
410 wellpads	2 ha/wellpad total: up to 1640ha		Includes drilling rig, prefabricated offices, storage, parking, laydown area, stockpiles.
4100 production wells	10 wells per wellpad		Drilling short-term, with ongoing production long-term, 10-30 years.
8 crew accommodation camps	1 ha/camp 2 camps per block total: 8 ha for 4 blocks	± 3m	Refurbished exploration camp. Probably prefabricated units. Moderate visual effect.
Access roads	0.5 – 1 km km/wellpad total: 205+ km	n/a	Probably gravel surface. Regular truck traffic. Potentially significant visual effect because of high density of roads and dust generation, particularly when seen from high points in the landscape.
Wellpad lighting	For 410 wellpads.	unknown	24 hour operational/security lighting. Significant visual effect at night on dark Karoo skies.
Flares during drilling and well-flow testing	For 410 wellpads	unknown	Installed for safe shutdown or routine maintenance. Short-term visual effect.
Gathering and export pipeline network	Length unknown	n/a	Some visual effect during excavation, (short-term, if below ground, but over a large distance). Mainly in road reserves.
Gas processing plants, incl. compressor stations	Number and footprint unknown	unknown	Long-term. Potentially significant visual effect depending on scale and height. Visual effect of flares at night in dark Karoo skies.
2 CCGT power stations 2000 MW each.	total: 30 ha Incl. upgrade of power station in Scenario 2.	unknown	Long-term. Significant visual effect depending on scale and height). Connecting substations and powerlines would be needed.
Total of 4 production blocks assumed.	Notional 30 x 30 km production block		Includes the single block for the Small Gas scenario.

14.2.6 Contributory factors in visual assessments

An indication of the scale of a typical wellpad with a drilling rig of 40 m, seen at a range of viewing distances, during the day or night, is given in Figures 14.1 to 14.7. The model indicates that the wellpads during drilling operations could be highly visible in the viewer’s frame of vision up to 2 km during the day, moderately visible from 2 to 5 km, and marginally visible beyond 5 km, depending on light conditions, background etc. The visibility of lights and flares at night, including ambient sky-glow, are potentially visible over greater distances in dark rural landscapes.

The figures are hypothetical, assuming a flat landscape, and although this provides some idea of the visibility of the wellpad, there are other contributory factors, such as skyline effects (where the wellpad is seen in silhouette against the skyline), which could emphasise the visibility of structures. Background topography or vegetation, and topographic complexity, could on the other hand reduce the potential visibility of structures in the landscape, especially at a distance. The landscape setting is another factor, with rural landscapes being more susceptible to visual impact than say industrial landscapes or the presence of other visual distractions. Scenic landscapes, (such as mountain passes), would be visually sensitive, particularly if they have heritage or tourism value. Finally, national parks and nature reserves are visually sensitive to even distant views, if their intention is to offer a wilderness experience. Therefore, although distance has a correlation with diminishing visibility, this does not imply that distant views of the wellpads (and other related activities) are always insignificant.

The contributory factors mentioned above were taken into consideration in determining visual sensitivity buffers and setbacks, described in Section 14.3.3 and Table 14.6, and in the visual sensitivity mapping. From the description of the scenarios in the tables above it is anticipated that the greatest visual impacts would occur during the construction and drilling phases, which although they occur over a short time period, will re-occur as new wells are opened up. Once the drilling rigs are removed the visual effect will be partly reduced, although tanks, access roads and other infrastructure would still be visible. During the decommissioning phase the site could be restored to a partly natural state over time, with reduced visual effects, taking into account the challenge of landscape rehabilitation in arid environments.

Figure 14.1: Visual simulation of a wellpad in a Karoo landscape at a distance of about 300 m. The adjacent farmhouse gives an indication of the scale of the drilling rig.

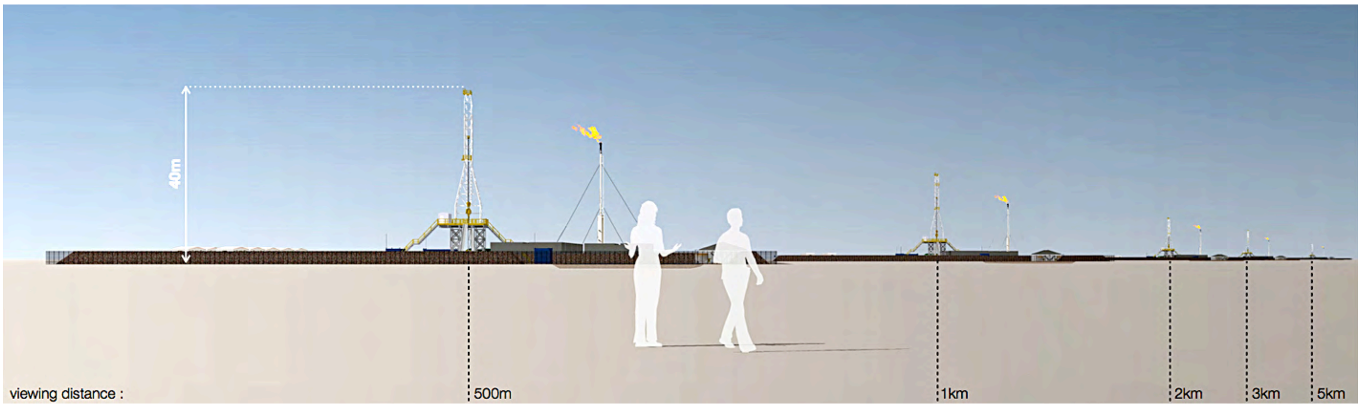

Figure 14.2: Visual simulation of a wellpad during the day indicating visibility at a range of distances from 500 m to 5 km in a flat landscape.

Figure 14.3: Visual simulation of a wellpad at night indicating visibility at a range of distances from 500 m to 5 km, (before mitigation). Visibility of lights and flares would tend to be pronounced in the dark rural landscape of the Karoo.

Figure 14.4: Wellpad with drilling rig (earthtimes.org)

Figure 14.5: Wellpad with drilling rig at night *(processingmagazine.com)*

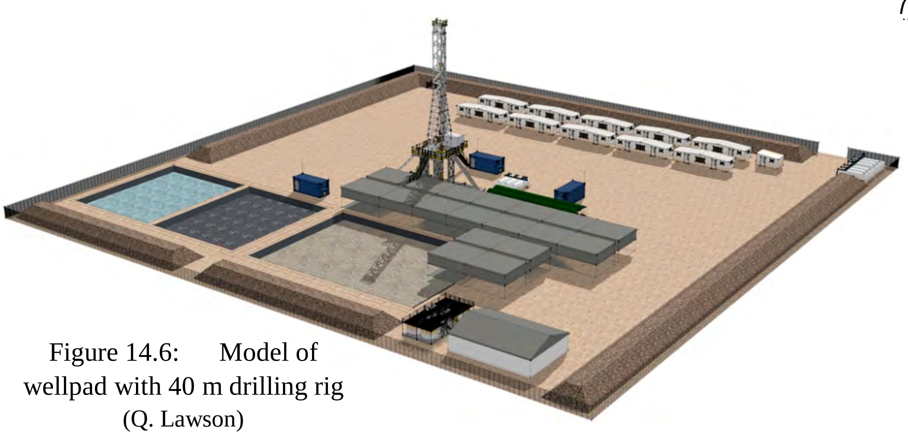

Figure 14.6: Model of wellpad with 40 m drilling rig (Q. Lawson)

Figure 14.7: Typical wellpad with drilling rig (rspb.org.uk)

14.3 Visual Sensitivity Evaluation

14.3.1 Visual characteristics of the study area

As previously indicated; landforms play a major role in determining scenic resources at a regional scale, with geology having a profound influence on landscape characteristics and therefore landscape typology. This is particularly true in the Karoo where the sparse vegetation means that the rock formations often stand out as features of interest. These geological features are described and celebrated in a number of publications (Norman and Whitfield 2006, Norman 2013).

Using a physiographic approach for landscape evaluation (Zube 1970), seven broad landscape scenic units were identified within the study area, each with their own landscape characteristics and range of significant visual features (Table 14.4). Many of these are also recognised on survey maps as distinct sub-regions, such as the Ceres-Tankwa Karoo (Figures 14.8 to 14.10).

Table 14.4: Landscape units, landform types and significant features within the study area.

Landscape Scenic Unit	Landform Type	Significant Visual Features
1. Ceres-Tankwa Karoo: Ecca Group shales with alluvium along drainage courses.	Broad, low-lying plain in the south-western part of the study area, Arid, flattish landscape with few topographic features.	The Groot, Tankwa and several other rivers (mainly dry) are the main features. The Tankwa Karoo National Park and dolerite koppies occur to the north.
2. Roggeveld-Nuweveld Mountains: Beaufort Group mudstones and sandstones	Steep escarpment and rugged mountainous terrain, the resistant sandstones forming the ridges and the mudstones in the lower lying areas. Includes the Moordenaars Karoo.	Visually sensitive scarp face and mountain ridges, as well as the SALT observatory near Sutherland. Karoo National Park and several scenic routes and mountain passes.
3. The Koup-Vlaktes-Camdeboo Plains: Beaufort Group and some Ecca Group to the south	Generally flat, arid and featureless plains with occasional dolerite dykes to the north.	Traversed by the N1, N12 and N9 National Roads, which are visual corridors. Large pans south of Beaufort West.
4. Great Fish River Valley: Ecca Group shales and Beaufort Group mudstones/sandstones	A dissected river plain in the softer Ecca shales, with gently rolling ridge and valley type topography.	Meandering Great Fish River, Sundays River and several tributaries. Addo Elephant National Park lies to the south.
5. Sneeuberg-Winterberg Mountains: Beaufort Group mudstone and dolerite intrusions	Mountainous area with high peaks over 2000m, created by the alternating sandstones and mudstones, and dolerite sills and dykes.	Camdeboo National Park, Mountain Zebra National Park. Numerous scenic *poorts* and mountain passes.
6. Great Karoo Plateau: Ecca and Beaufort Group shales and mudstone with dolerite intrusions	Vast arid and largely flat plains of the Great Karoo from Calvinia in the west to Richmond in the east.	Largely featureless, with some dolerite ridges and outcrops. Visually sensitive SKA observatory to the north. Dark skies at night.

Landscape Scenic Unit	Landform Type	Significant Visual Features
7. Eastern Plateau and Foothills: Beaufort Group sandstones and mudstones with prominent dolerite dykes and sills.	Grassy plains and mountains to the east, stretching from Middelburg to Queenstown. Higher rainfall than the west.	Scenic doleritic landforms with steep cliffs. Numerous scenic *poorts* and mountain passes.

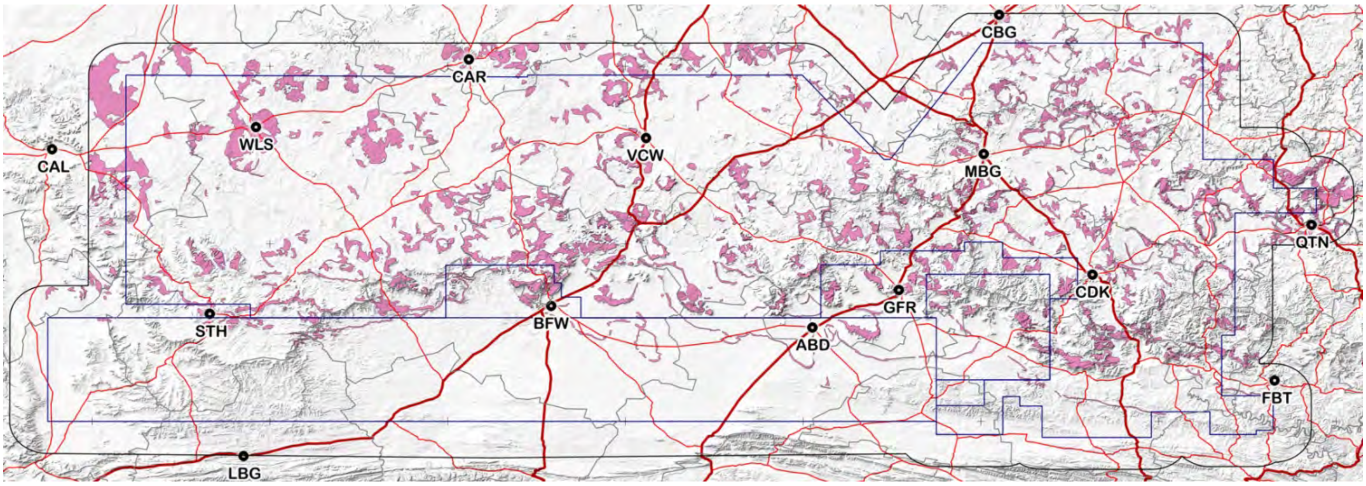

Figure 14.8: The distribution of dolerite dykes and sills in the study area have a strong influence on landscape topographic features, particularly to the east.

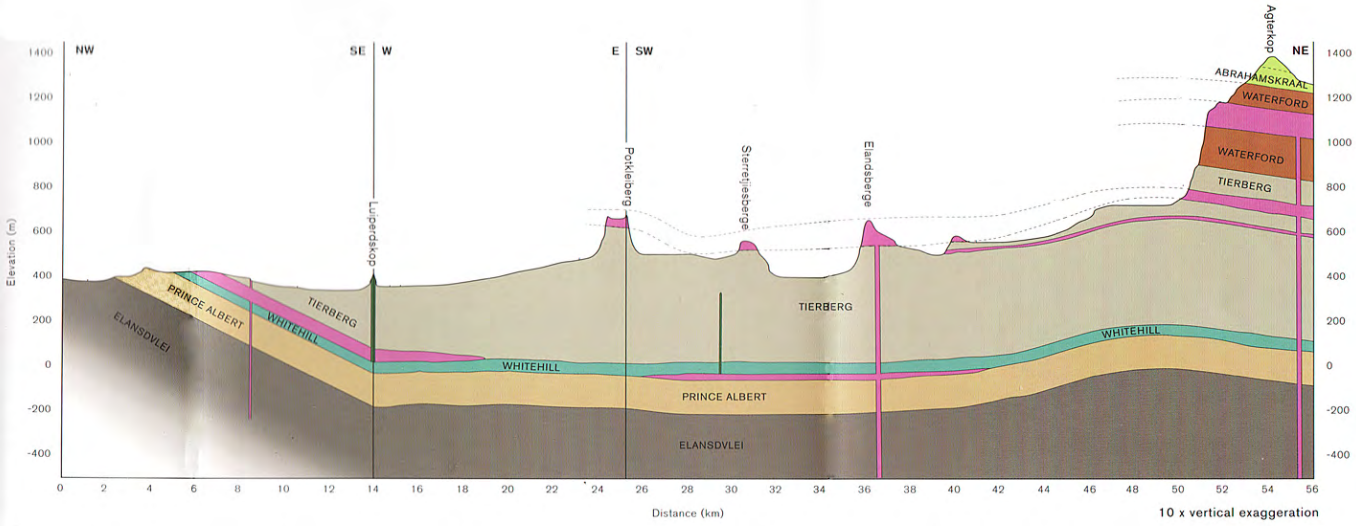

Figure 14.9: A typical section through the Tankwa Karoo indicating the influence of the dolerites (in pink) on the Karoo landscape and the shale gas formations at depth.

(Source: Rogers, J. and Smith, G. Undated. South African National Parks, 'Around the Tankwa Karoo National Park: A field guide to the geology and landscape').

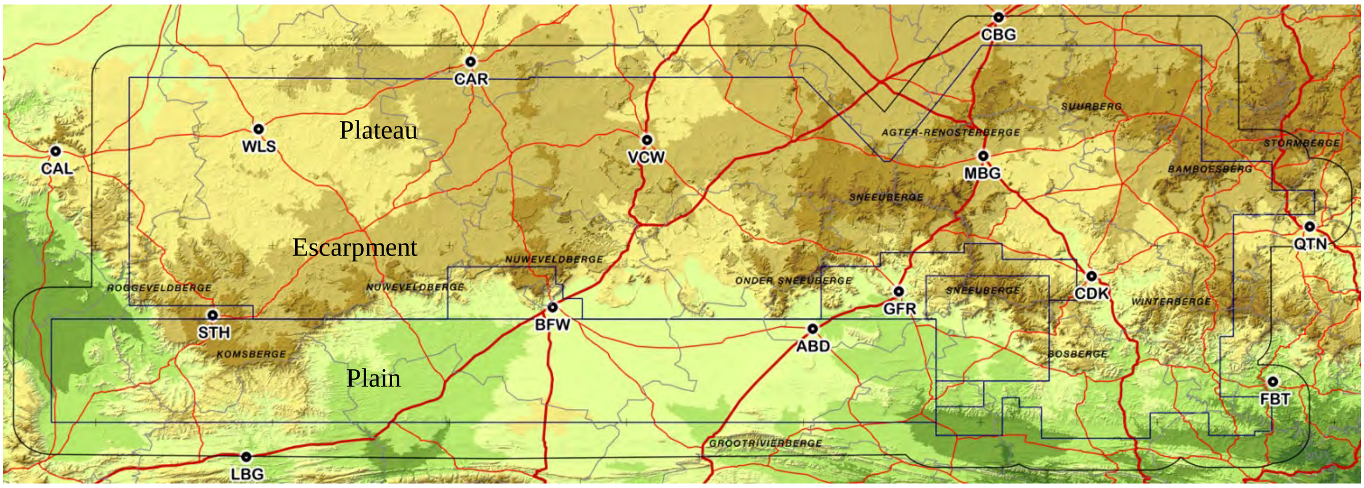

Figure 14.10: The physiography of the study area indicating the inland plateau to the north, the escarpment and mountains across the middle, and the lower-lying plains to the south.

14.3.2 Scenic resources and sensitive receptors

Aspects that play a role in visual assessments can be divided into *scenic resources* and *sensitive receptors*, as listed in Table 14.5 below, along with notes on the factors that influence their visual significance. Heritage sites have not been included here as they form part of Chapter 15 (Orton et al., 2016), although they can add to visual sensitivity.

Table 14.5: Contributing factors to visual sensitivity.

Scenic Resource	**Contributing Factors**
Topographic features (scenic units 2 and 5)	Includes features that provide interest or contrast in the generally flat Karoo landscape such as mountain peaks, escarpment rims, steep cliffs, dolerite rock outcrops or ridgelines (visually sensitive skylines), within the Roggeveld-Nuweveld Mountains, and the Sneeuberg-Winterberg Mountains.
Major rivers, water bodies, wetlands (scenic unit 4)	Water represents the lifeblood of the arid landscape, particularly in the Karoo, where it has high scenic, recreational and agricultural value. Even springs (*fonteine*), farm dams and wetlands are significant features in the arid landscape.
Cultural landscapes	Includes mainly patches of cultivated or grazing land, often along rivers in the dry Karoo landscape, notable for their rural scenic value and historical or cultural significance. Could also include proclaimed heritage sites, and important archaeological or spiritual sites relating to pre-colonial cultures.
Sensitive Receptors	(includes residents, commuters, visitors and tourists)
National Parks	Usually have scenic attributes in addition to their biological conservation role. Serve as visitor/tourist destinations. Visual significance is increased by their national protection status and visual sensitivity of visitors. Sensitive to loss of wilderness quality.
Nature Reserves	Similar scenic attributes to those of National Parks. Conservation, recreation and tourism importance. Visual significance is increased by their legislated provincial and

Scenic Resource	Contributing Factors
	municipal protection status.
Private reserves/resorts	Includes private nature reserves, game farms, recreation resorts and tourist accommodation, all of which tend to be sensitive to loss or degradation of scenic quality from visual intrusions.
Human settlements	Includes towns, villages and farmsteads where residential areas are particularly sensitive to visual intrusions, which could have an important effect on property values.
National and Provincial roads	Includes all major arterial routes which serve local and regional users for commuting, recreation and tourism, and which are visually sensitive within their view corridors.
Scenic routes and passes	Includes mountain passes and *poorts* which tend to have historical, recreational and tourism importance within the region. These are sensitive to visual intrusions along view corridors.
Passenger rail lines	Serve both commuting and tourism functions, and as in the case of roads, they are sensitive to visual intrusions along view corridors.
SA Large telescope (SALT)	Subject to core and central Astronomy Advantage Area regulations. Particularly sensitive to visual intrusions, including lights at night. Integrity of the viewshed is important.
Square Kilometre Array (SKA)	Subject to core and central Astronomy Advantage Area regulations. Radio astronomy particularly sensitive to electromagnetic intrusion. Requires a 'Radio Quiet Zone' (RQZ).

14.3.3 Visual sensitivity and visual buffers

The key scenic resources and visually sensitive receptors within the study area, within high, moderate and low visual sensitivity zones, are given in Table 14.6 below. In addition, visual buffers are indicated in response to the sensitivity zones (see Figures 14.11 and 14.12).

These buffers are seen as nominal distances for regional scale mapping and could be amended as more information becomes available at a detailed local scale. The buffers are not intended to be exclusion zones or prescriptive setbacks, but merely serve as indicators for the visual sensitivity mapping. The distinction between buffers, setbacks and exclusion areas, for the purpose of this study, is indicated in the box below (see NSW Government 2014).

Visual buffer zone	A nominal geographic area of visual sensitivity at the regional scale. Does not imply specific restrictions but could trigger the need for an EIA/VIA at the project scale.
Visual setback	A defined geographic area within which activities are regulated through bylaws or approval conditions at the EIA level. Implies specific restrictions for the siting of development.
Visual exclusion zone	A defined geographic area within which specific activities are excluded or prohibited.

At the project planning stage visual buffers could serve as a general guide, or even as a default setback, but could be reduced if the SGD activities are located outside the local viewshed or in a view shadow. Specific setbacks could be prescribed at the EIA or permitting stage of a project on a case by case basis. Furthermore, where SGD is proposed within the visual buffer zones, this could become a trigger for an EIA or Heritage Impact Assessment (HIA), including a visual assessment.

Another factor that needs to be taken into account is that setbacks at the project scale may vary depending on the scale of the infrastructure, such as large-scale wellpads, drilling rigs and gas processing plants, and smaller-scale, less visible access roads and pipelines.

A literature search revealed that there is limited information on visual buffers for scenic resources, particularly in relation to SGD, and neither is there any consistency among the various international jurisdictions or authorities. Certain states in Australia have legislated a 2 km distance between gas industries and residential areas, while in other countries it can range from 50 m to 2 km (NSW Government 2014). These are, however, usually related to noise and hazards rather than visual considerations.

The visual buffers listed in Table 14.6 below were derived partly from the contributory factors in Section 14.2.6 above, and partly from the authors' experience with similar regional-scale SEA projects (Lawson and Oberholzer 2014, 2015), where buffers were formulated for visual sensitivity mapping purposes.

The buffers relate mainly to the scale (and height) of the shale gas wellpads and related infrastructure, which could be distributed over a wide geographic area. Less is known about the gas processing plants and power station/s, which are site-specific and would require viewshed mapping. Some of the proposed visual buffers correlate closely with the recently gazetted Regulations for Petroleum Exploration and Production (Government Gazette, 3 June 2015), indicated in the Box below.

Setback regulations for protection of water resources (Government Gazette, 2015):

Distance between wellpad and municipal wellfield (water supply)	5 km
Distance between directional drilling and municipal wellfield	2.5 km
Distance between wellpad and existing water borehole	500 m
Distance between wellpad and riparian area or 1:100 year floodline	500 m
Distance between wellpad and a wetland	1 km

Table 14.6: Visual buffers in relation to visual sensitivity mapping.

Scenic Resources	**High visual sensitivity zone**	**Mod. visual sensitivity zone**	**Low visual sensitivity zone**	**Criteria**
Topographic features (mountains, scarps, steep slopes, geological features)	within 500 m	within 1 km	beyond 1 km	Relates to significant landscape features of scenic or natural heritage value. Distances relate to scale and importance of the feature, subject to a VIA, where applicable.
Major rivers, water bodies (vleis, wetlands, dams, pans)	within 500 m	within 1 km	beyond 1 km	Scenic and recreation value. Distances similar to those in the gazetted Petroleum Regulations for protection of water resources.
Cultural landscapes (incl. cultivated lands)	within 500 m	within 1 km	beyond 1 km	Rural scenic value and possible historical or heritage value. Subject to a HIA where applicable.
Sensitive Receptors / Protected Landscapes				
National Parks	within 5 km	within 7.5 km or viewshed	beyond 7.5 km	High wilderness and scenic value, including dark skies at night. Sensitive tourist receptors. Protected by National Parks legislation.
Nature Reserves (Provincial and Municipal reserves)	within 5 km	within 7.5 km or viewshed	beyond 7.5 km	Wilderness and scenic value, including dark skies at night. Sensitive visitor receptors. Protected by ordinances and local bylaws.
Private reserves (incl. game farms, tourist accommodation)	within 2.5 km	within 5 km or viewshed	beyond 5 km	Wilderness and scenic value. Sensitive visitor receptors. Important for local tourism industry. Subject to a Social Impact Assessment (SIA) where applicable.
Human settlements (towns and villages, excl. farmsteads, rural kraals)	within 5 km	within 7.5 km or viewshed	beyond 7.5 km	Visually sensitive residents and visitors. Relates to property values. Subject to Integrated Development Plans, zoning schemes and bylaws.
National and Provincial roads (major arterial routes)	within 1 km	within 2.5 km	beyond 2.5 km	Visually sensitive commuters, residents and visitors within the view corridor. Distances subject to a VIA with viewshed mapping, where applicable.
Scenic routes, mountain passes and *poorts*	within 2.5 km	within 5 km or viewshed	beyond 5 km	Visually sensitive visitors and tourists within the view corridor. Possible historical or heritage value. Distances subject to a HIA or VIA with viewshed mapping.
Passenger rail lines (commuter and tourist routes)	within 1 km	within 2.5 km	beyond 2.5 km	Visually sensitive commuters and tourists within the view corridor. Distances subject to a VIA with viewshed mapping, where applicable.
SA Large telescope (SALT)	within 15 km viewshed	within 30 km viewshed	beyond 30 km viewshed	Subject to gazetted Astronomy Advantage Area legislation. Involves avoidance of light pollution. Distances subject to a VIA with viewshed mapping.
Square Kilometre Array (SKA)	within 7.5 km of antennae	within 15 km of antennae	beyond 15 km of antennae	Subject to gazetted Astronomy Advantage Area legislation. Involves RQZ. No-go area to be determined by EMI specialists.
Heritage sites incl. grave sites and rock art sites	See Heritage Chapter (Orton et al., 2016)			Forms part of heritage chapter, but has visual implications. Subject to a HIA/VIA at the project scale.

Note 1: Areas shown in dark red on Figure 14.11 are the actual scenic resource, feature or receptor, considered as 'very high visual sensitivity', and potentially 'no-go' areas.
Note 2: 'Visual Sensitivity Zones' in Figure 14.11 and 14.12 are visual mapping categories and not prescriptive setbacks or exclusion areas.

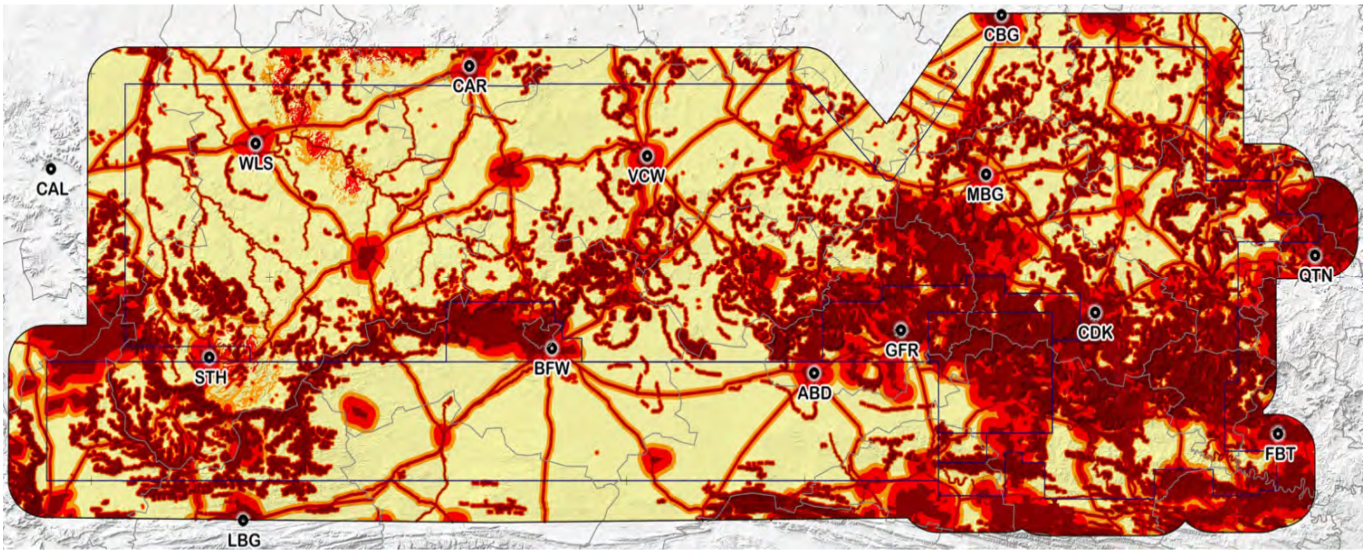

Figure 14.11: Composite map of all scenic resources and sensitive receptors, including visual buffers, indicating visual sensitivity levels from dark red (the actual feature or receptor), red (high visual sensitivity), orange (moderate visual sensitivity) and yellow (low visual sensitivity), as indicated in Table 14.6. These are not exclusion zones, but indicate visual sensitivity at the regional scale.

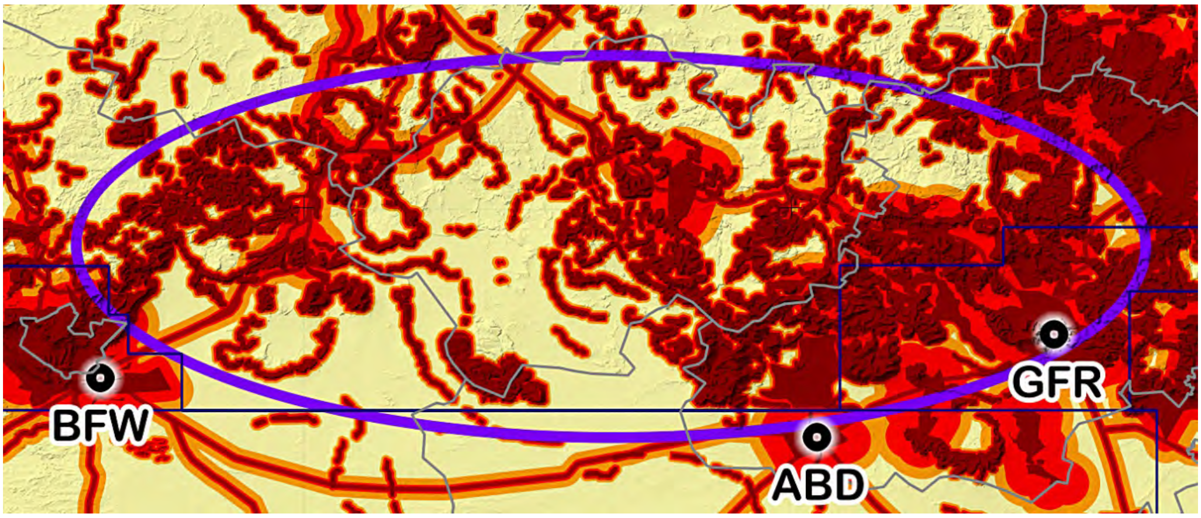

Figure 14.12: Visual sensitivity levels within an indicative prospectivity area (shown in purple). The actual prospecting area would depend on the geology.

Major Towns:

ABD	Aberdeen	GFR	Graaff-Reinet
BFW	Beaufort West	LBG	Laingsburg
CAL	Calvinia	MBG	Middelburg
CAR	Carnarvon	QTN	Queenstown
CBG	Colesberg	STH	Sutherland
CDK	Cradock	VCW	Victoria West
FBT	Fort Beaufort	WLS	Williston

14.4 Management of potential visual impacts

14.4.1 Strategies for the management of potential visual impacts

Management actions should be seen as an integral and necessary part of the planning and design of a SGD. Strategies can be divided into three possible approaches as follows (also see Table 14.7 below):

- Avoidance
- Mitigation
- Offsets

Avoidance can be seen as a pro-active approach, as it involves minimising visual impacts at the early planning stage through the identification and protection of valuable scenic resources, including the use of visual buffers where necessary. Avoidance should be achieved through Spatial Development Frameworks (SDFs) prepared by provincial and local authorities. In the case of SGD, the siting of wells is generally determined by geological and economic considerations, limiting the potential for avoidance in some cases. Micro-siting may be possible at the project scale where measures can be taken to avoid landscape or scenic features, such as relocating wellpads or re-aligning access roads.

Mitigation can be seen as a reactive approach as it involves reducing the effects of the SGD activities, and minimising visual intrusion on sensitive scenic resources or receptors at the design, construction, operational and decommissioning stages of the development (see Table 14.7). Mitigation measures could involve changes to the design or the visual screening of facilities, as well as controls through an Environmental Management Programme (EMPr). The mitigations would be formulated by the Environmental Practitioner and the specialist team, and enforced by the permitting authority.

Offsets can be seen as an inter-active approach and could take many forms. Offsets may need to be used where avoidance or mitigation measures cannot achieve the desired effect. For example, a feature or amenity that will be lost through SGD activities could be replaced with a similar amenity elsewhere as compensation, such as the establishment or enlargement of a nature reserve, or the creation of a park for residents in the area. The offsets may be proposed by the Applicant or Environmental Practitioner, and prescribed by the permitting authority.

Table 14.7: Possible visual effects and options for mitigation.

Scenario	Possible visual effects	Options for mitigation of impacts
Reference Case	*Status quo* with possibility of incremental urban sprawl, including townships. Continued construction of wind and solar energy farms with accompanying powerlines and substations. Possible increase in one-stop filling stations, billboards and other visually intrusive signage.	Commission a scenic resource study with sensitivity gradings similar to that for heritage resources (DEA). Ensure avoidance through SDFs and zoning schemes (Municipalities). Ensure mitigation through HIAs and VIAs (DEA).
Exploration only	**Localised effect on neighbouring farms/ settlements**, incl. visual clutter and noise emissions from seismic activities and wellpads/ drilling rigs. **Visual intrusion of cleared strips** in relatively uniform Karoo vegetation. **Dust and noise** created by trucks and other machinery along gravel roads. **Visual pollution, litter** from construction sites and accommodation camps. **Increased disturbance of dark skies** at night from operational lighting at wellpads, lighting from buildings and headlamps of vehicles. **Visually scattered effect in the landscape** of target areas for exploration.	Ensure setbacks from human settlements through SDFs and zoning schemes (Municipalities). Fit equipment with noise dampeners (Developers). Ensure that cleared strips are as narrow as feasible and that specimen shrubs or trees are retained where possible within the clearing (EMPr). Upgrade and stabilise public roads, where possible, as part of the exploration phase and minimise new roads as far as possible, through permit requirements (Developers). Include litter control and education in the EMPr, monitored by an Environmental Control Officer (ECO). Avoid high-mast lighting. Use reflectors to shade light sources. Use shades on windows. Avoid vehicle trips at night, through permit requirements (Developers, DEA). Cluster target areas where feasible. Select low-lying or visually absorptive areas if possible, through planning by the Applicant (Developers).
Small Gas	Increased traffic, noise and dust during the construction phase. **Fragmentation and industrialisation** of wilderness and rural areas. **Effect on rural/wilderness character** of the surroundings by SGD. **Possible visual degradation of landscape features** and historical sites from increased number of wellpads, pipelines and access roads. **Localised effect of wellpads on views** from farmsteads, settlements, possibly affecting property values.	Improve or seal road surfaces (Developers). Confine wellpads to carefully selected areas with low visibility, in zones of low visual sensitivity as indicated in Fig. 14.11 (Developers). Minimise footprint of wellpads as far as possible within the production block (Developers). Carefully site wellpads to avoid landscape features. Use existing roads where possible, and locate pipelines along roads (Developers). Ensure setbacks from human settlements (Municipalities). Create shelterbelts for visual screening (Developers).

Scenario	Possible visual effects	Options for mitigation of impacts
	Increased visual clutter arising from SGD in the exposed Karoo landscape.	Use planted berms to screen wellpads and related infrastructure. Control signage (Developers).
	Increased disturbance of dark skies at night from lighting at wellpads and from flares.	Avoid high-mast lighting. Use reflectors to shade light sources. Develop measures to screen flares from sensitive receptors (Developers).
	Perceived industrial character of 55 wellpads and of gas processing plants from visual corridors, incl. arterial and scenic routes.	Ensure setbacks from arterial and scenic routes and passenger rail lines (DEA, Municipalities). Strategically place planted berms along routes to screen development (Developers).
Big Gas	**Transformation** of rural/wilderness character, serenity and sense of place, by SGD, including 410 wellpads and heavy truck traffic.	**Avoid zones of high visual sensitivity indicated in Figure 14.11.** Apply prescribed visual setbacks from settlements and routes (DEA, Municipalities). Cluster wellpads where feasible and minimise footprints as far as possible (Developers).
	Possible visual degradation of cultural or historical landscapes from widespread wellpads, pipelines and access roads.	Carefully site wellpads to avoid landscape features. Use existing roads where possible, and locate pipelines along roads (Developers). Include protection measures in the EMPr.
	Diminished recreation amenity and tourism attraction, incl. the environs of National Parks and nature reserves.	Ensure visual setbacks from National Parks, nature reserves, and private game farms or resorts (DEA, Provincial Govertment and Municipalities).
	Disturbance of dark skies at night from lighting at 410 or more wellpads, and from flares during drilling operations.	Avoid high-mast lighting. Use reflectors to shade light sources. Develop measures to screen flares from sensitive receptors (Developers).
	Perceived industrial character of SGD activities within production block, and power station/s seen from visual corridors, incl. arterial or scenic routes and rail lines.	Site wellpads, gas processing plants and power station to minimise visibility (Developers). Ensure visual setbacks from arterial and scenic routes and passenger rail lines (DEA, Provincial Govt. and Municipalities). Locate planted berms along routes to screen development. Screen electrical substation/s from arterial and scenic routes. Avoid powerlines on visually exposed ridges or crossing arterial/scenic routes (Developers).
Cumulative Impacts	**Indirect visual impacts** from secondary industries or facilities attracted by SGD.	Subject secondary industries to similar visual scrutiny and mitigation measures (DEA, Provincial Govertment).
	Cumulative visual effect of 410 wellpads on views from settlements, possibly affecting property values.	Consider visual setbacks from human settlements (Municipalities). Locate wellpads outside viewsheds of settlements where feasible (Developers).
	Cumulative visual effects on heritage resources and sense of place.	Take into account mitigations recommended in Chapters 13 (Seeliger et al., 2016) and 15 (Orton et al., 2016) or prescribed by heritage authority (SAHRA, HWC).
	Cumulative visual effects in tandem with wind and solar energy farms, powerlines and possible uranium mining.	Ensure integrated planning at the regional scale to minimise competing land uses and excessive cumulative visual impacts, through SDFs. (Provincial and local authorities).

A possible offset for SGD in the Karoo would be the extension of existing protected landscapes in the study area to compensate for loss of scenic amenity caused by the SGD activities. This could take the form of a scenic wilderness corridor (and biosphere reserve) incorporating the current patchwork of national parks, nature reserves and river corridors into a more comprehensive, linked system of protected landscapes, within which the essential landscape qualities of the Karoo can be preserved, including dark skies at night.

The advantages of such a wilderness corridor would be to ensure the conservation of scenic diversity, biodiversity and geo-diversity as well as heritage resources (including Karoo palaeontology), as part of a broader sustainability and climate-change strategy. Economic benefits to the region could include increased eco-tourism through the introduction of trails and visitor accommodation within the corridor. Education benefits could include the provision of visitor centres explaining the geology of the Karoo and how shale gas is exploited.

The rehabilitation of shale gas drilling sites could provide useful scientific information or case studies for best practice landscape restoration in dry lands for other degraded areas in the Karoo.

14.4.2 The role of regulatory authorities

At the national level the regulations relating to Petroleum Exploration and Production (Government Gazette, 2015) should be extended to include measures for visual issues and the conservation of scenic resources, possibly with the involvement of the DEA. At the provincial level, SDFs need to take SGD into account along with appropriate best practice guidelines. At the district or local authority level, municipalities need to manage scenic resources through overlay zoning schemes and bylaws in preparation for possible SGD. An interim report on SGD has been prepared for the Western Cape (Western Cape Government, 2012), but further work, including policies and guidelines relating to scenic resources, is needed. Coordination with the Eastern and Northern Cape Provinces is also required.

14.4.3 Limits of Acceptable Visual Change

Unlike water pollution, air pollution or noise, there are no specific or quantifiable standards that can be used to determine limits of acceptable change in the case of visual impacts in the South African context. In addition, unlike heritage resources, there is no legislation in South Africa at present to specifically protect scenic resources. The default position therefore is that scenic landscapes are often, but not always, considered in heritage assessments, given that they are part of the 'national estate'.

The tipping point for the limit of acceptable change would be related to the number, distribution and density of wellpads and related infrastructure, particularly the accompanying heavy traffic, dust and noise during construction, resulting in an industrialised landscape and the loss of the current pastoral setting. This could be determined during the development application stage, particularly for the Big Gas scenario, which involves large scale SGD.

The primary indicator for limits of acceptable change in terms of visual impacts at the regional scale would be the areas defined in this chapter as ‘very high’ and ‘high’ visual sensitivity. At the local project scale limits would be determined through viewshed mapping and public participation, and by means of the regulatory framework, usually as part of the EIA process. Sensitive landscape features should normally be identified during SDF planning processes. Setbacks and exclusion zones would to some degree define levels of acceptable change, and a number of these are listed in Table 14.8 below.

Table 14.8: Potential exclusion zones for SGD

Scenic Resource	Exclusion Zone
Topographic features	Restricting development on steep slopes, elevated landforms (NEMA legislation).
Major rivers, water bodies	Restrictions within 500 m of water courses and 1 km of wetlands, as per Regulations for Petroleum Exploration and Production (Government Gazette, 2015).
Cultural landscapes	Protection of graded heritage sites and cultural landscapes (Heritage Resources Act, 2003).
National Parks	Protection of National Parks (National Parks Act).
Nature Reserves	Protection of Provincial and Municipal Nature Reserves (Provincial Ordinances and Municipal Bylaws).
Human settlements	Provisions included in local authority planning documents (SDFs, Municipal Zoning Schemes and Overlay Zoning Schemes).
Scenic routes and passes	Protection of proclaimed historical *poorts* and mountain passes, incl. rail routes (Heritage Resources Act, 2003).
SA Large Telescope (SALT)	SALT exclusion zone (Regulations in terms of the Astronomy Geographic Advantage Act, 2007).
Square Kilometre Array (SKA)	SKA exclusion zone (Regulations in terms of the Astronomy Geographic Advantage Act, 2007).

14.4.4 Risk Assessment

A number of steps have been followed in order to determine risks relating to SGD in terms of potential visual impacts, as described below:

Step 1 – Defining the nature of the impact: In visual terms this relates to the type and scale (or intensity) of the proposed SGD activities, as indicated in Table 14.7 above. These activities for example range from exploration only to large-scale SGD, which translate into potential visual hazards.

Step 2 – Defining and mapping **receiving environments:** These relate to scenic resources and visually sensitive receptors as indicated in Table 14.6 and Figure 14.11 above in the form of high, moderate and low visual sensitivity zones.

Step 3 – Defining visual **mitigation measures**: These are listed in Table 14.7 in the form of planning policies, design measures and environmental management controls.

Step 4 – Defining **consequence levels:** These are determined for this Chapter using a combination of potential hazard (intensity of the impact), exposure (extent and duration) and vulnerability (visual sensitivity of the receiving environment) as indicated in Table 14.9. Indicators for each of these are given in the box below.

Hazard (nature of impact)	**Exposure (extent)**	**Exposure (duration)**	**Vulnerability (sensitivity)**
Low intensity (Exploration Only) Moderate intensity (Small Gas) High intensity (Big Gas)	Site scale (site environs) Local scale (local viewshed area) Regional scale (beyond local area)	Short-term (0-5 years) Medium-term (5-15 years) Long-term (15+ years)	Low in scenic resources / sensitive receptors (<10% of the area) Moderate in scenic resources / sensitive receptors (10-50% of the area) High in scenic resources / sensitive receptors (>50% of the area)

Table 14.9: Calibration of consequence[1]

Slight	**Moderate**	**Substantial**	**Severe**	**Extreme**
Tends to be low intensity SGD at the site scale over the short-term in zones with low visual sensitivity. Scenically non-intrusive, with good possibility for mitigation.	Tends to be low-moderate intensity SGD at the local scale over the short-medium term in zones with low-moderate sensitivity. Some alteration to scenic quality/sense of place with moderate possibility for mitigation.	Tends to be moderate intensity SGD at the local scale over the medium-term in zones with moderate sensitivity. Strongly affects scenic quality/sense of place and tourism potential, with some possibility for mitigation.	Tends to be moderate- high intensity SGD at the local-regional scale over the medium-long term in zones with moderate- high sensitivity. Significantly affects scenic quality/sense of place and tourism potential, with minor possibility for mitigation.	Tends to be high intensity SGD at the regional scale over the long-term in zones with high sensitivity. Drastically affects scenic quality/sense of place and tourism potential, with limited possibility for mitigation.

[1] Only average levels of consequence are indicated. A number of permutations are possible when combining indicators.

Step 5 – finally, a risk assessment matrix is provided in Table 14.10 for each scenario, both before and after mitigation, by combining probability (likelihood) of the risk occurring with the consequence level from Table 14.9 above, and following Figure 5 in Scholes et al. (2016) to grade risks. The process is repeated for each type of receiving environment (visual sensitivity zone). The 'with mitigation' risk profile is dependent on the implementation of all the mitigation options listed in Table 14.7, and the 'best practice guidelines' in Table 14.11.

Table 14.10: Risk assessment matrix

			Without mitigation			***With mitigation***		
Impact	**Scenario**	**Location**	**Consequence**	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Visual intrusion of industrial-type facilities on the landscape, altering the rural / wilderness character of the Karoo, including dark skies at night.	Reference Case	Low visual sensitivity zones	Moderate	Likely	Low	Slight	Very likely	Very low
	Exploration Only		Moderate	Very likely	Low	Slight	Very likely	Very low
	Small Gas		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Big Gas		Severe	Very likely	High	Substantial	Very likely	Moderate
	Reference Case	Moderate visual sensitivity zone	Moderate	Likely	Low	Slight	Likely	Very low
	Exploration Only		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Small Gas		Severe	Very likely	High	Substantial	Very likely	Moderate
	Big Gas		Extreme	Very likely	Very high	Severe	Very likely	High
	Reference Case	High visual sensitivity zones	Moderate	Likely	Low	Slight	Likely	Very low
	Exploration Only		Severe	Very likely	High	Substantial	Very likely	Moderate
	Small Gas		Extreme	Very likely	Very high	Severe	Very likely	High
	Big Gas		Extreme	Very likely	Very high	Severe	Very likely	High

Figure 14.13 presents a risk map of visual intrusion on tharacter of the Karoo across four SGD scenarios, with- and without mitigation.

14.5 Best practice guidelines

As previously indicated, there is no precedent for SGD in South Africa and therefore best practice guidelines in Table 14.11 below have been generally gleaned from experience by the authors from projects of a similar nature locally (e.g. wind and solar development, gas pipelines and processing plants), as well as from overseas best practice manuals for SGD (American Petroleum Institute (API), 2009; New York State DEC, 2009; US Fish & Wildlife Service, 2007; Eshleman and Elmore, 2013; Kansal and Field, 2013). These guidelines should be incorporated into approval permits/EMPrs and therefore considered mandatory.

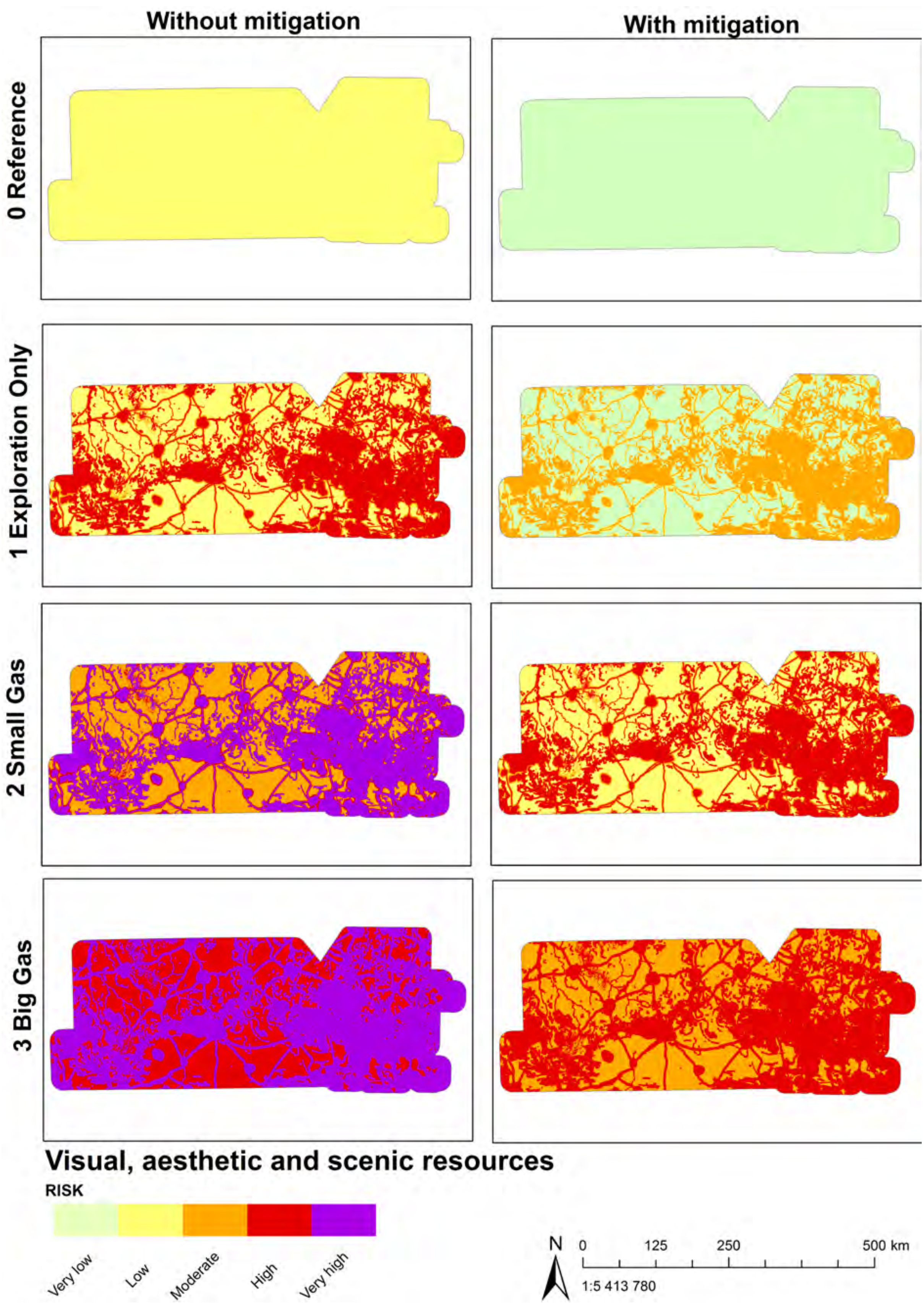

Figure 14.13: Map indicating the risk of impacts on visual, aesthetic and scenic resources across four SGD scenarios, with- and without mitigation.

Table 14.11: Best practice visual guidelines.

SGD Stage	Visual Guidelines
Exploration stage	**Location**: Take cognisance of visual sensitivity zones contained in this Visual Chapter and other regional planning documents for the various districts, including SDFs. Conduct detailed site analyses at the planning stage to identify visual constraints, important scenic features and visually sensitive receptors in the area. If necessary, commission a VIA with viewshed analyses, to determine visibility and other potential effects resulting from the proposed siting of wellpads and related infrastructure. Avoid placement of wellpads and other infrastructure on ridgelines and elevated landforms where possible because of their visual effect on the skyline. Use the mitigating effect of low-lying areas or belts of trees. Avoid placement of wellpads in proximity to visually sensitive receptors, such as National Parks, nature reserves, scenic and tourist routes. Align access roads with the natural contours and avoid steep gradients requiring additional earthworks. Use existing district and farm roads where feasible, and minimise new roads as far as possible.
Development and operation stage	**Footprint**: Minimise excessive fragmentation of natural or cultural landscapes as far as possible through grouping or sharing of infrastructure. Consider reducing the density of multiple wellpads within a specific area to reduce visual impacts on landscape character. Optimise use of multi-well drilling pads to minimise the scatter of individual wells across the landscape, and the proliferation of access roads. Reduce the footprint of wellpads as far as possible, particularly after drilling is complete. Avoid excessive loss of natural veld or agricultural land. Use previously disturbed areas in preference to pristine or agriculturally productive landscapes as far as possible. Protect surrounding veld from construction activities with temporary fencing or hoarding. Use low-profile structures where possible to reduce their visibility from adjacent viewsheds. Keep access roads as narrow as feasible. Minimise cut and fill earthworks. Locate pipelines adjacent to roads to minimise visual disturbance. **Screening**: Screen wellpads and other infrastructure by means of earth berms and/or planting. Spoil material or stored topsoil could be used in temporary berms. These are also effective if placed at strategic positions near public routes and viewpoints to screen foreground views. Locate parked vehicles under shaded carports where possible, using natural colours, to minimise their visibility in the landscape. Camouflage or disguise visually intrusive structures by means of form, colour and texture. Use colours in the olive-green or brown range to simulate the natural surroundings. Avoid reflective materials. Shade glazed surfaces to minimise reflection from windows. Consider emulating the Karoo agricultural building forms in the design of sheds and other wellpad structures to minimise their stark ‘industrial look’. **Lighting and Signage**: Minimise wellpad lighting to that required for safe operations. Use reflectors to avoid light spillage and ‘sky-glow’ effects. Use low-level bollard lights and bulkhead lights with downward reflectors in place of high level lighting for parking and footpaths. Minimise effect of flares on the Karoo sky. Consider available technology to minimise flare

SGD Stage	Visual Guidelines
	effects. Consider timing flaring to occur only in the day to avoid visual effect at night. Limit signage to only that which is absolutely necessary. Fix signage to walls or buildings to minimise visual clutter. Prohibit billboards or self-illuminated signs because of their visual intrusion. Restrict the size of signs to a maximum of 4 m^2. **Maintenance**: Maintain the wellpad and related infrastructure in a tidy, clean condition. Control litter and other waste to avoid visual impacts on the surroundings. Avoid visual scarring of the landscape caused by runoff and erosion.
Rehabilitation and post closure stage	Consider implementing interim or progressive rehabilitation as development activities cease or relocate. Remove all above-ground structures, stockpiles and storage dams at the wellpads. Grade the affected area to pre-development topographic conditions, unless the area is required for new specific uses. Scarify compacted areas and re-spread topsoil stored at the time of the initial clearing and re-seed exposed areas. Use stored rocks to simulate rock outcrops of the area. Vegetation used for the restoration to match that of the surrounding veld, unless new uses are planned for the site.
Monitoring	Ensure that the visual guidelines listed above form part of the EMP, and are included in on-going monitoring during the following stages: **Pre-construction monitoring:** Create procedures for the review of project plans, including landscape and rehabilitation plans as part of the EMP process to ensure that mitigations have been included in the design. Appoint a suitably qualified landscape architect to prepare a phased landscape development plan for all stages of the project. Implement the landscape plans by means of the mandatory EMP. **Construction monitoring**: Create procedures for ensuring that the specified visual management actions are carried out on site as part of the EMP. Appoint an ECO to educate construction workers, monitor the implementation of mitigation measures and report to the EMP Team on a weekly basis. The EMP team to include a suitably qualified rehabilitation ecologist and landscape architect. **Operational monitoring:** Create procedures for the on-going control of aesthetic aspects of the project including signage, lighting, fencing etc. to ensure that the management actions are being applied. The ECO to report on these aspects on a monthly basis. **De-commissioning monitoring:** Create procedures for the removal of structures and stockpiles at the end of the lifespan of each wellpad and related infrastructure, including re-use of the site and recycling of materials, as well as the rehabilitation or redevelopment of the site to a visually acceptable form. Monitoring of the rehabilitation by the Environmental Management Team is required, with signing off by the delegated authority.

14.6 Gaps in knowledge

An indication of limitations for the visual study, including the lack of a scenic resource baseline in the South African context, is given in Section 14.2.3. Further information on these aspects would assist in the visual-aesthetic study, including the following:

Standardised scenic resource baseline information:
A scenic resource inventory of South Africa, ideally with each resource graded according to national, regional and local significance, similar to that for heritage resources, would allow for better accuracy and consistency in visual sensitivity mapping and VIAs.

Cultural landscapes baseline information:
A clearer definition of what ‘cultural landscape’ includes in the South African context, with the help of heritage specialists, as well as significance grading and more detailed mapping, would help to refine overall visual sensitivity rating and mapping.

Game farms and guest farms baseline data:
A more detailed and complete inventory of all private reserves, game farms, guest farms, resorts and tourist accommodation would provide a better indication of visually sensitive receptors in the study area for mapping purposes.

Potential cumulative visual impacts:
Possible cumulative visual impacts can only be determined once a particular SGD scenario evolves and the location and density of the drilling wellpads, gas processing plants and power stations becomes more clearly defined, particularly in relation to other major activities, such as wind and solar energy developments, and possible uranium mining.

There is therefore a clear need for more detailed fine-scale mapping relating to the above at the local or district scale in order to inform visual assessments for SGD going forward.

Additional information would be needed on gas processing plants, power stations, substations and powerlines at the project stage so that viewsheds and setbacks can be determined.

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14.8 Digital Addenda 14A: A3 Visual Maps of Study Area

SEPARATE DIGITAL DOCUMENT

Map 1: Distribution of Dolerites

Map 2: Steep Slopes

Map 3: Physiography

Map 4: Landscape Scenic Units

Map 5: Scenic Resources

Map 6: Sensitive Receptors

Map 7: Scenic Resources with Buffers

Map 8: Sensitive Receptors with Buffers

Map 9: Visual Sensitivity Synthesis

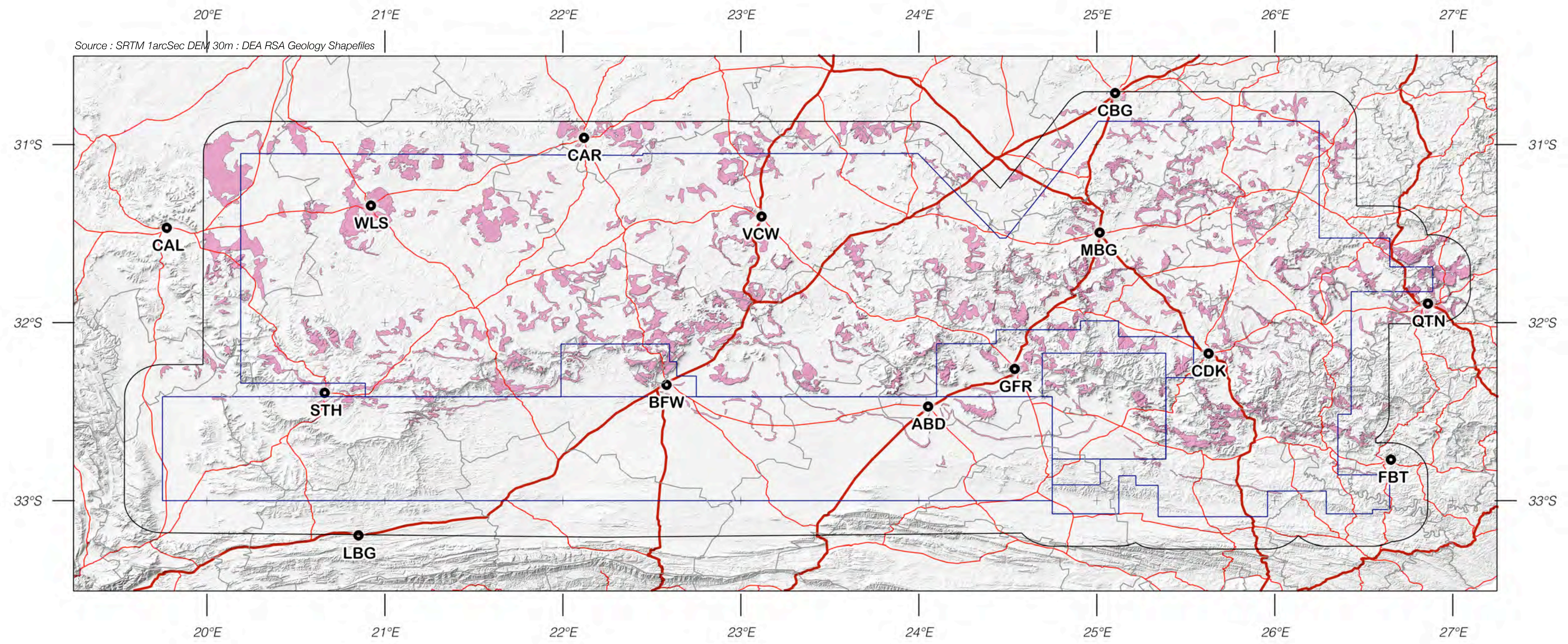
Map 10: Visual Sensitivity and Prospectivity Overlay

This addendum is available digitally at http://seasgd.csir.co.za/

SEA for Shale Gas Exploration Development and Production

Chapter 14: Impacts on Visual Aesthetics

ADDENDUM



FEATURES :

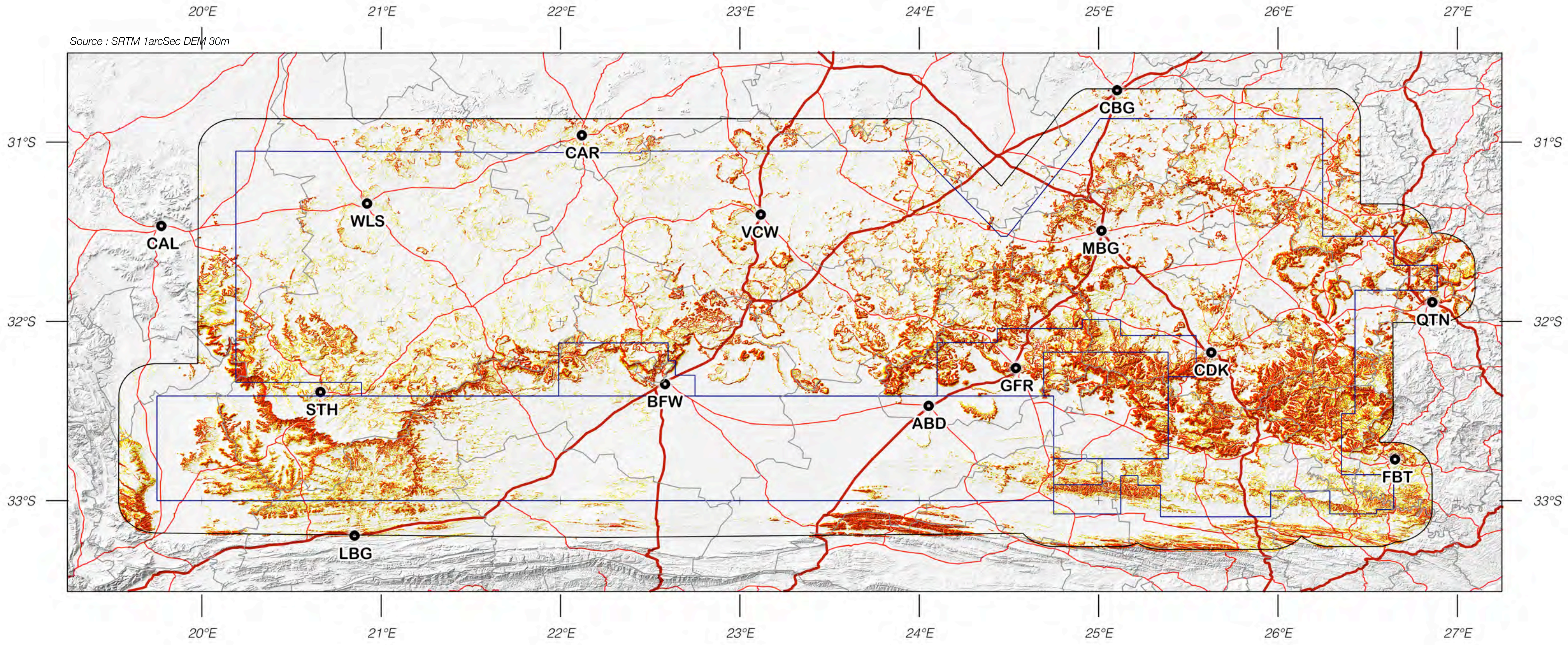
Dolerite

MAJOR TOWNS :

ABD	Aberdeen
BFW	Beaufort West
CAL	Calvinia
CAR	Carnarvon
CBG	Colesberg
CDK	Cradock
FBT	Fort Beaufort
GFR	Graaff-Reinet
LBG	Laingsburg
MBG	Middelburg
QTN	Queenstown
STH	Sutherland
VCW	Victoria West
WLS	Williston

0 50km 100km

Map 1 • Distribution of Dolerites



STEEP SLOPES :

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MAJOR TOWNS :

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BFW	Beaufort West
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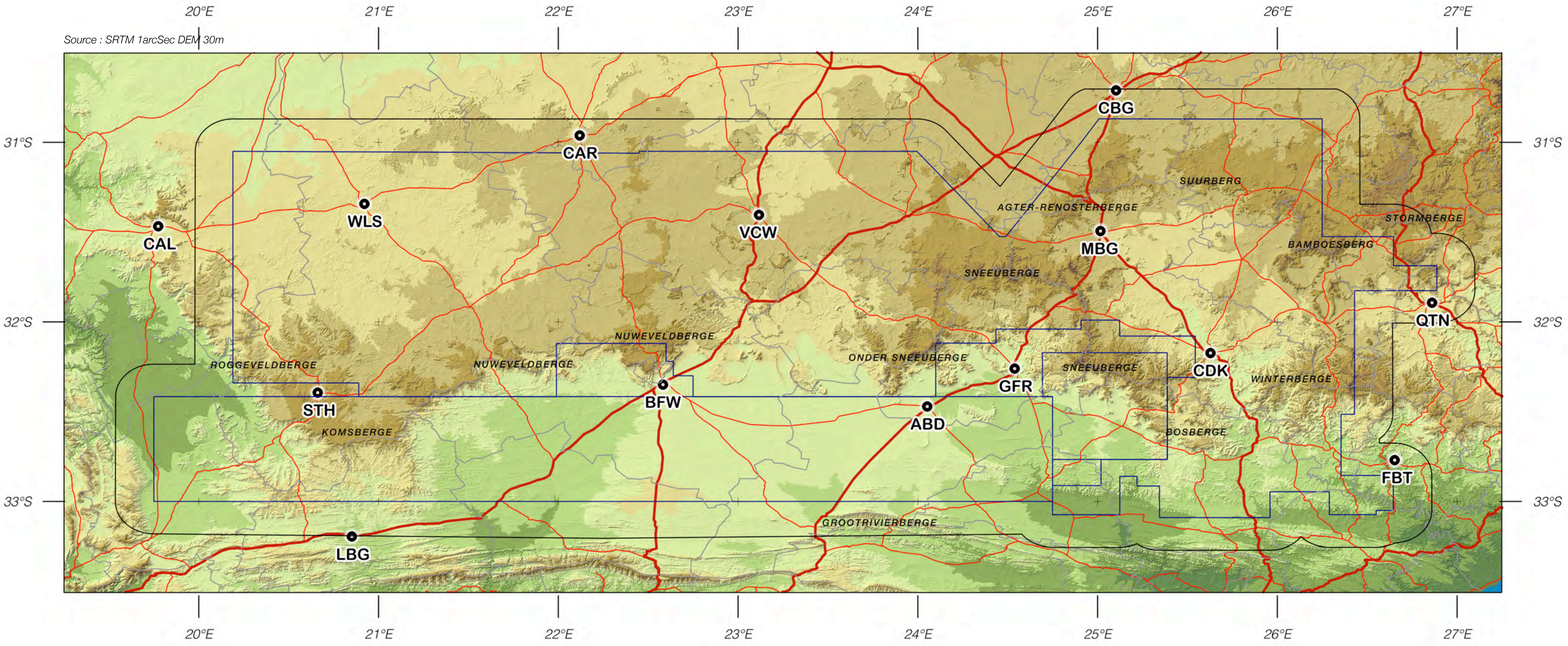
Map 2 • Steep Slopes



PHYSIOGRAPHY :

- 0 - 250m
- 500m
- 750m
- 1000m
- 1250m
- 1500m
- 1750m
- 2000m

MAJOR TOWNS :

ABD	Aberdeen
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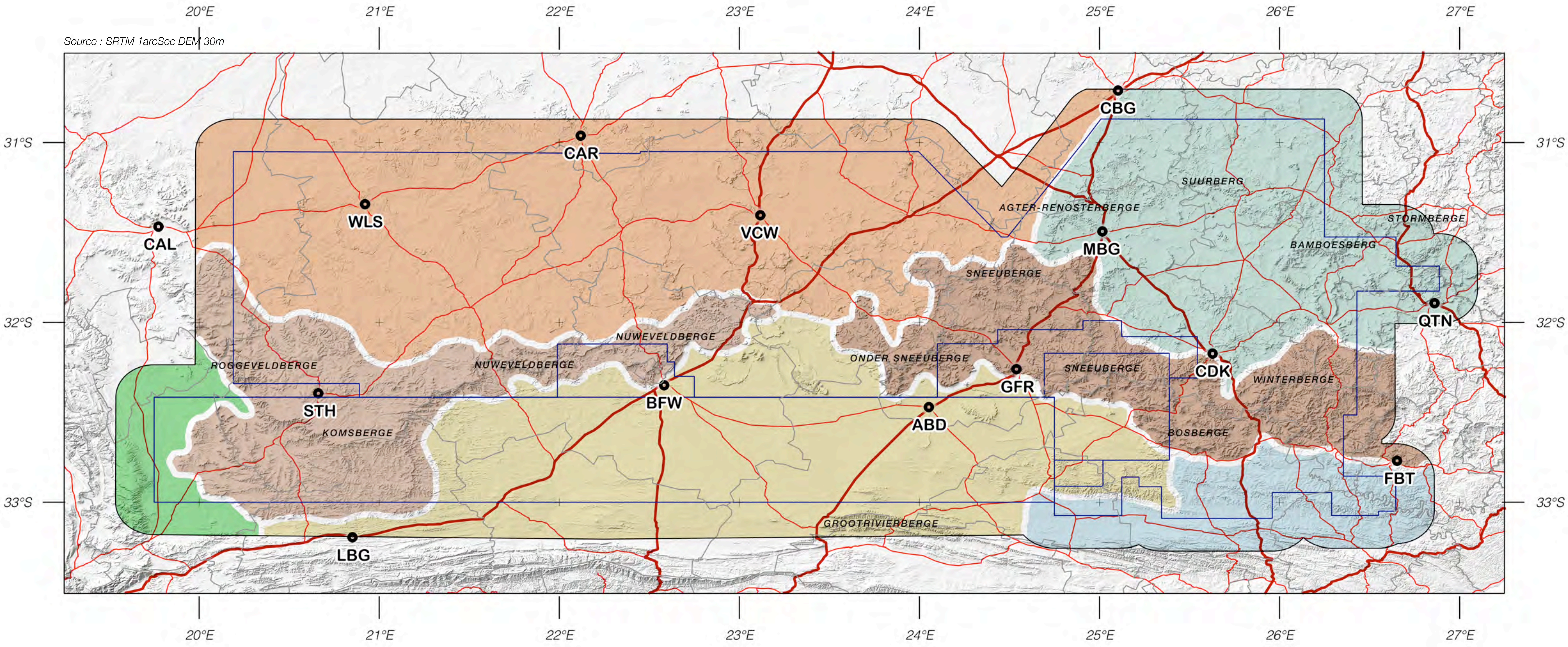
Map 3 • Physiography



SCENIC UNITS :

1. Ceres-Tankwa Karoo
2. Roggeveld-Nuweveld Mountains
3. Koup-Vlaktes-Camdeboo Plains
4. Great Fish River Valley
5. Sneeuberg-Winterberg Mountains
6. Great Karoo Plateau
7. Eastern Plateau

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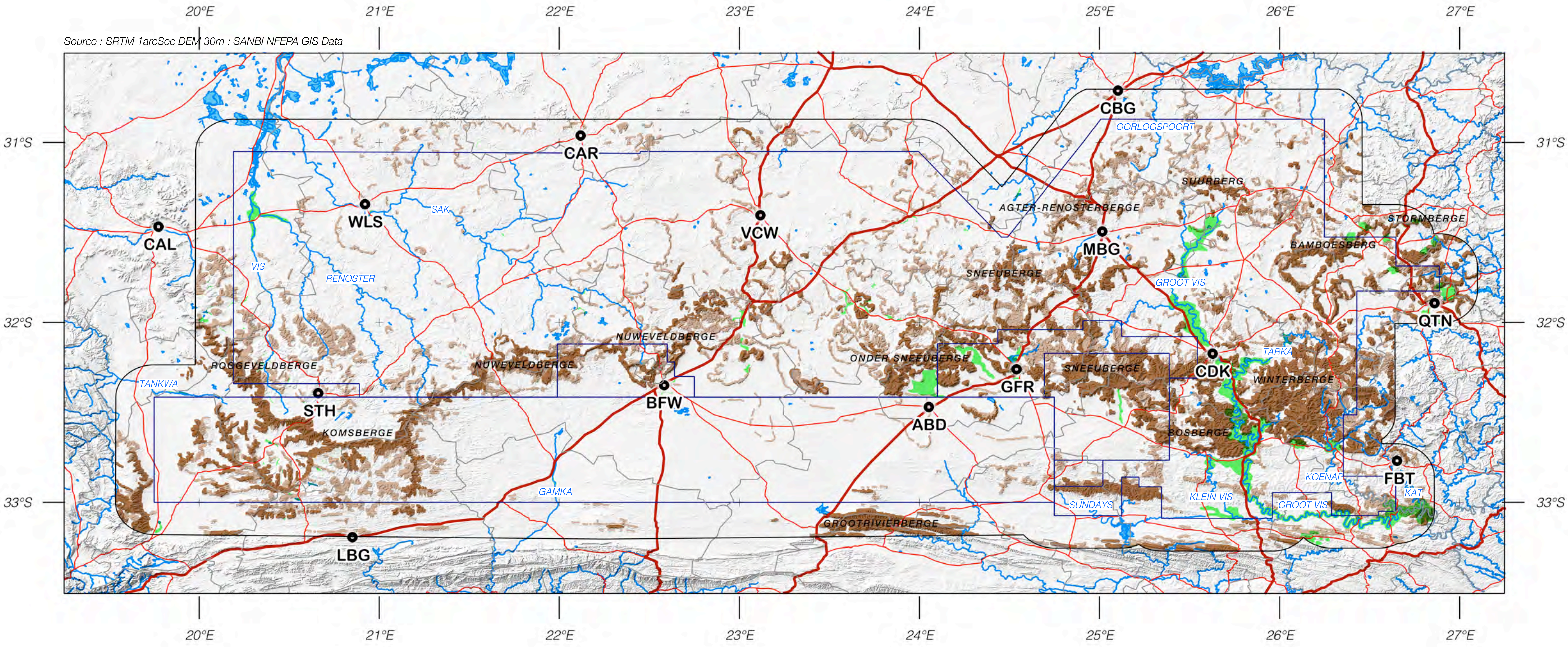
Map 4 • Landscape Scenic Units



SCENIC RESOURCES :

- Major Topographic Features
- Secondary Topographic Features
- NFEPA Major Rivers
- NFEPA Major Wetlands
- Cultural Landscapes

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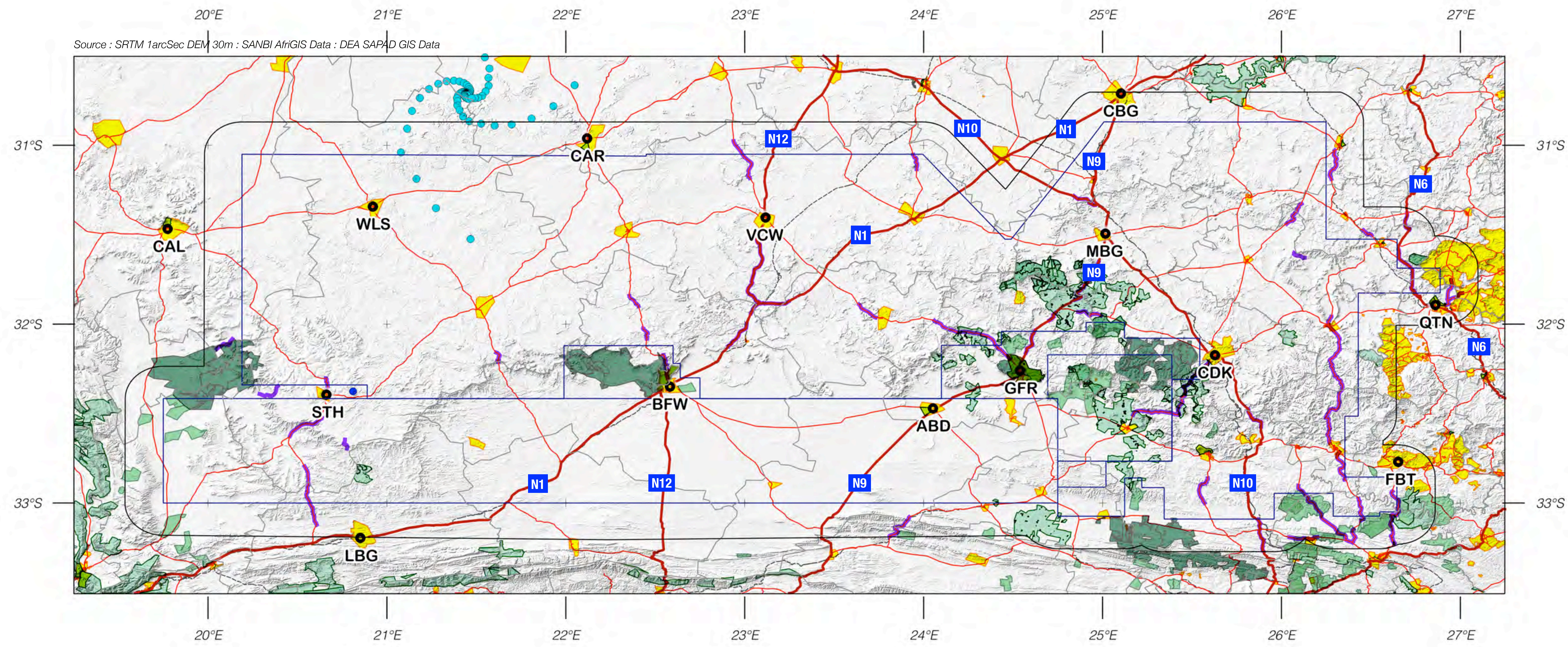
Map 5 • Scenic Resources



SENSITIVE RECEPTORS :

- SAPAD National Parks
- SAPAD Nature Reserves
- Private Reserves / Game Farms
- AfriGIS Towns / Settlements
- National Roads
- Provincial Roads
- Scenic Routes / Passes
- Passenger Railways
- SA Large Telescope
- Square Kilometer Array

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WLS	Williston

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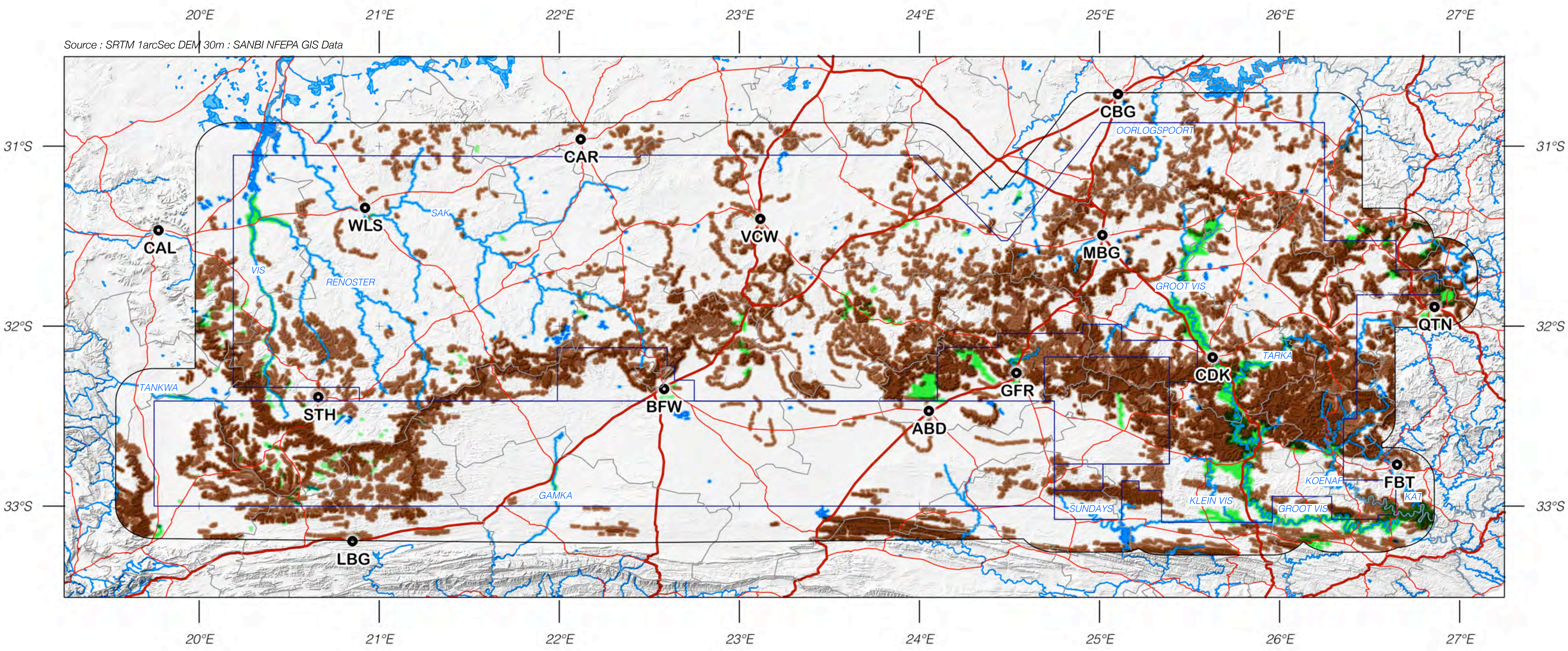
Map 6 • Sensitive Receptors



SCENIC RESOURCES : (with Buffers)

- Major Topographic Features
- Secondary Topographic Features
- NFEPA Major Rivers
- NFEPA Major Wetlands
- Cultural Landscapes

MAJOR TOWNS :

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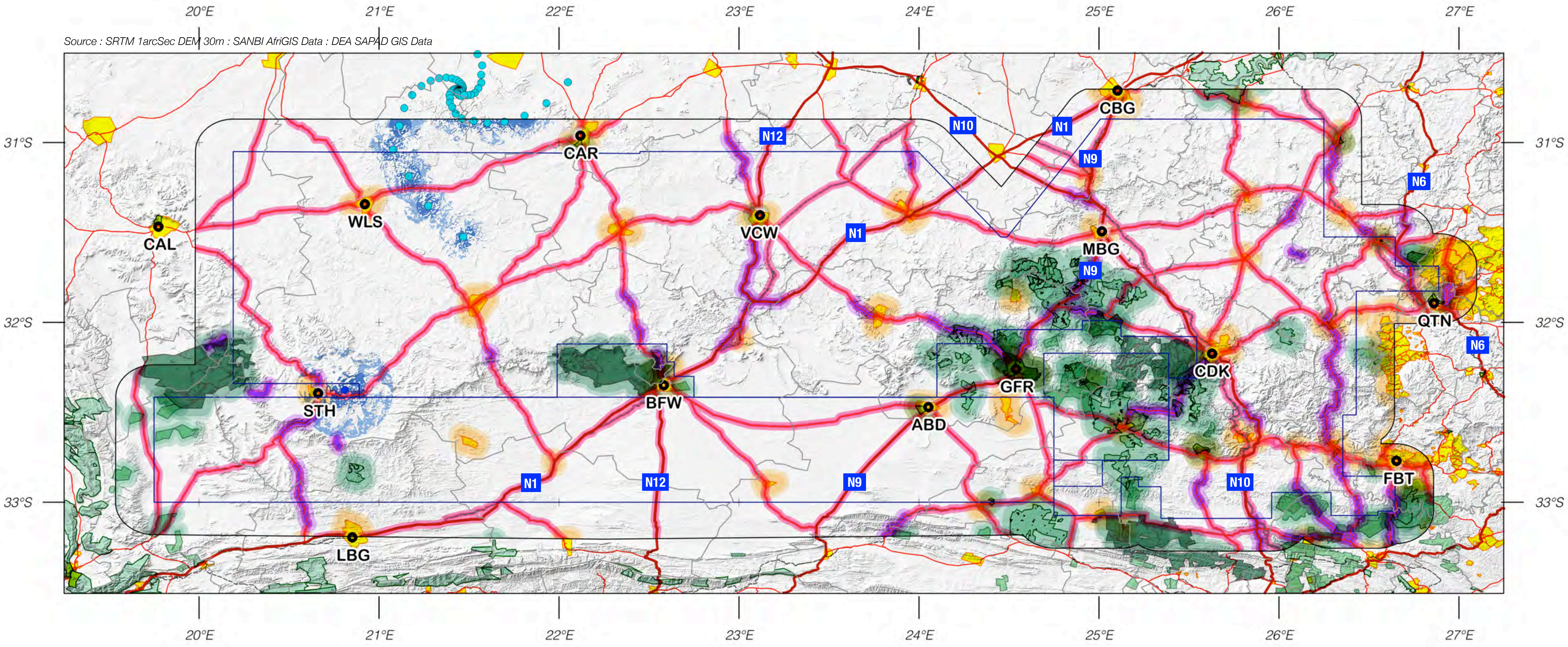
Map 7 • Scenic Resources with Buffers



SENSITIVE RECEPTORS : (with Buffers)

- SAPAD National Parks
- SAPAD Nature Reserves
- Private Reserves / Game Farms
- AfriGIS Towns / Settlements
- National Roads
- Provincial Roads
- Scenic Routes / Passes
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- SA Large Telescope
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WLS	Williston

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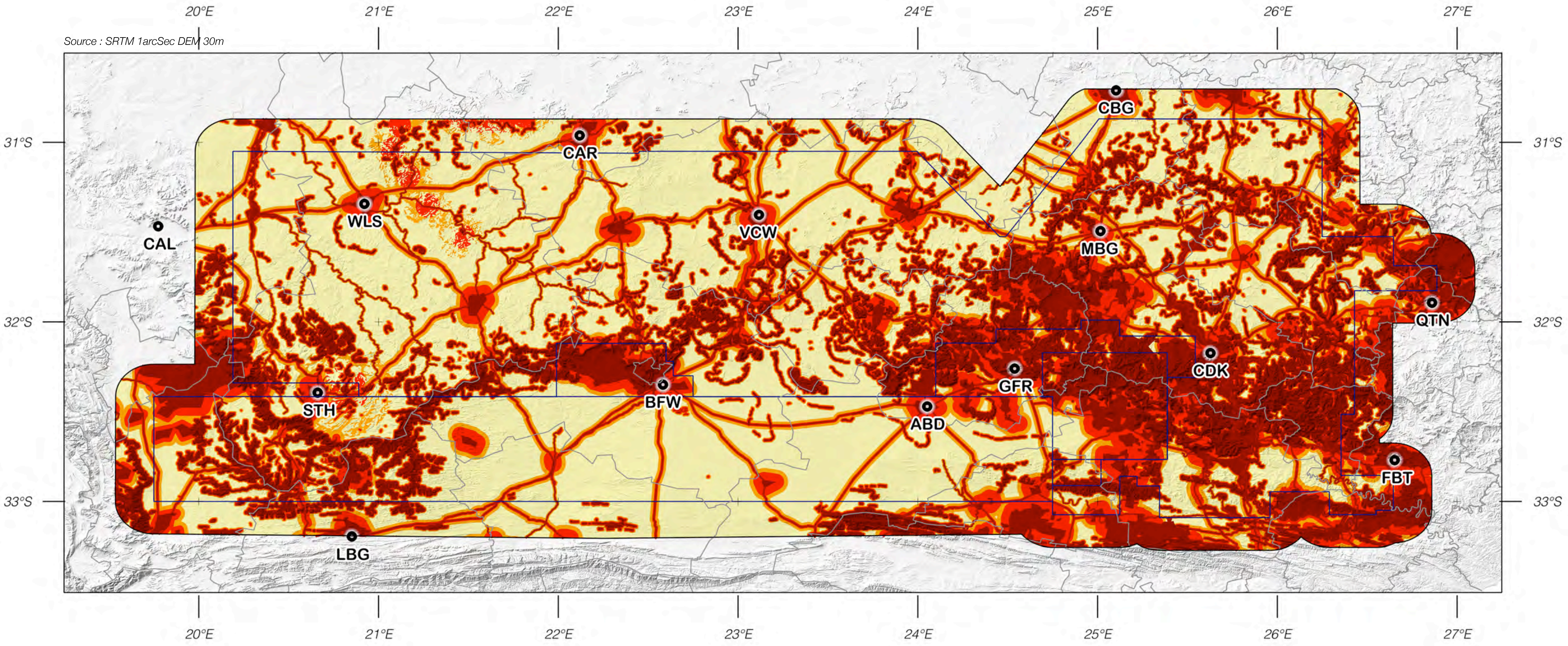
Map 8 • Sensitive Receptors with Buffers



VISUAL SENSITIVITY SYNTHESIS :

- VERY HIGH Visual Sensitivity Zone
- HIGH Visual Sensitivity Zone
- MODERATE Visual Sensitivity Zone
- LOW Visual Sensitivity Zone

MAJOR TOWNS :

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BFW	Beaufort West
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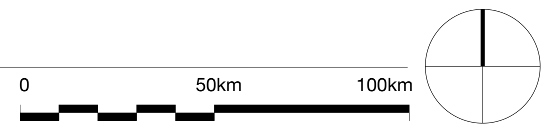
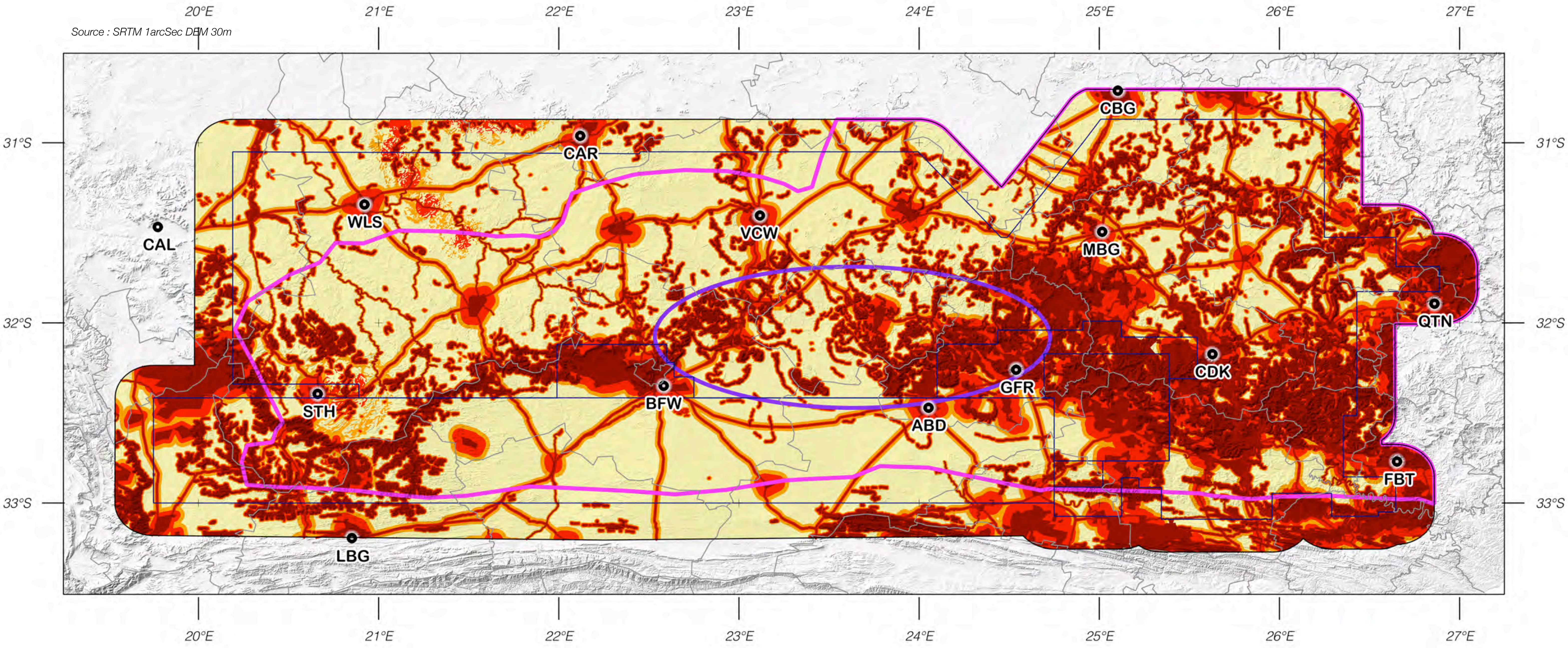


Map 9 • Visual Sensitivity Synthesis



VISUAL SENSITIVITY SYNTHESIS :

- VERY HIGH Visual Sensitivity Zone
- HIGH Visual Sensitivity Zone
- MODERATE Visual Sensitivity Zone
- LOW Visual Sensitivity Zone

PROSPECTIVITY ZONES :

- Prospectivity - HIGH Probability
- Prospectivity - MEDIUM Probability

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QTN	Queenstown
STH	Sutherland
VCW	Victoria West
WLS	Williston

0 50km 100km

Map 10 • Visual Sensitivity and Prospectivity Overlay

CHAPTER 15

Impacts on Heritage

CHAPTER 15: IMPACTS ON HERITAGE

Integrating Author:	Jayson Orton[1]
Contributing Authors:	John Almond[2], Nicholas Clarke[3], Roger Fisher[4]
Corresponding Authors:	Simon Hall[5], Patricia Kramer[6], Antonia Malan[5], Judy Maguire[7], Liana Jansen[8]

[1] Archaeological Services & Heritage Assessment (ASHA) Consulting (Pty) Ltd, Muizenberg, 7945

[2] Natura Viva CC, Cape Town, 8010

[3] Delft University of Technology, NL-2600 BL Delft, The Netherlands

[4] University of Pretoria, Hatfield, 0028

[5] University of Cape Town, Rondebosch, 7701

[6] University of Washington, Seattle, Washington 98195-3100

[7] Independent Consultant, Prince Albert, 6930

[8] Cape Winelands Professional Practices in Association (Pty) Ltd, Montagu, 6720

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Executive Summary

The study area contains a rich layering of heritage resources stretching over some 4.6 billion years. Geological heritage sites and meteorites are the oldest aspects of heritage considered here, while palaeontological resources cover more than 300 million years of prehistory. The archaeological record spans some 2 million years and covers the Early, Middle and Late Stone Ages, as well as the Iron Age and historical period. The latter is responsible for the bulk of the built heritage that occurs, including the well-known Karoo vernacular architecture. Ensembles of individual cultural heritage resources relate to one another in various ways to produce urban and rural cultural landscapes throughout the study area. Living heritage binds the physical resources together and provides much of the character that is so highly valued by a wide community of South Africans.

Heritage resources in the study area are part of the National Estate and thus belong to the people of South Africa. While most are of relatively low heritage significance, there are numerous sites of high significance scattered across the region, including many that are formally declared. Archaeological and palaeontological resources are found throughout the study area but, because of weathering and erosion of the land surface, the context, preservation, and academic value of much of this material is limited, especially in the case of archaeology. However, important sites will occur in most areas. Built heritage resources add much cultural value to the study area and comprise the vast majority of declared sites. Cultural landscapes are both rural and urban, and specific areas generally have high significance because of the spatial relationship between multiple individual resources. The entire study area, however, has seen some degree of human modification and thus can be considered part of the regional cultural landscape. Living heritage is a key element of the National Estate in the Karoo because the last vestiges of a number of communities are still represented there.

Shale gas development (SGD) will impact on heritage resources no matter where development occurs in the study area, but the risk would vary markedly depending on the specific locations of wellpads, access roads and related infrastructure, and the amount of induced seismic activity that occurs. Heritage resources are distributed in variable densities throughout the study area but, because of generally low survey coverage, the actual distribution of resources is poorly known. Small pockets of high coverage indicate that important resources of all types can occur anywhere in the landscape but that river valleys, rocky ridges and the undulating uplands tend to be more sensitive than the open plains for some categories of heritage, largely because of access to water. Seismic activity could affect heritage resources to varying degrees depending on their fragility, but built heritage is most at risk.

Due to the great variety of physical manifestations of the various types of heritage, the degree of risk relating to each is variable. Some aspects result in a low risk before mitigation, while others will result in high risk. Only one aspect produces a very high risk before mitigation, but this reduces to high with mitigation. The majority of post-mitigation risks are assessed to be of a low or very low level. Greater risks are generally an indication of those aspects of heritage that would experience residual impacts after mitigation.

When viewed from a heritage perspective, the limited SGD envisaged under Scenario 2 (Small Gas) and Scenario 3 (Big Gas) is feasible because the impacts would be confined to particular areas. However, the potential for extensive impacts from Scenario 1 (Exploration Only) is of concern because of the large area that might be impacted. Although it will not be possible to choose the exploration and/or development areas based on heritage resources, micro-siting of the infrastructure and the implementation of management and mitigation measures during all phases will help reduce the significance of the impacts. The most difficult aspects with which to deal in terms of mitigation are aspects relating to the cultural landscape and, along with minimising the amount of landscape scarring that occurs, effective closure phase rehabilitation will be key to the feasibility of the development.

CHAPTER 15: IMPACTS ON HERITAGE

15.1 Introduction and scope

15.1.1 What is meant by this topic?

15.1.1.1 <u>The Karoo and shale gas development</u>

The study area covers about 14% of South Africa, the greater portion of which falls within the Karoo, but a small portion in the southeast extends into the somewhat better watered Border Kei region. While the Karoo might mean different things for different people, the overriding sense is of a vast dryland. The very name ‘Karoo’ derives from a Khoekhoe word meaning ‘hard’ or ‘dry’ (Raper, n.d.). The unique sense of place and natural beauty of the Karoo derive from the expansiveness, remoteness and endless horizons that have inspired the creative genius in many of South Africa’s cultural icons and more recently has become a centre for astronomical research. The region has cultural significance to the local communities who have lived and farmed there since at least the early 1700s. Its agricultural sector provides employment and it has considerable and growing value as an income-generating tourism resource (Atkinson, 2016). It contains one of the longest and most complete fossil records in the world, the consequence of 120 million years of continuous sedimentation into the Karoo basin (something that occurred nowhere else in the world). It also preserves a rich layering of early evidence of its precolonial inhabitants in the form of archaeological deposits, rock art and in the more recent historical past, various sites of confrontation, contestation and conflict. The history of the San, Khoekhoen, Trekboers, Basters and a section of the Xhosa nation is encapsulated in the rich layering of heritage resources, as is the more recent history of Dutch and British Colonialism and apartheid. Any loss of this will impoverish what is in effect a National Treasure – our largely intact, authentic and largely under-utilised Karoo heritage.

With such large areas and the great potential for ancillary development it is important that shale gas development (SGD) is properly managed in relation to heritage resources so as to ensure their preservation for future generations.

15.1.1.2 <u>What is our heritage?</u>

The broadest definition of heritage – itself a very broad topic – is simply ‘that which is inherited’. Heritage includes physical objects and places, as well as the intangible aspects of culture and tradition that are passed down from earlier generations. This might be natural or cultural yet relates to the deepest past and is still being created, even as you read.

Grading of heritage resources

Section 7(1) of the NHRA provides for heritage resources to be assigned Grades I, II or III, while Section 7(2) provides for sub-categories of the latter two. Where Grades are referred to in this Chapter they follow the conventions established and applied by Heritage Western Cape (2016a) as follows:

- I: Sites of national significance.
- II: Sites of provincial or regional significance (no sub-categories).
- IIIA: Sites of high local significance (excellent examples of their kind or rare).
- IIIB: As for IIIA but at a slightly lower level of significance.
- IIIC: Significance is primarily contextual.
- NCW (Not Conservation-Worthy): Sites with little or no heritage value.

The protection of South Africa's cultural heritage is governed by the National Heritage Resources Act (NHRA) (No. 25 of 1999, 1999), which stipulates in Section 3(1) that any place or object is to be considered part of the National Estate if it has cultural significance or any other special value for current or future generations. Section 2(vi) of the NHRA mandates that something has cultural significance if it has aesthetic, architectural, historical, scientific, social, spiritual, linguistic or technological value or significance. These, then, are the qualities that allow something to fall within the ambit of the NHRA and hence heritage. Section 3(2) provides an extensive list of the types of heritage resources that might be included in the National Estate, while potential motivations are listed in Section 3(3). These sections of the NHRA (see Digital Addendum 15A) essentially provide a working definition for cultural heritage in South Africa and it is from them that this Chapter takes its lead. We describe the heritage resources under five sections, excluding aspects covered in other Chapters of this scientific assessment. Some aspects occur throughout the study area, while others have limited distributions. What follows is a brief overview of the five categories under assessment.

15.1.1.3 Built heritage (Section 34, Section 37)

Notwithstanding the definition of 'structures' as provided in the NHRA (see Digital Addendum 15A), here we take a broad view, so refer to 'built heritage' as also covering ensembles such as towns and farms, thereby not limiting the scope of what is included. The setting of individual built heritage resources, including monuments and memorials, as well as that of ensembles is of great importance and therefore incorporated. Military structures, which, according to the NHRA are also archaeological, are covered here, but precolonial structures are covered under archaeology.

In the harsh, resource-scarce Karoo environment with its restricted range of materials, necessity often was the mother of invention when it came to constructing shelter, resulting in a unique regional vernacular building tradition that displays the creative and technical achievement required to fashion an existence there. This relied on both traditional and conventional artisanal skills since buildings were hand-crafted from sun-baked bricks, locally occurring timber and quarried or collected stone. The result was a variety of local styles that we refer to collectively as Karoo vernacular. This is an aesthetic valued by a wide community and, although its frequency diminishes towards the southeast, it is present throughout the study area. While 'Karoostyle', as described by Marincowitz (2006), typically incorporates flat roofs and parapets above a simple rectangular house (Figure 15.1), Karoo vernacular buildings tend to have evolved organically according to need or fashion and reflect much historical layering (Figure 15.2). Unique building typologies that occur in the study area are the corbelled houses (see text box) that developed as a direct response to the lack of available timber in the north-western part of the study area (Figure 15.3; Kramer, 2012) and the '*brakdak*' houses (Fagan, 2008) that employed locally available sticks, reeds and mud (traditionally mixed with chaff, animal manure, sedge or densely matted roots) in the creation of their flat roofs. Corbelled houses are poorly known because of their remote locations. Several are declared Provincial Heritage Sites (PHSs).

Vernacular architecture?

The word vernacular (Latin: *vernaculus*) means 'domestic' or 'indigenous'. Vernacular architecture responds to local needs and the environment, reflects local cultural traditions and relies on local materials, technology and skills. It evolves in an organic manner in keeping with its historical context.

Figure 15.1: 'Karoostyle' houses: an abandoned rural dwelling near Williston that is being lost to neglect and a well maintained example from Victoria West.

Figure 15.2: Well-maintained Karoo vernacular dwellings: a cottage in Carnarvon and a farmhouse north of Matjiesfontein.

Figure 15.3: A small early corbelled house (likely 1820s or 1830s) may have originally been a kafhok, while a larger example has a square dome with a kitchen and wagon house added to the sides. Both are near Loxton.

Corbelled buildings – a unique and vulnerable vernacular resource

Corbelled buildings are built of blocks of flat stone. Each course of roof stones is laid in gradually smaller circles in two layers to create a dome-shaped roof. The floor diameter and roof height are directly related to one another to prevent collapse of the structure. They occur within the north-western part of the study area. Although corbelled buildings are found elsewhere in the world, the Karoo buildings are unique in displaying features related to the requirements of early Trekboer small stock pastoralists, both European and Basters (offspring of European/slave/Khoekhoen unions). Every structure is unique, thereby showing the level of proficiency and technological development of the builders and even their origins and social status. Karoo corbelled buildings (erected between about 1813 and 1870) are one of the first signs of permanent Trekboer or settler occupation of this harsh environment. As a physical statement of occupation they emphasised that the indigenous people had lost their land. Corbelled buildings are important examples of 'creolisation' (input from multiple sources, both European and indigenous) which was typical of frontier areas and they, along with their surrounding *werfs* (farmyards), allow us to understand early pastoralism in the area (Kramer, 2012).

The study area and surrounds have seen settlement by various cultures and has a diverse built heritage. The main activities that encouraged colonial settlement were pastoralism, religion, military and administrative needs, transport and infrastructural development and health care. Of late, astronomy (the South African Large Telescope [SALT] and the Square Kilometre Array [SKA]) has introduced a new driver for development. Colonial occupation of the Karoo was initially by Trekboers who lived from their wagons and left no built traces. They relied on their skills of animal husbandry to be successful. Gradually, as local knowledge grew, they settled in simple vernacular homes and, with the need for some agriculture, water-related technology such as dams, water pits (*gorra*) and wind pumps became important (see also Section 15.1.1.4 below). Some of the earliest towns were established as mission stations (e.g. Carnarvon, Williston, Colesburg), while others, particularly on the frontier, were administrative centres (e.g. Graaff-Reinet, Beaufort West, Victoria West). Still others were established around Dutch Reformed Churches in response to local need (e.g. Sutherland, Loxton, Fraserburg).

In the east one finds Xhosa settlements characterised by vernacular architecture in the form of rondavels. This part of the study area is also home to mission settlements, such as Fort Beaufort (founded in the 1830s as the Kat River Settlement to provide a refuge and livelihood for freed slaves), military infrastructure, such as Fort Brown (constructed by British forces during their successive wars against the Xhosa) and the Martello Tower in Fort Beaufort (PHS; Figure 15.4; one of only two free standing dressed stone masonry structures typical of the type in use by the British between 1848 and 1869, a third was demolished), and important educational heritage sites such as Healdtown (one of several places with strong links to the origins of the Liberation movement in South Africa).

Figure 15.4: Martello Tower, Fort Beaufort.

During the late 19th century transport infrastructure, especially railways began to be built across the hinterland of the country. This was initially to service the Kimberley diamond fields, but also to connect the developing interior with coastal ports (Burman, 1984). Although now largely disused, a number of late 19th and early 20th century railway stations still survive. The road network also became more strongly established with time. The bridges, culverts, retaining walls, stations, mountain passes and provisioning infrastructure associated with transport routes all became part of the region's built heritage. The rail network later became crucial to the British efforts during the South African War, with blockhouses being built in a variety of materials to protect towns and key rail infrastructure, especially bridges and junctions. Many survive today as the most tangible testament to the war; some are PHSs. The health benefits of the clean, dry Karoo air became well-known, especially during the 19th century British occupation, with people relocating there from their cool, damp homelands in order to recover from a variety of ailments.

Built heritage resources occur in low densities throughout the study area and are emphatic features of the cultural landscape (see Section 15.1.1.7 below). Individual farmsteads and their associated agrarian landscape settings present ensembles of vernacular built heritage that include not only houses, barns and labourers' cottages but also features like packed stone walls (including the very long ostrich walls found in the western part of the study area), *kraals* (livestock enclosures), mills, *kafhokke* (chaff and grain stores), *trapvloere* (threshing floors), dams, *gorras* (pits), irrigation channels, wind pumps, livestock pens, crushes and dips (Figure 15.5). Historical werfs often also include refuse middens which are archaeological sites.

Figure 15.5: A corbelled kafhok and trapvloer, now fenced and in use as an animal pen.

The towns of the study area are unique, with both their constituent parts and their settings contributing cultural value. The historic core of Victoria West, for example, is made particularly special by its longitudinal orientation in a narrow valley setting. Because of the constraints of the valley, modern urban development has occurred away from the core resulting in well-preserved Karoo vernacular streetscapes that include some 86 heritage register buildings (Figure 15.6). The towns contain localised concentrations of built heritage with most retaining a historic core often centred on the church, the spire forming a beacon in the landscape. These central areas usually comprise many conservation-worthy structures that, as a direct result of not being commercialised, retain their historical character. Graaff-Reinet has an especially high density of heritage structures, often restored, with many being PHSs. Its historic core preserves many buildings of exceptional cultural value. Beaufort West also retains many significant buildings but, largely through commercialisation of the town centre, the historic urban landscape has become somewhat degraded. A lack of commercialisation can also lead to urban degradation because insufficient finances are available for building maintenance. Inequitable spatial planning policies from the apartheid era have also left a lasting legacy in these towns.

Figure 15.6: The well-preserved streetscape of Church Street, Victoria West.

The Karoo townscape

Most Karoo towns are typified by simple grid-iron street layouts with a centrally located steepled church, invariably Dutch Reformed, that serves a broad rural community. Many streets are fronted by single or sometimes double storeyed Karoo vernacular houses with whitewashed parapets and deep-set verandas with single or double *stoep-kamers* (rooms created by enclosing the end of a veranda). These are interspersed with corner trading stores and petrol garages, the latter sometimes retaining the Art Deco style. Due to apartheid planning policies these 'formal' resourced towns are twinned by former townships and informal settlements served by a mission church and school, and often removed by a linear barrier such as a major road or railway line. Much still needs to be done to redress these inherited inequities.

As a landscape of conflict (see Section 15.1.1.4 below), the study area also contains many memorials to wars and those who lost their lives through conflict. These include the century-long series of Frontier (or Xhosa) Wars in Eastern Cape, the Second South African ('Anglo-Boer') War and the two World Wars. There are also sites and memorials dedicated to the memory of the internment camps of the Second South African War. Memorials to other events occur in various places as well. Examples include the Slagtersnek Monument, near Cookhouse, which commemorates the uprising that is considered one of the factors that triggered the Great Trek (Von der Heyde, 2013), and the Burgersdorp Taal Monument with its peculiar history (PHS; Figure 15.7). Originally erected in 1893 in honour of the Dutch language, the monument was damaged and removed during the South African War by the British who supplied a replacement in 1907. It was moved to its current location in 1933 and declared a National Monument in 1937. The damaged original was only relocated (buried in the Department of Public Works yard in King William's Town) and installed alongside the replica in 1939 (Oberholster, 1972).

Figure 15.7: The original (centre) and replica (left) Burgersdorp Taal Monuments.

Karoo architecture has attracted considerable interest with a number of local (Bakker, 2006; Herholdt, 1990; Matthews, 1958; University of the Free State, 2013) or thematic (Fagan, 2008; Kramer, 2012) architectural studies having been produced. Many compendiums of heritage architecture list structures in the study area (e.g. Fransen, 2004), while some towns have published their own built heritage guides for tourism purposes. Among other things, buildings and towns are also culturally significant for their connections to religion, historical characters, slavery, indentured and unfree labour (Malherbe, 1991), scientific research (e.g. Wellwood Fossil Museum) and the liberation struggle (e.g. the serial nomination of the internationally significant ‘Human Rights, Liberation Struggle and Reconciliation: Nelson Mandela Legacy Sites’), which is currently included in South Africa’s United Nations Educational, Scientific and Educational Organisation (UNESCO) World Heritage Tentative list (UNESCO, 2016a), and includes Healdtown, located in the study area and the University of Fort Hare and Lovedale, just outside the study area. These are sites where Nelson Mandela and other prominent Liberation leaders were educated; they have intangible value representing “the fight for a multi-racial democracy such as freedom from tyranny, racial harmony, reconciliation and restorative justice from a notorious regime” (UNESCO, 2016a). The University of Fort Hare is also included in the tentatively listed ‘Liberation Heritage Route’ (UNESCO, 2016b). Many built heritage resources are declared PHSs (Bluff and Orton, 2016) and countless others are worthy of nomination or receiving Grade II or IIIA status.

15.1.1.4 Archaeology (Section 35) and graves (Section 36)

Archaeological residues in the study area are common and generally highly visible on the eroding landscape. These residues include material from the Early (ESA), Middle (MSA) and Late (LSA) Stone Ages and from the historical period (Figure 15.8). Iron Age residues may also occur in the southeast. As a key factor for occupation of the dry interior of South Africa, permanent and temporary water sources play a key role in understanding settlement, especially during recent millennia when the climate was more similar to that prevailing today. Overprinting would have occurred around water sources with more recent occupations obscuring evidence of earlier settlement.

Figure 15.8: Examples of the kinds of archaeological artefacts that might be found within the study area. The upper two rows are ESA and MSA stone artefacts respectively, while the following row has LSA stone artefacts, beads and pottery. At the bottom are historical glass and ceramics.

The earliest archaeological material is represented by Pleistocene stone artefacts that are variably distributed across the landscape. Because of the variations in climate and erosion since their deposition, these artefacts are not always strongly tied to present water sources. Seldom are they unusual or dense enough to engender significance and their spatial distribution is largely a product of natural forces. Because of this, the vast majority of this material is considered to be background scatter, but in the case of very extensive, denser scatters the material can be thought of as forming a precolonial cultural landscape (Orton, in press). While most artefacts are adiagnostic, the presence of certain types and the degree of surface weathering present can indicate the general age of the material. Hand-axes, for example, are a particularly obvious marker of the ESA. On rare occasions open scatters of older material with high research value are encountered, like an ESA site along the escarpment south of Sutherland (Hart et al., 2010) and those along the Orange River just outside the north-eastern part of the study area (Sampson, 1972). Excavations at the Cradock Springs yielded ESA material including hand-axes and cleavers, while the upper levels contained MSA artefacts (M. Opperman, pers. comm., 2016). ESA material is also sometimes encountered on floodplains and abandoned river terraces. Most artefacts found on the Karoo landscape date to the MSA. Such artefacts have also been found buried in open contexts along river valleys near Noupoort (Bousman, 1991) and along the Seacow River (Sampson, 1968), while rock shelter excavations in the eastern (Deacon, 1976) and north-eastern (Wallsmith, 1990) parts of the study area have also yielded MSA material.

Glossary of archaeological terms

Adiagnostic artefact: an artefact with no features that allow its age or function to be discerned.

Background scatter: a widespread, low density scatter of artefacts whose distribution is governed more by natural forces than by human agency.

Early Stone Age (ESA): an archaeological period between about 2 million and 200 000 years ago.

Ex situ: no longer in primary context, could be in secondary or tertiary context.

Hand-axe: a distinctive bifacial stone tool produced during the ESA.

Hominin: any one of the various species of humans and human ancestors.

In situ: in primary/original context.

Late Stone Age (LSA): an archaeological period encompassing the last 20 000 years.

Middle Stone Age (MSA): an archaeological period between 200 000 and 20 000 years ago.

Patina: a thin weathering rind that forms over rock (among other materials) as a result of chemical weathering.

Note: see also the definitions from the NHRA included in Appendix A. For geological time periods see Section 15.1.1.5.

The LSA is of greater consequence to this assessment because many significant surface sites are known to occur throughout the study area, although again in strongly variable densities. The majority of LSA remains date to the Holocene, although the period from 8- 4 000 years ago is strongly under-represented in the radiocarbon record of the Karoo, presumably due to the warmer and drier climate of the early Holocene (Deacon, 1974; Meadows and Watkeys, 1999; Scott, 1993). Karoo populations likely increased during the late Holocene, particularly with the introduction of domestic livestock (sheep, goats and cattle) and pottery to the regional economy some 2000 years ago (Sadr, 2003; Sampson, 2010). In contrast to older sites, and largely because they have been subjected to far less erosion since their deposition, many LSA sites are in better context, sometimes preserving organic materials that yield far more information to the researcher than stone tools alone. These sites are largely tied to water sources, be they pans, stream beds or springs. Surface scatters preserving only stone artefacts are also found and can provide good research data (e.g. Brooker, 1977; Sampson, 1972). *In situ* occupation sites potentially containing subsurface archaeological deposits are very scarce in open contexts and of far greater value. Hart et al. (2010) found two such sites in protected valleys along the escarpment southeast of Sutherland and noted their vulnerability to disturbance due to their proximity to a road. In addition to flaked stone tools, such deposits may include grinding stones, pottery and organic remains like hearths, animal bones and ostrich eggshell fragments, beads and flasks. Piled stone structures such as kraals and windbreaks occur in various areas but are best known from the intensively studied and archaeologically rich Seacow River valley between Richmond and Middelburg where many structures likely attributable to late Holocene livestock-keepers of the last 2000 years have been documented (Figure 15.9; Hart, 1989; Sampson, 1985, 2010; Sampson, et al., 2015). Others have been identified near Sutherland (Hart, 2005; Hart et al., 2010; Orton and Halkett, 2011), some only from aerial photographs (Regensberg, 2016). Hart (1989) compiled a typology of their various forms and differentiated them from their more formally constructed historical counterparts. Rock shelters like Blydefontein (Figure 15.10) generally contain the debris of repeated occupations that demonstrate change in the archaeological record through time. Although rare in the study area, a number have been excavated in the north-eastern (e.g. Bousman, 2005; Hart, 1989; Plug, 1993; Sampson, 1967a, 1967b; Sampson et al., 1989), eastern (Deacon, 1976; Hewitt, 1931) and south-eastern (Hall, 1990) parts of the study area, while one small shelter near Sutherland has also been excavated (Evans et al., 1985). Many more likely exist, but research in the mountains of the Karoo and Border Kei areas has been relatively meagre. Research shows that LSA people were

Dolerite and archaeology

The presence of dolerite in the Karoo lends a particular character to the local archaeology for two reasons. Firstly, the closer one is to the area of dolerite outcrops the more likely it is that hornfels will dominate the stone artefact assemblages. This is a rock produced through thermal metamorphism of country rocks (usually shales) when molten dolerite intrudes from below. The second factor is that dolerite is the preferred rock type for engravings. This is because of its surface patina which, when removed reveals a light orange-brown colour (see Figure 15.11). The relative age of both artefacts and engravings can be discerned by the degree to which the patina has reformed.

adaptable and found ways to survive in the relatively dry Karoo, with much of their knowledge having been passed on to the communities of today.

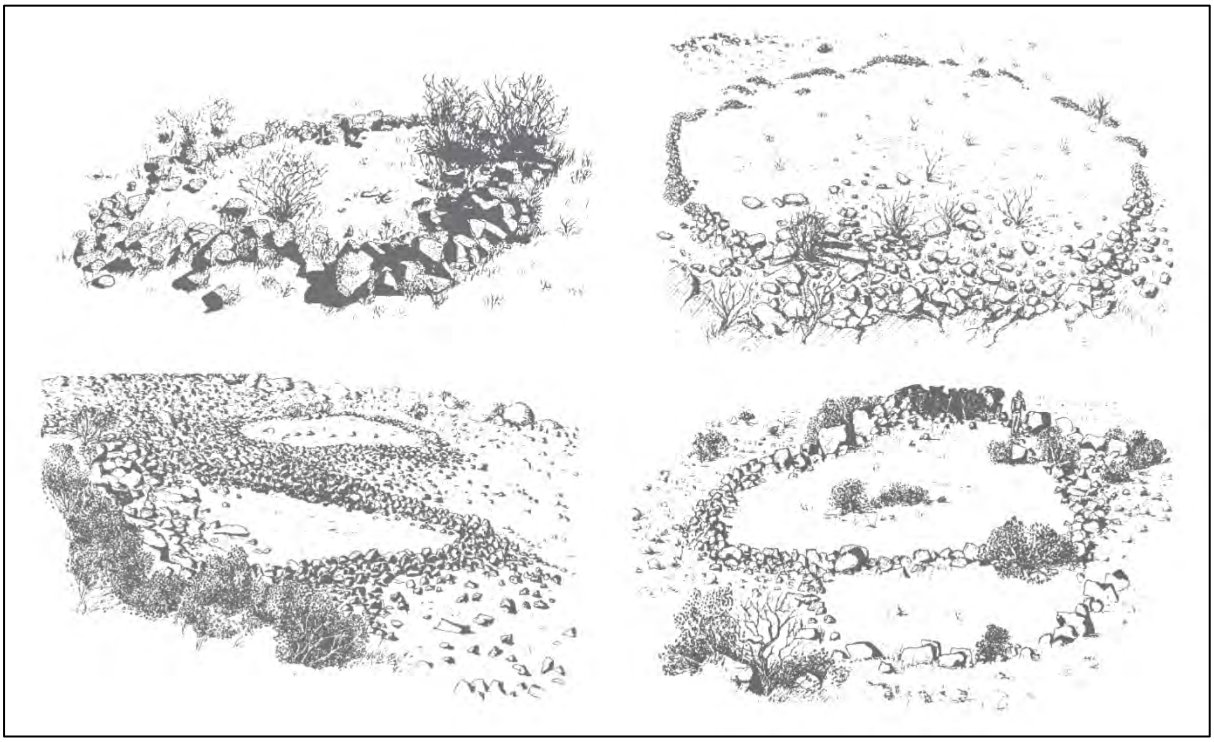

Figure 15.9: Examples of precolonial kraals from the Seacow Valley (original artwork by T. Hart, digital rendering by G. Sampson).

Figure 15.10: Blydefontein Rock Shelter near Noupoort.

There is no Iron Age archaeology known from the Karoo region because the climate did not allow the cultivation of summer rainfall crops. However, the 18th Century Frontier Wars of the Border Kei region (Von der Heyde, 2013) indicate that Xhosa people were living as far west as Grahamstown and that Late Iron Age remains should be present in the extreme south-eastern corner of the study area.

Rock art is one of the more tangible aspects of archaeology and occurs throughout the study area wherever suitable canvases present themselves. The art takes two main forms whose distribution is dependent on the type of rock available. The northern half of the study area (Bushmanland and the central Karoo) is well-known for the engravings that occur on dolerite outcrops, while painted art is most common on the steeper rocks of the escarpment and other mountains, occurring more densely in the far eastern part of the study area than in the west. This is not a strict rule, however, with Hollman and Hykkerud (2004) documenting a dense cluster of painted sites on sandstone outcrops around Williston. Engravings may be incised, pecked or scraped (Parkington et al., 2008), while paintings are either brush or finger painted. Two main art traditions occur in the study area and were both painted and engraved (Figure 15.11). The fine-line tradition of the indigenous Bushmen (San) is characterised by human and animal figures and associated with Bushman symbolism, ritual and religion (Lewis-Williams and Challis, 2011; Lewis-Williams and Dowson, 1999). In contrast, geometric tradition art was made by the Khoekhoen and has a cruder appearance with largely symbolic imagery. Its distribution is focused strongly on water sources across the northern, central and western parts of South Africa (Eastwood and Smith, 2005; Orton, 2013; Smith and Ouzman, 2004). During historic times colonial images like wagons, horses and figures in European dress were added to the subject matter of both engravings and paintings. Although not art, rock gongs are identified from the characteristic markings left on the edges of dolerite boulders from being beaten to produce sound. Perhaps because they are difficult to identify, they are not well mapped, although they are known to occur within the study area (Parkington et al., 2008). Another rock art layer that should be considered is historical graffiti. Early travellers and farmers frequently left their names, dates or other inscriptions at places they visited. The graffiti can be painted (e.g. Figure 15.11) or engraved and would need to be older than 100 years to be protected under Section 35 of the NHRA.

Figure 15.11: Clockwise from top: A well-patinated snake-like engraving from near Beaufort West; a historical incised engraving from near Beaufort West; a complex rock art panel from near Noupoort displaying faded fine-line imagery (inset) overpainted by bolder, finger-painted geometric tradition art which, in turn, has been covered by painted and scratched historical markings; a row of fine-line eland from near Noupoort.

Until the turn of the 18th century, the western part of the study area was occupied solely by the San and Khoekhoen but from this time onwards runaway slaves and colonial fugitives began moving into the Cederberg, Tankwa Karoo and Roggeveld areas to escape the colony. They persecuted the San and Khoekhoen but the expanding colonial frontier brought even worse conditions as the farmers took control of the land and the frontier became characterised by violence and conflict. In combination with the growing economic, social, psychological and political pressure, the smallpox epidemic of 1713 wreaked havoc among the indigenous populace of the south-western Cape Colony and terrified the inland clans lest the disease should spread among them. The San and Khoekhoen were soon subjugated and many became farm labourers. Throughout the 18th century escapes northwards continued but now with indigenous peoples joining the bands of runaways (Penn, 1999; 2005).

Little researched until recently, 18th and 19th century archaeology in the Karoo is remarkably diverse and records much of what has shaped the local communities of today. The use of wagons to transport people, food and goods and the introduction of the wind pump to South Africa in the mid-19th century (Walton and Pretorius, 1998) resulted in historical residues becoming more widely spread as time progressed. An important component is the domestic refuse middens associated with farmhouses and which contain large quantities of discarded material culture. An aerial photography survey in the south-western part of the study area has revealed the diversity of pastoralist settlement, both precolonial and historical (Regensberg, 2016). Changes in the visible built material culture identify the changing structure of pastoralist systems as land control and management changed. Merino sheep, and in places ostriches, became the focus of more commercialised farming practices and, during the latter half of the 19th century, wind pumps increasingly loosened the constraint of natural water sources on pastoralist management. Settler farmhouses became widespread across the Karoo and many of the earlier ones, sometimes now in ruin, have proximate ash heaps and rubbish dumps containing the material culture of the period. Traditional pastoralist practices would have been largely curtailed with the passing of the Fencing Act (No. 30 of 1883) which resulted in the enclosure of many farms, starting especially in the eastern part of the study area, and a switch to modern farming practices (Van Sittert, 2002). Recent work has demonstrated continuity in the cultural identity and practices of indigenous people in the Karoo and shown that these are deeply rooted in the precolonial past and continue to inform contemporary beliefs and values.

The Karoo and Border Kei regions have long been a landscape of conflict, originally between the indigenous San and migrant Khoekhoen. Later there was ongoing tension between these groups and the European settlers who sought to control the interior, all the while expanding the frontier of colonialism. The most recent archaeological layer derives from the influx of non-local groups like missionaries, Xhosas and other African migrants (Zachariou, 2013).

The Second South African War was an important event in South Africa’s history. It started on 12 October 1899 after the British Government ignored an ultimatum from the Government of the South African Republic regarding what the South Africans felt was unlawful interference in the internal affairs of the Republic (Grobler, 2004). Although smaller skirmishes were common across much of the country, the larger battles were limited to the northern and eastern regions with only two having been fought within the study area: the Battle of Stormberg north of Molteno, and the Battle of West Australia Hill southeast of Colesburg (Von der Hyde, 2013). The Boer forces, supported by their African and Khoekhoen retainers, initially fared quite well, but by February 1900, after considerable reinforcements had been brought in from Britain, the Boers were on the defensive and switched to guerrilla tactics (Von der Hyde, 2013). The war eventually ended with a peace treaty signed on 31 May 1902 (Grobler, 2004). From an archaeological view point, camps where soldiers spent the night are marked by the presence of food tins, drink bottles and occasional other artefacts. Battlefields are often less noticeable on the ground but they can have bullet cases, military buttons and other miscellaneous items on them.

Although protected by a separate section of the NHRA, graves, by their nature, form a subset of archaeological remains and can be found almost anywhere. Isolated precolonial graves are generally in areas where the substrate is more suited to hand excavation and are most often completely unmarked. This is not always the case, however, as demonstrated by graves with broken grindstones on them associated with Khoekhoe sites in the Roggeveld area (Hart et al., 2010). Historical graves are usually close to farmsteads, usually in formal walled or fenced graveyards. The graves of poor people and farm workers and older, often very isolated graves (perhaps from the early settlers who moved around the landscape on a seasonal basis) may just have natural rock slabs or cobbles as head and foot stones. Graves associated with the South African War and other conflicts could be in very remote locations, like Middelpos in the far west (Schoeman, 2013), although many slain soldiers were buried in formal municipal cemeteries in towns. In the Border Kei part of the study area there will certainly be many family graves associated with Xhosa homesteads. The most well-known grave in the study area is that of Dr Robert Mangaliso Sobukwe, in Graaff-Reinet, which is a declared National Heritage Site (NHS).

15.1.1.5 Palaeontology (Section 35), Meteorites (Section 35) and Geological heritage (National Estate)

The Great Karoo region of South Africa is internationally renowned for its exceptionally rich fossil record of terrestrial and freshwater plants and animals from the ancient supercontinent Gondwana (MacRae, 1999; Rubidge and Hancox, 1999; McCarthy and Rubidge, 2005). Thousands of vertebrate fossils have been collected from the Great Karoo including early finds near Beaufort West in the 1820s, the first known dicynodonts (two-tusked mammal-like reptiles) from the Fort Beaufort area discovered by the pioneer geologist Andrew Geddes Bain in the 1830s, and some of the earliest known dinosaurs near Aliwal North collected by "Gogga" Brown in the 1870s (MacRae, 1999).

What is a fossil?

Fossils are the traces of ancient life (animal, plant or microbial) preserved within consolidated rocks and other sediments and come in two forms:

- Body fossils preserve parts, casts or impressions of the original tissues of an organism (e.g. bones, teeth, wood, pollen grains); and
- Trace fossils such as trackways and burrows record ancient animal behaviour.

The Late Carboniferous to Early Jurassic fossil record is fairly continuous, spanning more than 100 million years. Karoo fossils have long played a central role in understanding the origins and evolution of several key groups of terrestrial vertebrates, such as amphibians, tortoises, early dinosaurs and mammals. Both primitive and advanced therapsids ("mammal-like reptiles") are especially well represented here, ranging in body size from rats to rhinos. They dominated vertebrate life on land up to 40 million years before the first dinosaurs evolved. Trackways of crocodile-sized amphibians, therapsids and dinosaurs provide insights into the behaviour of extinct vertebrates, while studies of remarkably well-preserved fossil bones and teeth illuminate their development and physiology. Invertebrate fossils are poorly represented in the Karoo, but the main exceptions are freshwater bivalves and crustaceans. The wealth of fossil plant material from the ancient Karoo assemblages – including compressions of stems, leaves and fruiting structures, petrified woods, microscopic spores and pollens – is far more impressive. World-class fossil plant assemblages from the Coal Measures of the Ecca Group and younger carbon-rich rock horizons (e.g. Normandien and Molteno Formations) document the diversification and ecological turnover of vegetation on Gondwana in the Permian and Triassic Periods. Interestingly, the Middle Permian Whitehill Formation (Ecca Group) – the main target for SGD – is renowned for its exquisitely preserved fossils of intact mesosaurid reptiles, primitive bony fish and bottom-dwelling crustaceans as well as a range of fossil plants and microfossils. Identical fossils found in Brazil provided some of the most convincing early evidence for continental drift and the ancient supercontinent Gondwana. All-in-all, the sediments and fossils of the Karoo Supergroup provide us with the best available picture of how the first complex terrestrial and freshwater ecosystems developed on Earth. Also recorded in Karoo rocks is how these early ecosystems responded to dramatic environmental changes leading to a series of three catastrophic extinction events within or towards the end of the Permian and Triassic Periods, some 260, 250 and 200 million years ago respectively. The ever-changing wildlife of the ancient Karoo (e.g. Figure 15.12) is reflected in the series of eight successive fossil assemblages zones formally established for the Beaufort Group rocks of the Main Karoo Basin. These serve as international references for terrestrial biotas of the Middle Permian to Early Triassic time interval (Van der Walt et al., 2010; Smith et al., 2012).

Geological time

The following periods are relevant to archaeology and/or palaeontology in the Karoo:

Period	Age (years)
	0
Holocene	
	12 000
Pleistocene	
	2.5 million
Neogene	
	23 million
Paleogene	
	65.5 million
Cretaceous	
	145.5 million
Jurassic	
	201.6 million
Triassic	
	251 million
Permian	
	299 million
Carboniferous	
	359.2 million

Figure 15.12: Reconstruction of Late Permian wildlife in the Main Karoo Basin (Source: Victoria West Museum, original artwork by Maggie Newman).

Locally the much younger superficial deposits mantling the ancient Karoo bedrocks - notably thick alluvial, spring or pan deposits and ancient cemented soils (pedocretes) – also contain a valuable but poorly-known fossil record. Examples spanning the last 20 million years or so include the bones, teeth and horn cores of extinct Pleistocene mammals, tortoise and snail shells, petrified termitaria as well as very rare examples of early *Homo sapiens* such as the so-called Hofmeyr skull discovered in the eastern part of the study area (Grine et al., 2007). Pollen and other records from springs, pans, valley alluvium or hyrax middens, for example, provide valuable information regarding late Pleistocene and Holocene palaeoenvironments (Holmes et al., 2003; Meadows and Watkeys, 1999; Scott, 1993) that complement and enrich archaeological research.

As a consequence of the exceptional scientific significance and abundance of Karoo fossils in the Beaufort Group (the thick sedimentary rock unit underlying the majority of the study area; Figure 15.13), its outcrop area is rated as very highly sensitive in palaeontological heritage terms on the South African Heritage Resources Information System (SAHRIS) Palaeosensitivity Map (Figure 15.14). There is, as yet, no comprehensive database of known or formally protected fossil sites within the Great Karoo, and most potentially fossiliferous areas have never been palaeontologically surveyed. Type areas for each of the various Beaufort Group fossil assemblage zones have been designated and are of international significance (Rubidge, 1995); each covers substantial portions of one or more Karoo farms. Prominent fossil sites of tourism importance include the Gansfontein palaeosurface near Fraserburg with its wealth of fossil trackways, therapsid fossils in the Gatsrivier near Nieu Bethesda (Kitching Fossil Exploration Centre), and the Grade I, 253 million year old dicynodont herd trackways at Asante Sana Nature Reserve near Graaff-Reinet (Figure 15.15; De Klerk, 2002).

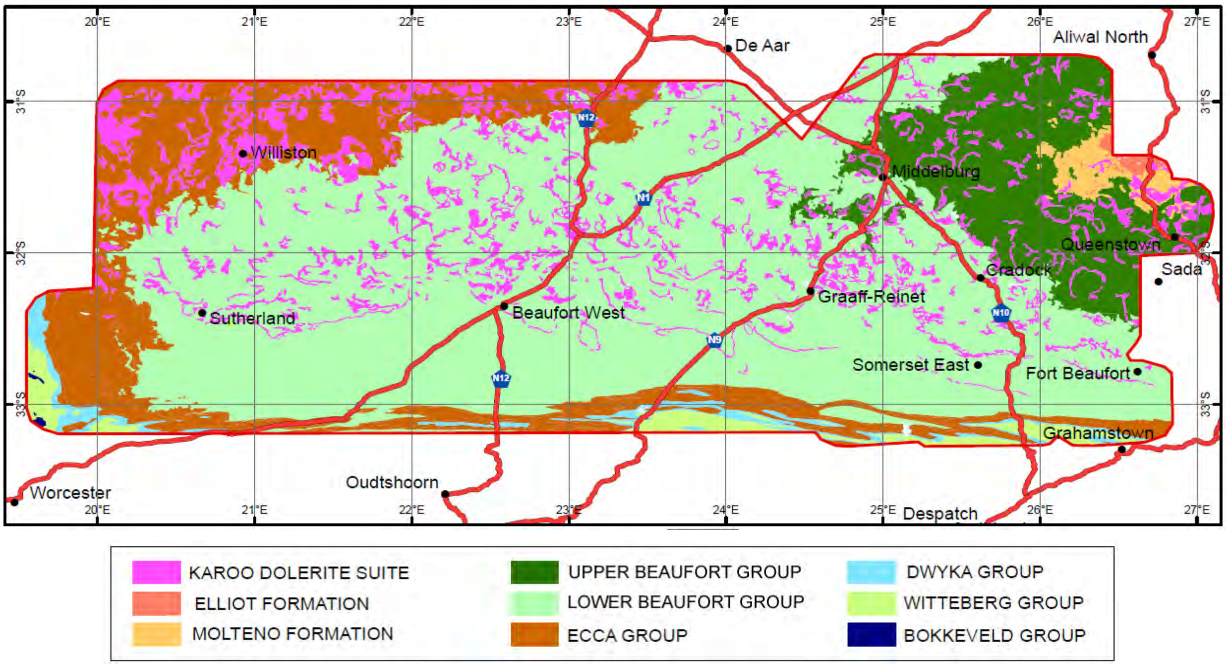

Figure 15.13: Geological map showing the outcrop areas of the main rock units represented within the study area (map provided by the Council for Geoscience (CGS), Pretoria). Note that almost all of these rock units are sediments of the Karoo Supergroup that are known to contain significant fossil heritage.

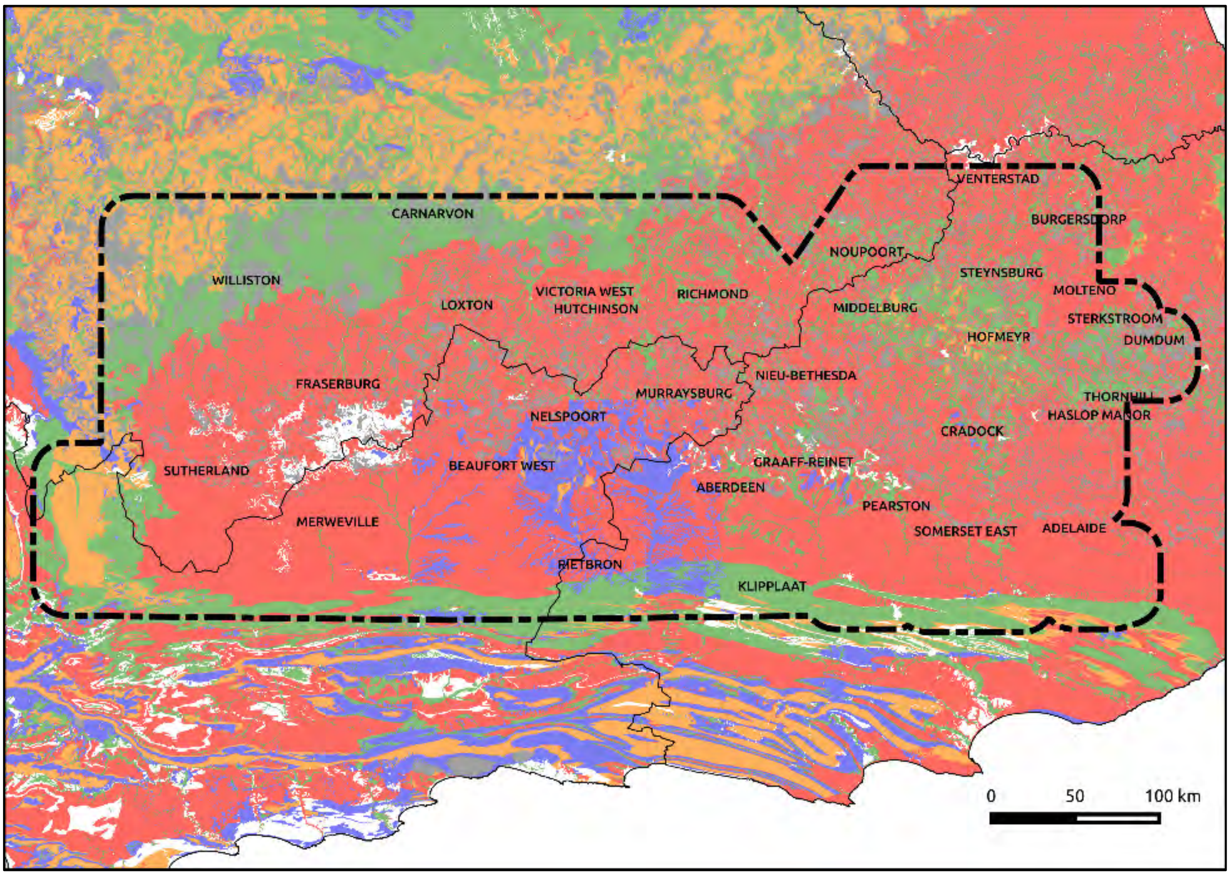

Figure 15.14: Extract from the SAHRIS Palaeosensitivity Map showing the study area. Red shading denotes ‘very high palaeontological sensitivity’, orange is ‘high’, green is ‘moderate, blue is ‘low’, grey is ‘zero’ and

white is ‘unknown’. Although several Karoo rock units are highly sensitive (including the potentially hydrocarbon-rich Whitehill Formation), the majority of the red shading within the study area represents the various formations making up the Beaufort Group.

Figure 15.15: Dicynodont footprints in Late Permian (c. 255 million year old) alluvial sediments of the Balfour Formation (Lower Beaufort Group) from near Graaff-Reinet (Source: SAHRIS, n.d.).

Most Karoo vertebrate fossils are variously preserved within river channel sandstone bodies or within overbank mudrocks representing ancient flood deposits. In the second case they are often partially or completely enveloped in pedogenic calcrete nodules associated with ancient soil horizons. Most recorded fossil vertebrate finds from the Beaufort Group occur within a broad arc stretching from Merweville, through Three Sisters to Graaff-Reinet (Nicolas, 2007; Figure 15.16). Fossil vertebrate sites are especially dense in the western Karoo, perhaps because of the more arid climates currently prevailing there and facilitating preservation as well as the finding of specimens exposed at the surface, while rich fossil plant sites are more concentrated in the east. It is important to note that previously-buried fossils are continually being exposed by surface weathering. If not collected, they will ultimately be destroyed by natural weathering processes and erosion. Most well-preserved, scientifically important fossils are collected at or near the surface where they are often already partially exposed by weathering. Articulated or semi-articulated vertebrate remains are especially significant. Fossils require skilled excavation by professional palaeontologists, taking care to record contextual geological data reflecting when and how the animal died and became preserved.

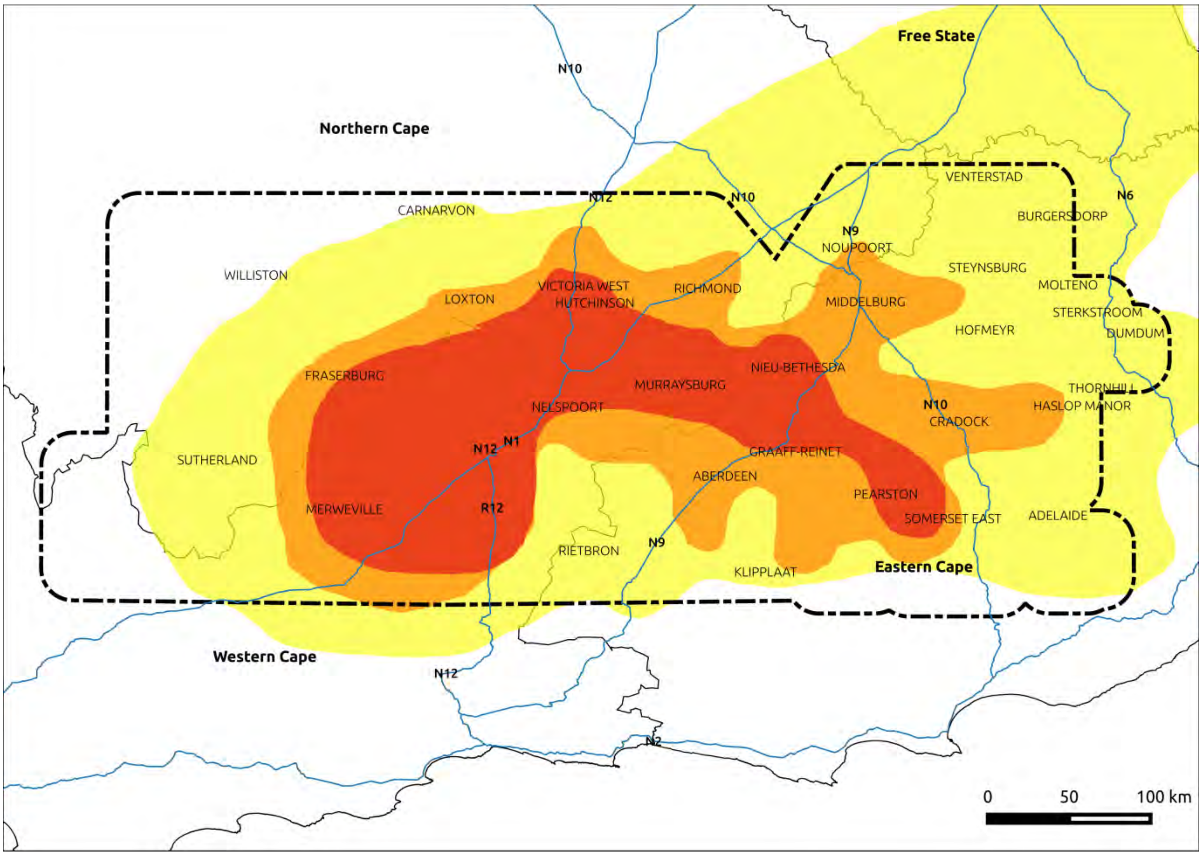

Figure 15.16: Map of the study area indicating the density of previously-recorded fossil vertebrate sites within the Permo-Triassic Beaufort Group (red: high; orange: medium; yellow: low). Note that this is not a palaeosensitivity map since it does not show key fossil groups such as plants or trace fossils (e.g. vertebrate trackways) (Redrawn from Nicolas, 2007).

Meteorites are rocky or metallic fragments of extra-terrestrial bodies (e.g. the Moon, planets, asteroids, comets), weighing anything from a few grams to many tons, that have fallen to Earth individually or as part of a swarm. These very rare natural objects provide unique data on the origins, early history and evolution of the Solar System, including planet Earth (Reimold and Gibson, 2005; McKenzie, 2014). They include some of the oldest objects to be found on Earth - up to 4.6 billion years old. The majority of meteorites have been collected in arid areas like the Karoo where rates of natural weathering are low, soils are thin and vegetation cover is sparse. Rocky meteorites (‘stones’) are much more common than metallic ones (‘irons’). Historical sightings (‘falls’) are very rare and most specimens found must have landed on earth during earlier millennia. Iron-rich meteorites, such as those found in the Gibeon district of south-central Namibia, have occasionally been exploited by local peoples to make weapons and tools. Only about 50 meteorites are recorded for South Africa on scientific databases (e.g. The Meteoritical Society, 2016). However, due to fragmentation before and on impact, some may comprise hundreds or thousands of fragments within a strewn field that may be tens to hundreds of kilometres (km) across. Several major meteorite impact structures are known in southern Africa. They include the approximately 250 000 year old Kalkkop, a 640 m wide crater infill between Jansenville and Graaff-Reinet within the study area. Meteorites have been reported from South Africa since the 1790s, with famous Karoo examples including Hofmeyr (fall, 1914) and several from the Beaufort West area such as Jakkalsfontein (fall, 1903), Merweville (find, 1977) and Wittekrans (fall, 1880).

The Great Karoo landscape records more than 100 million years of geological history related to the southern supercontinent Gondwana, and spanning the Late Carboniferous to Early Jurassic Periods with no major breaks. The iconic flat-topped *koppies* and endless undulating *vlakte* are sculpted from a pile of sedimentary and igneous rocks more than 12 km thick that is known as the Karoo Supergroup (Rubidge and Hancox, 1999; McCarthy and Rubidge, 2005; Johnson et al., 2006). Many features of the Karoo Supergroup succession in the Main Karoo Basin contribute to its international fame among geologists including:

- 300 million year old glacial deposits and ice-scoured rocky pavements of the Dwyka Group;
- Early to Middle Permian submarine fan and deltaic deposits of the Ecca Group with their economically valuable cool-climate coals and untapped oil and gas potential;
- Varied river and lake deposits of the Beaufort Group, globally one of the best-known rock successions for documenting the evolution of continental environments and their rich plant and animal biotas during the Permian and Triassic Periods;
- Arid climate fluvial and sandy desert deposits of the Elliot and Clarens Formations (Stormberg Group) recording environmental changes associated with major faunal turnover across the critical Triassic/Jurassic boundary; and
- Early Jurassic (*c*. 180 million years old) igneous intrusions of the Karoo Dolerite Suite. These dykes and sills represent huge volumes of hot magma that were forced upwards through the overlying sediments along lines of crustal weakness before solidifying into tough igneous rock below the Earth’s surface or erupting at the surface as basaltic lavas (Drakensberg Group). Evidence of small-scale, more recent igneous activity in Late Cretaceous times (*c*. 70 million years ago) is seen at the Salpeterkop volcano near Sutherland (Verwoerd, 1990).

These ancient Karoo bedrocks are locally mantled by thick alluvial deposits (river sands, silts, gravels) and arid-climate pedocretes (e.g. lime-cemented deposits of ancient soils) that record the complex, ever-changing history of aridification, crustal uplift and drainage development in the South African interior over the past several tens of millions of years. Excellent sections through these younger deposits are seen in deep erosion gullies, especially in the eastern Karoo.

The spectacular natural scenery and exceptionally good exposures of fresh (i.e. unweathered) bedrocks available in the Great Karoo – along river and stream banks, on hillslopes, in erosion gullies, around farm dams and in quarries as well as road and railway cuttings – have attracted geologists and other naturalists over the past 200 years or more. Locations such as the Nuweveld Escarpment in the Karoo National Park near Beaufort West and the Valley of Desolation in the Camdeboo National Park near Graaff-Reinet are now being increasingly exploited for ecotourism (Norman, 2013; Norman and Whitfield, 2006). Numerous scientifically significant geosites in the Karoo region exhibit important geological features and are worthy of protection from future development but, unfortunately, no national database of these sites and materials is currently available. Good examples of international significance are the key geological sections (termed stratotype sections) for all the constituent sedimentary formations of the Karoo Supergroup that have been, or are in the process of being, designated by the South African Committee for Stratigraphy (e.g. Abrahamskraal Formation exposures along the Gamka River south of Leeu-Gamka and Burgersdorp Formation sections near Burgersdorp).

15.1.1.6 Living heritage (National Estate)

Living (or intangible) heritage encompasses all those ideas, traditions, customs, associations and memories that are passed from generation to generation. It includes things such as language, folklore, traditional medicine, music, songs, dances and recipes. Knowledge, skills and practices related to the local economy, such as shepherding, animal husbandry and seasonal movement between summer and winter grazing areas, are also important because without them the Khoekhoe herders, early colonial settlers after them, and even modern farmers and their workers would never have survived. Many places in the study area are associated with living heritage or with works of literature or art and bear cultural value for this reason. These are all things that contribute to the identity of a group. The Department of Arts and Culture (DAC; 2009:5) defines living heritage as “cultural expressions and practices that form a body of knowledge and provide for continuity, dynamism, and meaning of social life to generations of people as individuals, social groups, and communities.” Part of the importance of living heritage is that it helps to create a new national identity and promotes heritage that was repressed by missionaries, colonists and the apartheid regime (DAC, 2009).

One of the most well-known aspects of living heritage in South Africa is the Bleek and Lloyd archive recorded during the 1860s and 1870s (Bleek and Lloyd, 1911). It records much of the folklore of the Bushmen people and has, through analogy, been used extensively in the interpretation of southern African precolonial rock art (Lewis-Williams and Dowson, 1999), some of which occurs within the study area. Because it was collected during the 19th century, it is also directly informs the interpretation of 19th century Karoo rock engravings. An aspect of indigenous mythology that deserves special mention because of its widespread importance relates to water. Among a number of groups certain permanent water sources (pools, rivers or springs) are inhabited by the ‘River People’ or water spirits. These can be in the form of snakes, mermaids (‘*watermeide*’) or other creatures. These places are regarded as sacred and are particularly important to traditional healers (Bernard, 2003). Rock art sites are often located in proximity to such water sources thus creating an associational link between the art and riparian landscapes (Rust and Van der Poll, 2011). Furthermore, the Water Snake is often depicted in rock art and still plays a prominent role in people’s lives today (Hoff, 1997).

Recent research has aimed to collect contemporary narratives that continue some of the themes, structures and moral codes set out in the Bleek and Lloyd archive (De Prada-Samper, 2014). These narratives are important because the range of subject matter recorded by De Prada-Samper (2014:106) emphasises the continuities into the 21st century and therefore links contemporary Karoo dwellers with both their immediate and painful colonial past and their deeper precolonial past. Living heritage is constantly recreated in response to environmental and historical factors as reflected across the Karoo, for example, in the variability evident among stories that were clearly about the same character. In general, the Karoo region is the heartland of what remains of Bushman and Khoekhoe culture in South Africa.

While the majority of the study area affects typically Karoo – and frequently Afrikaans – heritage, a small section includes a traditionally Xhosa area – the former Ciskei. This introduces a wide body of living heritage related to initiation, marriage and other social and religious customs. Another more recent and often painful aspect of living heritage is the legacy of inequitable spatial planning left by apartheid. The memory of the Liberation Struggle and its activists is an important component of living heritage nationally and parts of the study area were key in the formation and history of the Liberation Movement.

Of course living heritage is constantly being created and inherited, with perhaps the most famous example in the context of modern South Africa being Karoo Lamb (protected under Notice 1074 of 2013 annexed to the Merchandise Marks Act 17 of 1941 (1941)), which now has a formal certification process (Karoo Development Foundation, 2016). This brand and others, like Mohair South Africa, encompass products that have become deeply entrenched in local heritage and are critical to the livelihood of many in the Karoo. Adaptations of traditional dances for tourism purposes and the publication of Karoo recipe and music books, for example, are preserving some of this heritage in ways that become tangible to outsiders. But the fortunes are mixed: the ‘Rieldans’ is a traditional Bushman dance form that has recently been revived and received world-wide attention (Johns, 2015), while the ‘Karretjie Mense’ (small family units migrating across the land in donkey carts in search of sheep shearing work) are rapidly disappearing because of modern transport and farming practices (De

Jongh, 2012). Much great South African literature (especially Afrikaans literature) has emanated from the Karoo with a number of prominent authors (e.g. Olive Schreiner; J.M. Coetzee; and Pauline Smith), and poets (e.g. N.P. van Wyk Louw; D.C. Esterhuyse; and Guy Buttler) having been brought up or spent time there (Schoeman, 2013). The Karoo has also produced visual artists (e.g. Walter Battiss; Helen Martin; and Johannes Meintjies). Many of these people have drawn inspiration from specific Karoo places and some have museums dedicated to their memory within the study area (e.g. Owl House in Nieu-Bethesda (Helen Martin), and the Walter Battiss Museum in Somerset East). The Afrikaans language is thus also an integral part of the living heritage of the study area. It can be very difficult to capture those aspects of living heritage that have not been publicised and interviews with local residents of all backgrounds are important in this regard.

Place names are also an aspect of living heritage that are, in a way, more tangible. They are a rich source of reference to various aspects of the local environment or culture, such as the climate (Karoo), animals (Leeu-Gamka), and places where food can be obtained (Hantam). Famous or respected people are commonly represented in street names throughout the area. Some street names indicate the original centre of town (Church Street in cases where towns developed around their first church) or the edge of town (Buitenkant Street, Burgersdorp), while others point to geographical places or sites (Carnarvon Street, Loxton; Location Street, Murraysburg). Street names also recall the broader history of South Africa (Constitution Street, Adelaide; Voortrekker and DF Malan Streets, Cradock).

15.1.1.7 Cultural landscapes (National Estate)

The cultural landscapes of the study area (some may argue for one large regional cultural landscape) are richly layered in history and give spatial and temporal expression to the many processes and products resulting from the interaction of people and the environment through the ages. As such, the cultural landscape may be seen as a particular configuration of topography, vegetation cover, land use and settlement pattern that establishes some coherence – or legibility – of natural and cultural processes (Müller and Gibbs, 2011). Cultural landscapes weave together all the aspects of heritage already described and, although they occur throughout the study area, the density of individual contributing elements will vary greatly from place to place.

Defining and understanding cultural landscape

The cultural landscape is an aspect of heritage not defined in the NHRA but nevertheless listed as part of the National Estate. A cultural landscape is “a set of ideas and practices embedded in a place” (Julian Smith and Associates Contentworks Inc., 2004) and serves to “map our relationship with the land over time” (The Cultural Landscape Foundation, 2015). While the cultural landscape is itself a heritage resource, it also unites the physical cultural resources of an area (tangible heritage) and its associated memories, perceptions, stories, practices and experiences (living heritage) in order to give a particular place or region its meaning. Because heritage sites are embedded in, and interwoven with, their landscape settings, the cultural landscape also gives these resources their sense of place and belonging through the provision of physical and metaphysical context (Müller and Gibbs, 2011). The concept of cultural landscape is thus very broad. Like the warp threads of a tapestry, the cultural landscape is the setting which holds together all the other aspects of heritage discussed in this Chapter.

After the palaeontological landscapes of the deep past, the first human-related cultural landscapes to form were precolonial ones (Orton, in press). Stone Age people had intimate physical and spiritual relationships with the landscape because their livelihoods depended on it. The multitudes of stone artefacts, rock engravings and paintings bear testimony to and provide tangible reminders of this relationship. The landscape of engravings at Nelspoort has been recognised as potentially of national significance (Winter and Oberholzer, 2013). The area has both fine-line and geometric tradition engravings and represents the greatest concentration of engravings in the central Karoo region.

One of the most prominent features of the Karoo landscape is the patterns of land use that developed during the long history of colonial pastoralist settlement. Wire-fenced, and occasionally stone-walled, grazing camps and jeep tracks stretch to the horizon, while farmsteads are often noticeable from a distance by their prolific exotic tree (*Eucalyptus* sp. and *Populus* sp.) growth in an otherwise sparsely vegetated landscape (Figure 15.17). Stands of *Agave americana*, for fencing or fibre, avenues of Pepper Trees (*Schinus molle*) and the ubiquitous wind pumps and associated concrete reservoirs are important features, often acting as landmarks. Likewise, the tall spires of Dutch Reformed Churches herald the existence of small, widely-spaced towns. Aspects of these patterns are direct responses to ecological systems and landscape features: farmsteads, agricultural fields and towns, for example, are often placed in relation to existing water sources or hills. Houses were built from local materials and designed for the climate. The long, straight roads and railways respond to the open plains, particularly to the south of the Great Escarpment, while the limited traffic on minor roads means that many retain the character imparted by their original gravel surfaces.

Figure 15.17: Aerial view of a south-western Karoo farmstead comprised of houses, outbuildings, stone kraals and walls, arable lands, wind pumps, tree plantings and a graveyard (Source: Google earth).

Also important cultural landscape features are the natural beauty systems of the Karoo (Winter and Oberholzer, 2013). These include the expansive views, hills and mountains, vast open spaces (Figure 15.18), clear horizons and, at night, the starry skies. Geological features such as the dolerite sill hills (e.g. the Three Sisters in the centre of the study area) and the Great Escarpment form termini to many viewscapes, while mountain passes and other scenic routes showcase these features and the achievements of South Africa’s early road engineers, like Thomas Bain. Many mountain passes occur in the study area; some are wagon routes dating back more than 200 years and are long disused (Neville et al., 1994). Whether built features or cultural landscapes is debatable, but all are important heritage features in their own right. A number of scenic routes cross the study area, although only those in Western Cape are formally mapped (Winter and Oberholzer, 2013).

Figure 15.18: An expansive view from a back road between Nelspoort and Murraysburg.

The natural beauty of the Karoo lies in the patterns of muted greens, browns and sandy colours that combine with the coarse textures and forms derived from the vegetation and unique geology (Figure 15.19). The harshness of the Karoo landscape, which even informed its name, was often remarked upon by early adventurers, explorers, hunters and travellers who passed through it. A landscape of contrasts, it was at times extremely hot or cold, intensely dry and drought-stricken or subject to frosts and floods. The negative associations evoked by its natural attributes are reinforced by the sparse human settlements, but those who live or actively participate in the landscape have developed deeper meanings associated with its richness. Much of this meaning finds expression within the realms of living heritage. In contrast, the somewhat greener Border Kei region has a cultural landscape characterised by different features: rivers are more prominent features and traditional Xhosa settlement still occurs in places. Although rectangular dwellings have largely replaced rondavels, stock enclosures are still common outside homes in rural villages.

Figure 15.19: Typical Karoo koppie scenery in the Nuweveld Mountains, Karoo National Park near Beaufort West.

Karoo climates also inform the cultural landscape positively. Perhaps most important, in the context of the semi-arid Karoo, is the traditional spiritual association with rain and water as reflected in the Bushman mythology recorded both in the Bleek and Lloyd archive and in rock art. The stories give special meaning to places and impart spirituality to the landscape (Rust and Van der Poll, 2011). Rain is considered sacred and is personified in the rain animal and its legs which are represented by the columns of rain watering certain parts of the landscape (Parkington et al., 2008). As described above, water sources are also relevant to other aspects of oral tradition and form important aspects of the cultural landscape. Throughout time, humans and nature alike have responded exuberantly in the event of a rainstorm. When it is not raining, the vast, clear skies also contribute to the sense of place of the Karoo and attract people seeking the peaceful solitude it offers. These skies, along with the high altitude, tectonically stable geology and absence of artificial lights, are also the reason for the landscape of astronomy that has existed in the Karoo since the opening of the South African Astronomical Observatory near Sutherland in 1973 (Laney, 2013). The SKA is further testimony to the scientific value of the Karoo landscape.

15.1.1.8 Summary

A notable trend in the above review is that as one progresses through time the various categories of heritage become more strongly linked and the richness of the layering manifested in the cultural landscape increases dramatically. The earliest heritage – fossils – relates to the development of the earth, southern Africa and the Karoo. ESA and MSA archaeology allows us to understand hominin and modern human development as well as how the Karoo landscape was first populated and used. The LSA preserves a more diverse set of resources that elucidate precolonial life. Through the contact period we find a diversity of European and African residues, including locally developed architectural styles, being added to the LSA package, all of which is tied together by the living heritage developed and transferred inter-generationally by past and present communities. The relatively recent past then developed from this cultural fusion to give us the Karoo of today with its distinctive landscapes, architecture and rural character.

15.1.1.9 Why is our heritage important?

The importance of heritage in South Africa revolves around its significance as described in Section 2(vi) of the NHRA (see digital Addendum 15A). Cultural significance is “embodied in the place itself, its fabric, setting, use, associations, meanings, records, related places and related objects” (Australia International Council for Monuments and Sites (Australia ICOMOS), 1999:2). We identify here and discuss the types of cultural significance applicable to each heritage resource category today. Of course significance can be fluid with change through time occurring as a result of actions, legal or otherwise, natural or human, that can increase or decrease the cultural value of specific resources or categories.

- Built heritage can have aesthetic, architectural, social, spiritual and/or technological value for the contributions it makes to society and the cultural landscape. This echoes internationally accepted norms that state that “built vernacular heritage is important; it is the fundamental expression of the culture of a community, of its relationship with its territory and, at the same time, the expression of the world's cultural diversity” (ICOMOS, 1999:1).
- Archaeology (Stone Age and/or historical) can have historical, scientific, social, spiritual and technological significance for its contribution to the shared history of South Africa and our understanding of past societies.
- Graves, monuments and memorials can have historical, social and spiritual significance because they commemorate people and events that have shaped who we are as individuals and who we are as a country.

- Palaeontology, meteorites and geological heritage have scientific significance for their contributions to our understanding of changing prehistoric environments and life on Earth as well as the evolution of our planet.
- Living heritage has historical, social, spiritual and linguistic significance as it represents all those intangible things that make our multi-cultural society what it is today. In the context of apartheid South Africa, living heritage, including popular memory, was often all that people could cling to as their tangible heritage was removed from them and it is thus important to celebrate it today.
- Cultural landscapes can be significant for all the reasons cited above because they describe a complex and diverse history of association between generations of South Africans and their homeland. By imparting special meaning to places they create feelings of belonging and harmony with the land.

Aside from the formal attributes of cultural significance and what it can tell us about our past and present, all the above aspects of heritage have considerable importance for tourism and hence provide sustainable economic benefits to local communities. An unspoilt natural and cultural environment presents a far more sustainable economic opportunity when used for tourism purposes than the short-term benefits of mineral resource exploitation. It is important that the fragile heritage of South Africa is treasured in the present so that we may pass it on to future generations of South Africans.

Furthermore, Section 3(3) of the NHRA lists criteria that should be met for a place or object to form part of the National Estate. Table 15.1 shows how each criterion is met within the study area. Each achieves a high degree of significance in at least some parts of it.

Table 15.1: Criteria for inclusion in the National Estate.

NHRA qualities	Heritage aspects	Motivation
Importance in the community, or pattern of South Africa's history	• Cultural landscapes and all their constituent features	• Critical in understanding the history of South Africa, e.g. settlement patterns, townscapes, oral traditions, natural landscapes
Possession of uncommon, rare or endangered aspects of South Africa's natural or cultural heritage	• Built heritage • Archaeology • Geological and palaeontological sites	• Corbelled structures, British forts, Martello Tower, Karoo farmsteads, mills, wind pumps • Precolonial herder settlement • Certain aspects poorly understood
Potential to yield information that will contribute to an understanding of South Africa's natural or cultural heritage	• All heritage types • Geology and palaeontology	• High degree of intactness offers high research potential • Data expected from fresh excavations, road cuttings, borrow pits, borehole cores
Importance in demonstrating the principal characteristics of a particular class of South Africa's natural or cultural places or objects	• Built heritage • Archaeology • Geology and palaeontology	• 'Karoostyle' architecture, corbelled structures, British military fortifications - Martello Tower, block houses • Khoekhoe livestock enclosures, geometric tradition engravings and paintings • Continental rocks and fossils from the Permian and Triassic Periods
Importance in exhibiting particular aesthetic characteristics valued by a community or cultural group	• Built heritage • Archaeology • Cultural and natural landscapes.	• Karoo architecture • Engravings and paintings • Karoo sense of place
Importance in demonstrating a high degree of creative or technical achievement at a particular period	• Built heritage • Living heritage • Astronomical developments	• Architecture adapted to climate, British Military installations and forts • Strategies for arid environment agriculture, pastoralism and animal husbandry • Scientific developments of international importance
Strong or special association with a particular community or cultural group for social, cultural or spiritual reasons	• Built heritage • Archaeology • Geology and palaeontology • Astronomy	• e.g. Vernacular Architecture Society of South Africa, local interest groups • Rock art valued by descendant communities, and by locals as tourism resources • Geologists and palaeontologists, and locals as tourism resources • Scientific community
Strong or special association with the life or work of a person, group or organisation of importance in the history of South Africa	• Living heritage	• e.g. Chris Barnard (heart surgeon); Olive Schreiner, J.M. Coetzee (authors); Guy Buttler, N.P. van Wyk Louw (poets); Matthew Goniwe, Robert Sobukwe (struggle heroes); James Kitching, Sidney Rubidge, Robert Broom (palaeontologists)
Sites of significance relating to the history of slavery in South Africa (Note that although not listed in the NHRA, sites associated with indentured and unfree labour are also considered here)	• Built heritage • Various farms and missions throughout the study area	• Williston (Peerboom), Fort Beaufort • Slave and unfree labour

15.1.1.10 Links to other topics

There is a two-way relationship between heritage and various other scientific assessment Chapters because of the contributions they make to each other's meaning. The study area would not be what it is without its cultural attributes, and these attributes, in turn, are strongly defined by the local environment that gave them birth. Table 15.2 summarises these links.

Sense of place

Sense of place is a recognised heritage concept but, because of its broad scope extending beyond the realms of heritage, has been allocated its own Chapter in this scientific assessment. From the heritage perspective then, it refers to the meaning, identity, setting and intrinsic character of a place, as provided by its natural and cultural features and one's experience thereof.

Table 15.2: Aspects of heritage that link to other topics.

Topic	Heritage aspects	Links
Earthquakes (Durrheim et al., 2016)	• Built heritage • Archaeology (especially rock art)	Induced seismic activity could have a detrimental effect on heritage structures and possibly rock art sites and an understanding of expected induced seismic activity will help plan heritage buffers. Findings from Durrheim et al. (2016) have informed the conclusions of this Chapter.
Water Resources (Hobbs et al., 2016)	• Archaeology • Built heritage • Living heritage • Cultural landscapes	Surface water resources in the dry interior of South Africa were critical in allowing settlement across the region prior to the advent of the wind pump. As such, many archaeological sites, built heritage resources and smaller-scale cultural landscapes have developed around water sources. Water is also an important aspect of indigenous mythology.
Biodiversity and ecology (Holness et al., 2016)	• Built heritage • Living heritage • Cultural landscape	The natural features of the study area, especially its vegetation and geological features, contribute strongly to the cultural landscape because of their influence on both precolonial and historical settlement patterns and land use. They also form part of the natural heritage of South Africa. There is a large body of knowledge relating to the traditional use of plants and animals for medicinal, construction, ritual and other purposes.
Agriculture (Oettle et al., 2016)	• Built heritage • Living heritage • Cultural landscape	To be successful, agriculture and pastoralism require traditional knowledge of climates and land management practices. Many of the best places for cultivation will have long-since been developed and form part of the cultural landscape. Farming and its related built structures in turn comprise an important component of the cultural landscape.
Tourism (Toerien et al., 2016)	• Built heritage • Archaeology (especially rock art, military history) • Palaeontology • Geological heritage • Living heritage • Cultural landscape	While many Karoo tourists choose a destination for the overall cultural landscape character, specific heritage resources also function as tourist attractions. Obvious examples include rock art sites, battlefield tours, significant geological and palaeontological sites and festivals celebrating living heritage. Tourism has value for heritage in that it offers the opportunity to develop heritage sites in sustainable, income-generating ways that enhance and celebrate their cultural value. Tourist routes are of value in this regard.

Topic	Heritage aspects	Links
Social fabric (Atkinson et al., 2016)	• Built heritage • Living heritage	Built heritage aids the continuation of living heritage as communities associate with churches, schools, memorials and other structures that embody memory. Social fabric is partly defined by living heritage (memory and tradition).
Sense of place (Seeliger et al., 2016)	• Built heritage • Archaeology (especially rock art) • Palaeontology • Living heritage • Cultural landscape	Sense of place is determined by the natural and cultural landscape, setting, and its embedded heritage, which includes, among other things, the built environment, rock art, the aura around fossil dinosaurs and other long extinct creatures, local customs and culinary traditions.
Visual aesthetics (Oberholzer et al., 2016)	• Built heritage • Archaeology (mainly rock art) • Living heritage • Cultural landscape	Appreciation of urban and rural cultural landscapes and rock art is largely dependent on their settings which combine sights, sounds and smells. Visual, air and sound pollution can affect setting, sense of place and cultural landscape quality. Many aspects of living heritage are tied to places in the landscape that could be visually impacted by SGD.
Noise (Wade et al., 2016)	• Built heritage • Cultural landscape	The liveability of built heritage is strongly tied to the qualities of its environment. A negative change in the environmental qualities will, over time, erode the vitality of the resource. Appreciation of the cultural landscape depends partly on the sounds that come with it. Noise pollution can affect the sense of place and hence the cultural landscape quality.
Integrated spatial and infrastructure planning (Van Huyssteen et al., 2016)	• Built heritage • Cultural landscape	Many infrastructural elements, such as roads, bridges and railways, are heritage resources. Historical spatial planning (including under apartheid) has created the townscapes of today. Potential SGD-related changes to the urban landscapes and streetscapes of Karoo towns as well as wider landscape interventions could dramatically impact on built heritage resources, their settings, and cultural landscapes.

15.1.1.11 <u>Assumptions and limitations</u>

Scenario 1 (Exploration Only), Scenario 2 (Small Gas) and Secnario 3 (Big Gas) as provided in Burns et al. (2016) are assumed to be realistic. Any substantial changes to the scope of these scenarios may affect the conclusions of this Chapter and the requirements of later Heritage Impact Assessment (HIA) studies. We assume that seismic surveys, access roads and wellpads could be sited almost anywhere in the study area with only steep or inaccessible terrain and certain prescribed no-go areas (e.g. conservation or urban areas) being exempt. We assume that exploration and related impacts would be widespread, while SGD under the Small and Big Gas scenarios and any related impacts would occur within limited footprints. Although our heritage knowledge is necessarily limited by the low level of survey coverage, we assume that there are on record sufficient examples of all the general types of heritage that might occur in the study area to allow reasonably accurate predictions of potential impacts.

In the absence of fieldwork, previous research and our working knowledge of the area form the basis of this assessment. Academic and commercial research has been patchy and of variable quality, frequently focusing on a limited set of heritage resources. As such, fine-grained mapping of heritage resources across the entire study area is impossible. Although the NHRA requires preparation and maintenance of heritage inventories by local authorities, this has not occurred.

15.1.2 Overview of international experience

Literature relating to the impacts of hydraulic fracturing ("fracking") on heritage resources is rare and it is notable that in countries where SGD has been banned environmental and human health reasons are the driving force behind the actions; heritage sites are rarely mentioned. Nevertheless, various sources have allowed an estimation of the kinds of problems that might arise.

A primary concern stemming from the experiences of fracking in the United States of America (USA) is the economic boom and rapid population increases that can occur in conjunction with the discovery of a good resource, as has recently been the case in North Dakota (Brown, 2014). With population inflow heritage sites can be at direct risk from the increased development, while rapid urbanisation has been recognised by UNESCO (2011) as causing degeneration in the quality of both historic urban environments and their surrounding rural areas. Ancillary infrastructure related to the industry, like pipelines, also increases impacts. In the context of the present study, such a boom might only happen under the Big Gas scenario. In Utah, USA, the Navajo people were expecting employment when fracking commenced on their land. However, outsiders were brought in to do the work and according to a Navajo representative, this resulted in physical, financial and cultural suffering for the local population (Peacock, 2011).

Another key risk is that of increased seismicity. The underground disposal of waste water in deep wells, a practice banned in the Karoo (Mineral and Petroleum Resources Development Act (MPRDA), No 28 of 2002, Regulation 2015), has been blamed for most induced earthquakes in the USA (Rubinstein and Mahani, 2015), but in Alberta, Canada, the situation is different with the timing of fracking operations and induced earthquakes found to be very strongly correlated (Schultz et al., 2015). Given the fragility of vernacular Karoo architecture, there is a real risk of damage to buildings (particularly elements such as gables, domes and chimneys) and monuments should earth tremors occur. This has already been illustrated when a tremor in 2010 caused the collapse of at least three corbelled buildings and may have resulted in cracks in many more (Kramer, 2012). Although the literature lacks assessments of the impacts of induced earthquakes on heritage buildings, impacts have been recorded in the Netherlands where conventional gas extraction has resulted in earthquake-related property damage (Van der Voort and Vanclay, 2015).

Given the widespread occurrence of archaeological sites, this is also a resource type that can experience considerable impacts. Swaminathan (2011) reports from Pennsylvania, USA, that the natural gas industry has been considered a risk to archaeology since the 1980s. Although the South African study area does not contain precolonial built heritage on the scale of the American Southwest, the case of the Chaco Culture National Historical Park in New Mexico, a declared World Heritage Site, sounds a strong warning regarding impacts to a heritage landscape that is far greater than the sum of its associated sites (Dronkers, 2014). While some of the heritage resource is protected within the park, a large proportion of it lies outside the park and is seen as vulnerable to the effects of SGD.

Legislation covering environmental assessment and SGD is highly variable. While the United Kingdom (UK) has fairly stringent controls in place (Department of Energy and Climate Change (DECC), n.d.; The Town and Country Planning (Environmental Impact Assessment) Regulations No. 1824 of 2011: schedule 2, 2011), those in some USA states are weak. For example, the Antiquities Code of Texas applies only to developments undertaken by federal agencies and whose surface disturbance will exceed five acres (20 234 m^2) unless a known heritage resource will be affected (Texas Historical Commission, 2016). Furthermore, with respect to water and waste, Texas has not imposed any testing regulations specific to SGD (ALS, n.d.) and have recently enacted legislation preventing the banning of fracking by local authorities anywhere in the state (Texas House Bill, No 40 of 2015, 2015). The State authorities in Pennsylvania have actively promoted natural gas over heritage (Swaminathan, 2011). A law was passed stating that any gas project covering 10 acres (4.04 ha) or less does not have to be reviewed by the Pennsylvania Historical & Museum Commission (PHMC), and they do not even need to be notified of the application. Thanks to a 1995 legislative amendment, for projects larger than 10 acres the PHMC is notified but are required to conduct archaeological mitigation at their own expense. With shrinking staff and budget, they can do nothing but watch as sites of proven research value are destroyed. At least some authorities in the USA thus favour SGD over environmental, health and heritage concerns.

Heritage resources authorities (status quo)

Due to a lack of capacity, the heritage management system anticipated by the NHRA is not fully operational. As things stand at present, the following applies in each province under the NEMA process:

- Western Cape: Heritage Western Cape (HWC) is fully functional and applications within Western Cape would be commented on by them;
- Eastern Cape: Although the Eastern Cape Provincial Heritage Resources Authority (ECPHRA) is formally functional, it is poorly resourced and has limited capacity to respond to applications; and
- Northern Cape: The Northern Cape PHRA, Ngwao-Boswa Ya Kapa Bokoni (NBKB), is functional but also poorly resourced. Powers in terms of the NHRA for built environment and landscape matters have been devolved to the PHRA, but not those relating to archaeology and palaeontology (South African Heritage Resources Agency (SAHRA) handles those aspects on its behalf).

Although difficult to prove, this could relate to the corruption reported in the media and in documentaries.

Although the literature seems to deal almost exclusively with the extraction phase of SGD, it seems logical to conclude from the above that pressure on the authorities is likely to mount should a good resource be discovered and that the risks to heritage resources would grow in tandem.

15.1.3 Relevant legislation, regulation and practice

The NHRA (Act No. 25 of 1999, 1999) defines the heritage resources of South Africa in Section 2 and Section 3 (relevant definitions are reproduced in Digital Addendum 15A). Chapter II governs the protection and management of heritage resources. Important in this context is Section 38 which prescribes the manner in which an impact assessment should be carried out. It provides triggers for various activities that would require an impact assessment, however, under Section 4(b)(iii) of the National Environmental Management Act (NEMA) No. 107 of 1998, 1998) one is required to include an assessment of the impacts to the National Estate into any impact assessment triggered by the provisions of that act. Under the NHRA, Section 34 protects structures older than 60 years; Section 35 protects archaeology, palaeontology and meteorites; Section 36 protects burial grounds and graves; and Section 37 protects public monuments and memorials. The definitions mentioned above provide specific details of what is included within each of these categories. The study area contains two NHSs and more than 350 PHSs, declared as such under Section 27 of the NHRA. Under Section 28 heritage resources authorities may provide a measure of protection to certain areas over and above the basic provisions of Sections 34-37, while Section 29 allows the authorities to provisionally protect a heritage resource in order to allow for the consideration of further protection as may be required, often when the resource is under threat.

The World Heritage Convention Act (No. 49 of 1999, 1999) governs World Heritage Sites. Although the study area does not currently host such sites, it does include part of the previously described 'Human Rights, Liberation Struggle and Reconciliation: Nelson Mandela Legacy Sites' serial nomination as well as the Succulent Karoo Protected Areas (UNESCO, 2016c). There are also various national and provincial regulations and guideline documents as well as international guides (largely from ICOMOS and UNESCO) and charters that exist to guide development and mitigate change. There is a Western Cape Government guideline document for involving heritage specialists in Environmental Impact Assessment (EIA) processes (Winter and Baumann, 2005), while both SAHRA (2007) and HWC (2016b) have issued guidelines and standards for conducting specialist assessments of archaeology and palaeontology. International guidelines for heritage studies also exist (e.g. Australia ICOMOS, 1999; ICOMOS, 1999). Regulations concerning the exhumation and relocation of graves have been published by SAHRA (National Heritage Resources Act 25 of 1999, Regulations R.548 of 2000, 2000).

In the context of SGD in which the Department of Mineral Resources (DMR) would be the decision-making body, heritage impact assessments produced under NEMA (No. 107 of 1998, 1998) and according to the guidelines of Section 38(3) should be submitted to the relevant heritage authorities (see text box) for comment. In the event of free-standing HIAs being conducted (if a development application fails to trigger NEMA), then the heritage resources authorities would be the decision-making authority.

15.2 Key potential impacts and their mitigation

The various heritage resource types are likely to be affected to greatly differing degrees by the many activities that might occur during SGD. This is both because of their variable distribution across the study area and because of the varying degrees to which avoidance or other mitigation measures are likely to be attainable. The activities that could cause direct, negative impacts include driving seismic exploration vehicles across the landscape, the preparation of wellpads and the construction of roads, pipelines, water storage reservoirs, gas processing and storage facilities, Combined Cycle Gas Turbine (CCGT) power stations, transmission lines, substations, and staff accommodation. Indirect impacts may occur through earth tremors, vandalism and a general lack of maintenance of heritage resources. There is currently a lack of proper heritage management throughout much of the study area and this should be redressed in areas where SGD takes place. While a degree of organisation will be required amongst the authorities, formal mitigation measures that require implementation must, in terms of South African legislation, be commissioned at the expense of the developer.

15.2.1 Built heritage

The built heritage resources located in the study area are diverse and only patchily recorded. Assessment for SGD thus has the potential to reveal many as yet unknown sites. Built heritage is generally visible and can be avoided but, without assessment, there is the chance of direct, negative impacts that might occur through any of the activities listed above. Direct impacts would generally occur in rural areas where most structures are likely to be of Grade IIIB or IIIC significance. Clearing of land in preparation for development could result in direct destruction of built heritage, while indirect impacts could also result if activities are situated too close to fragile resources – this applies equally to new development (e.g. roads and wellpads) and upgrades of existing infrastructure. Even if built heritage resources are successfully avoided, they would remain vulnerable to vandalism and the risk becomes greater when more people are on site. Vandalism can result in low intensity impacts through, for example, breaking windows, but deliberate collapsing of fragile drystone structures, often to reuse the stone, presents a high intensity impact. Although relocation of people is not envisaged; indirect impacts can be exacerbated if people move away from their homes in order to avoid SGD. This would result in buildings not being maintained. Direct, negative impacts could be of medium to high intensity, but predicting the intensity of indirect impacts is very difficult, since human nature cannot be predicted and it is unknown to what degree earth tremors might occur if SGD is implemented. Should increased seismicity become a feature of the study area, then high intensity impacts could become widespread. All built heritage, including monuments and memorials, could be affected with impacts including cracking and partial or total collapse. Tall historical structures are especially vulnerable and damage may be irreparable. If seismic activity potentially great enough to result in widespread damage to fragile structures is expected; then this should be considered a fatal flaw.

Although it is expected that staff would be accommodated in purpose-built housing, the possibility of secondary industrial growth could well lead to impacts to towns. Population influx could have a positive impact on the built heritage (including townscapes) of both the study area and other settlements that lie along provisioning routes. The increased investment, if well managed, could reinforce economic and social structures that support built heritage and lead to appropriate restoration and maintenance practices. The potential economic injections could also be used to redress the legacies of apartheid planning still evident, and being perpetuated, in the townscapes of the study area. Poor management of investment, on the other hand, may result in uncontrolled development (from inappropriate planning approval or lack of heritage skills) that could negatively impact individual heritage structures and townscapes. An influx of new inhabitants unfamiliar with the maintenance of vernacular structures could bring about irreparable damage.

All impacts are permanent but some may be repaired to a degree. It should be noted that repairable damage is not insignificant: although it results in a smaller overall impact, it is not a preferred mitigation strategy. The degree to which impacts may be repaired, however, cannot be predicted during an impact assessment. Cumulative impacts are expected to increase dramatically as development progresses from Scenario 0 (Reference Case) to the Big Gas scenario. Should the study area remain in the Reference Case state, then many undiscovered heritage resources would continue to suffer from poor management and natural degradation. They would also be vulnerable to damage resulting from livestock, agricultural, ecotourism, mining and renewable energy development, inappropriate alteration and adaptive reuse, and the expansion of towns and related infrastructure. Also of concern, especially in rural areas, is the ongoing deliberate demolition of heritage structures to recover building materials that are either sold to the second hand market or used in new farm buildings or guest houses. Built heritage is the only aspect under consideration here that has direct financial value: although the heritage belongs to the state, people can still sell properties that have heritage buildings on them. Under the Reference Case, the already marginal economic feasibility of many built heritage resources could be further reduced to the extent that they could be lost.

Should development proceed, it is envisaged that the first stage of assessment would be the identification, mapping, and photographic recording of all exteriors of built heritage structures within and close to the relevant study areas by a suitably qualified consultant, commissioned by the developer. This would apply to all aspects of Exploration only to the Big Gas scenario and would likely occur initially during archaeological surveys. Recommendations could then be put forward for the detailed recording and assessment of all built heritage where it is deemed that a risk of impact exists. This latter assessment, also commissioned by the developer, should be carried out by a suitably qualified heritage practitioner familiar with the built heritage of the Karoo region and, where appropriate, should include those less prominent elements (like dry-stone walls, furrows and the built aspects of historic roads) scattered across the landscape and which form an integral part of the regional cultural landscape. Recording would include, among other things, photography, digital three dimensional scanning (African Conservation Trust, 2016), measured drawings, plaster sampling and possibly archaeological excavation. If built heritage is known and serviced appropriately during SGD, the potential exists for positive impacts (benefits) to occur. The option also exists, depending on the willingness of the developers, to commission a large-scale built heritage survey of broad areas due to be prospected. This would be costly (incorporating student researchers could mitigate cost) but could introduce several benefits: heritage knowledge would benefit substantially, the confidence levels of built heritage impact assessments would increase, and a standardised record of potentially vulnerable structures would be put in place that could serve as a benchmark for the evaluation of any insurance claims that may arise in the event of structural damage. In addition, it is likely to be the only viable partial mitigation measure (even though not entirely acceptable) should widespread damage occur as a result of tremors.

15.2.2 Archaeology and Graves

Because archaeological resources are so widespread across the study area, it is likely that many sites and artefact scatters will be directly and negatively impacted by surface activities related to SGD. Graves are less common, but are as much at risk, especially the many unmarked or minimally marked graves of precolonial people, farm workers, early colonists and victims of conflict that could be less easy to locate. Assessment of any development activities would very likely result in the recording of large numbers of previously unknown archaeological sites and occurrences. The various development activities listed above would require clearing of the land surface which would damage or destroy any archaeological material or graves occurring within the development footprint. It should be noted, however, that the majority of this material is likely to have limited scientific value and hence heritage significance (mostly Grade IIIC or Not Conservation Worthy (NCW)) but can still meaningfully inform the interpretation of larger scale patterns. Impacts to rock art could also occur. A minor consideration is the potential impact of quantities of dust (from drilling) settling on their surfaces, while the worst-case scenario could see rock art sites spalling or even collapsing as a result of seismic activity. Visual impacts to the setting of rock art sites are also a concern.

Impact intensity would generally be low-medium for the seismic exploration activities because of the relatively limited ground disturbance, but all other activities that physically break the land surface would result in high intensity impacts. All impacts are permanent. Indirect impacts could involve illegal collection of heritage objects and/or vandalism of archaeological sites. Ruined structures, rock art and graves are likely to be most at risk in this regard. These secondary impacts are likely to be of medium to high intensity and are generally permanent. All of the above impacts could occur in conjunction with any of the four scenarios and, because every archaeological site is unique, the intensity of impacts could vary more according to the discovered heritage resources than to the scenarios. However, as the sequence of potential development advances from the Reference Case through to the Big Gas scenario, the cumulative impacts will increase in intensity and extent. Other developments, such as renewable energy and mining, will also continue to impact on archaeology and graves, although micro-siting of infrastructure tends to avoid some impacts.

In the event of development proceeding, archaeological field studies would be required for all aspects of development because surface archaeological sites are very fragile and easily disturbed. It is expected that the surveys could generally recommend small locational adjustments of the relevant activities so as to avoid direct impacts to significant sites. Sites graded Grade IIIA or higher should be protected from harm, but if avoidance is not possible for Grade IIIB and IIIC sites, then mitigation involving excavation and collection by a suitably qualified and experienced archaeologist would be required at the expense of the developer. Insignificant sites (graded NCW) could be sufficiently recorded during the surveys with no further actions required before development. There is a chance that archaeological monitoring of construction work in certain areas may be required in order to identify any sites not visible at the surface. Graves should preferably be avoided and access to historic graveyards should never be blocked. Because unmarked graves are not easily located at the surface, it is possible that they may be uncovered during development. Should this happen, the remains would need to be protected, reported to the relevant authorities and then exhumed by a professional archaeologist before development continues. This should follow the process outlined in Chapter IX of the NHRA Regulations (National Heritage Resources Act 25 of 1999, Regulations R.548 of 2000, 2000). Archaeological impacts should not result in any fatal flaws, although there may be rare occasions where no-go areas need to be delineated to protect a particularly special resource for which mitigation is either not feasible or perhaps not the desired outcome from a heritage point of view.

15.2.3 Palaeontology, Meteorites and Geological heritage

While meteorites and designated geological heritage sites are generally rare (records for the latter are held by the CGS but are not published on SAHRIS), palaeontological resources are widespread both at and below the ground surface throughout the study area, with most of it considered highly sensitive on the SAHRIS palaeonsensitivity map (Figure 15.14). Since most scientifically useful fossils, rock exposures and meteorites are situated close to or at the surface, direct, negative impacts to fossils, geological sites and meteorites could occur through all of the same mechanisms outlined for archaeology above. Fossils may also be impacted by drilling through deeply-buried fossiliferous rocks (especially the carbon-rich mudrocks of the Whitehill Formation) during Exploration Only, and the Small and Big Gas scenarios. However, since such rocks and fossils are unlikely to ever be available for palaeontological study (with the exception of microfossils that can be extracted from drill cores), the impacts on them are not of concern in the present context.

Positive impacts can also result from SGD. For example, fresh road cuttings, borrow pits and borehole cores that are made available for scientific study promote geological and palaeontological knowledge. In the same way, any mitigation work carried out would enhance our understanding of Karoo geology and palaeontology. Because palaeontological material can be widely distributed within a particular rock unit (e.g. formation), which may have an outcrop area of tens to hundreds of square kilometres, impacts would likely be of low-medium intensity. They would, however, be permanent. Disturbance or destruction of key fossils – such as rare species or well-preserved, articulated specimens in their original geological context – or the designated type localities of fossil assemblage zones would represent localised, high-intensity impacts. Such localities are best avoided. Although just outside the study area, the extraordinary number of fossils discovered in a road cutting near Grahamstown (Van Rooyen, 2016) provides a dramatic example of a situation in which substantial palaeontological mitigation work may become necessary. Secondary negative impacts can also occur due to the influx of people who might illegally collect or disturb fossils. Like many archaeological artefacts, the value of a fossil often lies as much in its provenance (geographic, stratigraphic and sedimentological setting) as in the object itself. Because fossils are often difficult to recognise, these secondary impacts are likely to be of low intensity but are permanent. Meteorites and geological heritage sites are rarely identified, so impacts to them are difficult to assess and address. Relevant sites would need to be identified during EIA studies. Meteorites could be collected, while geological sites would need to be mapped and avoided. All of the above impacts could occur in conjunction with any of the three development scenarios, although it is likely that the intensity of impacts will be greater as the level of SGD increases. The cumulative impacts would also increase as development progresses from Exploration Only to the Big Gas scenario.

Should development proceed, palaeontological field studies would be required during EIA studies for all aspects of development. For Exploration Only, a desktop study may be sufficient, however, unless extensive surface clearance, building of roads or substantial bedrock excavation is expected. Avoiding all sensitive palaeontology is generally not feasible and it is expected that recording and judicious sampling of representative surface or near-surface fossil material within the development footprint will sometimes be required before construction for Grade IIIB and IIIC material. Monitoring of excavations may still be recommended in certain sensitive areas to record subsurface geological and palaeontological data. Should the monitoring palaeontologist discover highly significant fossil material then it is likely that work would need to stop in order to allow for appropriate recording and collection by a suitably qualified and experienced palaeontologist. All such work is commissioned at the expense of the developer. Largely because of the positive impacts expected from such mitigation, palaeontological issues should not result in any fatal flaws.

15.2.4 Living heritage

Living heritage occurs throughout the study area but, because of its generally intangible nature, it is unlikely to be heavily impacted by SGD. Certain places will have very strong links to living heritage, especially where it informs land use and settlement patterns. Water sources associated with indigenous mythology are also important. In such instances direct negative impacts to the physical manifestations of living heritage could occur, but the majority of traditions, memories and customs are not tied to specific places and should not be unduly impacted. Two exceptions are noted: traditional knowledge related to the pastoral way of life is poorly recorded and can be easily lost when left unpractised, and the *Karretjie Mense*, with their fragile economic base could easily be forced to abandon their traditional practices. The conversion of sheep farms to game farms, for example, is already eroding traditional knowledge and taking people off the land. Should people choose to leave the SGD area then this will also remove the knowledge and cultural continuity that has been accumulated over many generations of Karoo family history. An influx of large numbers of non-local people, particularly speakers of ‘non-Karoo’ languages, might result in secondary impacts to local traditions and customs because of new equivalents being introduced. Generally, impacts to living heritage are likely to be unimportant, but some impacts may be of great concern to certain groups or in specific places. While Exploration Only should not result in many impacts, cumulative impacts are likely to worsen with the Small and Big Gas scenarios because of the larger areas of land being transformed, the potential greater influx of non-local people and the changes to the economic base of the developed areas. The Reference Case has minimal impact.

Mitigation of impacts to most living heritage could not be meaningfully attained, although during any EIA work it would be necessary to ascertain if there are specific places that have social significance and then determine practical measures to avoid erosion of that significance. This can be achieved through interviews with local inhabitants. Interviews could also be conducted if farms are sold so that any links to living heritage that are known to the inhabitants can be recorded prior to them leaving the land. A readily implementable mitigation measure is to use local names, or names derived directly from local culture (in its broadest sense) to name components of the developments like production areas or housing schemes. The introduction of non-local names should be avoided.

15.2.5 Cultural landscapes

Cultural landscapes are ubiquitous across the study area. The rural Karoo landscape contrasts strongly with the overtly industrial nature of SGD such that it could be easily disrupted by the occurrence of incompatible activities, especially from the longer-term Small and Big Gas scenarios. With the exception of the renewable energy facilities located in certain parts of the Karoo, the prevailing local activities are overwhelmingly related to farming, especially pastoralism. Extensive tracts of land also have wilderness qualities. Physical features of the cultural landscapes, such as fence lines, tree rows, livestock drovers' routes, old wagon routes and agricultural lands can also be physically disturbed. Some of these features are very ephemeral and thus vulnerable to inadvertent damage. Another impact of concern is the potential for the uncontrolled expansion of towns if many new workers need to be accommodated or if secondary industry develops to service SGD. Erosion of the integrity of the historical layouts and inappropriate adaptive reuse of historical structures are potential concerns that can impact townscapes. Although it is noted that the workforce would most likely be accommodated in purpose-built villages close to the development blocks, it may well become feasible to rather expand town areas if, after exploration, a development block was placed close to a town. The impacts could be direct and negative, although there is the potential for a positive impact if good planning is employed. Streetscapes could be enhanced and new life brought to towns that are struggling economically. Because of the short duration of the visual intrusions related to the Exploration Only scenario and the relatively light footprint of the associated activities, the impact intensity for exploration is likely to be low. However, a progression to Small and Big Gas would likely result in high intensity impacts within the 30 x 30 km development blocks, especially in river valleys, and medium intensity impacts to areas within several kilometres around them. The latter distance would vary depending on topography and would be informed by the visual studies. If development occurs in areas visible from great distances, then impacts of medium to low intensity could be experienced still further away. Although drilling rigs are incompatible with the agricultural landscape and highly visible due to their height, a relatively small number would be employed within the development block with each well taking about one month to drill. Impacts would thus be of short duration. The longer term impacts of concern are the alteration of the landscape through clearing and levelling of the many wellpads and access roads that would be required.

Should development proceed, then it is likely that studies investigating the visual impacts to the cultural landscape would be required in order to inform the potential delineation of no-go areas. This is because impacts to the cultural landscape tend to relate more to visual intrusion with the physical impacts to components of the landscape being less concerning. Mitigation measures could include shifting the locations of wellpads and access roads away from sensitive parts of the landscape, and avoiding road alignments that cut across contours and are visible from greater distances. Minimising the length of access roads will be important, although reducing cut and fill operations should be a priority. Wellpads should preferably be located in slight depressions in the landscape or areas that will be easy to rehabilitate. Impacts to the cultural landscape could be seen in a serious light by the heritage authorities but, with every attempt made to reduce visual impacts and good rehabilitation plans in place, it should not be a fatal flaw.

15.3 Risk assessment

15.3.1 How the risks are measured

15.3.1.1 <u>Built heritage</u>

The potential number and cultural significance of built heritage sites that could be impacted is important, although hard to predict. An intact but unused corbelled or stone-walled house in a remote location could have just as much cultural significance as a well-maintained historic hotel in Beaufort West or Graaff-Reinet. Also, significant heritage sites are distributed in varying concentrations throughout the study area. Because of the low level of survey coverage of the region, we are forced to extrapolate the potential density of built sites from better-known areas which makes it unfeasible to distinguish low and high risk parts of the study area. A consideration of the landscape to be impacted assists in this regard because in undulating terrain historic structures tend to be located in valley bottoms close to patches of alluvial soil, while in open areas far from topographic relief such sites are less predictable, especially because boreholes allowed settlement to occur on the plains away from rivers after the mid-19th century. The degree to which the likely locations of rural built heritage features, and the risk to them, can be predicted is thus variable. More reliable are towns and the structures related to road and rail transport. It is thus necessary to make some broad assumptions regarding the potential density of built heritage when measuring the risk.

There are very few areas that have not seen historical settlement and we thus do not expect any parts of the study area to be particularly exempt from risk – these would require consideration during HIA reporting. Significance of individual heritage resources and ensembles such as towns and farmsteads, is not based solely on typological and architectural aspects, but includes consideration of authenticity, historical layering, rarity, representivity, associations and relationship with setting. The latter is surprisingly vulnerable and demands careful consideration. The significance of heritage resources can be compromised or even destroyed by changes to their setting, whether these relate to sights, sounds or even smells. There is also a management risk stemming from both poor quality HIA reporting (many assessments focus on archaeology) and the likelihood that formal comments on built heritage and cultural landscapes in the Northern and Eastern Cape Provinces may not be forthcoming from the respective Provincial Heritage Resources Agencies (PHRAs) because of lack of capacity – this lack of capacity poses a direct threat to heritage resources. Proper mitigation and management measures pertaining to built heritage may therefore never be carried through into Environmental Authorisations (EAs).

Therefore, in general, three factors inform the measurement of risk in relation to built heritage:

- Undulating landscapes – particularly those containing river valleys and alluvial floodplains – are likely to pose a somewhat higher risk. Although open areas also pose risks, these are less predictable and can occur anywhere in the study area;
- The more vehicles, people and activity occurring within the landscape, the higher the risk to built heritage resources is likely to be; and
- Parts of the study area are potentially susceptible to less rigorous assessment, mitigation and management of built heritage because of the limited capacity of some heritage resources authorities.

15.3.1.2 Archaeology

In the case of archaeology, the potential number and cultural significance of sites that may be affected is important. Because of the low level of survey coverage of the region, an assessment of the landscape to be impacted and thus the potential density of archaeological sites present is the most reliable way to determine these risks. This is because throughout the drier parts of South Africa a greater number of sites with higher significance is expected to occur in the vicinity of landscape features like river valleys, pans, dolerite outcrops and cliffs than would be the case in open, less protected situations far from water and shelter. More than half of the study area has undulating terrain (including dolerite outcrops) in which a greater density of archaeological sites might be expected. It is this aspect that is used to map higher and lower sensitivity areas for the risk assessment. Graves could occur anywhere and, while precolonial graves are more likely to occur close to habitation sites, historical graves, if not located alongside farmsteads, may be in far more open contexts. The risks posed by graves are thus less easily assessed, although graves are likely to be very sparsely distributed on the landscape. It is assumed that the risk mapping for archaeology will approximate the risk for graves.

Therefore, in general, two factors inform the measurement of risk in relation to archaeology and graves:

- Rocky areas and more undulating landscapes – particularly those containing river valleys and alluvial floodplains – are likely to pose a far higher risk than flat, open plains that lack landscape features; and
- The more vehicles, people and activity occurring within the landscape, the higher the risk to archaeology and graves is likely to be.

15.3.1.3 <u>Palaeontology, Meteorites and Geological heritage</u>

Palaeontological resources of high sensitivity occur throughout most of the study area which means that risk will be virtually unavoidable. Many important palaeontological and geological type localities exist and such areas should be seen as very highly sensitive because of their established scientific value. Because of the low level of survey coverage of the region, the surface distribution of fossil heritage is not well known in detail. All the formations within the Beaufort Group as well as the Whitehilll Formation of the Ecca Group (the principal target of SGD) are rated as highly sensitive, for example. The Beaufort Group underlies the majority of the study area, approximately one third of which has yielded a high density of vertebrate fossil sites (Figure 15.16). It should be noted that palaeosensitivity maps are a very useful scoping tool but tend to exaggerate the palaeosensitivity of some rock formations in parts of their outcrop area by not taking into account factors such as levels of tectonic deformation, weathering, metamorphism and level of surface exposure. Furthermore, small-scale sedimentary units such as ancient alluvial deposits, *vlei* and pan sediments that locally may be highly fossiliferous are not usually represented on available palaeosensitivity maps. Nevertheless, to map risk we have taken all areas of high and very high sensitivity on the SAHRIS PalaeoSensitivity Map as higher risk and the remainder (rated as zero to moderate sensitivity) as lower risk. Intrusive works, like cut and fill operations for road construction or borrow pits, are likely to have the greatest impact, but negative risks are moderated by the degree of potential positive impact that might result from these works. Because of the relative scarcity of meteorites and geological heritage sites (i.e.

extremely low density and spatial coverage within the study area), these aspects of heritage are not expected to pose much risk.

Therefore, in general, two factors inform the measurement of risk in relation to palaeontology:

- The inferred palaeosensitivity of the bedrocks within the study area will indicate areas of higher and lower risk; and
- The more surface clearance or earthmoving that is required in the construction of, for example, access roads, the higher the risk to palaeontology is likely to be. Note that scientific study of cuttings and clearings may also result in positive impacts (benefits) to palaeontological and geological heritage.

15.3.1.4 Living heritage

Quantifying the amount of living heritage that exists in the study area, and hence the risk to it, is impossible. However, significant impacts are relatively unlikely with the result that risk is likely to remain low. This study reveals three possible sources of risk related to the loss or contamination of places associated with living heritage (especially water sources), large-scale influx of non-local populations and the possible loss of local family history should people choose to leave the area rather than live with SGD happening around them.

Three factors inform the measurement of risk in relation to living heritage:

- Risk will increase if contamination of or loss of access to water sources occurs;
- Risk will increase in the event of large-scale population influx; and
- Risk will increase should long-standing local residents choose to leave the Karoo.

15.3.1.5 Cultural landscapes

Because cultural landscapes occur throughout the study area, risk will be experienced in all parts of it. However, certain landforms and areas are more susceptible. Areas more conducive to farming, especially agriculture, generally contain the more developed rural landscapes – such areas are invariably close to reliable water sources. River valleys containing alluvial soils are particularly susceptible because of their contained nature and predisposition for historic and prehistoric settlement. Areas visible from a distance, especially steeper or undulating terrain, will present higher risk because of the greater possibility for perception of impact due to visible landscape scarring from, among other things, cut and fill operations that might be required to create access roads and wellpads. Town contexts are less likely to be impacted visually by fracking because of the buffers that would be imposed but could still be affected by poor planning if they expand. Risk will be higher in proximity to landscapes possessing high cultural significance (as per Section 2(vi) of the NHRA) but this will vary based on the degree of intactness, representativity and layering and the presence of screening topography. Such factors must be incorporated into HIA assessments.

Therefore, in general, four factors inform the measurement of risk to cultural landscapes:

- Undulating landscapes – particularly those containing river valleys and alluvial floodplains – are likely to pose a high risk;
- Steep terrain where landscape scarring could be visible from a distance will pose high risk;
- Areas that were the focus of historical occupation pose high risk; and
- Intact rural and wilderness landscapes with minimal modern/industrial disturbance pose high risk.

15.3.2 Limits of acceptable change

Although every heritage resource and ensemble is considered unique and, in most cases, negative change to either their fabric or setting are undesirable, it is recognised that change must happen in order to allow for development. Although unauthorised alteration, disturbance, destruction or removal of any heritage resource is a criminal offence and entirely unacceptable when unmitigated, the impact assessment process is there to guide the degree of change that might be acceptable for any given heritage resource and to establish under what circumstances such change would be permitted. Because of the uniqueness and greatly variable heritage significance of individual heritage resources, and the uniqueness of their settings and the important vistas towards and from them, it is not possible to make sweeping statements as to the degree of change that is acceptable. Likewise, mapping of areas of higher or lower risk is difficult because significant resources can occur anywhere in the study area and, should seismic activity be a consequence of SGD, the location and timing of impacts cannot easily be assessed. Furthermore, in recognising the occasional need for change, the NHRA, under Section 38(3)(d), requires an evaluation of impact relative to the sustainable social and economic benefits to be derived from the development in order to allow for the fact that human needs take preference over those of heritage. This means that any limit discussed here would need to be reviewed in context during an impact assessment. The limits discussed below are based on a combination of experience, precedent and established regulations, and should be authorised and implemented under an EA.

15.3.2.1 <u>Built heritage</u>

For direct impacts to built heritage, very little change can be deemed acceptable because this aspect is one of the most tangible and accessible aspects of heritage and adequate mitigation of high significance resources is generally impossible. Of course there are many built heritage resources that are in very poor condition due to neglect, inappropriate renovation and/or adaptive reuse, and their alteration or demolition may be acceptable. During field assessment decisions would need to be taken based on condition, rarity, representivity and setting as to which resources and their constituent attributes could be altered or destroyed if necessary, and the degree of prior investigation and recording that might be required. Change would only be allowed in exceptional circumstances if it is impossible to avoid the resource. At a broader level, any long-term infrastructural development that disrupts the setting, character and sense of unity of a built heritage resource or precinct would be unacceptable. Particularly important in this regard is the potential for insensitive industrial development in support of SGD that could occur in or on the peripheries of intact historic towns with a strong sense of place. Any widespread damage to built heritage resources that might occur through induced seismic activity or any other SGD related activity would be considered entirely unacceptable in heritage terms and, should the possibility of such widespread damage be expected then this may be considered a fatal flaw.

15.3.2.2 Archaeology and graves

Field experience has shown that the majority of recorded archaeological heritage resources (>90%) are of low heritage significance and can be destroyed without undue negative impact to the National Estate. A small proportion of these would require mitigation, while the remainder could be suitably recorded during the EIA Phase. Because of the unique nature of archaeological resources, degrees of change are not an appropriate measure – they should either be conserved or else destroyed, either with or without mitigation depending on their significance. Unacceptable change would therefore be if those sites set aside for *in situ* preservation (the other <10%) are disturbed or if sites requiring mitigation are disturbed prior to that mitigation being effected. By necessity, archaeological heritage resources that do not have formal protections (declaration or grading) in place or have not been identified during earlier assessments can only be identified at the EIA Phase. Only then could the number of sites requiring further attention be delineated for any particular area.

15.3.2.3 Palaeontology

Field experience has shown that the majority of identified palaeontological heritage resources (> 90%) are of comparatively low heritage significance and can be destroyed without undue negative impact to the National Estate. A small proportion of identified fossil sites would require mitigation (*i.e.* collection or protection *in situ*), while the remainder could be suitably recorded during the EIA Phase. The nature of palaeontological resources – the majority essentially hosted by large-scale geological units that can vary spatially in palaeontological sensitivity – means that degrees of change cannot be meaningfully suggested. Unacceptable change would apply if those exposed geological sections / palaeontological sites set aside for *in situ* preservation (the other <10%) are damaged or disturbed, or if sites that require mitigation are disturbed prior to that mitigation being effected. Of necessity, palaeontological heritage resources that do not have formal protections (declaration or grading) in place, or that have not been identified during earlier assessments, can only be identified at the EIA Phase. Only then could the number of sites requiring further attention be delineated for any particular area. Formally recognised geological heritage sites and meteorites are very rare in comparison to other types of heritage. While meteorites can be recorded, collected and housed in a museum, geological sites and palaeontological type localities derive their meaning from their location and can therefore not be adequately mitigated; their destruction would be unacceptable unless equally good equivalents can be designated.

15.3.2.4 Living heritage

Because of its intangible nature, most living heritage should survive in the face of development. However, with large-scale population influx, new cultural traditions could arrive and possibly influence the degree to which local traditions continue to be practised. Marginalised communities like the Karretjie People are already struggling and with the addition of a new economic driver these communities would be particularly vulnerable. Unacceptable change would occur should local traditions, practices and customs be abandoned or forced out in favour of non-local ones. The addition of a new living heritage layer would not be unacceptable though. The irreparable damage to a place that has strong associations with living heritage, such as a water hole, would also be regarded as unacceptable change.

15.3.2.5 Cultural landscapes

Cultural landscapes cannot be destroyed but their integrity is eroded and their character changed through inappropriate development. The degree of erosion is impossible to quantify and universal limits cannot be set. This is partly due to the very personal nature of one’s perception of the landscape and the amount of inter-observer variability that would result. Given the degree of variation in topography, vegetation cover, land use, settlement patterns and other cultural factors involved in the creation of cultural landscapes, it is likely that, given a consistent observer, the limits of acceptable change would also be strongly variable across space. In general, however, the wellpads and access roads should be sited in such a way as to not become the focus of attention when viewed from the middle to long distance. Because impacts to the cultural landscape are largely visual in nature and very variable across space, the limits of acceptable change would need to be set through the application of viewshed analysis with appropriate visual buffers established on a case-by-case basis during EIA studies.

It is also necessary to consider that the merino sheep and the wind pump massively changed the cultural and economic landscape of the Karoo at the time of their introductions and are now revered as heritage. The landscape has also been changed by the ongoing addition of an astronomical layer which also has cultural significance. The introduction of SGD would introduce yet another new layer to the cultural landscape. However, this new layer would need to be carefully managed in order to maintain the complexity of the historical layering.

15.3.2.6 No-go areas

The no-go areas and buffers identified in this scientific assessment pertain to surface disturbance and risk to tangible heritage fabric only and are a guideline. Larger or smaller buffers may be determined during EIA studies depending on the specific resource, its setting, any shielding topography that may occur, and the nature of any possible threats to the resource. The buffers suggested are based on previously established precedents (see for example CNdV Africa, 2006; Fourie et al., 2014) but modified at times because of the greater amount of activity expected (for example around wellpads) over longer periods of time (Table 15.3). Built heritage buffers are informed by Durrheim et al. (2016). The categories include known sites and areas as well as those that may be identified during EIA studies. Note that many archaeological heritage resources in this arid environment will likely be protected by the already gazetted buffers from riparian areas (500 m) and wetlands (1 km) (MPRDA, No 28 of 2002, Regulation 2015).

Table 15.3: No-go areas.

Category	**Applicable buffer**
All sites/areas formally protected under the NHRA (see Digital Addendum 15B). • National and Provincial Heritage Sites; • Grade I, Grade II and Grade IIIA sites; • All heritage register sites (in Northern Cape and Eastern Cape). (Note that declarations can be of individual sites, land areas or groups of sites and in the latter case could fall within multiple administrative areas). Buffers should extend from the edge of the declared area.	> 10 km minimum for wellpads. > 1 km for other activities. Impact on setting to be evaluated on an individual basis.
All urban areas for their individual resources and townscapes (note that additional buffering should be determined in consultation with a seismologist during EIA/HIA phase)	> 10 km minimum for wellpads. Impact on setting to be evaluated on an individual basis.
Other built heritage resources requiring *in situ* conservation (note that additional buffering should be determined in consultation with a seismologist during EIA/HIA phase)	> 10 km minimum km for wellpads. > 500 m for all other related infrastructure. Impact on setting to be evaluated on an individual

Category	Applicable buffer
	basis.
Other archaeological sites, graves and graveyards requiring *in situ* conservation (note that additional buffering of fragile rock art sites should be determined in consultation with a seismologist during EIA/HIA phase)	> 50 m from all activities.
Other palaeontologically sensitive areas. Extensive buffering of very high sensitivity areas (e.g. Fourie et al., 2014) is unlikely because of the potential benefits that might occur through SGD, but limited areas (especially areas of unconsolidated sediment like pans and alluvial terraces) may be delineated in the field for exclusion.	> 50 m from all activities.
Cultural landscapes cannot easily be defined from the desktop. The visual sensitivity of the landscape (see Oberholzer et al., 2016) serves as the best proxy but would require moderation at EIA phase. They do not always require buffering and development within certain cultural landscapes may be permissible on a case-by-case basis depending on topographic shielding. The same applies to scenic routes and passes.	Variable but suggest > 5 km from wellpads and other visually intrusive components for highly sensitive landscapes. Impact on setting to be evaluated on an individual basis.
Living heritage is not conducive to the establishment of buffers. No-go areas may be suggested by EIA studies.	Impact to be evaluated on an individual basis.

15.3.2.7 <u>Risk assessment table</u>

Table 15.4 indicates the assessed risks in terms of the impacts to various categories of heritage resources. The majority of assessments are indicated as of low or very low risk after mitigation. Those with higher levels of risk are generally those for which mitigation will still result in a residual impact, often because mitigation is difficult to implement. The cultural landscape is the most problematic but it should be borne in mind that the study area is large and the indicated assessment would only pertain to the eventual area(s) chosen for development if highly significant landscapes were impacted. This aspect is probably the only one for which a greater risk could be expected with development greater than the Big Gas scenario. For the rest the risk would be similar but occurring over a greater extent. The assessment is based on the expected consequence of impacts (explained in Table 15.5) and the likelihood of them occurring. The areas listed under Location are mapped in Figure 15.20 to 15.24.

A number of notes are provided to assist with the interpretation of the risk assessment:

- All impacts are seen as accumulative. That is, even though the impacts of the specific activities related to Exploration Only may, in some instances, be of less consequence than those relating to the Reference Case, the level of risk cannot be lower in the Exploration Only scenario. This is particularly relevant to the built environment and palaeontology where the impacts from illegal demolition of rural buildings and the construction of renewable energy facilities respectively (Reference Case) are likely to be worse than those from shale gas exploration (Exploration Only).
- Because the consequences of impacts could vary greatly within each category of heritage, the consequence levels assigned in Table 15.4 reflect an expected ‘average’ consequence.

- It is assumed that mitigation of direct impacts would be relatively successful, usually through micro-siting, but that indirect impacts, predominantly vandalism, would be difficult to control.
- For the Reference Case it is assumed that the present pace of urban growth, livestock and game farming, and ecotourism, mining and renewable energy development would continue into the foreseeable future and that most impacts would be as a result of these types of development. In addition, the continuing impact of ignorance results in the loss of many heritage resources that have little or no perceived value to the owner but yet which form part of the National Estate. These impacts occur, for example, through demolition, renovation or unregulated land use changes.
- In the case of palaeontology and geological heritage, negative impacts are, to a large degree, offset by positive impacts – provided that appropriate mitigation measures are fully implemented – which helps keep the risk lower. Other areas, like wetlands and alluvial terraces, are too small to be mapped on 1:250 000 geological maps. Their partial protection is anticipated through the already gazetted water resource buffers but this would not apply to ancient defunct drainage systems.
- With regards to the mapping of different levels of sensitivity across the study area for the risk assessment, the following observations are made:
    - For built heritage we consider all areas within 10 km of towns and settlements as high sensitivity although it is likely that this area could be reduced substantially on a case-by-case basis during EIA Phase studies. The remaining areas are considered as being of medium sensitivity. It has been necessary to separate the impacts to built heritage that might occur through earth tremors from all other impact sources because the risk from tremors is impossible to compare with other sources of risk. This is because of the unpredictability of earth tremors and the fact that they could have widespread, extreme impacts that are difficult or impossible to mitigate. Durrheim et al. (2016) have considered the occurrence of a seismic event due to a fracking within 10 km of a town to have potentially severe consequences, and state that fracking is very unlikely to induce such an event. Only one risk assessment is provided in relation to earthquakes for the entire study area (with no specific sensitivity) because the potential risk is very difficult to accurately quantify.
    - For archaeology (including and graves) the plains and low foothills present an environment that is generally of low to medium sensitivity, while the uplands with their variable topography, rock outcrops and more prominent river valleys present far more opportunity for precolonial and historical occupation and are considered highly sensitive.

- For palaeontology, we have used the SAHRIS PalaeoSensitivity Map with all areas denoted high and very high sensitivity being mapped and assessed as highly sensitive for the purposes of this assessment and the remainder as low sensitivity. Geological heritage and meteorites are neither mapped nor assessed because they are too rare to merit meaningful assessment.
- Living heritage occurs throughout the study area and, because significant impacts are unlikely, we have assessed the entire study area as low sensitivity.
- For cultural landscapes we have provided a single sensitivity class with the entire study area considered to be highly sensitive because the identification and interpretation of this aspect will vary greatly among specialists and authorities alike. This is therefore a cautious approach. We recommend that the visual sensitivity synthesis be consulted as a proxy for where cultural landscapes are more likely to be found but note that all parts of the study area could still be seen as sensitive.

- Because every heritage resource is unique, the potential exists for impacts of varying consequence. The levels indicated reflect the probable 'average' consequence in each case.

Table 15.4: Risk assessment.

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Impacts on built heritage, monuments & memorials (all impacts except earth tremors)	Reference Case	High sensitivity areas (land less than 10 km from towns and settlements)	Moderate	Likely	Low	Moderate	Unlikely	Low
	Exploration Only		Moderate	Likely	Low	Moderate	Unlikely	Low
	Small Gas		Substantial	Very Likely	Moderate	Substantial	Likely	Moderate
	Big Gas		Severe	Very likely	High	Substantial	Likely	Moderate
	Reference Case	Medium sensitivity areas (land more than 10 km from towns and settlements)	Moderate	Likely	Low	Moderate	Unlikely	Low
	Exploration Only		Moderate	Likely	Low	Moderate	Unlikely	Low
	Small Gas		Moderate	Likely	Low	Moderate	Unlikely	Low
	Big Gas		Substantial	Likely	Moderate	Moderate	Unlikely	Low
Impacts on built heritage, monuments & memorials (earth tremors only)	Reference Case	All areas	Extreme	Extremely unlikely	Very low	Extreme	Extremely unlikely	Very low
	Exploration Only		Extreme	Very unlikely	Low	Extreme	Unlikely	Low
	Small Gas		Extreme	Unlikely	Moderate	Extreme	Likely	Moderate
	Big Gas		Extreme	Likely	High	Extreme	Likely	High
Impacts on archaeology & graves	Reference Case	High sensitivity areas (uplands and areas with highly variable topography)	Substantial	Unlikely	Moderate	Moderate	Extremely unlikely	Very low
	Exploration Only		Severe	Likely	High	Substantial	Very unlikely	Low
	Small Gas		Severe	Likely	High	Substantial	Very unlikely	Low
	Big Gas		Severe	Very likely	High	Substantial	Very unlikely	Low

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
	Reference Case	Medium and low sensitivity areas (foothills and areas with undulating topography)	Moderate	Likely	Low	Slight	Extremely unlikely	Very low
	Exploration Only		Substantial	Likely	Moderate	Slight	Unlikely	Low
	Small Gas		Substantial	Likely	Moderate	Substantial	Very unlikely	Low
	Big Gas		Severe	Likely	High	Substantial	Very unlikely	Low
	Reference Case	Low sensitivity areas (lowlands and plains)	Moderate	Unlikely	Low	Slight	Very unlikely	Very low
	Exploration Only		Substantial	Very unlikely	Low	Slight	Very unlikely	Very low
	Small Gas		Substantial	Very unlikely	Low	Slight	Very unlikely	Very low
	Big Gas		Severe	Very unlikely	Low	Slight	Unlikely	Very low
Impacts on palaeontology, meteorites & geological heritage	Reference Case	High sensitivity areas	Moderate	Likely	Low	Slight	Unlikely	Very low
	Exploration Only		Moderate	Likely	Low	Slight	Unlikely	Very low
	Small Gas		Substantial	Likely	Moderate	Slight	Unlikely	Very low
	Big Gas		Substantial	Likely	Moderate	Moderate	Likely	Low
Impacts on palaeontology, meteorites & geological heritage	Reference Case	Low sensitivity areas	Slight	Likely	Very low	Slight	Unlikely	Very low
	Exploration Only		Slight	Likely	Very low	Slight	Unlikely	Very low
	Small Gas		Slight	Likely	Very low	Slight	Unlikely	Very low
	Big Gas		Substantial	Likely	Moderate	Moderate	Unlikely	Low
Impacts on living heritage	Reference Case	All areas	Slight	Extremely unlikely	Very low	Slight	Extremely unlikely	Very low
	Exploration Only		Slight	Very unlikely	Very low	Slight	Extremely unlikely	Very low
	Small Gas		Slight	Very unlikely	Low	Slight	Extremely unlikely	Very low
	Big Gas		Moderate	Very unlikely	Moderate	Slight	Extremely unlikely	Very low
Impacts on cultural landscapes	Reference Case	All areas	Substantial	Likely	Moderate	Moderate	Likely	Low
	Exploration Only		Substantial	Likely	Moderate	Moderate	Likely	Low
	Small Gas		Severe	Likely	High	Substantial	Likely	Moderate
	Big Gas		Extreme	Very likely	Very high	Severe	Very likely	High

Table 15.5: Definitions of consequence levels. They combine significance (here measured through grading) and degree of impact. Note that Phases 1 and 2 refer to the impact assessment and mitigation phases respectively and that grades refer to formal and proposed grades (see text box in Section 15.1.1.2).

Consequence	Definition
Built heritage	
Slight	A NCW site is demolished without basic recording at Phase 1.
Moderate	A Grade IIIC site altered without detailed recording at Phase 2.
Substantial	A Grade IIIC site is demolished without detailed recording at Phase 2. A Grade IIIB site is altered without detailed recording at Phase 2. Medium significance negative impacts to the setting of one of the above or a conservation-

Consequence	Definition
	worthy town or protected area.
Severe	A Grade IIIB site is demolished without detailed recording at Phase 2. A Grade IIIA site is altered without detailed recording at Phase 2. A Grade I, II or IIIA site set aside for *in situ* conservation is damaged. High significance negative impacts to the setting of one of the above or a conservation-worthy town or protected area.
Extreme	A Grade I, II or IIIA site set aside for *in situ* conservation is destroyed. The setting of one of the above or a conservation- worthy town or protected area is changed to such an extent that the value of such is irrevocably destroyed.
Archaeology & Palaeontology	
Slight	A NCW site is destroyed without basic recording at Phase 1.
Moderate	A Grade IIIC site damaged without recording/sampling/excavation at Phase 2.
Substantial	A Grade IIIC site is destroyed without recording/sampling/excavation at Phase 2. A Grade IIIB site is damaged without recording/sampling/excavation at Phase 2.
Severe	A Grade IIIB site is destroyed without recording/sampling/excavation at Phase 2. A Grade IIIA site is damaged without recording/sampling/excavation at Phase 2. A Grade I, II or IIIA site set aside for *in situ* conservation is damaged.
Extreme	A Grade I, II or IIIA site set aside for *in situ* conservation is destroyed.
Living heritage	
Slight	An element of living heritage or an associated place is slightly affected.
Moderate	Multiple elements of living heritage or associated places are slightly affected.
Substantial	One or more elements of living heritage or associated places are significantly affected.
Severe	An element of living heritage or an associated place is completely eliminated or irreparably damaged.
Extreme	Multiple elements of living heritage or associated places are completely eliminated or irreparably damaged.
Cultural landscapes	
Slight	The cultural landscape is NCW. A Grade IIIC cultural landscape is compromised in limited areas such that development is barely noticeable or only visible from certain places. A Grade IIIB cultural landscape adequately screens or absorbs development.
Moderate	A Grade IIIC cultural landscape is compromised such that development becomes distinctly noticeable in the landscape. A Grade IIIB cultural landscape is compromised in limited areas such that development is barely noticeable or only visible from certain places. A Grade IIIA cultural landscape adequately screens or absorbs development.
Substantial	A Grade IIIC cultural landscape is heavily compromised such that development becomes a focus of attention. A Grade IIIB cultural landscape is compromised such that development becomes distinctly noticeable in the landscape. A Grade IIIA cultural landscape is compromised in limited areas such that development is barely noticeable or only visible from certain places.
Severe	A Grade IIIB cultural landscape is heavily compromised such that development becomes a focus of attention. A Grade IIIA cultural landscape is compromised such that development becomes distinctly noticeable in the landscape.
Extreme	A Grade IIIA cultural landscape is heavily compromised such that development becomes a focus of attention. A Grade I or II cultural landscape is compromised in any way by development.

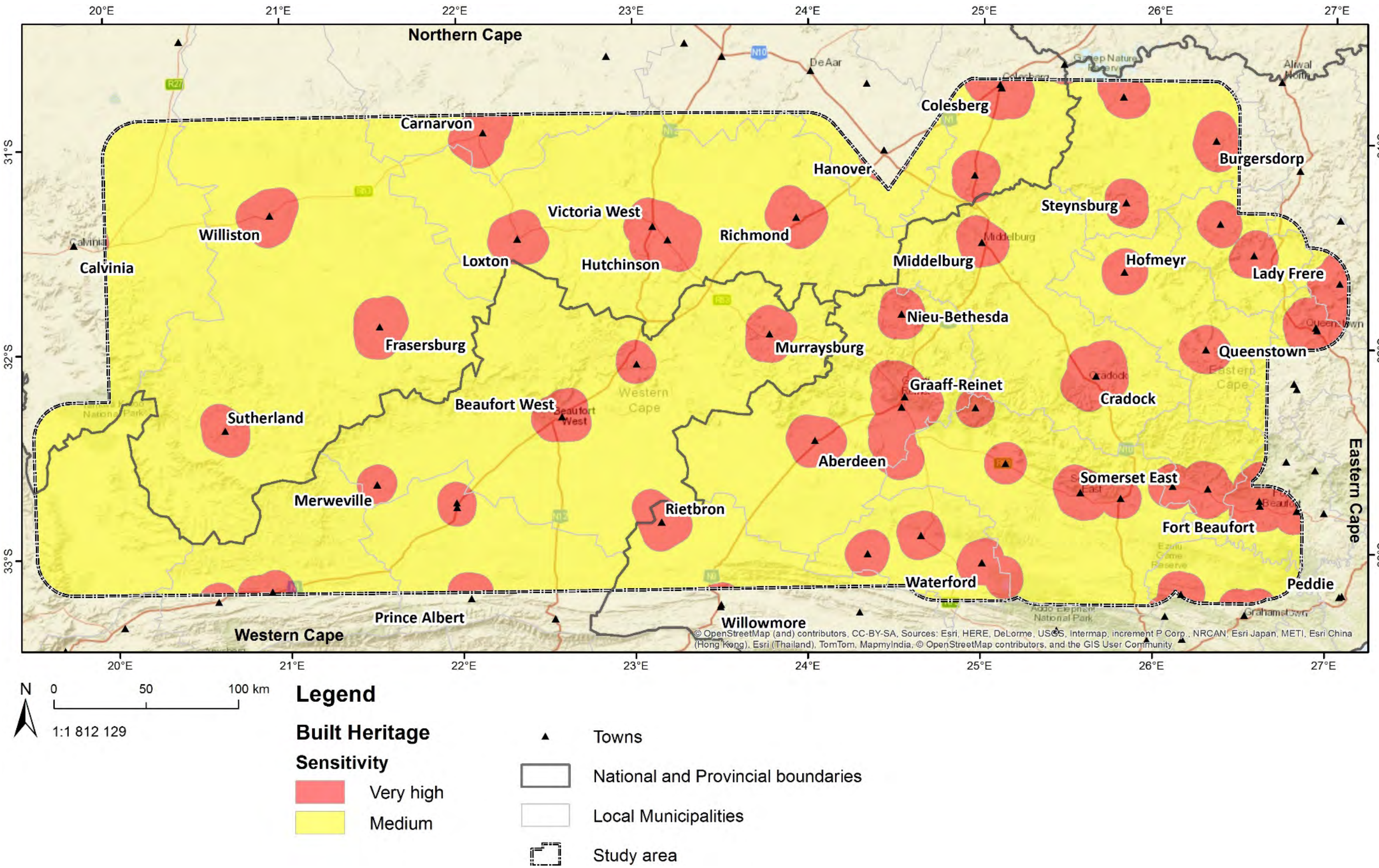

Figure 15.20: Sensitivity mapping for built heritage resources.

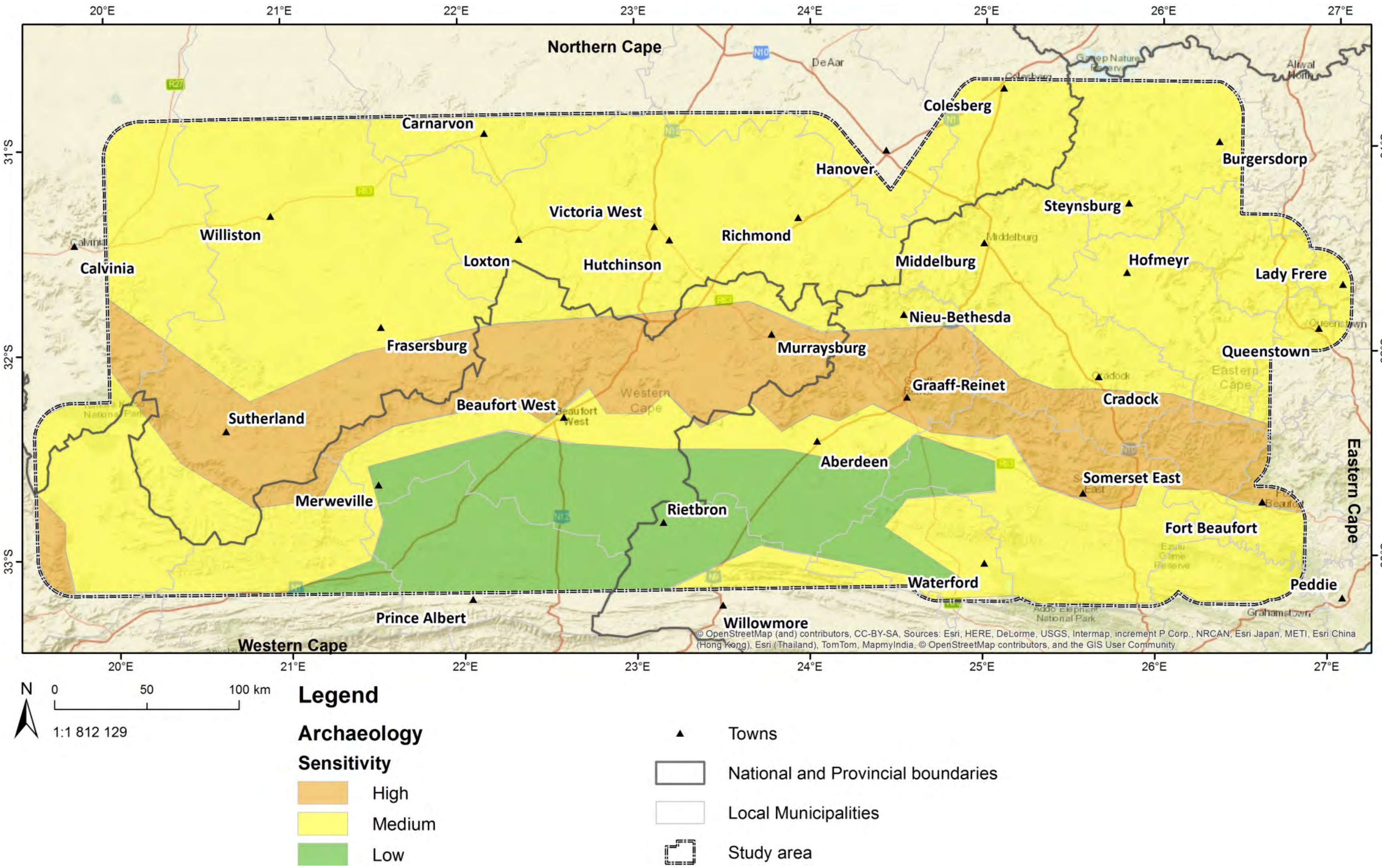

Figure 15.21: Sensitivity mapping for archaeological resources.

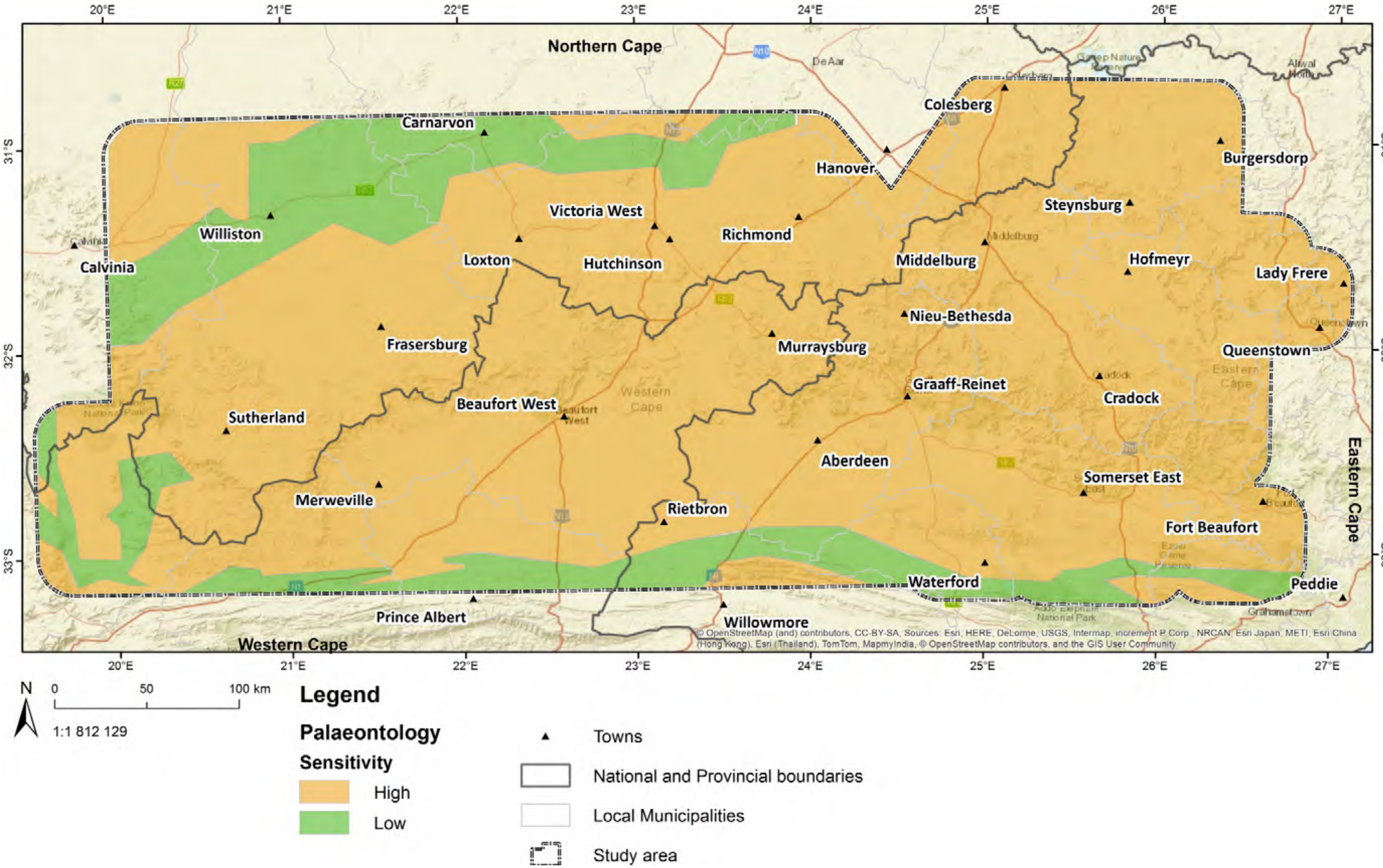

Figure 15.22: Sensitivity mapping for palaeontological resources.

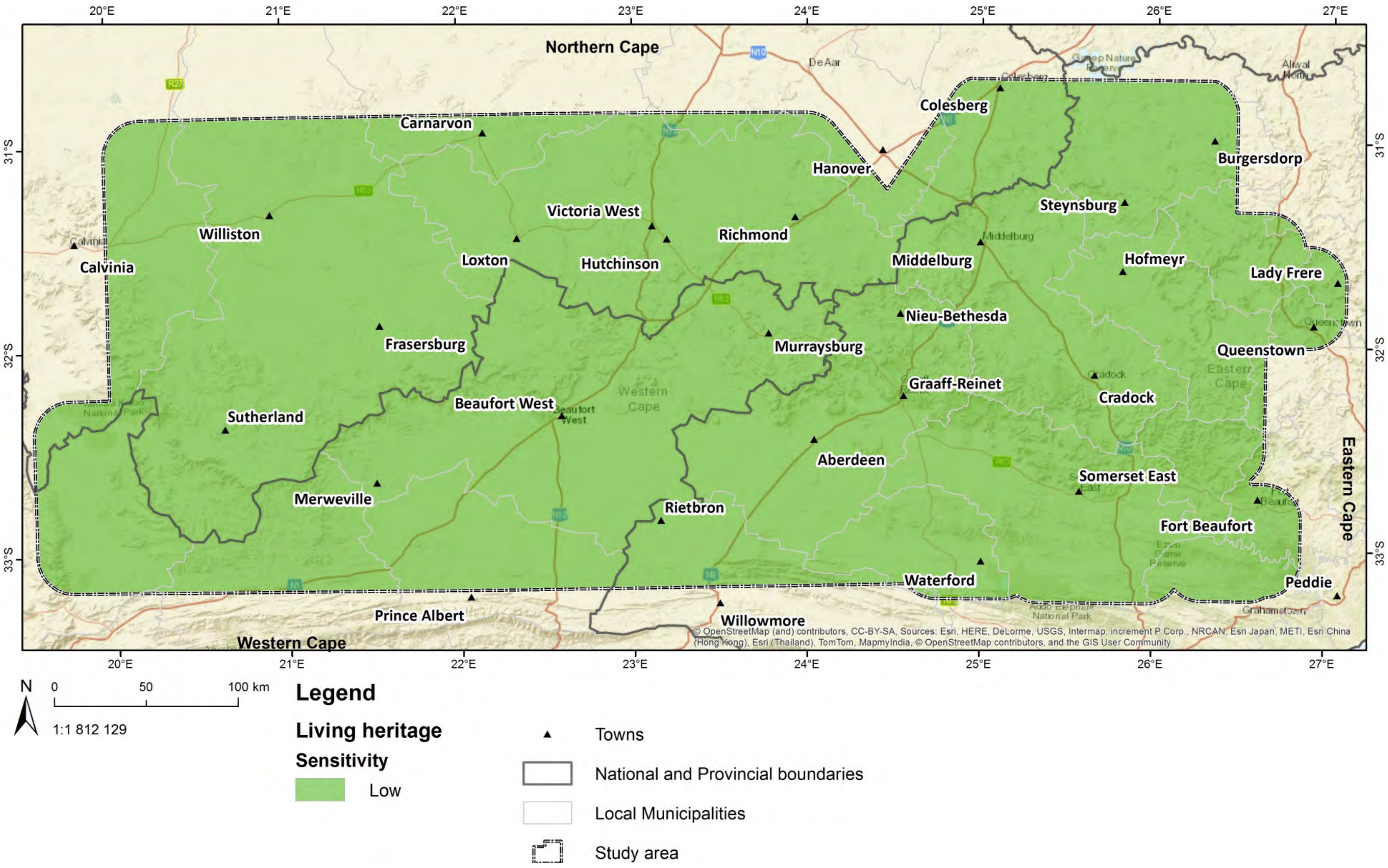

Figure 15.23: Sensitivity mapping for living heritage resources.

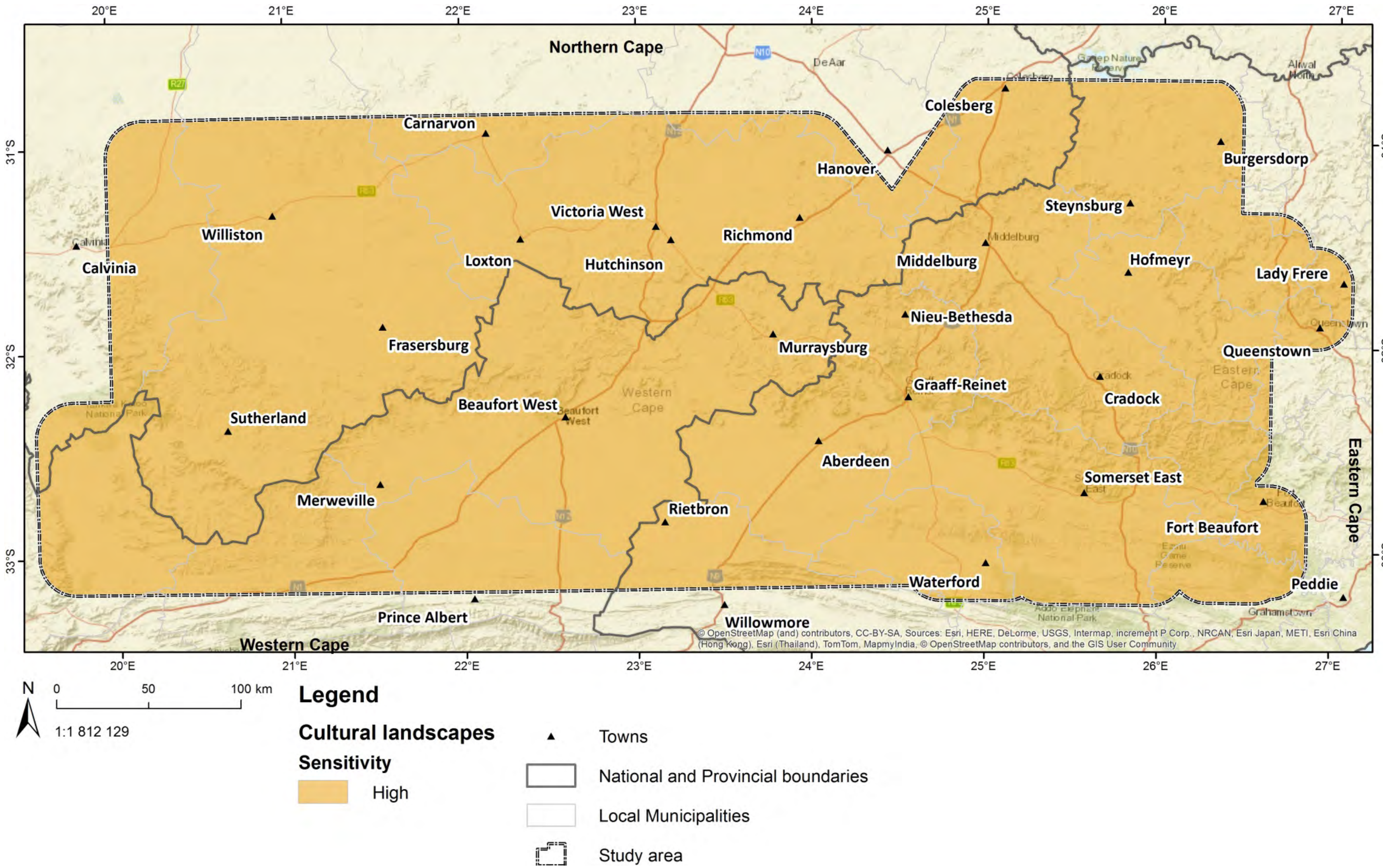

Figure 15.24: Sensitivity mapping for cultural landscapes.

Figures 15.25 to 15.27 present risk maps of impacts on built heritage, palaeontology and archaeology across four SGD scenarios, with- and without mitigation. Note: maps of regional risks to living heritage and cultural landscapes have not been produced.

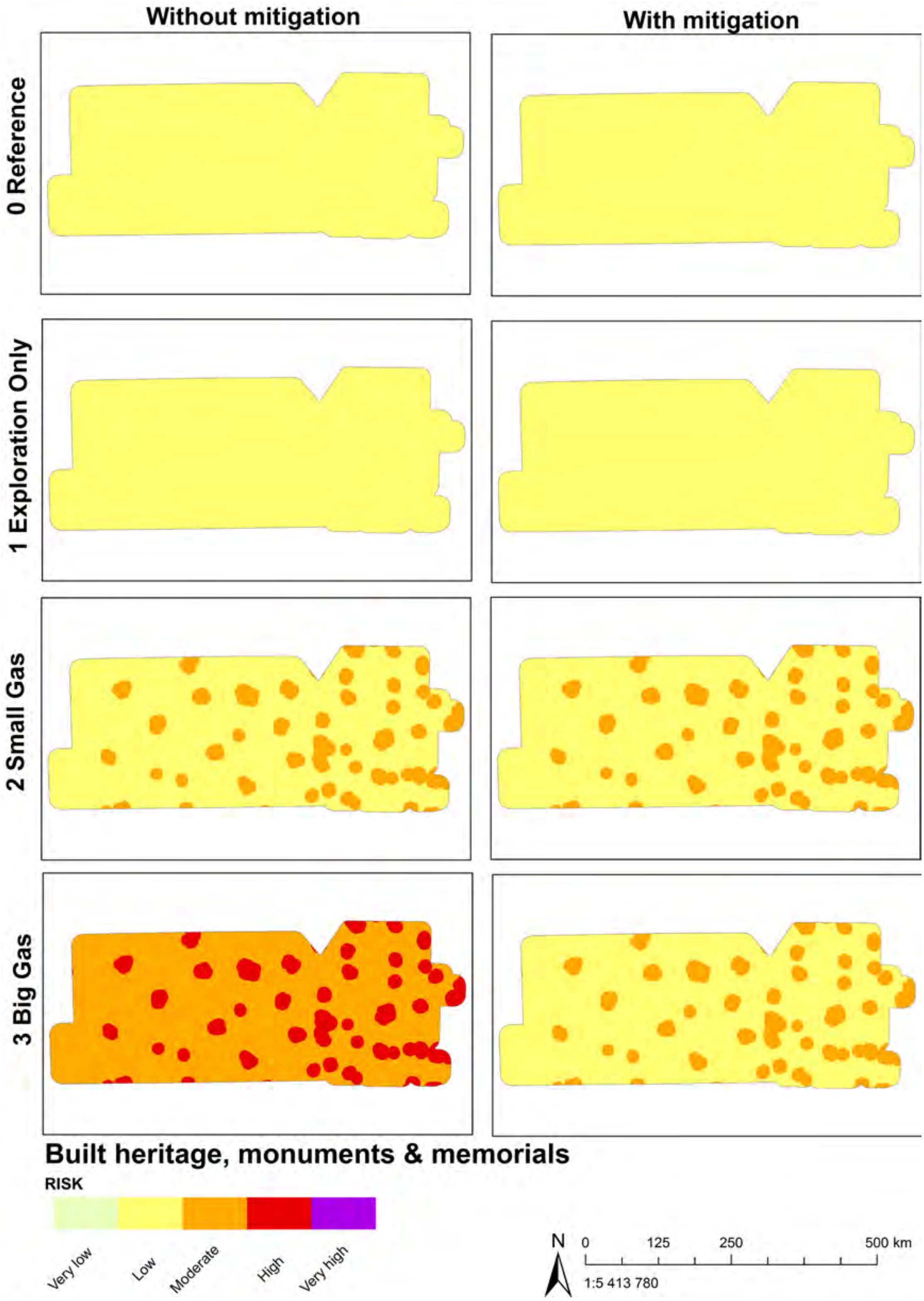

Figure 15.25: Map indicating the risk to built heritage, monuments and memorials across four SGD scenarios, with- and without mitigation.

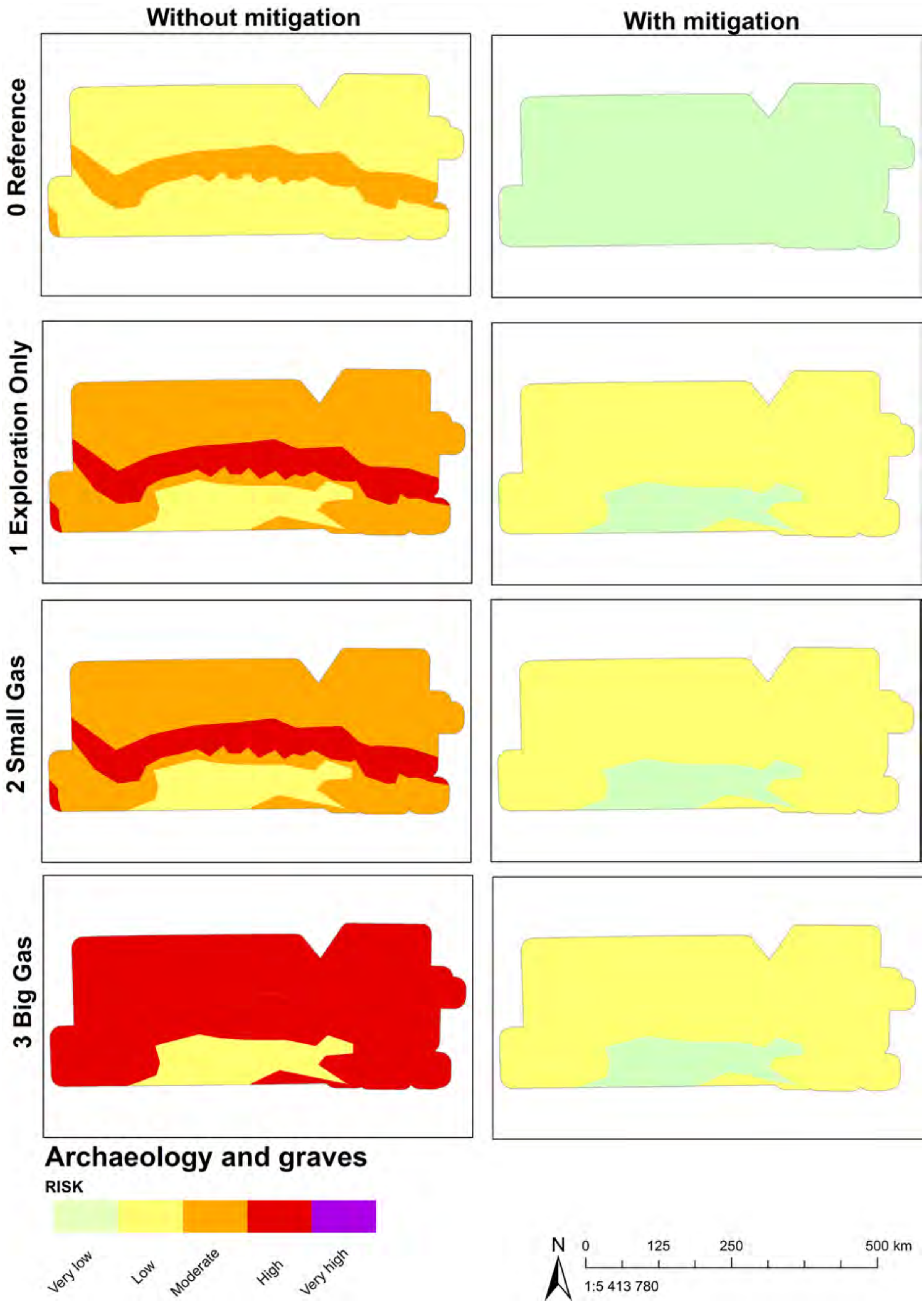

Figure 15.26: Map indicating the risk to archaeology and graves across four SGD scenarios, with- and without mitigation.

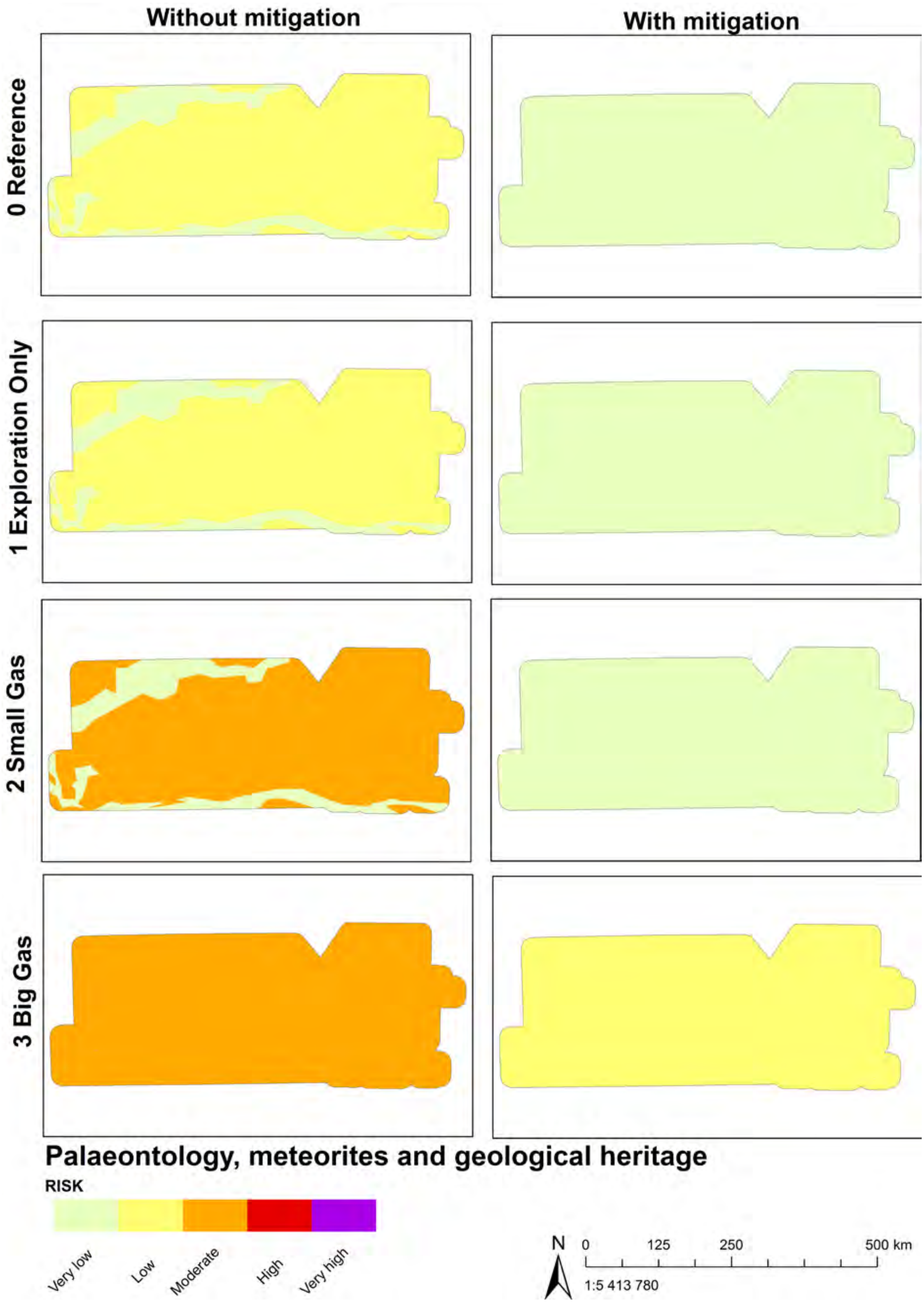

Figure 15.27: Map indicating the risk to palaeontology, meteorites and geological heritage across four SGD scenarios, with- and without mitigation.

15.4 Best practice guidelines and monitoring requirements

15.4.1 Planning phase

In many respects, the Planning Phase is the most critical phase of any development. It is at this stage in the process that the most significant potential impacts can be avoided by an awareness of all known important heritage resources. Responsibilities lie both with the heritage and planning authorities and with any potential developers and, as such, we discuss them separately.

15.4.1.1 <u>Authority responsibilities</u>

- Because SGD and related activities have the potential to span provincial boundaries, it is recommended that SAHRA, under Section 38(1)(e) and with input from provincial and local authorities, draft a set of guidelines for the implementation of shale gas exploration and development which will serve to guide the assessment and monitoring of all activities.
- For the same reason, where necessary, SAHRA, with input from provincial and local authorities, should be responsible for comments and decisions related to SGD. This should occur under a Memorandum of Understanding between SAHRA and each PHRA as appropriate.
- Heritage monitoring is generally only requested during excavations that may reveal buried heritage resources. It is recommended, however, that more extensive monitoring (similar to that carried out by an Environmental Control Officer (ECO) in the EIA context) be encouraged by Heritage Resources Authorities in order to monitor Development Phase impacts, especially those associated with built heritage. International guidelines should be taken into consideration.
- In terms of Section 30 of the NHRA, all PHRAs should have an updated heritage register. Local planning authorities are required, under certain circumstances, to submit to the PHRA a list of heritage resources under their jurisdiction. The PHRA is then responsible for adding to the Provincial heritage register those sites that it considers to be conservation-worthy and that meet the requirements for listing on the register. This is an existing legal requirement that has not yet been complied with throughout the study area but is considered important to action should SGD be permitted. Such heritage registers should include urban and rural areas and should be updated so as to adhere to the 60 year provision of Section 34 of the NHRA.
- Heritage Resources Authorities are also required to have an up-to-date register of communities who have expressed interest in heritage. Such registers should be in place before exploration commences. To date, of the three provinces included in the study area, only Western Cape is reasonably functional in this regard.

- Section 31 of the NHRA requires that all new Spatial Development Frameworks (SDFs) include the investigation of heritage areas for protection. All towns where population growth is to be expected as a result of SGD should preferably have SDFs in place and, if required, should therefore have heritage areas identified and formally promulgated. Although capacity may constrain this process, it should ideally take place before any exploration is carried out and for all towns within 50 km of an exploration area. Additionally the principles of the UNESCO (2011) “Recommendation on the Historic Urban Landscape” should be applied to all such towns.

15.4.1.2 Developer responsibilities

- The commissioning of a screening study is recommended for each prospecting, exploration or production project in order to identify as many sensitive heritage resources as possible (especially those for which adequate mitigation is difficult or impossible). This will enable developers to plan to avoid such heritage resources with appropriate buffers at the earliest possible stage.
- A key aspect once the result of the screening study are known will be the baseline documentation of the current physical condition of all potentially affected heritage structures, both for the purposes of protection against legal claims because of the risks posed by earth tremors and to create a built heritage database from which to commence future studies. A standardised format that briefly describes each resource and complies with relevant guidelines as issued by the various heritage authorities should be used throughout the study area and detailed photographic and or three dimensional records should be created. All structures within 10 km of wellpads and 250 m of any related infrastructure and transport corridors should be included. For tall structures such as church steeples or obelisk-type monuments and infrastructure such as dam walls, the study should include engineering assessments of their structural soundness. The records should be lodged on the SAHRIS database.
- It is recommended that all EIA and HIA studies explore potential impacts from possible seismic activity and establish no-go buffer-zones.
- It is recommended that a trust fund be established for the repair of damage to built heritage resultant from SGD. This fund should be managed by an independent body, representing a broad range of stakeholders. Financial input to the fund will be required on a long-term basis, extending far beyond the end of the closure phase, as it is unknown when/if seismic activity might cease.
- Monitoring of seismic activity in the study area should be intensified in order to assist with predictions of induced activity and to plan appropriate buffers from important historic structures.

- A continuous monitoring system should be established to monitor all built heritage resources at regular intervals as well as after seismic events. The frequency of such monitoring could be reduced during later years once the degree of impact from tremors and vibrations has been better established, but such frequency should not be less than once per year.
- A geologist should be commissioned to compile a full database of conservation-worthy geological heritage sites located within the study area.
- Because of the institutional and professional capacity constraints within the heritage industry, it is suggested that developers and their appointed environmental assessment practitioners ensure that sufficient time is allowed in which to complete the necessary heritage studies. This may require commissioning such studies well before the start of an EIA, given the 300-350 day timeframe allowed for during an EIA process.

15.4.2 Exploration Phase

- EIAs in advance of exploration must always include specialist heritage assessments that consider *all* potentially vulnerable heritage resources and hence satisfy Section 38(3) of the NHRA. It will generally be the case that such assessments are carried out by more than one individual to ensure that the necessary range of skills are present to address those aspects of heritage that are seldom considered in assessments (e.g. living heritage, geological heritage, meteorites). An archaeological field study is mandatory since such studies are generally the point at which isolated examples of heritage in remote locations (e.g. ruined structures or graves) are found and recorded. Because of the potential for widespread impacts, both from SGD and ancillary development, cumulative impacts must also be considered.
- Adhering to mitigation requirements (including micro-siting to avoid heritage sites and reduce landscape scarring) and footprint restrictions as stipulated in an EA will greatly reduce impacts (the EA should specify the heritage mitigation requirements resulting from the HIA process).
- If the baseline documentation suggested above is not in place, then mitigation should include such documentation of all built heritage resources following the same guidelines.
- Any EA amendment applications for disturbance of areas not originally assessed must include heritage assessments.
- Monitoring as suggested above will serve to identify damage and, where feasible, such damage should be repaired from the fund established for the purpose. Appropriate heritage techniques and materials should be used.

15.4.3 Development Phase

- All stipulations under Exploration Phase above apply equally to the Development Phase.
- Additionally, because of the longer term presence of people and activity, the appointed ECO or an appropriate heritage practitioner should conduct regular inspections of heritage resources that are protected *in situ* to ensure that indirect impacts are not occurring.

15.4.4 Closure Phase

- Adhere to footprint restrictions as stipulated in an EA.
- Any new disturbance not included in original application needs to be assessed. This might, for example, include areas from which topsoil is sourced to be used in rehabilitation.
- Adhere to all rehabilitation as stipulated in an EA.
- Assess the residue of the industrial landscape resulting from SGD as an important historical phase of the development of not only the Karoo Basin but of the country as a whole. Identify structures and sites of historical importance, stabilise these and ensure protection and interpretation of these new heritage resources.

15.4.5 Monitoring guidelines

Any monitoring will be strongly linked to the limits of acceptable change established above. Monitoring will serve largely to ensure that EA conditions are respected and implemented such that change can be kept within the established acceptable limits. Table 15.6 proposes monitoring guidelines that could be implemented from both the heritage and environmental points of view. The frequencies indicated are a guideline only and may need revision on a case-by-case basis. Some monitoring could be dealt with by the ECO, but other aspects might require specialist input. Some aspects, however, could be handled by a ‘heritage monitor’ who could be trained specifically to fulfil the role. Reports describing the monitoring activities and any finds made will need to be submitted to the relevant heritage authorities.

Table 15.6: Heritage monitoring guidelines for SGD.

Objectives	Methodology	Frequency	Responsibility
Exploration and Development Phases			
Avoid premature direct or indirect damage to any heritage resources that are to be mitigated prior to development and in order to allow their destruction.	Ensure that any required mitigation measures have been carried out prior to commencement of SGD activities and that mitigation reports have been submitted to relevant heritage authorities.	Once-off prior to commencement of any activities.	ECO
	Ensure that positive comments have been received from heritage authorities prior to commencement of activities.	Once-off prior to commencement of any activities.	ECO
Avoid direct or indirect damage to any heritage resources that are to be protected *in situ*.	Establish no-go areas and ensure that these are appropriately marked (on plans or on the ground).	Once-off prior to commencement of any activities.	ECO/heritage monitor
	Monitoring will aim to check that such areas remain undisturbed.	Weekly during site establishment and construction periods, 6-monthly during production.	ECO/heritage monitor
Avoid direct or indirect damage to any heritage resources not discovered during the EIA Phase	Such monitoring is only likely to be required if development is to occur on alluvial plains or in close proximity to pans. Monitoring will aim to locate and protect any buried heritage resources (generally archaeological) until such time as they can be assessed by an archaeologist and, if required, be mitigated.	Daily or as and when required during excavation works in alluvial plains or close to pans.	Archaeologist
Early detection of damage to built heritage in order to minimise overall impacts.	Monitoring will aim to detect any damage to the fabric of built heritage resources so that repairs can be affected quickly and the source of the impact identified and prevented.	At least every three months at first but reduced to at least once per year when the degree of impact has been properly established; and immediately after any seismic events deemed of high enough magnitude to have caused damaged.	Heritage architect/ Heritage monitor
Identification, protection and rescue of buried palaeontological resources.	Monitoring will aim to identify any palaeontological material that might be revealed during earthmoving activities in areas where palaeontological monitoring has been requested.	Daily in areas of high sensitivity and/or areas of intense activity.	Palaeontologist
		Weekly/bi-weekly as determined during impact assessment for areas of lesser sensitivity and less intense impact.	Palaeontologist/ ECO with training by palaeontologist
Closure Phase			
Avoid direct or indirect damage to any heritage resources that have been protected *in situ*.	Establish no-go areas and ensure that these are appropriately marked (on plans or on the ground).	Once-off prior to commencement of any activities.	ECO/Heritage monitor
	Monitoring will aim to check that such areas remain undisturbed.	Weekly during site rehabilitation.	ECO/Heritage monitor

15.5 Gaps in knowledge

Built heritage resources are perhaps most at risk and, because of a lack of understanding on how the area might be affected by seismic activity, it is impossible to present a full picture of this risk. The gathering of seismic data would help build models to predict this risk. The vulnerability of built heritage in general is difficult to assess in the absence of completed heritage registers (as required by the NHRA) and large-scale built heritage surveys, particularly in rural areas. Improvements in the capacity of heritage and municipal authorities should allow for compilation of these databases, but completion times are likely to be lengthy. Despite the limited survey coverage of the study area and the fact that the locations of any SGD remain unknown, our confidence in the assessment of the remaining risks is relatively high.

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15.7 Digital Addenda 15A – 15B

SEPARATE DIGITAL DOCUMENT

Digital Addendum 15A: Extracts from Sections 2 and 3 of the National Heritage Resources Act (No. 25 of 1999)

Digital Addendum 15B: Spatial distribution of formally protected heritage sites within the study area.

DIGITAL ADDENDA 15A – 15B

Digital Addendum 15A: Extracts from Sections 2 and 3 of the National Heritage Resources Act (No. 25 of 1999)

Definitions[1]

2. In this Act, unless the context requires otherwise—

(ii) "archaeological" means—

(a) material remains resulting from human activity which are in a state of disuse and are in or on land and which are older than 100 years, including artefacts, human and hominid remains and artificial features and structures;

(b) rock art, being any form of painting, engraving or other graphic representation on a fixed rock surface or loose rock or stone, which was executed by human agency and which is older than 100 years, including any area within 10 m of such representation;

(c) wrecks, being any vessel or aircraft, or any part thereof, which was wrecked in South Africa, whether on land, in the internal waters, the territorial waters or in the maritime culture zone of the Republic, as defined respectively in Sections 3, 4 and 6 of the Maritime Zones Act, 1994 (Act No. 15 of 1994), and any cargo, debris or artefacts found or associated therewith, which is older than 60 years or which SAHRA considers to be worthy of conservation; and

(d) features, structures and artefacts associated with military history which are older than 75 years and the sites on which they are found;

(vi) "cultural significance" means aesthetic, architectural, historical, scientific, social, spiritual, linguistic or technological value or significance;

(viii) "development" means any physical intervention, excavation, or action, other than those caused by natural forces, which may in the opinion of a heritage authority in any way result in a change to the nature, appearance or physical nature of a place, or influence its stability and future well-being, including—

(a) construction, alteration, demolition, removal or change of use of a place or a structure at a place;

(b) carrying out any works on or over or under a place;

(c) subdivision or consolidation of land comprising, a place, including the structures or airspace of a place;

(d) constructing or putting up for display signs or hoardings;

[1] Only definitions relevant to the present Chapter are listed.

(e) any change to the natural or existing condition or topography of land; and

(f) any removal or destruction of trees, or removal of vegetation or topsoil;

(xiii) "grave" means a place of interment and includes the contents, headstone or other marker of such a place, and any other structure on or associated with such place;

(xvi) "heritage resource" means any place or object of cultural significance;

(xvii) "heritage resources authority" means the South African Heritage Resources Agency, established in terms of Section 11, or, insofar as this Act is applicable in or in respect of a province, a provincial heritage resources authority;

(xviii) "heritage site" means a place declared to be a national heritage site by SAHRA or a place declared to be a provincial heritage site by a provincial heritage resources authority;

(xxi) "living heritage" means the intangible aspects of inherited culture, and may include—

(a) cultural tradition;

(b) oral history;

(c) performance;

(d) ritual;

(e) popular memory;

(f) skills and techniques;

(g) indigenous knowledge systems; and

(h) the holistic approach to nature, society and social relationships;

(xxv) "meteorite" means any naturally-occurring object of extraterrestrial origin;

(xxvii) "national estate" means the national estate as defined in Section 3;

(xxxi) "palaeontological" means any fossilised remains or fossil trace of animals or plants which lived in the geological past, other than fossil fuels or fossiliferous rock intended for industrial use, and any site which contains such fossilised remains or trace;

(xxxii) "place" includes—

(a) a site, area or region;

(b) a building or other structure which may include equipment, furniture, fittings and articles associated with or connected with such building or other structure;

(c) a group of buildings or other structures which may include equipment, furniture, fittings and articles associated with or connected with such group of buildings or other structures;

(d) an open space, including a public square, street or park; and

(e) in relation to the management of a place, includes the immediate surroundings of a place;

(xxxvii) "provincial heritage resources authority", insofar as this Act is applicable in a province, means an authority established by the MEC under Section 23;

(xxxviii) "public monuments and memorials" means all monuments and memorials—

(a) erected on land belonging to any branch of central, provincial or local government, or on land belonging to any organisation funded by or established in terms of the legislation of such a branch of government; or

(b) which were paid for by public subscription, government funds, or a public-spirited or military organisation, and are on land belonging to any private individual;

(xiil) "site" means any area of land, including land covered by water, and including any structures or objects thereon;

(xivl) "structure" means any building, works, device or other facility made by people and which is fixed to land, and includes any fixtures, fittings and equipment associated therewith;

National estate

3. (1) For the purposes of this Act, those heritage resources of South Africa which are of cultural significance or other special value for the present community and for future generations must be considered part of the national estate and fall within the sphere of operations of heritage resources authorities.

3. (2) Without limiting the generality of Subsection (1), the national estate may include—

(a) places, buildings, structures and equipment of cultural significance;

(b) places to which oral traditions are attached or which are associated with living heritage;

(c) historical settlements and townscapes;

(d) landscapes and natural features of cultural significance;

(e) geological sites of scientific or cultural importance;

(f) archaeological and palaeontological sites;

(g) graves and burial grounds, including—

(i) ancestral graves;

(ii) royal graves and graves of traditional leaders;

(iii) graves of victims of conflict;

(iv) graves of individuals designated by the Minister by notice in the *Gazette*;

(v) historical graves and cemeteries; and

(vi) other human remains which are not covered in terms of the Human Tissue Act, 1983 (Act No. 65 of 1983);

(h) sites of significance relating to the history of slavery in South Africa;

(i) movable objects, including—

(i) objects recovered from the soil or waters of South Africa, including archaeological and palaeontological objects and material, meteorites and rare geological specimens;

(ii) objects to which oral traditions are attached or which are associated with living heritage;

(iii) ethnographic art and objects;

(iv) military objects;

(v) objects of decorative or fine art;

(vi) objects of scientific or technological interest; and

(vii) books, records, documents, photographic positives and negatives, graphic, film or video material or sound recordings, excluding those that are public records as defined in Section 1(xiv) of the National Archives of South Africa Act, 1996 (Act No. 43 of 1996).

3. (3)Without limiting the generality of Subsections (1) and (2), a place or object is to be considered part of the national estate if it has cultural significance or other special value because of—

(a) its importance in the community, or pattern of South Africa's history;

(b) its possession of uncommon, rare or endangered aspects of South Africa's natural or cultural heritage;

(c) its potential to yield information that will contribute to an understanding of South Africa's natural or cultural heritage;

(d) its importance in demonstrating the principal characteristics of a particular class of South Africa's natural or cultural places or objects;

(e) its importance in exhibiting particular aesthetic characteristics valued by a community or cultural group;

(f) its importance in demonstrating a high degree of creative or technical achievement at a particular period;

(g) its strong or special association with a particular community or cultural group for social, cultural or spiritual reasons;

(h) its strong or special association with the life or work of a person, group or organisation of importance in the history of South Africa; and

(i) sites of significance relating to the history of slavery in South Africa.

Digital Addendum 15B: Spatial distribution of formally protected heritage sites within the study area.

The following maps indicate the spatial distribution of all heritage sites that have been formally graded and/or declared as NHSs or PHSs or placed on the heritage register. Because a grading must precede a declaration, the listed grade serves to indicate the following:

- Grade I: The site is formally graded I and/or has been declared a NHS;
- Grade II: The site is formally graded II and/or has been declared a PHS;
- Grade IIIA: The site is formally graded IIIA (in Western Cape only) and/or has been listed on the provincial heritage register.

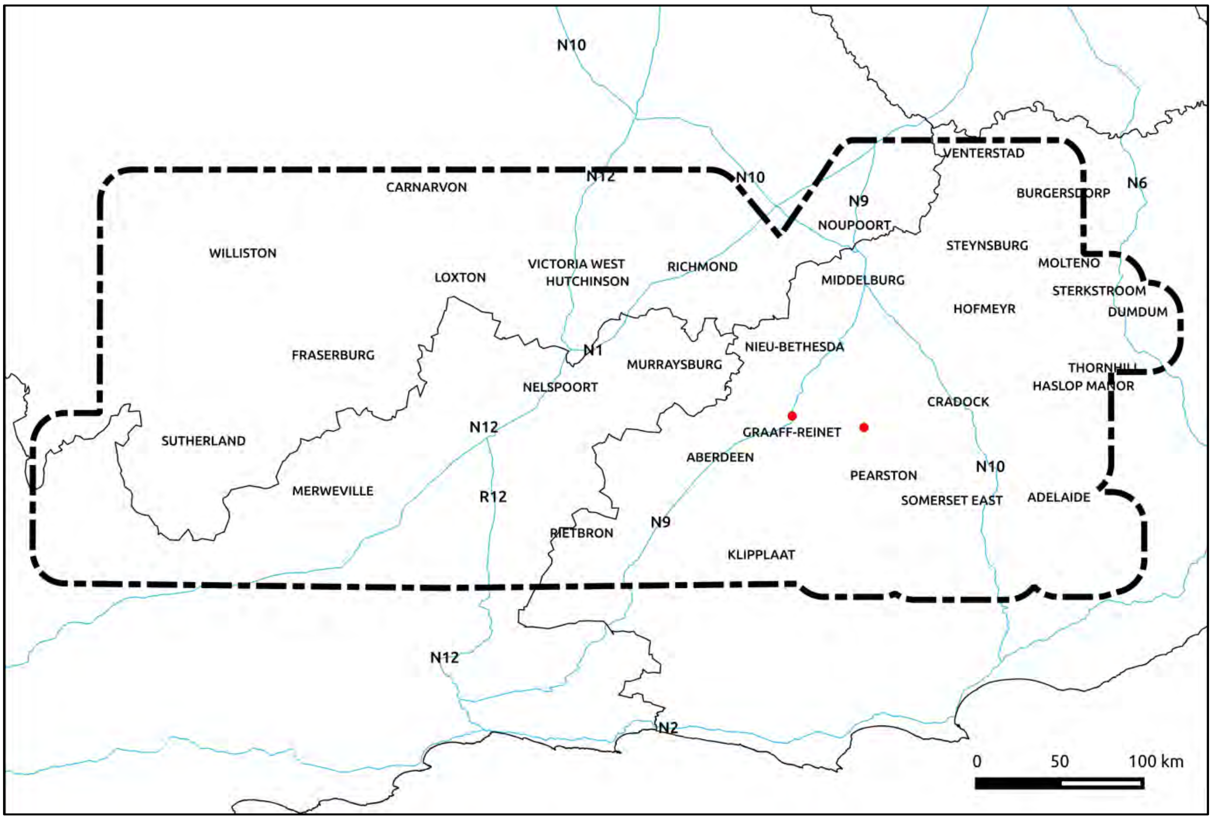

Figure B1: Spatial distribution of Grade I resources in the study area.

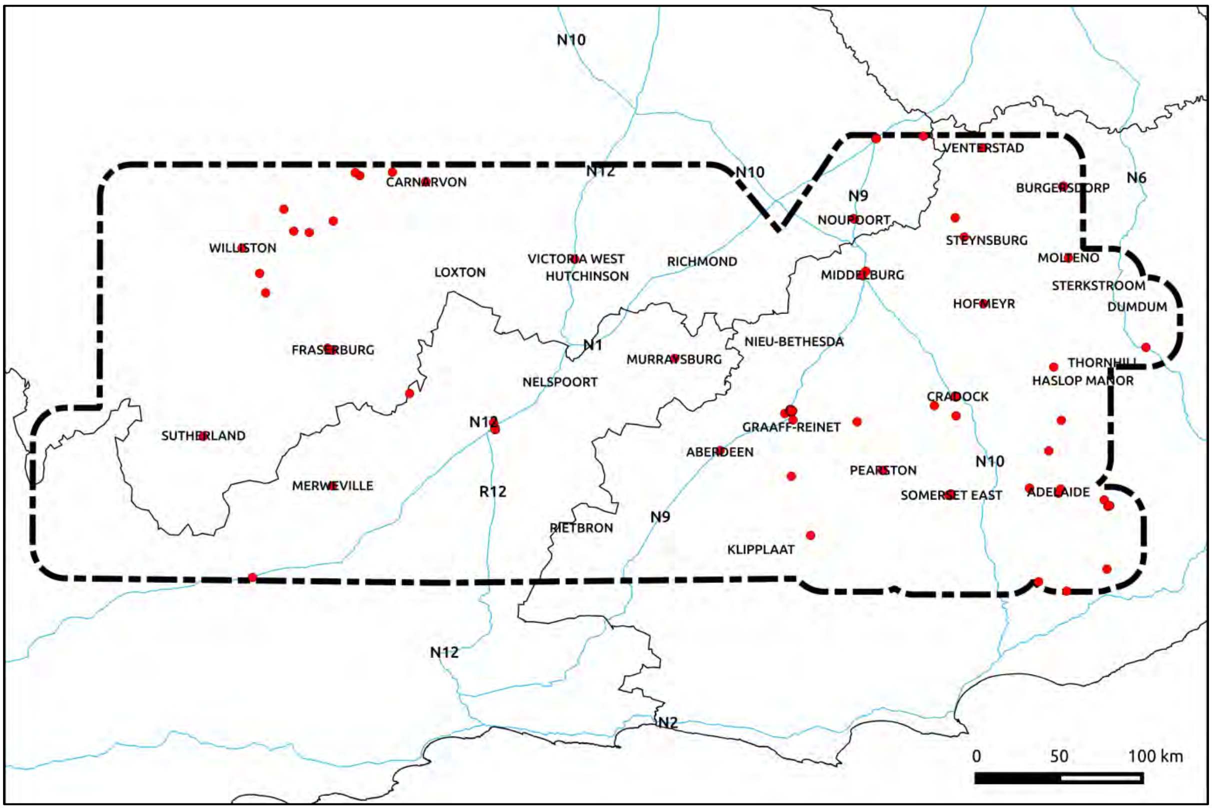

Figure B2: Spatial distribution of Grade II resources in the study area.

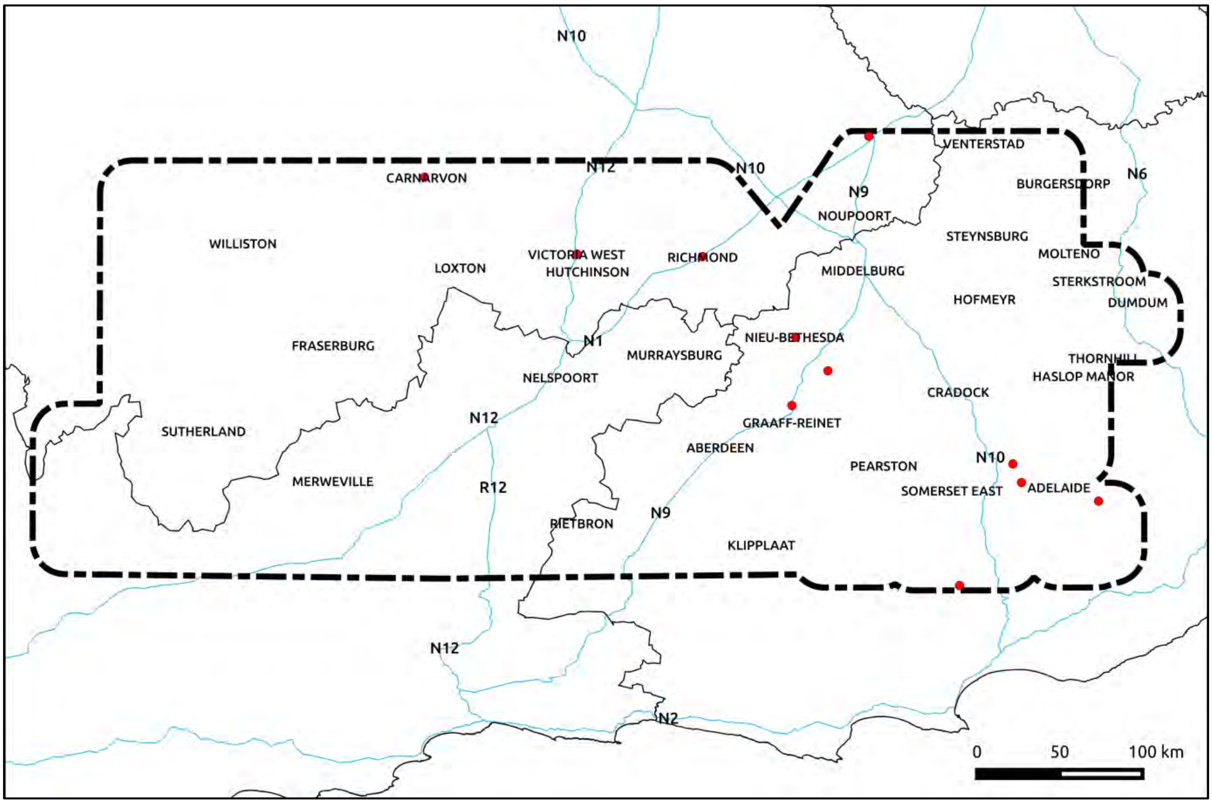

Figure B3: Spatial distribution of Grade IIIA resources in the study area.

CHAPTER 16

Noise Generated by Shale Gas-related Activities

CHAPTER 16: NOISE GENERATED BY SHALE GAS-RELATED ACTIVITIES

Integrating Author:	Andrew Wade[1]
Contributing Authors:	Adrian Jongens[2]
Corresponding Authors:	Wikus van Niekerk[1]

[1] Sound Research Laboratories South Africa (Pty) Ltd, Cape Town, 7705

[2] Jongens Keet Associates, Constantia, 7806

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Executive Summary

Noise produced or caused by humans and generally referred to as environmental noise has a marked impact on the physical health of people, and on their psychological wellbeing.

The Karoo is a quiet area. Residual day- and night-time noise levels are approximately L_{Aeq} 33 dBA and 25 dBA, respectively. This is 10 dB below the typical levels published in local and international standards for rural areas. Subjectively a change of 10 dB is perceived as a doubling or halving of "loudness". A 10 dB difference is therefore a significant difference.

The noise impact of the exploration phase is likely to be localised and of short duration (a day). Noise would be generated predominantly by trucks, and would only be noticeable in the immediate vicinity of exploration activities, for the duration of the activities. Any core drilling exploration is likely to have a longer-term (six to eight weeks), more widespread (up to 5 kilometres (km)) noise impact, especially if any activity is done at night.

The construction, operation and decommissioning phases will likely cause noise impacts for humans and animals on sites within at least 5 km of the sites. Operational phases are expected to run constantly (day and night) for six to eight weeks. Night time noise impacts are therefore most likely, when residual noise levels are at a minimum.

Proposed sites will need individual noise impact assessments in accordance with South African National Standards (SANS) 10328 to determine the likelihood and severity of noise impacts.

There is additionally a risk of road noise impacts emanating from the surrounding roads due to increased heavy goods vehicle road traffic, especially during a Big Gas scenario, and if the roads used are otherwise quiet and seldom used.

Noise control, attenuation and monitoring will likely be required for all sites. The extent of the required measures will be determined by the noise impact assessment.

CHAPTER 16: NOISE GENERATED BY SHALE GAS DEVELOPMENT ACTIVITIES

16.1 Introduction and scope

Environmental noise has a marked impact on the physical health of people (Fritschi, 2011; Department of Environmental Affairs, 1989), and on their psychological wellbeing (Berglund, 1999). The noise climate of an environment is inextricably linked to its sense of place. As noise levels in urban areas increase, areas with low residual noise levels are becoming sought after (Visit Finland, 2016).

This chapter investigates the existing information on noise created by shale gas development (SGD) activities, and the impact that this could have on the study area in the Karoo.

This scientific assessment relies on existing, published data and recommends where more information is required to make a better assessment of the impacts. The main current shortfall in data is for reliable noise spectrum measurements (preferably in Sound Power levels, L_w) of the construction, operation and decommissioning of wells. Existing measured data is reported in A-weighted single-figure dBA levels. This must be investigated further.

> ***Environmental noise:*** noise produced or caused by humans.
>
> ***Residual noise***: the prevailing noise level without the assessed noise present.
>
> ***Ambient noise***: the noise level with the assessed noise present.
>
> ***Disturbing noise***: a noise that raises the ambient noise level by 3 or 7 dBA above the residual level depending on applicable Noise Control Regulations.
>
> ***Noise nuisance***: a noise that disturbs the peace of a person.

16.1.1 Overview of international experience

The New York State Department of Environmental Conservation (NYSDEC) released in 2015 a regulatory programme for shale gas exploration (NYSDEC, 2015). This document quantified, in single-figure dBA values only, the potential impact of noise from the activities on the surrounding people and animals. It found that noise from truck traffic and during fracturing operations would cause adverse noise impacts on nearby people and animals. The report predicted an increase in noise levels of 37–42 dBA at 2000 feet (600 metres (m)) from wellpads in “quiet rural areas” with an existing noise level of 30 dBA. Areas in the Karoo are up to 10 dBA quieter than this at night.

There are currently few specific legal conditions attached to the noise associated with shale gas exploration (Chamberlain, 2012); rather the activities are assessed within the existing legal frameworks of each country.

16.1.2 Special features of the Karoo acoustic environment

The Karoo is a quiet area. Noise measurements over many years show that noise levels in the Karoo are generally L_{Aeq} 33 dBA during the day and L_{Aeq} 20–30 dBA at night (Jongens, 2011). These levels are far below the typical rating levels in Table 2 of the South African National Standards (SANS) 10103 for rural areas, which are set at L_{Aeq} 45 dBA in the day and L_{Aeq} 35 dBA at night. It is also far below the 30 dBA noise level used in the NYSDEC report for "quiet rural areas". Karoo noise levels are also notably unaffected by wind noise (Jongens, 2011) and there is little rainfall in the area.

The Karoo is therefore notably quiet, and these noise levels are notably constant and reliable.

16.1.3 Relevant legislation, regulation and practice

Environmental noise in South Africa is generally governed by the Noise Control Regulations (NCRs) in terms of Section 25 of the Environmental Conservation Act, 1989 (Department of Environmental Affairs, 1992). For those parts of the study area that fall in the Western Cape, the provincial Western Cape (2013) NCRs supersede the national regulations. These regulations set the concepts of a disturbing noise and a noise nuisance. While these two terms are defined differently by different provincial regulations, essentially a disturbing noise can be objectively measured, while a noise nuisance is a subjective "annoyance" that cannot be reliably measured, such as a dog barking or other discrete events.

Two standards, SANS 10328 and SANS 10103 further expand on these regulations. SANS 10328 specifies the standard procedure for conducting a noise impact assessment. SANS 10103 specifies procedures for assessing the noise under investigation.

16.2 Key potential impacts and their mitigation

16.2.1 The effect of noise on humans

Humans are demonstrably impacted by acoustic noise (Berglund, 1999). The World Health Organisation (WHO) recommends a noise limit of $L_{night,outside}$ 40 dB and $L_{Amax,inside}$ 35 dB (Fritschi, 2011). These limits are set to help prevent health issues related to impaired sleep. The WHO estimated that in western European countries, at least one million healthy life years are lost every year from traffic-related noise, predominantly due to sleep disturbance. These two papers showed the relationship between environmental noise and specific health effects, including cardiovascular disease, cognitive impairment, sleep disturbance and tinnitus. It further showed that living in a loud environment leads to chronically raised levels of stress hormones.

The noise levels associated with health effects, where sufficient evidence is available, is shown in Table 16.1. For open windows, the difference between indoor and outdoor noise levels is approximately 10 dBA (Berglund, 1999). This means that the noise thresholds in Table 16.1 are exceeded when external night time noise levels exceed 42–45 dBA.

Table 16.1: Summary of effects and threshold levels for effects where sufficient evidence is available (from Table 1 of World Health Organisation [WHO], 2012).

Effect		Indicator	Threshold, dB
Biological effects	Change in cardiovascular activity	*	*
	EEG awakening	$L_{Amax,inside}$	35
	Motility, onset of motility	$L_{Amax,inside}$	32
	Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep	$L_{Amax,inside}$	35
Sleep quality	Waking up in the night and/or too early in the morning	$L_{Amax,inside}$	42
	Prolongation of the sleep inception period, difficulty getting to sleep	*	*
	Sleep fragmentation, reduced sleeping time	*	*
	Increased average motility when sleeping	$L_{night, outside}$	42
Well-being	Self-reported sleep disturbance	$L_{night, outside}$	42
	Use of somnifacient drugs and sedatives	$L_{night, outside}$	40
Medical conditions	Environmental insomnia**	$L_{night, outside}$	42

* Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

** Note that "environmental insomnia" is the result of diagnosis by a medical professional whilst "self-reported sleep disturbance" is essentially the same, but reported in the context of a social survey. Number of questions and exact wording may differ.

16.2.2 The effect of noise on animals

There is a growing body of evidence that increased environmental noise levels has a wide range of impacts on animals (Barber, 2009; Francis, 2013) notably four behavioural changes:

1. Temporal patterns, i.e. changes in the times that animals do a certain activity.
    - Boat traffic noise changes the times that West Indian manatees forage (Miksis-Olds, 2007).

   - In noisy environments, European robins sing at night when it is otherwise quieter (Fuller, 2007).
2. Spatial distributions and movements.
   - Usually the abandonment of a noisy area (Francis, 2013).
3. Decreases in foraging or provisioning efficiency and increased vigilance and anti-predator behaviour.
   - Increased ambient noise reduces the distance that prey can hear approaching predators. This increases the amount of time animals spend looking around for predators, reducing foraging time (Gavin and Komers, 2006).
   - Predators that rely on sound take longer to find prey, reducing their hunting efficiency and increasing energy usage (Siemers and Schaub, 2011).
4. Changes in mate attraction and territorial defence.
   - Higher noise levels mask mating calls. Some birds and frogs have been seen to change their calls to higher frequencies to avoid the masking frequencies of the ambient noise. It seems though that this is correlated with lower clutches and fewer fledglings (Halfwerk et al., 2011).

The overall effect of noise on the environment depends on the specific environment. Disruptions in the ecosystem (such as a predator or a prey leaving the area), and can have unknown and complex knock-on effects on the local ecosystem. This would require further study.

16.2.3 Other key noise impacts

The introduction of man-made noise that raises the residual noise level appropriate to a district has a negative impact on the human experience of the space and possibly health. Toerien et al. (2016) shows that noise will adversely affect tourism in the Karoo where visitors expect to experience naturally quiet and peaceful wilderness spaces.

16.2.4 Key noise sources associated with SGD

The four main phases of SGD each have notable noise sources:

1. Exploration
   - Vehicles associated with surveying and seismic investigations
   - Exploration core drilling
2. Construction
   - Increased vehicle movements
   - Construction vehicles (diggers, lorries, bulldozers, etc.)

  - Plant (generators, pumps, etc.)
3. Extraction
  - Extraction plant, pumps, etc.
  - Generators and air handling equipment
  - Tankers bringing water and chemicals to site
4. Decommissioning
  - Increased vehicle movements removing debris, etc.
  - Construction vehicles (concrete breakers, diggers, etc.)
  - Plant (mainly generators)

The exploration survey phase will have localised, short duration (a few days) noise impacts. The impact will therefore be low. The exploration core drilling, depending on the depth, would require up to 80 days for the drilling, excluding site preparation (SLR, 2014). Noise associated with this drilling would occur 24 hours a day.

The most significant noise sources during the construction and extraction phases are the increased traffic flow and plant noise.

Traffic noise has been noted as disturbing rural communities due to the constant traffic flow to and from site, especially at night (Weigle, 2010; Ireland, 2012). Table 1.4 in Burns et al. (2016) estimates each drilled well requires 500, 10–20 tonne truck trips for the transport of construction materials, hydraulic fracturing ("fracking') chemicals, water, oil, etc. The traffic flows directly relating to SGD are estimated in Van Huyssteen et al. (2016) as:

- Scenario 0 (Reference Case): Negligible
- Scenario 1 (Exploration Only) & 2 (Small Gas): 25 vehicles per day
- Scenario 3 (Big Gas): 166 vehicles per day

Note that these traffic flows do not include traffic due to supporting activities such as employee traffic, or support services.

Construction, drilling and fracking noise levels have been estimated in Table 16.2, based on current research (NYSDEC, 2015) and standards (BSI British Standards, 2009). These noise levels for the construction activities use a "Usage Factor" (*UF*) to account for the approximate amount of time the equipment is used during a 16 hour daytime period. Note that these calculations are simple approximations, making no allowance for factors such as topography, atmospheric conditions, frequency content of the noise levels, and the condition of the equipment. In reality, dBA values cannot be simply added together; noise spectrum data is required in octave bands to be able to accurately combine noise levels.

The noise level $L_{p,2}$ at a distance r_2 is calculated using the simplified formula:

$$L_{p,2} = L_{p,1} + 10\log\left(\frac{UF}{100}\right) - 20\log\left(\frac{r_2}{r_1}\right) + 10\log(n)$$

here n is the number of pieces of equipment.

Table 16.2: Estimated composite noise levels at 4 km

Activity	**Noise level L_p, dBA at 4 km from the activity**	
	Daytime	**Night time**
None (residual)	33	25
Exploration core drilling	28	28
Access road construction	37	37
Wellpad construction	32	32
Rotary air well drilling	29	29
Horizontal drilling	28	28
Fracking	56	56

The following activities as listed by NYSDEC (2015) were used to calculate the noise levels in Table 16.2:

Access road construction:

- Excavators
- Graders
- Bulldozers
- Compactors
- Water trucks
- Dump trucks
- Loaders

Wellpad construction:

- Excavators
- Bulldozers
- Water trucks
- Dump trucks
- Pickup trucks

For drilling, the drill rig drive engine is based on a CAT 32 ACERT 1000–1200 bhp industrial diesel engine housed in a CAT ISO Energy 30ft Container, rated at 85 dBA at 3 m (Caterpillar, 2011). An option is available for an 85 dBA at 1 m Container, which will reduce engine noise levels by approximately 10 dBA. Note though that the compressors would also require attenuation for this 10 dBA reduction to be realised.

Rotary air well drilling:

- Drill rig drive engine
- Compressors
- Hurricane boosters
- Compressor exhaust

Horizontal drilling:

- Drill rig drive engine
- Generators
- Top drive
- Draw works
- Triple shaker

The fracking process is usually done once during the life of the well, for a period of two to five days. The required water volume and pressure requirements mean that up to 20 pumper trucks are likely required (NYSDEC, 2015). Depending on the load on the engines, noise levels can be between 110 and 115 dBA at 1 m, with the main noise in the frequency range 50–250 Hz.

Fracking:

- Pumper trucks

It is reasonable to assume that construction will be done during the day, while the drilling and extraction processes run continuously (day and night) for approximately one to two months (Xiphu et al., 2012; Weigle, 2010; Broderick, 2011). Construction noise impact would therefore need to be assessed during the day, while drilling and extraction would be assessed at night time, when residual noise levels are lowest.

The decommissioning phase will likely have similar noise sources to the construction phase with the addition of potential demolition equipment, such as concrete breakers. This equipment is noisy, and often with impulsive sound, which makes the noise much more noticeable over long distances (SANS 10103).

16.2.5 Likelihood and areas of noise impact

The likelihood of noise impacting on noise sensitive receivers depends on three main factors:

1. Residual noise level (the prevailing noise level without any activities);
2. Noise level of the activities at the receiver; and
3. The character of the noise, i.e. whether the noise draws attention to itself (a tone, intermittency, impulsive noise, etc.). SANS 10103 requires that these noise levels are adjusted by adding (usually) 5 dB depending on the respective noise characteristic.

16.2.5.1 Drilling activities

Since the drilling activities will run continuously, the associated noise levels are likely to be assessed against the night time residual noise level of L_{Aeq} 20–30 dBA.

Single- figure dBA noise levels have been documented in a recent study by the NYSDEC (2015).

Most of the noisy activities at a wellpad will have a noticeable low frequency character, especially engines/generators and compressors. Demolition plant such as concrete breakers emit noise with an impulsive character, which attracts an extra correction of +5 dB.

Assuming a point source for noise sources on the wellpads, noise levels generally reduces by 6 dB for every doubling of distance (SANS 10357; Fry, 1988). This means that if an object has a noise level of 95 dB(A) at 1 m to equal the residual night time noise levels, one must travel:

- 1.75 km to reduce by 65 dB to 30 dB(A), and
- 5.6 km to reduce by 75 dB to 20 dB(A)

This ignores the “near field effect” of large equipment such as generators, where the noise level at 1 m and at 5 m can be very similar. This also excludes screening, topography or any meteorological effect such as temperature inversions, which will affect these distances. An assessment radius of at least 5 km around a site is therefore recommended. Large sites with more, noisy plant might require a substantially larger study area. This might exceed the guaranteed limits of some noise modelling software.

16.2.5.2 Vehicle noise

Exploration work is done using light and heavy vehicles. Drilling activities are supported by vehicles, which bring equipment, water, chemicals and other supplies to the wellpads.

Vehicles are expected to visit the wellpads at regular intervals. The anticipated number of large support vehicles (10 and 20 tonne vehicles) for each scenario is as follows:

- Reference Case: Negligible
- Exploration Only and Small Gas: 25 per day (i.e., 1 per hour)
- Big Gas: 166 per day (i.e. 7 per hour or one every 9 minutes)

Note that this does not include light vehicles, or vehicles for ancillary activities such as staff vehicles.

There is clearly no noise impact from vehicle noise for the Reference Case.

The impact of vehicle noise for Exploration Only to the Big Gas scenario will depend on:

- The existing traffic flow on the roads being used.
    - The noise impact on a remote, seldom used road will be higher than on a regularly used road.
- The condition of the roads being used.
    - Traffic noise is higher on rough, poorly maintained roads than on smooth roads in good condition.
- The proximity of noise sensitive receivers to the roads.
    - Receivers next to roads are more affected by increased traffic flow than receivers far from the roads.

These aspects will need to be considered for each wellpad site.

In general, the Exploration Only and Small Gas scenarios road traffic noise is unlikely to cause significant noise impacts. One vehicle per hour for one to two months is a small noise impact, even for receivers close to the road.

The Big Gas scenario road traffic noise could cause noticeable and significant road traffic noise impacts, especially if:

- noise sensitive receivers are close to the roads,
- the roads are currently rarely used especially at night
    - a heavy vehicle every nine minutes, day and night, on a seldom used road is a significant increase in vehicle noise, and

- the roads are poorly maintained.

16.2.6 Noise mitigation

There are several potential noise mitigation methods recommended in BSI British Standards (2009) and in use in many operating sites (NYSDEC, 2015; Perenco, 2012). The appropriate methods for each site will need to be investigated on a site by site basis. Below are common techniques that must be considered to reduce noise impact.

- Traffic noise control
  - Ensure all vehicles used are in good working condition, with no faulty silencers, squeaking brakes or screeching fan belts.
  - Ensure that roads are in good condition to minimise bangs and other impulsive noise associated with heavy vehicles driving over rough roads.
  - Plan traffic routes that use busy roads, and road far from noise sensitive receivers.
- Plant noise control
  - All generators, compressors and noisy drilling equipment installed in acoustic enclosures, with silencers fitted to the flues. These reduce noise levels by approximately 20 dB(A). This was required at three drill sites at the Wytch Farm site (Perenco, 2012).
  - See comments below on the ineffectiveness of localised screening for these sites.
  - Fit fans with attenuators.
- Noise monitoring
  - The noise impact assessment for the site will identify the noise limits for the site.
  - Set up noise monitoring stations as required to check that the noise limits are not being exceeded.
  - This is to protect:
    - the noise sensitive receivers from excessive noise, and
    - the operator from spurious noise complaints.
  - This monitoring may also show that the noise limits (which would likely have been based on calculations and predictions) need to be adjusted up or down.
- Financial compensation
  - If the drilling noise is predicted to impact on a sensitive receiver such that there will be a financial impact on the receiver (e.g. a tourism venue that sells “solitude” or “silence”) then this receiver could be financially compensated for the likely loss of income for the duration of the noisy activities.

It is important to note that for this application, noise screening will not be an effective method of noise control for the following reasons:

1. Noise screens will only provide significant noise reduction if located close to the sound source or close to the receiver.
   - Distances between the receptors and the screens will necessarily be further for this application (likely kilometres away), making screening less effective.
2. Noise screens are more effective at higher frequencies of sound (Berglund, 1999).
   - The noise from the drill sites is likely to have significant low-frequency content.

16.3 Risk assessment

16.3.1 Risk measurement

The nearest noise sensitive receivers to a proposed well point must be identified. Due to the constant activity on these sites, this means that noise measurements are required (day and night) at the nearest noise sensitive receivers prior to any activity on site. Measurements must be daytime (06h00–22h00) and night time (22h00–06h00). It has been proposed that measurements are done for two to five years before drilling is done, taking into account seasonal variations of noise levels (Centre for Environmental Rights (CER) 2014). Existing noise levels show that noise levels change very little in the Karoo with weather conditions (Jongens, 2011). Residual noise measurements must nevertheless be done during calm and dry conditions, as required by SANS 10103.

The noise levels for the proposed plant and activities for a wellpad are then calculated using published or measured noise level data and predicted for the intended site. It is recommended that in addition to the L_{Aeq} requirements in SANS 10103, maximum noise levels (L_{Amax}) are measured for equipment, processes and vehicles to better compare the noise impacts to the WHO limits for sleep disturbance. Typical plots are not possible for this assessment as accurate activity noise levels are not available. Noise travel propagation is also affected by topography, so an assessment will be required for each wellpad. If equipment and layout is similar at each wellpad, then these assessments will be relatively quick and easy to repeat.

Corrections of tonality and impulsivity must be added to any relevant noise sources. The measurement and assessment of noise in accordance with South African Standards and Noise Regulations are obliged to be based on the Impulse L_{AIeq}. The impulsivity is thus included in all noise assessments.

Noise impacts due to road traffic noise, especially for the Big Gas scenario activities must be assessed.

The calculated activity noise levels are then compared to the measured noise levels at the noise sensitive receivers.

16.3.2 Limits of acceptable change

The NCRs state that a disturbing noise is created if the activity noise (with corrections added, if applicable) raises the ambient noise level by 3 or 7 dBA or more above the residual noise level depending on the NCR applicable to the province.

Furthermore, a noise nuisance is created if a noise impairs the peace of a person. This is a subjective assessment, and is often closely related to audibility of the noise source, and whether the person approved of the activity related to the noise. A person hostile to an activity will be more likely to be annoyed by a noise associated with that activity. People also blame unrelated noises on the activity. For assessing risk, the likelihood of audibility is a good assessment method, but can be difficult to predict or prove as "discernible noise" is often not measureable.

SANS 10103 gives categories of community or group response to noise. These can be translated to a consequence table (Table 16.3).

16.3.3 Consequence table

Table 16.3: Consequence table

	None	**Slight**	**Moderate**	**Substantial**	**Extreme**
Excess $\Delta L_{Req,T}$	0	0–10	5–15	10–20	>15
Description (Human reaction)	No detectable change in noise climate	Sporadic complaints	Widespread complaints	Threats of community or group action	Vigorous community or group action

$\Delta L_{Req,T}$ is the amount, in dB, the ambient noise level exceeds the residual noise level.

Table 16.4 shows for different activities the estimated excess above residual noise levels at 4 km, from Table 16.2. The impact of each excess can be compared to the consequence in Table 16.3 above. The night time excesses show that more detailed assessment is required for sites within 5 km of the activity site. Fracking will likely exceed day and night time residual levels even further from the wellpad than 5 km.

Table 16.4: Predicted excess of activity noise levels over residual noise levels at 4 km.

Activity	Noise level L_p, dBA at 4 km from the activity	
	Daytime	Night time
None	0	0
Access road construction	4	12
Wellpad construction	-1	7
Rotary air well drilling	-4	4
Horizontal drilling	-5	3
Fracking	23	31

Animal species differ in their sensitivities to noise exposure. Some animals will be negatively impacted, for example if they require a quiet environment to hunt or to hear predators (Barber, 2009). Consequentially, prey could thrive if their natural predators can no longer find them using hearing.

16.4 Risk assessment

For the Exploration Only scenario, noise levels from the multiple wellpad example used in Burns et al. (2016) are shown in Figure 16.1 as an illustration of noise levels at a distance, and their associated risk levels from Table 16.5. The figure shows that the risk of noise impacts from well activities reduces to low once approximately 5 km from the well. This figure does not include potential disturbance due to increased road traffic noise if roads are otherwise quiet.

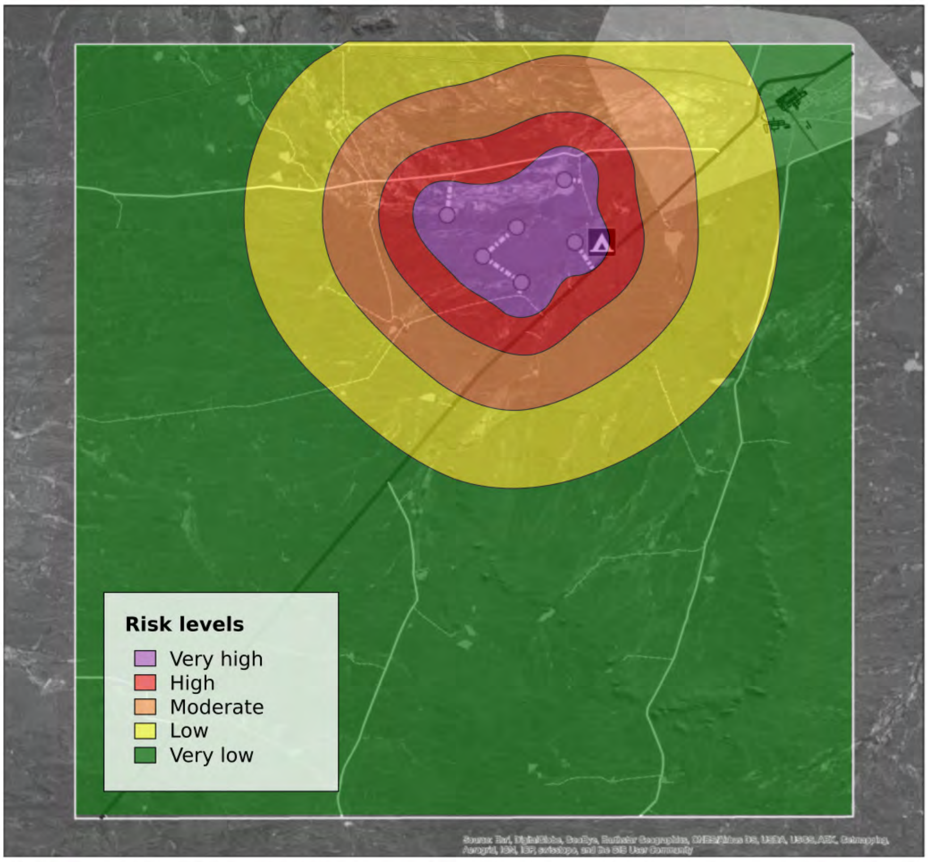

Figure 16.1: Risk levels at a distance from multiple wellpads for a 30 km x 30 km area.

Table 16.5: Risk assessment table for noise impacts that may be caused by SGD.

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Disturbance to humans due to wellpad noise	Reference Case	Within 5 km of wellpads	Substantial	Extremely Unlikely	Very Low	Substantial	Extremely Unlikely	Very Low
	Exploration Only		Substantial	Extremely Unlikely	Very Low	Substantial	Extremely Unlikely	Very Low
	Small gas		Substantial	Very Likely	High	Substantial	Likely	Moderate
	Big gas		Extreme	Very Likely	Very High	Extreme	Likely	High
Disturbance to humans due to road traffic noise	Reference Case	Within 3 km of remote, quiet roads	Substantial	Extremely Unlikely	Very Low	Substantial	Extremely Unlikely	Very Low
	Exploration Only		Substantial	Unlikely	Low	Substantial	Unlikely	Low
	Small gas		Substantial	Unlikely	Low	Substantial	Unlikely	Low
	Big gas		Substantial	Very Likely	High	Substantial	Likely	Moderate
Disturbance to sensitive species	Reference Case	Within 3 km of wellpads and remote, quiet roads	Substantial	Extremely Unlikely	Very Low	Substantial	Extremely Unlikely	Very Low
	Exploration Only		Substantial	Extremely Unlikely	Very Low	Substantial	Extremely Unlikely	Very Low
	Small gas		Substantial	Likely	Moderate	Substantial	Unlikely	Low
	Big gas		Substantial	Very Likely	High	Substantial	Likely	Moderate

16.5 Best practice guidelines and monitoring requirements

At all times, the recommendations of the site's noise impact assessment must be followed. Depending on the location of the site and the plant used, the requirements may be onerous or easily complied with.

16.5.1 Planning

Avoid obviously noise sensitive areas, such as residential properties, resorts, areas where the quiet and calm nature of the place is material to its appeal. A noise impact assessment for the planned site must be done according to the methods of SANS 10328. A Noise Management Plan must be written based on this assessment, which the operator must adhere to at all times.

16.5.2 Construction

Follow the recommendations of the noise impact assessment, including noise monitoring if required. Follow the best practice guidelines in BS 5228-1 for controlling noise on open sites. Attenuate all noisy plant.

16.5.3 Operations

Follow the recommendations of the noise impact assessment, including noise monitoring if required. Follow the best practice guidelines in BS 5228-1 for controlling noise in open sites, such as the use of localised enclosures as required for noisy activities. Attenuate all noisy equipment.

16.5.4 Decommissioning

Follow the recommendations of the noise impact assessment, including noise monitoring if required. Follow the best practice guidelines in BS 5228-1 for controlling noise in open sites. Attenuate all noisy equipment. The combination of short-term, high noise level, and longer-term, constant level noise will need to be addressed in the site's Noise Management Plan.

16.5.5 Monitoring and Evaluation

It is recommended that some noise monitoring is conducted for the sites. The extent required will be determined by the noise impact assessment.

The operator must submit regular noise reports, showing that they are complying with the requirements of the noise impact assessment.

The operator should be responsible for the purchasing, installation and maintenance of any noise monitoring stations.

16.6 Gaps in knowledge

There is a lack of published and reliable measurement data in octave or third-octave bands for the noise created by SGD activities for the exploration, operation and decommissioning phases.
Such data is required by SANS for accurate propagation predictions used in the noise impact assessments and hence in the risk assessment formulation.

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CHAPTER 17

Electromagnetic Interference

CHAPTER 17:
ELECTROMAGNETIC INTERFERENCE

Integrating Author:	Adrian Tiplady[1]
Contributing Authors:	Paul van der Merwe[2], Braam Otto[1]

[1] Square Kilometre Array radio telescope South Africa (SKA SA), Cape Town, 7405

[2] Mesa Solutions (Pty) Ltd, Stellenbosch, 7600

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Investment in astronomy is part of a concerted strategy by the Department of Science and Technology (DST) to establish South Africa as an international hub for astronomy. Investments have not only targeted local projects, but also international projects that have been located in South Africa, such as the Southern African Large Telescope (SALT) and the Square Kilometre Array (SKA).

In order to protect these multi-billion Rand investments from increased levels of interference (and thereby reducing the scientific performance of the facilities), protection of the observing environment is critical. Such increased levels are expected with an increase in industrial and telecommunications activity.

The potential increase in interference resulting from activities associated with shale gas development (SGD) has been assessed, and separation distances, or buffers, derived to ensure no detrimental impact on the SKA. Buffers are classified in terms of risk classes, where any activities that are proposed to be undertaken within specific buffers will be required to implement appropriate and effective mitigation measures before proceeding with such activities. The identification of these measures will be subject to further detailed, site specific assessments.

Calculated separation distances can reach up to 40 km for the most sensitive parts of the SKA. There is an opportunity to reduce these distances, should further detailed studies be undertaken to provide site specific detail.

CHAPTER 17: ELECTROMAGNETIC INTERFERENCE

17.1 Introduction and scope

17.1.1 Relevance of electromagnetic interference (EMI) for radio astronomy developments

Southern Africa has a rich history in astronomy, dating back to 1820 and the establishment of the Cape of Good Hope Royal Observatory. More recently, however, the development of astronomy in South Africa has been part of a considered strategy that has its origins in a white paper on Science & Technology, drafted in 1996. The white paper identified the need for a basic competence in flagship sciences such as astronomy. This strategic position was carried forward into the National Research Development Strategy, published in 2002 by the Department of Science and Technology (DST), in which astronomy, together with human palaeontology and indigenous knowledge, is identified as an area in which South Africa is most likely to succeed because of an inherent natural geographic advantage. This led to the DST adopting a vision that South Africa should become the preferred destination for major astronomy projects and associated international investment in construction and operations of astronomical facilities (DST 10 Year Plan 2008-2018). This commitment is repeated in the DST's Strategic Plan for the fiscal years 2011-2016:

"In growing its knowledge base, South Africa also needs to build on its niche strengths, especially those in which it has a geographic or natural advantage, such as astronomy, biodiversity, Antarctic research, minerals processing and palaeontology."

As a result of this strategy, the South African government has undertaken multi-billion Rand investments into world class astronomical facilities: firstly, the multinational 10 metre (m) Southern African Large Telescope (SALT) in Sutherland – at the time of writing, the largest optical telescope in the southern hemisphere; and secondly, the successful African[1] bid to host the international Square Kilometre Array (SKA)[2] project. This includes the establishment of the South African funded and designed MeerKAT[3] radio telescope, which will be the premier centimetre (cm)-wavelength radio astronomy facility in the world until the SKA is built. Investments in both facilities are supported by a wide range of human capital development programs. These are meant to increase the capacity of South African scientists and engineers who are able to participate in the scientific programs of these facilities. South Africa's bid was supported by the Heads of States and Government of the African Union in a Declaration at their 2010 Assembly. This Declaration expressed unequivocal support for

[1] South Africa's bid to host the SKA was on behalf of eight other African Partner Countries, including: Namibia, Botswana, Zambia, Mozambique, Madagascar, Mauritius, Kenya and Ghana.
[2] For further information, go to: www.skatelescope.org.
[3] For further information, go to: www.ska.ac.za.

South Africa to lead the bid to locate the SKA in Africa, and committed Africa to participate in the global SKA project. The SKA was also recognised as a flagship project by the African Ministerial Council on Science and Technology.

Once fully constructed, the SKA will extend over 3 000 kilometres (km), representing a multi-billion Euro investment by the global scientific community in one of the premier technological developments in the world. A radio astronomy facility, such as the SKA, is an extremely sensitive radio receiver with more than 15 orders of magnitude greater sensitivity when compared to a typical cellular phone. It is designed to receive extremely weak radio signals that are emitted naturally from cosmic sources. Its scientific performance is highly dependent on the technical scope of the facility, as well as the scientific properties of the environment in which it is located. Such properties would include tropospheric and ionospheric disturbances and precipitable water vapour, as well as various geo-hydrological and meteorological dependencies. These would all be cost drivers for the establishment of such a project. However, the principle risk to the scientific performance of a radio astronomy facility is the presence of radio frequency interference (RFI), which, for radio astronomy; are radio signals not of cosmic origin. RFI is generated from a variety of terrestrial sources that include intended radiators such as television broadcasters, global system for mobile communications (GSM) transmissions and wireless networks, but also unintended radiators that include the operations of most commercial electronic devices. Even microwave ovens and the spark plugs of petrol vehicles are unintended sources of RFI. For this reason, the identification of sites for the establishment of new radio astronomy areas is a highly scientific and technical process.

The Northern Cape Province of South Africa, and in particular the Great Karoo, has been shown, through an international SKA site selection process, to be one of the best locations in the world to establish a cm-wavelength radio astronomy site. This was confirmed following the recommendation by an independent panel of experts that South Africa, along with the SKA African Partner Countries, be awarded the right to host the SKA. To protect the region for astronomy, the South African government promulgated the Astronomy Geographic Advantage (AGA) Act, Act No. 21 of 2007. This Act empowers the Minister of Science and Technology to declare Astronomy Advantage Areas, and protect these areas through regulations. The Northern Cape Province has been declared as an Astronomy Advantage Area.

In a report by the Working Group of the Task Team on Shale Gas and Hydraulic Fracturing (Department of Mineral Resources (DMR), 2012), an impact analysis of shale gas development (SGD) on the SKA is undertaken (Digital Addenda 17A and 17B). In it, the author provides a concrete assessment framework to determine the impact of RFI on the SKA. The framework is based on internationally accepted principles for protection of the radio astronomy services, as described by the International Telecommunications Union (ITU). Required protection threshold levels for the radio astronomy service are described in ITU Recommendation ITU-R RA.769-2 (Digital Addendum 17C). The basic principles upon which this recommendation is developed has been used in the derivation of the South African Radio Astronomy Service (SARAS) protection level (DST, 2011). This protection level has been promulgated in terms of the AGA Act (Appendix D - Government Gazette Notice No. 35007, 10 February 2012), and adopted in South Africa to provide a clear and objective decision making process in the assessment of RFI on the SKA and other radio astronomy facilities. This process is sufficiently robust to be applied to an extensive range of scenarios that may be the cause of RFI, including television broadcasting, public communications, household and industrial activities, and renewable energy. A literature survey suggests that, other than the report prepared for the South African Working Group of the Task Team on Shale Gas and Hydraulic Fracturing (DMR, 2012), there is no other published national or international impact assessment conducted on the risk of RFI from hydraulic fracturing ("fracking") activities on radio astronomy facilities.

Figure 17.1 describes, at a high level, typical uses of the electromagnetic spectrum across which the SKA will be operating (the SKA will operate between 100 MHz and 25 GHz at its fullest extent). Low level electromagnetic interference, produced by the use of electrical and industrial equipment, would typically fill a large part of the radio frequency spectrum below 1 GHz (not shown). The risks posed by these sources are typically dependent on the distance from an SKA receiver that they are used, the transmitter power of the relevant device, and any relaxation of the protection levels. This figure is only illustrative, and should not be used in isolation to determine potential risk to the SKA.

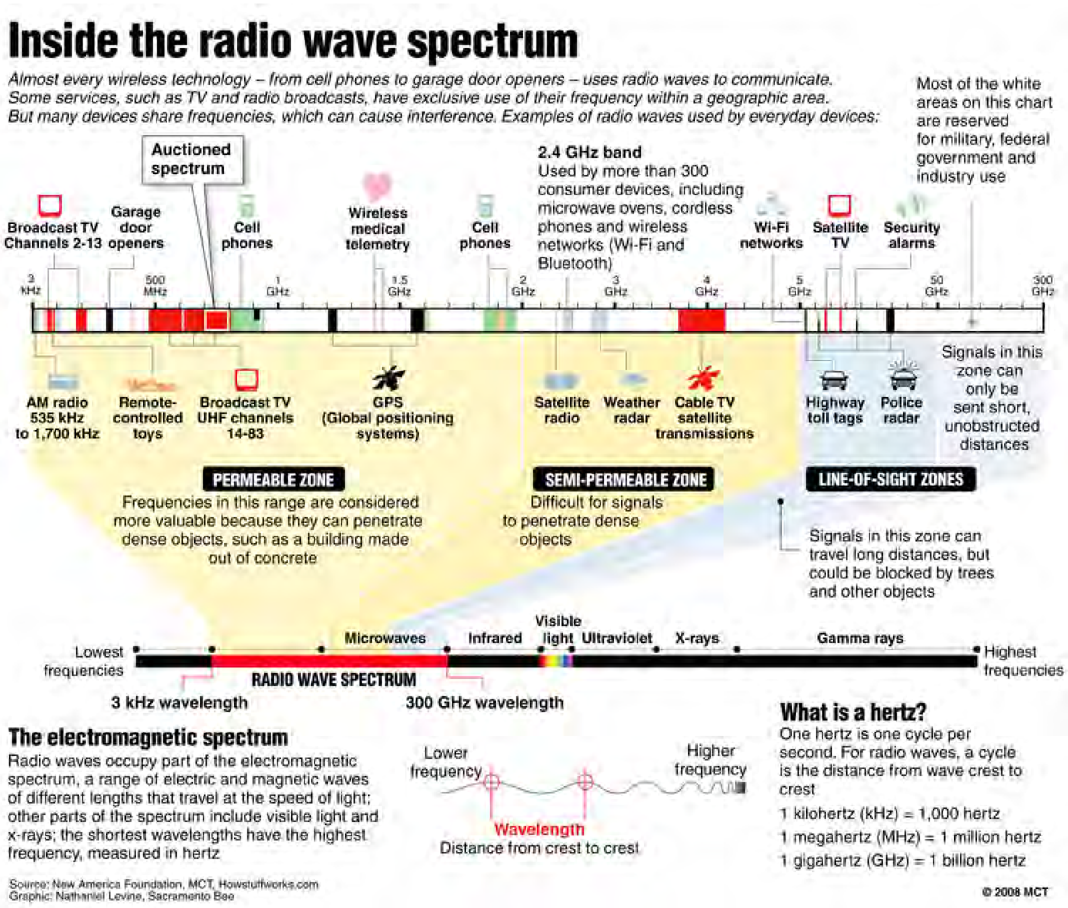

Figure 17.1: Everyday uses of the radio frequency spectrum (image credit: http://theconversation.com/wireless-spectrum-is-for-sale-but-what-is-it-11794 [Online: 19-09-2016])

17.2 Scope of main strategic issues

The scientific return of a radio telescope relies on an environment that is as free as possible from RFI within the radio frequency band of interest. Historically, radio telescopes have operated within narrow parts of the radio frequency spectrum (approximately 1% of the radio frequency spectrum is allocated for use of the radio astronomy service by the ITU). Modern and next-generation radio astronomy facilities, such as the SKA, aim to operate across very wide frequency ranges. The component of the SKA in South Africa, at its fullest extent, will operate from 100 megahrtz (MHz) to 25.5 gigahertz (GHz). As a result, it is dependent on domestic legislation to ensure protection of the international community’s investment into South Africa.

For the first phase of the SKA, capital investment amounts to approximately R5 billion, whilst phase two of the SKA could be at least five times this. Operational costs are expected to be anywhere between 8% - 10% of the total capital cost per annum, for 50 years. However, it is the indirect socio-economic benefits resulting from participating in the SKA project that are of greatest value, and include:

- Skills development, and spin-off products, in next-generation engineering and computing technologies as well as 'big data' processing;
- Establishment of knowledge generation capacity, and hence contribution towards the growth of a knowledge-based economy in South Africa;
- The promotion of South Africa as a viable destination for international investment in high-tech infrastructure and scientific projects; and
- Attracting youth into careers of science, technology, engineering and mathematics.

17.3 Key potential impacts

17.3.1 Nature of impact

The SKA is sensitive to two classes of RFI. The first class includes relatively high power, narrow band radio signals commonly associated with a variety of telecommunication services such as GSM, Wi-Fi and Bluetooth. These narrowband signals tend to be strong, and can have one of three potential detrimental impact (in increasing order of RFI signal strength):

i. The RFI signal pollutes a narrow part of the radio frequency spectrum of interest. The radio telescope continues to operate, but the polluted part of the spectrum must be filtered out. The cosmic information in the filtered band cannot be recovered, resulting in decreased scientific performance due to reduced access to the radio frequency spectrum;

ii. The RFI signal is strong enough to cause saturation in the radio astronomy receiver equipment. Saturation causes non-linear artefacts across the entire observing band that cannot be removed. No observations can be made by the equipment;

iii. The RFI signal is sufficiently strong to cause permanent damage to radio astronomy receiver equipment.

In recent years, the demand for higher data throughput has seen an increase in availability of consumer devices using ultra-wideband protocols. These devices are typically used for short distance communication (such as spread spectrum technologies), or in radar technologies (such as vehicle parking assist).

The second class of RFI includes relatively low power broadband emissions that are generated as a by-product from the use of electrical equipment. This is commonly referred to as EMI, and examples include welding activities and the sparking on electrical power lines. Although typically low power, EMI can potentially cover a large part of the frequency spectrum relevant to the SKA, making it unusable for radio astronomy observations. In this case the spectral occupancy of the interference makes it equally destructive as saturation or permanent damage to the receivers. The result is a significant loss in scientific performance.

The assessment of interference also considers its transient nature as a result of its operational use or physical movement of the interference source (e.g. satellites or vehicles). More recently, detailed studies have been undertaken into short duration transient events that are typical of the permanent operation of an interference source. Sufficiently complex to be classified as a separate sub-class of EMI, this interference often requires more sophisticated equipment to measure and the source is usually more difficult to identify. They tend to exist for only a short period, but can occupy a large part of the spectrum. Significant peak interference levels, for example mechanical relays used for switching of electric motors, could lead to short duration saturation of a sensitive receiver. This again produces non-linear artefacts in the observable band, making it unsuitable for astronomy observations.

This assessment of the impact of EMI takes into account the uncertainty presented by the limited information on the nature of potential sources associated with SGD activities. It also treats EMI as the primary source of detrimental risk. Whilst the use of radio communication equipment does represent a significant risk of detrimental impact, this risk is technology dependent. Through the adoption of key guidelines and principles this risk can be addressed and reduced. Furthermore, the use of such equipment will be subject to relevant regulations promulgated in terms of the AGA Act where relevant.

17.3.2 Methodologies and assumptions

17.3.2.1 <u>Decision-making framework</u>

A framework to assess the impact of EMI, and RFI, on or around the SKA site is provided in Digital Addendum 17E. To ensure no detrimental impact on SKA stations, in the generalised case for each frequency f_i we require the following condition to be true:

$$\text{Compliance} \rightarrow Loss_{det} \geq Loss_{required}$$

where:

$$Loss_{required} = ProtectLevel - EmissionLevel$$

Each variable ($Loss_{required}$) is described as follows:

- $Loss_{required}$ = the required attenuation of an EMI/RFI signal [dB]

- *EmissionLevel* = characteristic profile of radio emission of the EMI/ RFI source, and can be expressed in units of spectral power density [dB(W/Hz)]
- *ProtectLevel* = required protection threshold level. Unless otherwise prescribed, the default level is defined by SARAS as:

$$\text{SARAS[dBm/Hz]} = -17.2708 log10(f) - 192.0714 \quad \text{for } f < 2GHz,$$
$$-0.065676 log10(f) - 248.8661 \text{ for } f > 2GHz$$

Where; f is in MHz, and where:

$$Loss_{det} = PathLoss + Shielding$$

Each variable ($Loss_{det}$) is described as follows:

- $Loss_{det}$ = predicted/measured attenuation of EMI/ RFI signal [dB]
- *PathLoss* = attenuation resulting from radio propagation, including the free space loss between the EMI/ RFI source and radio astronomy receiver, and diffraction losses [dB]. These losses may be determined via the following methods, in order from most conservative to least conservative:
  - Free space loss;
  - Free space loss + diffraction model;
  - Measurement.
- *Shielding* = attenuation resulting from additional physical shielding [dB]

17.3.2.2 Methodology

To ensure compliance with protection levels, the principle adopted in the assessment methodology is to assume that the required attenuation ($Loss_{Required}$) is equal or less than the predicted attenuation ($Loss_{Det}$) between EMI/ RFI sources and radio astronomy receivers. Determination of $Loss_{Required}$ relies on, as input; the protection threshold levels (SARAS) and the characteristic emission profile of the potential EMI/ RFI source. Determination of the predicted attenuation ($Loss_{Det}$) relies either on site specific path loss measurements, which would be impractical to implement on a large scale, or on propagation models. In the case of propagation modelling both free space loss and loss as a result of topographical diffraction over a fixed separation distance are calculated. Additional shielding may be considered in situations where free space loss and topographical diffraction is insufficient. However, this should only be considered as part of site specific mitigation measures.

The radio frequency propagation model ITU Recommendation ITU-R P.526 is used to determine separation distances required between sources of EMI/ RFI and SKA receivers to ensure compliance. The model is highly dependent on the following:

i. Relative heights of receiver and transmitter;
ii. Receiver technologies, and characteristic emission profile of transmitters;
iii. Local topographical features.

To determine the characteristic profile of EMI, a variety of methods can be adopted. The most accurate is to undertake a series of measurements under all potential operational conditions, using accepted measurement methodologies. One approach would be to do individual measurements for a wide range of equipment typically used in SGD to derive an average characteristic profile during operation. A second approach would be to do emission characterisation of an entire fracturing site during various stages of development. In the absence of such measurements, national or international standards can be adopted. Whilst a SGD site can be considered a fixed installation, International Special Committee on Radio Interference (CISPR) standards can be adopted to provide EMI limitations of general classes of equipment to be used in SGD activities. The South African National Standards Authority adopts CISPR standards for use in South Africa. Digital Addendum 17A describes a wide range of CISPR standards. Given the frequency dependency of the SARAS protection levels (DST, 2011) and the nature of radio frequency propagation; Digital Addendum 17A shows that the lowest frequency limit of each receiver technology (see Section 7, Digital Addendum 17A) determines the largest required separation distance. This aspect will be used to determine the required separation distance in this assessment.

17.3.2.2.1 Transient assessments

The assessment of transient sources of interference is guided by ITU Recommendation ITU-R RA.1513-1, which considers the acceptable loss of data for a radio astronomy facility as a result of interference. This is expressed as a percentage of time, where no single network of interference can result in greater than 2% data loss, whilst a total data loss of no more than 5% for all sources can be tolerated. This requirement is considered in the assessment of various operational use profiles, such as the treatment of moving sources of interference (see Digital Addendum 17A).

In the case of regular use, or mixed use of multiple pieces of equipment, or large density of transient sources of interference are treated as permanent sources.

17.3.3 Impact systems

17.3.3.1 Radio astronomy systems

The only radio astronomy system that may be impacted by SGD activities in the study area is the SKA[4]. At its fullest extent, the SKA in Africa will consist up to 3 000 dishes, each of which is similar to a MeerKAT[5] dish as shown in Figure 17.2, and specialised aperture arrays[6]. The configuration will be split into three different components: a highly concentrated core, measuring up to 5 km in diameter and consisting of 50% of the antennas; a set of spiral arms stretching out to 180 km and including a further 30% of the antennas; and final, up to 25 SKA remote stations distributed across South Africa and the African Partner Countries. Each dish will be approximately 15 m high, and operate over a frequency range from 350 MHz up to 25.5 GHz. Co-located with the dishes, within the core and spiral arms, will be aperture arrays that operate below 350 MHz at a height of 1 m. Consistent with international recommendations, and for the purposes of this assessment, the gain of each of these antennae is assumed to be 0 dB in the direction of the EMI/ RFI source. Current timelines for the construction of the SKA are as follows:

i. **SKA Phase 1**
    a. Construction: 2018 – 2023
    b. Operations: 2023 onwards
ii. **SKA Phase 2**
    a. Design: 2021 - 2023
    b. Construction: 2023 - 2030
    c. Operations: 2030 onwards

[4] See www.skatelescope.org for further details.
[5] MeerKAT is a South African funded and designed pre-cursor facility, and will consist of 64 dishes when completed in 2017. It will be one of the world's premier cm-wavelength radio astronomy facilities when completed, and is designed as a Strategic Infrastructure Project (SIP) by the Presidential Infrastructure Coordinating Commission (PICC). See www.ska.ac.za for more details.
[6] See www.skatelescope.org/aperture-arrays/ for further details.

Figure 17.2: Photograph of MeerKAT dish (image credit: SKA South Africa)

Figure 17.3 indicates the study area, with superimposed SKA Phase 1 and SKA Phase 2 configuration. Corridors for the core and spiral arms have been pre-identified, inside which the density of SKA stations will increase over time. Individual points identify the locations of SKA Remote Stations. The black polygon identifies the Karoo Central Astronomy Advantage Area (KCAAA), declared in terms of the AGA Act. Any activities, and use of radio communication equipment, located within this area, is subject to compliance with regulations for the protection of radio astronomy, as promulgated by the Minister of Science and Technology. These regulations will impose conditions and restrictions on use, subject to a prescribed impact assessment.

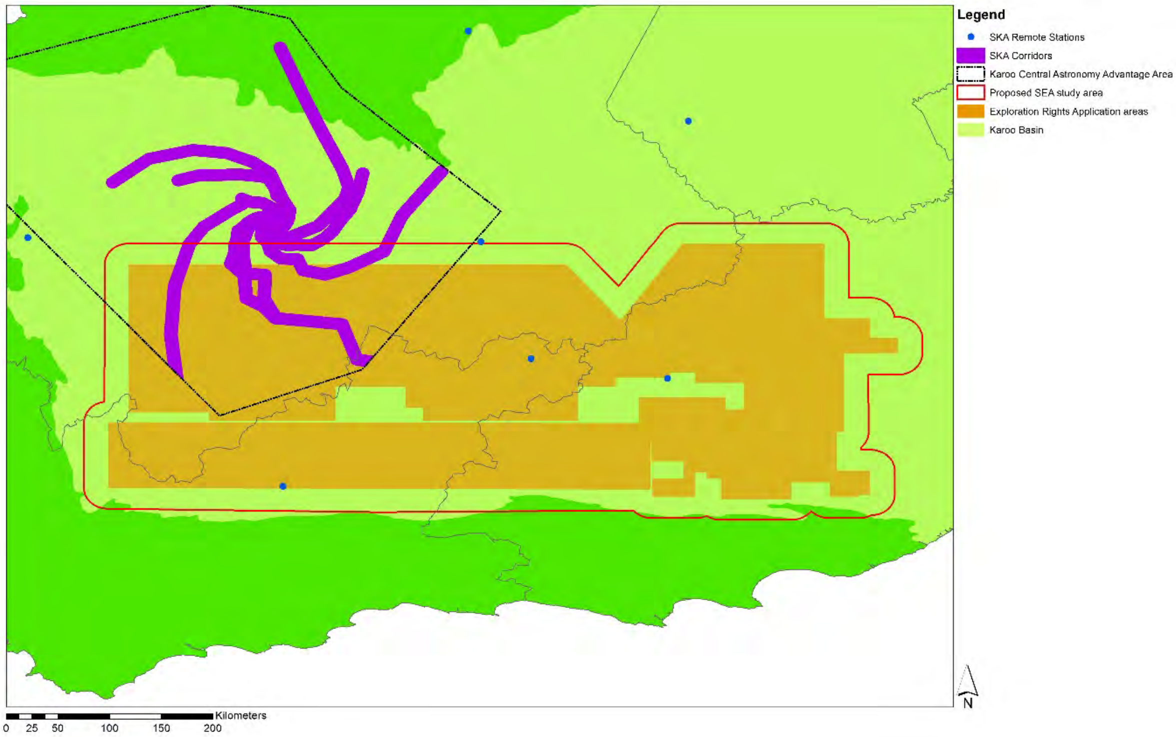

Figure 17.3: Study area with SKA Phase 1 and Phase 2 configuration.

The key outcome of this assessment is to ensure protection of the SKA stations within these geographic locations, through the determination of masks that identify areas of high detrimental impact.

17.3.4 Production of EMI resulting from SGD

17.3.4.1 Key sources of risk

Given the unavailability of measurements, the characteristic emission profile of EMI sources is described by CISPR recommendations, which are adopted by the South African Bureau of Standards (SABS) as a national standard. These standards prescribe an upper limit on allowable levels of emission.

A description of the expected characteristic EMI profile for a single SGD site and supporting activities is provided in Table 17.1. This profile is based on a proposed inventory of equipment[7] for each potential phase of construction, operations and decommissioning. It is assumed that the equipment will be operated at an average height of 2 m.

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[7] The authors engaged with technical staff within the petroleum industry to acquire further technical information. However, this information is preliminary and may vary from site to site. It is recommended that this table is updated following more detailed planning by the developers.

Table 17.1: Description of expected EMI profile of SGD sites and supporting activities during construction and operation. The decommissioning state is expected to be similar to construction state.

EMI Source	Characteristic Profile	Use Profile [% Time]	Use Profile [Location]	Level at 350 MHz [dB(uV/m) @ 10m]	No. per Site	Integrated Level at 350 MHz [dB(uV/m) @ 10m]
Site Preparation [one month]						
Diesel Vehicles	CISPR 12:2009 - 20dB	40%	On-Site, Road	17	5	24
Petrol Vehicles	CISPR 12:2009	40%	On-Site, Road	37	5	44
Pumps/ Compressors/ Generators	CISPR 12:2009	100%	On-Site	37	5	44
Local Wireless Communication Systems (ISM) at 464 MHz	ICASA Radio Regulations: Short Range Devices (Non-Specific SRD)	100%	On-Site	115[8]	1	115[9]
Computer Systems	CISPR 22:2009 (Class B)	100%	On-Site	37	3	42
Bulldozers/ Concrete Mixers/ Forklifts/ Crane	CISPR 12:2009	40%	On-Site	37	5	44
Electrical Appliances (Domestic)	CISPR 14-1:2009	100%	On-Site	37	10	47
Electrical Appliances ISM (Industrial)	CISPR 11:2009 (Class A)	10%	On-Site	47	5	54
Data Testing Systems	CISPR 11:2009 (Class A)	10%	On-Site	47	1	47
					Total On-Site:	**115**
					Total On Road:	**44**
					Total On-Site (Excl. Communication Systems):	**54**
Drilling/Securing [three months]						
Drilling Rig	CISPR 12:2009	50%	On-Site	37	1	37
Drilling Services (Trucks)	CISPR 12:2009	40%	On-Site, Road	37	3	42
Local Wireless Communication Systems (ISM)	ICASA Radio Regulations: Short Range Devices (Non-Specific SRD	100%	On-Site	115	1	115
Computer Systems	CISPR 22:2009 (Class B)	100%	On-Site	37	3	42
Electrical Appliances (Domestic)	CISPR 14-1:2009	100%	On-Site	37	5	44
Electrical Appliances ISM (Industrial)	CISPR 11:2009 (Class A)	10%	On-Site	47	3	52
					Total On-Site:	**115**
					Total On Road:	**42**

[8] This level is prescribed at a frequency of 464 MHz. For the purposes of calculating the impact, it is assumed that this maximum emission level is at 350 MHz as opposed to 464 MHz. The impact on the results due to this change in frequency is negligible.

[9] See footnote 8.

EMI Source	Characteristic Profile	Use Profile [% Time]	Use Profile [Location]	Level at 350 MHz [dB(uV/m) @ 10m]	No. per Site	Integrated Level at 350 MHz [dB(uV/m) @ 10m]
Total On-Site (Excl. Communication Systems):						**52**
Stimulation and Well Test [12 months]						
Drilling Services (Trucks)	CISPR 12:2009	40%	On-Site, Road	37	3	42
Well testing equipment	CISPR 11:2009	10%	On-Site	47	1	47
Local Wireless Communication Systems (ISM)	ICASA Radio Regulations: Short Range Devices (Non-Specific SRD	100%	On-Site	115	1	115
Computer Systems	CISPR 22:2009 (Class B)	100%	On-Site	37	2	40
Electrical Appliances (Domestic)	CISPR 14-1:2009	100%	On-Site	37	5	44
Total On-Site:						**115**
Total On Road:						**42**
Total On-Site (Excl. Communication Systems):						**48**

Key points for consideration:

i. The profile addresses both on-site and supporting activities on roads;

ii. Expected EMI levels are prescribed in relevant CISPR standards as average levels. In the case of CISPR 22 (Class B), and CISPR 11 (Class A), quasi-peak levels are prescribed;

iii. The profile addresses the nature of use of the equipment. However, given the mix of equipment and the commonality in the CISPR descriptions, the overall EMI profile will remain constant and should be treated as a permanent source of EMI;

iv. The inventory of equipment includes local communication devices, such items as Wi-Fi, Bluetooth and any other proprietary communication equipment that could be used by the developer (either separately, or built into the equipment). The use of such equipment can potentially be mitigated should appropriate guidelines and principles be adopted; and

v. Cumulative impact may be considered in the various scenarios, dependent on the relative location of each of the potential sites to an SKA station. For *n* sites that are equidistant to an SKA station, the cumulative impact will scale as $10\log_{10}(n)$.

Based on a single site, and following the prescribed methodology as per Section 17.3.2, the required attenuation is determined and described in Table 17.2 (detailed calculations provided in Digital Addendum 17F) for each phase of the development (construction, operations, decommissioning). The table covers the following situations:

i. On-Site (excl. Communication Service) – attenuation required to ensure that EMI resulting from the use of electrical and industrial equipment poses no risk of detrimental impact to SKA stations;

ii. On-Site – this is the same as per On-Site (excl. Communication Service), but includes the use of short range wireless devices for short range communication as part of the assessment. Additional shielding would be required as part of a more detailed and site specific mitigation strategy. This is dependent on the technology and mode of communication to be used;

iii. On Road – supporting transport activities;

Table 17.2: Required attenuation for each phase, on a site-per-site basis.

Phase		Required Attenuation [dB @ 350MHz]	Additional Shielding [dB]
On-Site (excl. Communication Service)			
Construction	Site Preparations	155	0
	Drilling Securing	153	0
Operations	Stimulation & Well Test	149	0
Decommissioning	Site Preparations	155	0
On-Site			
Construction	Site Preparations	155	61
	Drilling Securing	155	61
Operations	Stimulation & Well Test	155	61
Decommissioning	Site Preparations	155	61
On Road			
Construction	Site Preparations	145	0
	Drilling Securing	143	0
Operations	Stimulation & Well Test	143	0
Decommissioning	Site Preparations	145	0

The required attenuation is used as the primary input in determining required separation distances, or buffers (see Section 17.3.5). Activities located within these buffers will not have achieved the required attenuation, and would therefore produce detrimental impact on SKA stations. In the case of stations located in the spiral arms, these buffers will assume average topographical terrain. Any additional shielding required, or mitigation measures, should be determined on a site specific basis as and when required. In the case of SKA remote stations, site specific topography will be considered.

17.3.4.2 <u>Scenarios</u>

i. Scenario 0: Reference Case

Detailed studies have previously been undertaken on the existing radio frequency environment to determine suitability of hosting the SKA. Inputs such as population density (used as a proxy for general presence of EMI), transport routes and location of licensed transmitters were used. The background EMI currently presents an acceptable level of interference for the SKA stations. Any change in this EMI background in the vicinity of SKA stations could result in a detrimental impact on the SKA.

ii. Scenario 1: Exploration Only

It is expected that a limited number of sites will be tested during the exploration phase. It is also assumed that, given the description in Table 17.1, the EMI profile for each fracturing site will not change substantially for the three phases of construction, operation and decommissioning.

Given the low density of exploration activities, the cumulative impact of activities will not significantly increase the required attenuation beyond current levels on a per site basis. It is also unlikely that more than one or two exploration activities will take place within the vicinity of an SKA station[10]. The increase in vehicle volume is expected to be negligible[11], and SKA remote stations would not have been established prior to the commencement of exploration activities.

iii. Scenario 2: Small Gas

It is assumed that 55 wellpads within one production block, located somewhere in the Central Karoo will be established, with the characteristic EMI emissions described as per Table 17.1. The cumulative impact of the Small Gas activities[12] will not increase the required attenuation beyond what would be required for a single SKA site, since it is assumed that no more than one production block would be established within the vicinity of an SKA station (see footnote 10). It is likely that the increase in vehicular would be insignificant (see footnote 11).

iv. Scenario 3: Big Gas

The Big Gas scenario will result in the establishment of four production blocks with around 410 well pads in total. This will result in an increased cumulative impact. It is likely that many SGD activities may be established fairly close to each other, and will be operating within the vicinity of an SKA station (see footnote 10). Such cumulative impact will scale with the number of wellpads and their location, raising the required attenuation by one class level (see Section 17.3.5). A significant increase in vehicular activity may see roads becoming permanent sources of EMI.

[10] More specifically, sites that are equidistant to an SKA station, and within or adjacent to a pre-determined buffer.
[11] Subject to a detailed operational plan for exploration and development activities by the relevant developers.
[12] For the purposes of this chapter, an activity is interpreted to mean the full scope of relevant construction, or operation, activities at a single well pad.

17.3.4.3 Mitigation options

Various mitigation options exist to address EMI and RFI sources, which can be separated into two different categories. The first category deals with mitigation options that are technology dependent, as well as being dependent on the use profile of the relevant equipment. These options include the following:

i. Wireless communication equipment – the use of any wireless communication equipment, including consumer devices such as Bluetooth, Wi-Fi, as well as wireless local area networks (WLAN), may pose an unacceptably high risk and should be replaced by fixed communication services only. In the case of use within the declared KCAAA, the proposed infrastructure and any subsequent replacement these will be subject to the appropriate impact assessment process, as and when required;

ii. Vehicles –petrol vehicles generate excessive levels of interference due to sparking events associated with the spark plugs. An alternative will be to change to diesel vehicles, which may mitigate the impact but not completely due to the subsidiary electronic equipment located in vehicles. Vehicle use in buffer zones will have to be monitored and reduced if required;

iii. Pumps and Generators - tend to generate interference below the lowest frequency of interest to the SKA, assuming that in the case of pumps or electric motors, brush fewer units are used. However, typically the control hardware used to switch on/off pumps or generators make using of noisy switching electronics. Mechanical contactors used for switching larger currents produce sparking interference each time they operate. The effect of this interference can reliably be reduced by placing all associated hardware in shielded enclosures;

iv. Micro controllers and monitoring hardware - typically have well defined clock frequencies and interference associated with communication protocols. Placing all such hardware inside shielded enclosures that make use of proper cable interfaces will help to reduce generated interference;

v. All electrical/electronic cabling - can contribute to interference generated by the plant. Depending on the type of cable, conducted interference in the form of common mode current will flow on the outside of the cable. This conducted interference can radiate into the environment at frequencies where the cable becomes a resonant structure. Mitigation of such interference can be reduced by either improving the EMI performance of the cables used through the use of filters at interfaces to shielded enclosures, the use of shielded cables with appropriate grounding, or by placing them directly in soil. Sleeving should not be used as this prevents close capacitive contact between the cables and the soil around it. This approach can, however, have significant cost implications and would have to be evaluated based on the site location and stage of operation.

The second category of options is dependent on site specific information. In principle, site specific topographical features may be taken advantage of to increase the predetermined attenuation to an SKA station. This helps to reduce the effective separation distance of that specific proposed SGD site. However, this mitigation strategy may only be undertaken on an individual site by site basis, and cannot be implemented generally.

17.3.5 Risk assessment

A map of sensitivity zones, derived from Table 17.2, is shown in Figure 17.4. The sensitivity zones are relevant for all construction and decommissioning phases, and are calculated assuming a generic, flat Karoo landscape[13]. A second map of sensitivity zones, relevant for all operational phases, is shown in Figure 17.5. The separate locations beyond the spiral arms, pertaining to the SKA remote stations, should only be considered for activities to be proposed beyond the year 2023. Both maps have been calculated with the exclusion of short range radio communication devices, which would require an additional 61 dB of attenuation or the adoption of alternative technologies that can provide the same level of service in a more 'radio astronomy friendly' manner (i.e. the use of wired, as opposed to wireless, technologies). It is unlikely that the use of these short range devices can be mitigated entirely through the implementation of a separation distance, and other measures would have to be considered – particularly within the declared KCAAA.

The sensitivity zones are categorised into various classes from 1 – 5, where each sensitivity class is informed by a specific separation distance. SGD activities beyond the pre-identified sensitivity zones do not represent a risk of detrimental impact on the SKA as a result of EMI (assuming that general guidelines concerning the use of communication equipment is followed). Should an activity be proposed to take place within a defined sensitivity area, additional attenuation would be required in order to comply with the protection level requirement of the SKA. The additional attenuation required per sensitivity class and the phase specific separation distance is described in Table 17.3. Should numerous SGD activities be undertaken within the same sensitivity class (this may be the case during the Big Gas scenario), the effective impact would increase, requiring additional attenuation to mitigate (the effective sensitive of the area increases). This is due to the cumulative effect of SGD activities (e.g. four well pads under construction in the same vicinity near an SKA station would result in an

[13] It would not make sense to calculate sensitivity zones taking into account site specific topography, as individual sources of RFI would have varying impact depending on the exact location of SKA stations within the spiral arms. Such calculations would be undertaken in cases where site specific information is required to reduce the potential of RFI sources.

increase in additional mitigation of up to 6dB). Using the sensitivity class descriptions described in Table 17.3, the assessment of risk for each of the scenarios, with and without mitigation, is set out.

Figure 17.6 presents a risk map of electromagnetic interference impacts to radio astronomy (SKA) across four SGD scenarios, with- and without mitigation.

The generic case for *n* activities located within the same sensitivity class is described by Figure 17.7, which determines the additional mitigation required (in addition to that determined by the specific sensitivity class) as a function of the number of activities. For example, eight wellpads located within sensitivity class 2 would require an additional 19 dB of attenuation and effectively increase the risk to that described by sensitivity class 5. It is likely that such a situation would only arise during the Big Gas scenario.

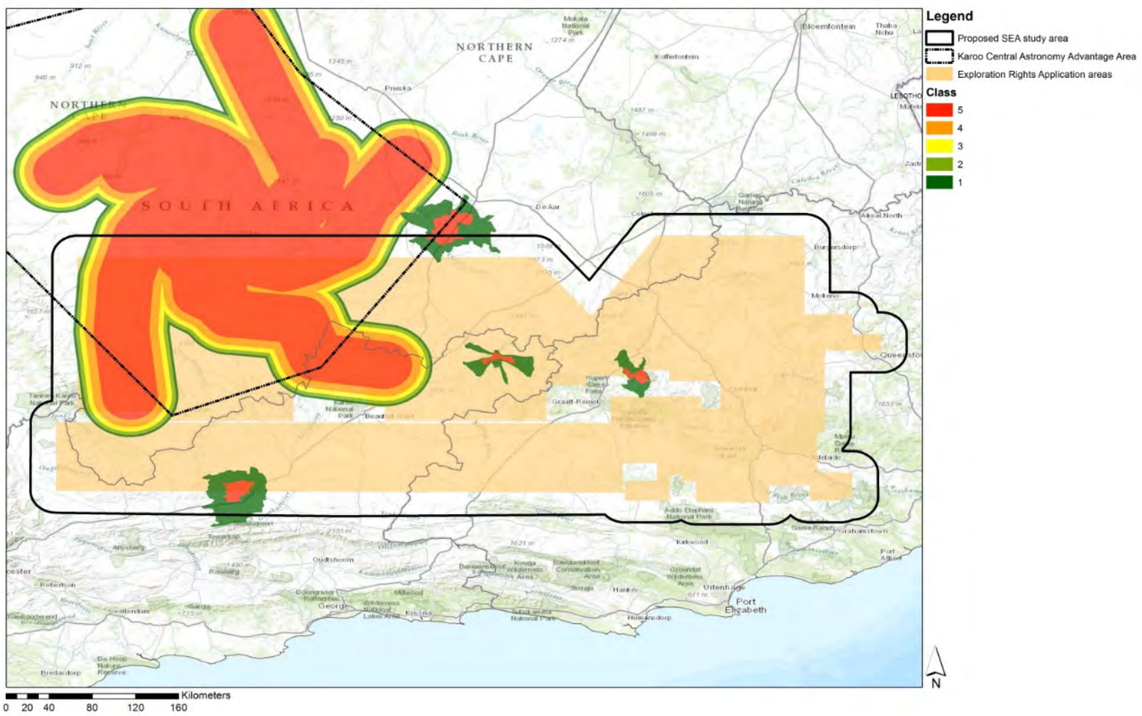

Figure 17.4: Map of sensitivity areas for the construction and decommissioning phase. In this phase up to 155 dB of attenuation is required in total.

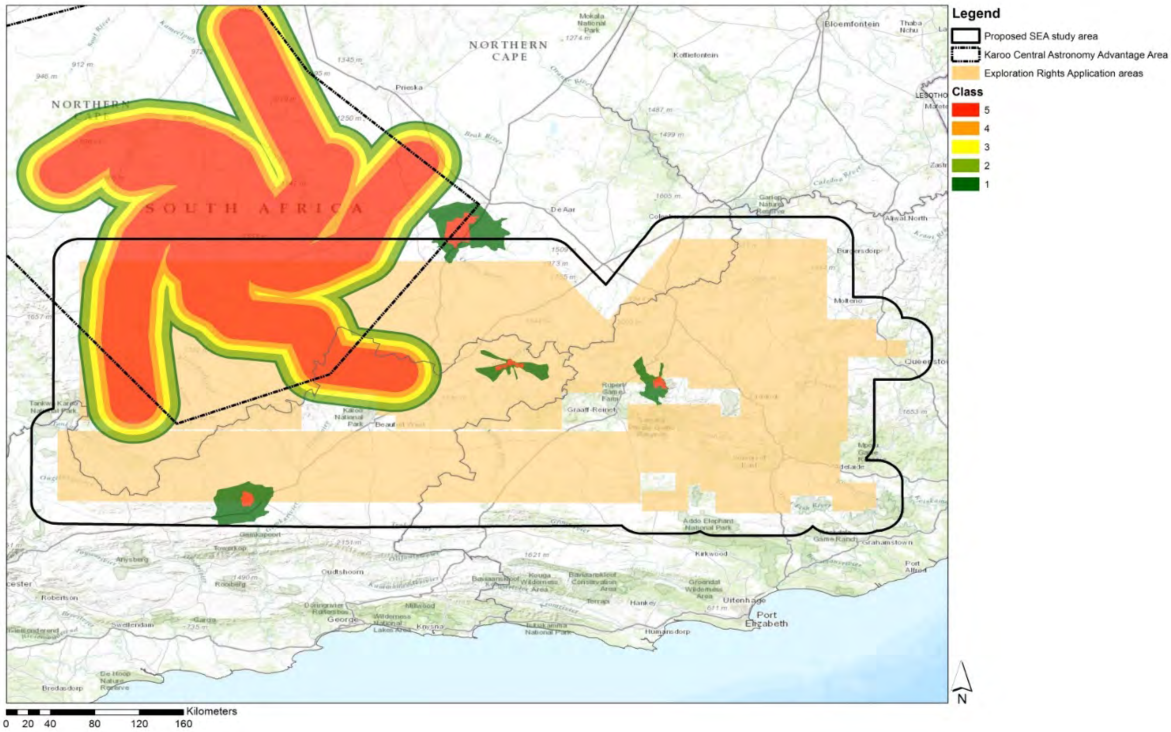

Figure 17.5: Map of sensitivity areas - operations phase. In this phase, up to 149 dB of attenuation is required in total.

Table 17.3: Sensitivity class description

Sensitivity Class Description					
	1	**2**	**3**	**4**	**5**
Separation Distance (Construction and Decommissioning)	**38 km**	**36 km**	**33 km**	**29 km**	**22 km**
Separation Distance (Operations)	**36 km**	**34 km**	**28 km**	**23 km**	**18 km**

Table 17.4: Consequence terms defined for the risk assessment.

Consequence term	Description
Slight	Limited pollution (20%) of radio spectrum, limited radio observations can be undertaken at an SKA station
Moderate	Moderate pollution (40%) of the radio spectrum, limited radio observations can be undertaken at one or more SKA stations
Substantial	High pollution (60%) of the radio spectrum, very limited radio observations can be undertaken at one or more SKA stations
Severe	Very high pollution (100%) of radio spectrum, no radio observation can be undertaken at an SKA station or limited observations at multiple SKA stations
Extreme	Very high pollution (100%) of radio spectrum, no radio observations can be undertaken at multiple SKA stations

Table 17.5: Risk assessment table sets out the assessment of risk for each of the scenarios, with and without mitigation. No SGD takes place in the Reference Case, and limited shale gas production takes place in Small Gas, and extensive SGD takes place in Big Gas.

Impact	Scenario	Location	*Without mitigation*			*With mitigation (identified and carried out in accordance with Table 17.5)*[14]		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Electromagnetic interference impact on radio astronomy (SKA)	Reference Case	SKA Sensitivity Class 5	Slight	Very Unlikely	Very low	Slight	Very Unlikely	Very low
	Exploration Only		Extreme	Very Likely	Very high	Moderate	Likely	Moderate
	Small Gas		Extreme	Very Likely	Very high	Moderate	Likely	Moderate
	Big Gas[15]		Extreme	Very Likely	Very high	Moderate	Likely	Moderate
	Reference Case	SKA Sensitivity Class 4	Slight	Extremely Unlikely	Very low	Slight	Extremely Unlikely	Very low
	Exploration Only		Severe	Very Likely	High	Slight	Very Unlikely	Very low
	Small Gas		Severe	Very Likely	High	Moderate	Very Unlikely	Low
	Big Gas[16]		Extreme	Very Likely	Very High	Moderate	Very Unlikely	Moderate
	Reference Case	SKA Sensitivity Class 3	Slight	Extremely Unlikely	Very low	Slight	Extremely Unlikely	Very low
	Exploration Only		Substantial	Very Likely	Moderate	Slight	Very Unlikely	Very low

[14] The success of mitigation methods is not guaranteed, and subject to further analysis and detailed assessment. The consequence and likelihood can therefore be amended accordingly. **Mitigation includes prohibition of all SGD activities within sensitivity class 5 and the KCAAA.**

[15] The risk identified in this table assumes vicinity Big Gas scenario where 410 wellpads are developed across 4 different production blocks, and should be amended in accordance with the method described in Section 17.3.5 for the cumulative impact of multiple activities.

[16] See Footnote 14.

Impact	Scenario	Location	*Without mitigation*			*With mitigation (identified and carried out in accordance with Table 17.5)*[14]		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
	Small Gas		Substantial	Very Likely	Moderate	Slight	Very Unlikely	Very low
	Big Gas[17]		Severe	Very Likely	High	Moderate	Very Unlikely	Low
	Reference Case	SKA Sensitivity Class 2	Slight	Extremely Unlikely	Very low	Slight	Extremely Unlikely	Very low
	Exploration Only		Moderate	Very Likely	Low	Slight	Extremely Unlikely	Very low
	Small Gas		Moderate	Very Likely	Low	Slight	Extremely Unlikely	Very low
	Big Gas[18]		Substantial	Very Likely	Moderate	Moderate	Extremely Unlikely	Very low
	Reference Case	SKA Sensitivity Class 1	Slight	Extremely Unlikely	Very low	Slight	Extremely Unlikely	Very low
	Exploration Only		Slight	Very Likely	Very low	Slight	Extremely Unlikely	Very low
	Small Gas		Slight	Very Likely	Very low	Slight	Extremely Unlikely	Very low
	Big Gas[19]		Moderate	Very Likely	Low	Moderate	Extremely Unlikely	Very low

[17] See Footnote 14.
[18] See Footnote 14.
[19] See Footnote 14.

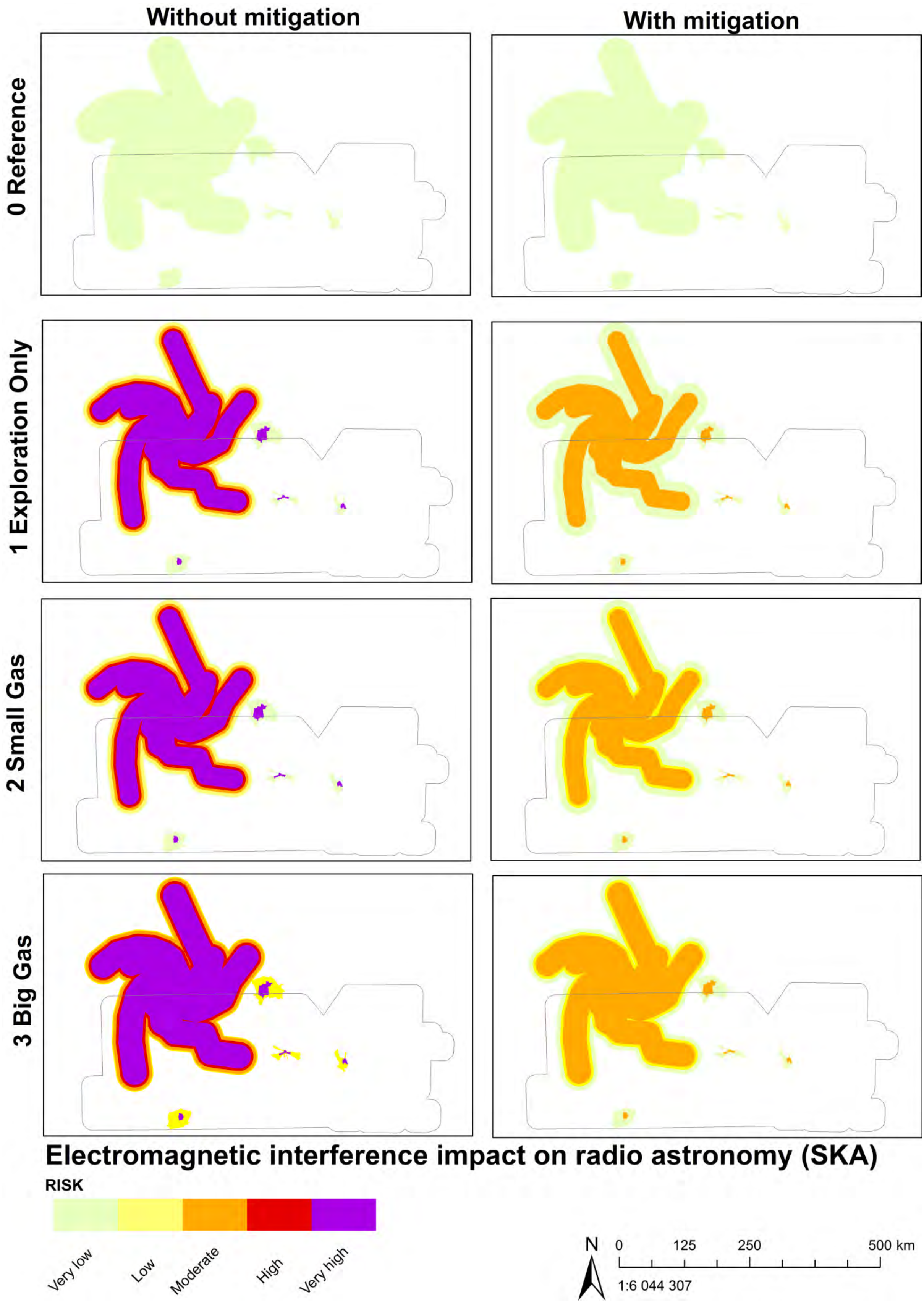

Figure 17.6: Map indicating the risk of electromagnetic interference on radio astronomy across four SGD scenarios, with- and without mitigation.

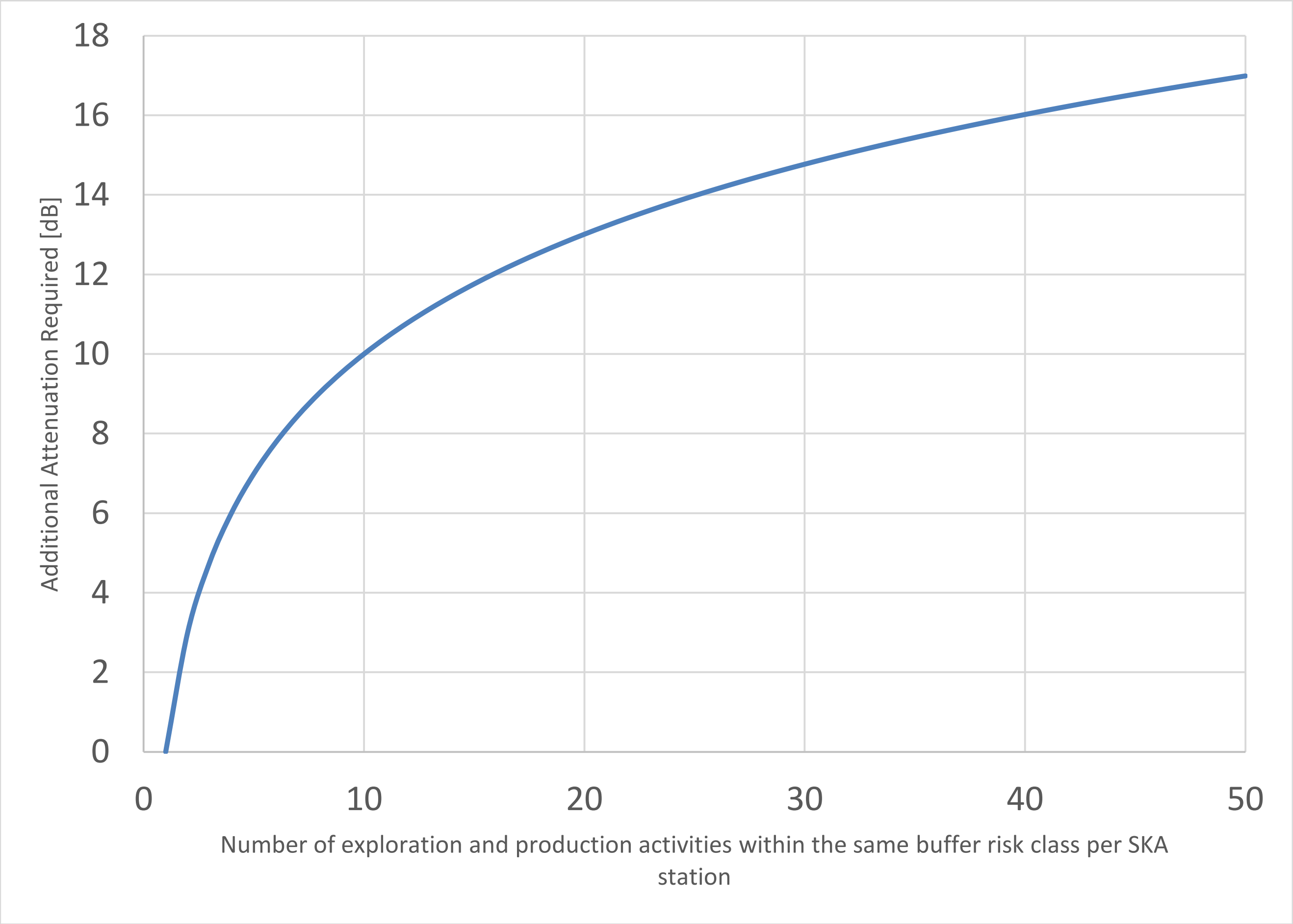

Figure 17.7: Additional attenuation required as a result of cumulative effect of multiple wellpads.

17.3.6 Limits of acceptable change

17.3.6.1 EMI

The acceptable threshold level of interference is determined by the SARAS protection level (DST, 2011). Any received signal that is in excess of this protection level is deemed to be an interference source. No increase in the background EMI environment is acceptable at each of the SKA stations if it is to increase the level of EMI (as detected by an SKA station) above the SARAS protection level (DST, 2011).

17.3.7 Best practice guidelines for minimisation of risk impact

Best practice guidelines are applicable to all phases of construction, operations and decommissioning. These guidelines take into account the current state of information regarding inventory of equipment and use profiles during construction, operations and decommissioning, and should be reconsidered once further information can be made available for site specific assessments. Table 17.6 presents a series of guidelines to be adopted in the event that a SGD activity is proposed to be located within a specific sensitivity class.

Table 17.6: Best practice guidelines for the mitigation of EMI and RFI.

	Guidelines				
Sensitivity Class	**1**	**2**	**3**	**4**	**5**
Mitigation Required	**5 dB**	**10 dB**	**15 dB**	**20 dB**	**>25 dB**
Guideline	High level site specific EMI assessment, to be undertaken by electromagnetic compatibility (EMC) specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements.	Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements.	Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements.	Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements.	**No SGD activity to be undertaken if located within sensitivity class 5 or the KCAAA.** If located beyond the KCAAA, detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements.
Potential Level of Mitigation	Highest sources of interference identified and mitigated through modest shielding implementation.	Highest sources of interference identified and mitigated through proper shielding implementation. Cable routing evaluated; depending on level of interference identified (cables below ground if possible).	Sources of interference across a wider frequency range anticipated. More extensive mitigation through proper shielding of higher number of equipment likely. Cable routing below ground if possible. Improved earthing to reduce interference current distribution.	Detailed implementation of shielding measures required. This includes more extensive shielding of every aperture from which interference can be generated. Greater attention to cabling and earthing required to ensure minimal contribution.	**No SGD activity to be undertaken if located within sensitivity class 5 or the KCAAA.**

17.3.7.1 Monitoring and evaluation

The following is proposed to ensure compliance with the protection requirements of the SKA stations:

i. Should any SGD activities be proposed within any buffer areas during the relevant phase of construction, operations or decommissioning, the developers will be required to engage with the Astronomy Management Authority, a unit of the DST, prior to the commencement of any such activities. The developers will be required to undertake detailed impact assessments to identify risk and adopt mitigation strategies. The successful implementation of the specified mitigation strategies that ensure attenuation requirements are complied with, have to be demonstrated to the satisfaction of the Astronomy Management Authority, in consultation with the National Research Foundation (NRF);

ii. Ongoing radio frequency measurements to be undertaken, according to a methodology determined by the Astronomy Management Authority in consultation with the NRF, at relevant sites once activities are commenced;

iii. SKA stations to undertake continuous monitoring of the radio frequency environment during all construction, operation and decommissioning activities.

17.4 Gaps in knowledge

The following areas have insufficient information, requiring the authors to make assumptions in the impact analysis process:

i. EMI characteristic profiles – the lack of radio frequency measurement information meant that internationally accepted standards had to be adopted to characterise the expected emission profiles. This does represent a minimum risk approach, as CISPR standards do prescribe an upper limit on the expected emissions. Actual measurements will provide more accurate EMI characteristic profiles, and will lead to a better representative risk/impact assessment;

ii. Use profile – the use profile, primarily time but also location, is assumed. It is likely that some equipment will not be used 100% of the time. However, the variety of equipment operating at different times means that the emission levels were considered to be the overall characteristic EMI profile on a per site basis. Further information on this may impact this assumption;

iii. Equipment inventory – an approximate inventory of equipment was obtained from technical staff. However, the use of specific equipment that has not been captured could produce large uncertainty. As a result, improved site specific information would need to be confirmed;

iv. Supporting activities – more detailed information on supporting activities that would provide greater level of understanding on increased vehicular volumes.

It is recommended that:

i. EMI characterisation measurements[20] of a representative installation that incorporates the majority of equipment to be used should be done. This will be more accurate than evaluation of individual components, which does not fully take into account the combined effect of interconnecting devices;

ii. Developers provide detailed inventory of equipment to be used during the various phases of SGD, and relevant characteristic profiles of EMI emissions (either measurement data, or standard);

iii. Developers provide detailed schedule of site construction, operations and decommissioning, to enable a greater level of understanding of the use profile of equipment;

iv. Developers provide a detailed list of communication requirements to enable the identification of mitigation options for radio communication services.

Should the further information described in items i.-iv. above be available, a review of the defined risk areas, guidelines and mitigation measures could be undertaken.

17.5 References

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Department of Science and Technology (DST). 2007. Astronomy Geographic Advantage (AGA) Act, Act No. 21 of 2007. *Government Gazette* No. 31157, Notice 666, 17 June 2008, Pretoria

Department of Science and Technology (DST). 2007. Innovation towards a Knowledge-Based Economy; Ten-Year Plan for South Africa (2008-2018), Draft. DST, 10 July, Pretoria. 34pp.

Department of Science and Technology (DST). 2011. Radio Astronomy Protection Levels Regulations, *Government Gazette* No. 35007, Notice R90, 10 February 2012, in terms of Astronomy Geographic Advantage (AGA) Act, Act No. 21 of 2007, DST, Pretoria.

Independent Commmunications Authority of South Africa (ICASA). 2015. The Radio Frequency Spectrum Regulations, in terms of the Electronic Communications Act, Act No. 36 of 2005. *Government Gazette* No. 38641, Notice 279, 30 March 2015, Pretoria.

International Special Committee on Radio Interference (CISPR). 2009. CISPR Product Standards 11 Class A: Industrial, scientific and medical equipment, Radio-frequency disturbance characteristics, Limits and methods of measurement. International Electrotechnical Commission (IEC), Geneva

International Special Committee on Radio Interference (CISPR). 2009. CISPR Product Standards 12: Vehicles, boats and internal combustion engines, Radio disturbance characteristics, Limits and methods of measurement for the protection of off-board receivers. International Electrotechnical Commission (IEC), Geneva

International Special Committee on Radio Interference (CISPR). 2009. CISPR Product Standards 14-1: Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission. International Electrotechnical Commission (IEC), Geneva

[20] EMI measurements should be conducted using peak detector equipment, from which average levels can be derived if required.

International Special Committee on Radio Interference (CISPR). 2009. CISPR Product Standards 22 Class B: Information technology equipment, Radio disturbance characteristics, Limits and methods of measurement. International Electrotechnical Commission (IEC), Geneva

International Telecommunications Union- Recommendation (ITU-R). 2003. Recommendation ITU-R RA.769-2: Protection criteria used for radio astronomical measurements, Geneva, ITU-R.

International Telecommunications Union- Recommendation (ITU-R). 2013. Recommendation ITU-R RP.526: Propagation by diffraction, Geneva, ITU-R.

International Telecommunications Union- Recommendation (ITU-R). 2015. Recommendation ITU-R RA.1513-5: Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis, Geneva, ITU-R.

17.6 Digital Addenda 17A - 17F

SEPARATE DIGITAL DOCUMENT

Digital Addenda 17A - 17F

Impact Analysis of Hydraulic Fracturing on the SKA:

An Initial Assessment

Dr. Adrian Tiplady

SKA South Africa

atiplady@ska.ac.za, +27 11 442 2434 (w), +27 72 372 0134

04-08-2011

Report compiled for the South African Task Team on Hydraulic Fracturing

Contents

1. Preamble

This report considers the potential impact of hydraulic fracturing, and its associated activities, on the Square Kilometre Array telescope, and its precursor telescope, the MeerKAT. Its conclusions are based on generic approximations in the absence of detailed information regarding the hydraulic fracturing operational scenario. The results in this report should therefore not be taken as final conclusions, but rather illustrative of proposed methodologies.

2. About the Author

Dr. Adrian Tiplady has a PhD in radio astronomy from Rhodes University, and has been working for the South African SKA Project Office since 2005. He is responsible for site characterisation of the Square Kilometre Array (SKA), including the analysis and impact of the nature of radio frequency interference. He is currently involved in the following local and international spectrum management activities:

i. Represents South Africa (and the only African representative) on the European Science Foundation expert Committee on Radio Astronomy Frequencies (CRAF);
ii. Represents CRAF on the ITU sector member, the Scientific Committee on the Allocation of Frequencies for Space Science and Radio Astronomy;
iii. South African rapporteur for WRC-12 Agenda Item 1.6;
iv. SKA representative on the ICASA SKA Special Working Committee.
v. Responsible for the drafting of declarations and regulations, to be promulgated in terms of the Astronomy Geographic Advantage Act

3. Introduction

This report considers the potential impact of hydraulic fracturing (commonly referred to as 'fracking'), and its associated activities on the Square Kilometre Array (SKA) radio astronomy facility, as well as the precursor instrument MeerKAT. In order to address this in an appropriate manner, the following is required:

i. an exact geographic location of hydraulic fracturing activities;
ii. a detailed description of all equipment associated with 'fracking', including electromagnetic characteristics;
iii. use profile of all the equipment referred to in ii. above
iv. full operational model during the lifetime of the 'fracking' operations, including support infrastructure.

Due to the very short timescales allowed for the development of this report (approximately 2 weeks), as well as the current status of 'fracking' operations, this detailed information was not available. However, placeholders have been used where information is lacking in order to derive a reasonably appropriate impact analysis. The derived methodology should be used to assess the impact of a 'fracking' site once all the items list in i. to iv. above are known.

'Fracking' activities may result in a wide variety of detrimental impacts on the radio astronomy environment. However, radio frequency interference (RFI) poses the most significant threat. Measures to mitigate against RFI should result in the protection of the radio astronomy environment from other potential sources of interference.

Section 4 considers the nature of RFI, and shows how it produces a potential detrimental impact on radio astronomy. Section 5 attempts to identify potential sources of RFI in 'fracking' activities, and characterises these sources in terms of potential electromagnetic emissions. Section 6 presents an impact analysis based on the potential sources of interference, providing an accurate methodology for future impact assessments.

4. The Nature of Radio Frequency Interference (RFI)

4.1. Spectrum Management

The ability of a radio telescope to conduct radio astronomy observations relies on a radio frequency environment that is as free from sources of interference as possible. Historically, radio telescopes have operated in narrow parts of the radio frequency spectrum. The International Telecomunications Union (ITU) recognises the radio astronomy service, and allocates approximately 1% of the spectrum to radio astronomy on a primary basis, split into a number of small channels. This primary allocation gives protection rights to the radio astronomy service internationally. One of the most important of the allocated channels is situated between 1,400 MHz and 1,427 MHz, and is aimed at protecting the critically important neutral hydrogen spectral line (HI) for radio astronomy.

Modern and next-generation radio astronomy facilities operate across very wide frequency ranges, due to the red-shift of HI that allows it to be measured at any frequency below 1,421 MHz. The SKA will operate from 70 MHz to 10 GHz, later to increase to an upper frequency limit of 25.5 GHz.

The protection threshold limits for the radio astronomy service are prescribed in the ITU Recommendation ITU-R RA.769-2. Received artificial, or man-made, radio signals that exceed the prescribed limits are considered to be detrimental to radio astronomy observations. As a guide to the reader, these threshold limits are in general 15 orders of magnitude more sensitive than a conventional cellular phone, making a radio telescope an extremely sensitive radio frequency receiver. It is therefore particularly sensitive to radio frequency signals that may either interfere radio astronomy observations, or even damage radio astronomy receiver equipment.

The protection threshold limits for radio astronomy in units of dB(W/m^2/Hz) are provided in Figure 1, and indicated by the red dots on the graph. The blue line, which indicates an interpolated and relaxed level, is illustrative of the protection limits for a radio interferometer. Examples of such an interferometer is the SKA – a large array of individual radio telescopes that operate together to form one large radio telescope, distributed over a wide area. This technique provides greater resolution in the images produced by the telescope, and allows for an increase in available collecting area without the difficulties of constructing one very large dish aperture. A further advantage of this technique is a slight immunity to localised interference, known as interferometric attenuation. This is due to RFI at one receiver being uncommon to all other receivers, and its impact can be reduced in the data processing stage. This technique can provide approximately 15dB of relaxation in the protection threshold limits. This attenuated level is provided in units of dB(W/Hz) in Figure 2.

The Minister of Science and Technology is due to promulgate the South African Radio Astronomy Service standard, in terms of the Astronomy Geographic Advantage Act. This standard prescribes protection threshold limits across the entire operating frequency range of the SKA, and do not include a relaxation as a result of interferometric attenuation.

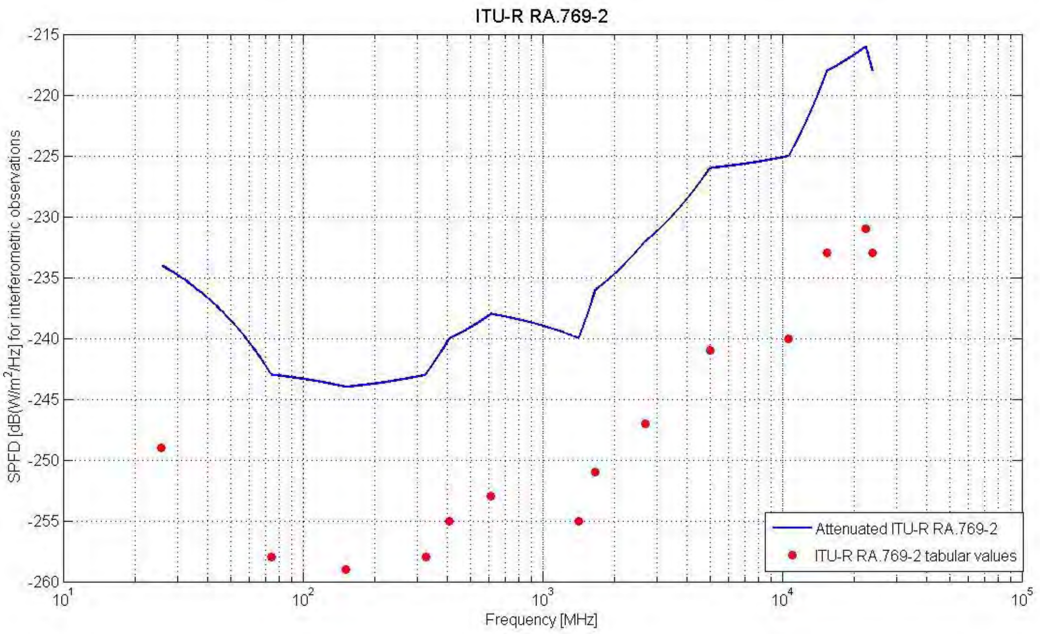

Figure 1: ITU-R RA.769-2 threshold levels. The markers indicate the tabulated levels, whilst the plotted line indicates those levels expected for interferometric observations.

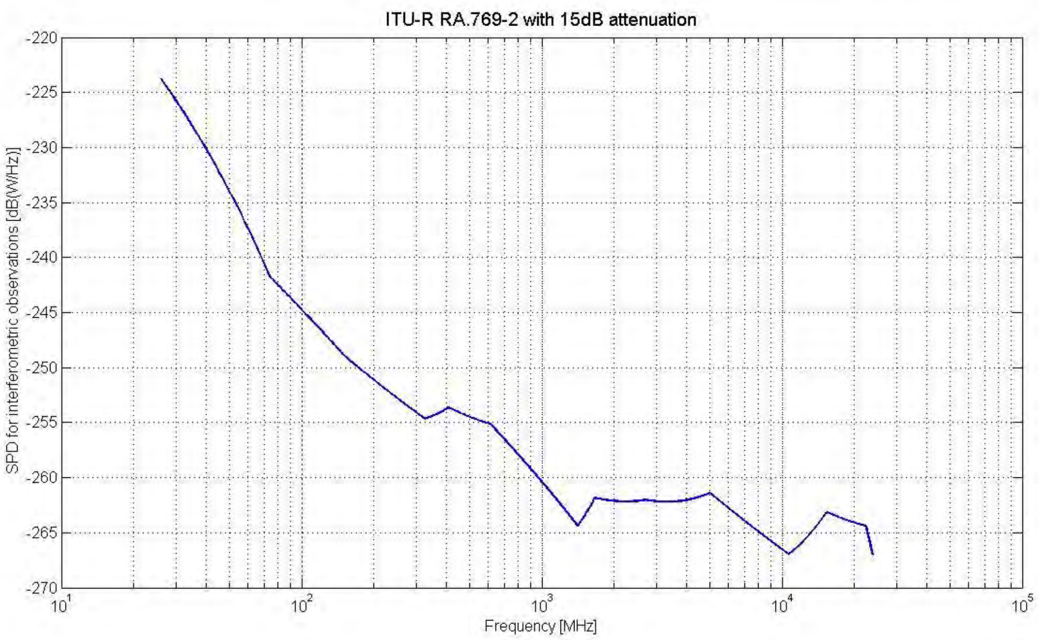

Figure 2: ITU-R RA.769-2 threshold levels in units of dB(W/Hz)

4.2. Impact of RFI

Radio astronomy facilities are sensitive to two classes of RFI. Firstly, the narrow band radio signals commonly associated with telecommunication services such as GSM, broadcasting services and Wi-Fi. These narrow band radio signals tend to be strong, and have one of three potential impacts on radio astronomy facilities (in order of increasing received signal strength):

i. The telescope would be required to filter out the narrowband interference, but may still continue to operate and perform radio astronomy observations outside of the particular frequency band. This will result in increased cost of the telescope, and decreased scientific performance;

ii. The telescope receivers would be rendered inoperational, due to the narrowband interference saturating the radio astronomy receiver equipment. Saturation produces artefacts across the entire observing band, and pushes the receiver equipment outside of its operational limits;

iii. The telescope receivers are permanently damaged. Reports have been received of radio telescopes in Germany being damaged from satellite transmission.

Any mobile radio communication equipment in use at a ‘fracking’ site would produce narrowband signals that could potential produce detrimental interference at one of the SKA stations.

Secondly, broadband radio emissions which are not used to provide telecommunication services, but instead are consequential electromagnetic interference (EMI) that is generated by electrical equipment. An example of this are the radio emissions generated from arc welding activities, or the sparking on power lines that may interrupt terrestrial analogue television reception. This broadband emission covers a large part of the spectrum and, although the strength of the emission does not pose a significant risk to damaging radio astronomy receivers, it fills large parts of the radio frequency spectrum and renders it unusable for radio astronomy observations, thereby reducing the scientific performance of the facility. The nature of electrical equipment is such that the bulk of EMI is produce in the critical low frequency part of the spectrum.

5. Identifying Sources of Potential Interference

This section attempts to provide a guide by addressing some of the potential sources of interference associated with ‘fracking’, and other industrial processes. The report focuses on broadband interference due to the following:

i. Any transmitters that are established to provide mobile telecommunication services would be required to comply with declarations and regulations governing use of the radio frequency spectrum, as promulgated in terms of the Astronomy Geographic Advantage Act;

ii. Broadband EMI is the area of greatest uncertainty in the analysis of potential sources of detrimental interference associated with ‘fracking’ activities.

5.1. Broadband Electromagnetic Interference (EMI)

In addressing sources of broadband interference, a variety of methodologies could be adopted. The most accurate method is to undertake a series of measurements, using accepted methodologies, to provide detailed measurement reports under all operational conditions. This would be undertaken over a wide sample of equipment to obtain a good statistical representation of the EMI characteristics associated with equipment used in ‘fracking’ activities. The very short timescales provided for the writing of this report do not allow for such a measurement activity to be undertaken. However, it is advised that this activity is undertaken in the future to provide the necessary detail required for a site-specific impact analysis.

The absence of such measurement results requires an adoption of national or international standards. In the case of this report, CISPR standards are adopted to provide EMI characteristics of general classes of equipment. The South African National Standards Authority adopts CISPR standards for use in South Africa.

Although EMI from a ‘fracking’ site is an integrated effect, in general it is the source of greatest interference that drives the strictest requirements in terms of mitigation, usually but not always resulting in a separation distance requirement between ‘fracking’ operations and the SKA. For this reason, the scope of identification has been limited. However, the analysis does provide for a generic process of identification, to be undertaken when more information becomes available.

5.1.1.CISPR Standards

The CISPR standards provided in the subsections below are the more common standards expected to be used in the EMI characterisation of ‘fracking’ sites and operations.

5.1.1.1. CISPR 11:2009

CISPR 11: 2009 covers the use of scientific, industrial and medical equipment, such as arc welding. Arc welding is characteristic of maintenance operations at any industrial site, and is a major source of radio interference. The expected emissions, as prescribed in the standard, are shown in Figure 3 as a function of frequency in units of dBW/Hz.

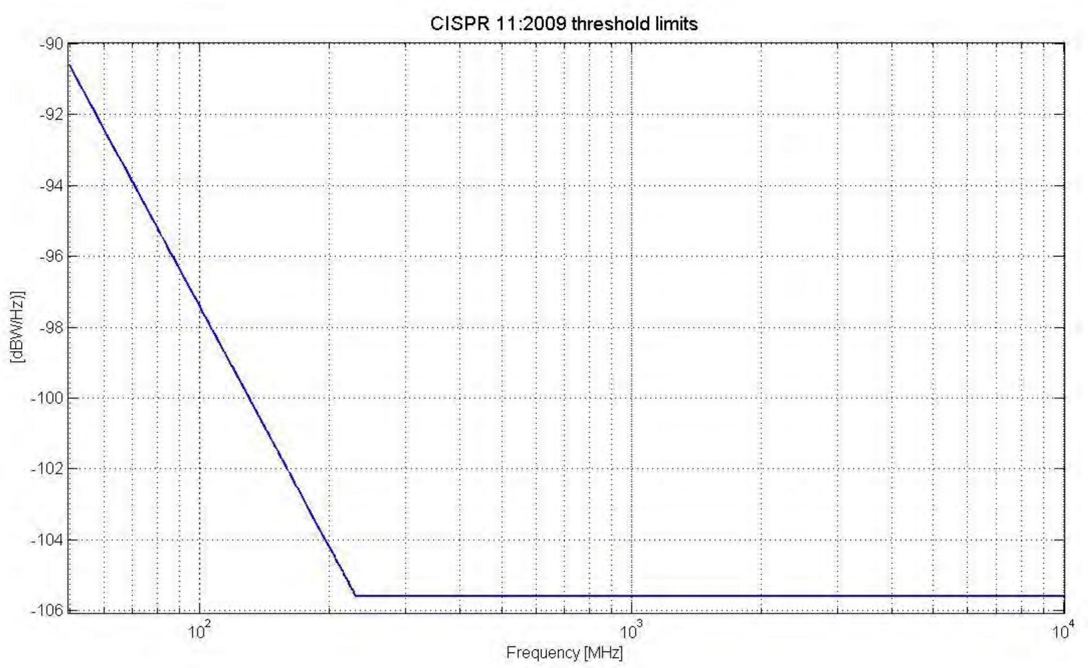

Figure 3: CISPR 11:2009 threshold limits.

5.1.1.2. CISPR 14-1:2009

CISPR 14-1:2009 covers the use of electrical appliances and tools. Use of power tools is common at any industrial site. The expected emissions as prescribed are shown in Figure 4. The interference is characterised by power ratings for the difference appliances.

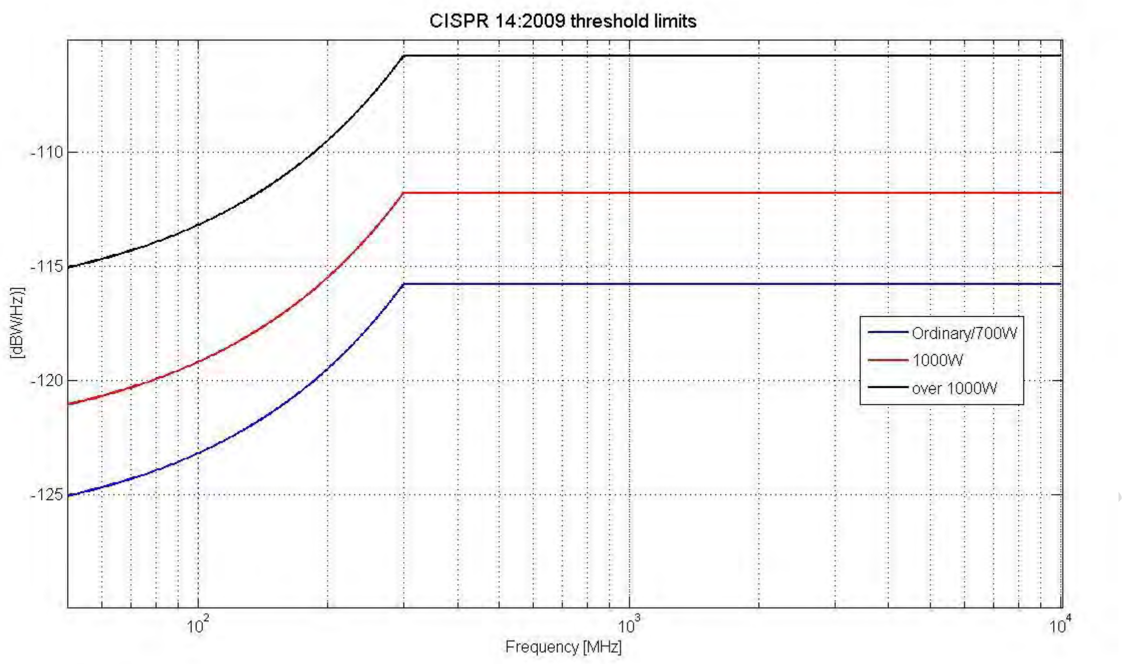

Figure 4: CISPR 14-1:2009 threshold limits

5.1.1.3. CISPR 22:2009

CISPR 22:2009 covers the use of Information Communication Technology (ICT) equipment, such as laptops and similar electronic devices. The expected emissions are shown in Figure 5.

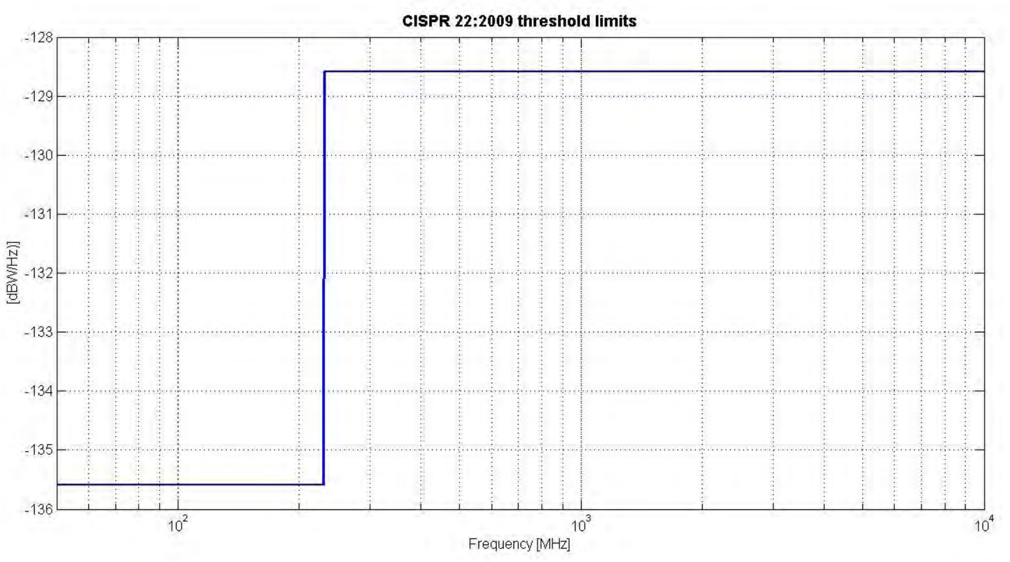

Figure 5: CISPR 22:2009 threshold limits.

5.1.1.4. CISPR 12:2009

CISPR 12:2009 covers the use of a variety of equipment, as summarised in the table below.

Examples of equipment included in the scope of CISPR 12				
Air Compressor	Concrete Grinder	Garden Trimmer	Moped	Quad Bike
Blower Vacuum	Concrete Mixer	Generator	Motor Bike	Snow Blower
Boat (< 15m)	Concrete Saw	Go Cart	Motorised Bike	Snow Mobile
Bus	Concrete Trowel	Golf Buggy	Motorised Scooter	Stump Grinder
Car	Concrete Vibrator	Hedge Trimmer	Outboard Engine	Tractor
Chain Saw	Dune Buggy	Jet Ski	Post Hole Digger	Truck
Compactor	Garden Mulcher	Lawn mower	Pressure Washer	Water Pump

This table covers a large part of the expected on-site and off-site equipment associated with 'fracking' operations, including cars, trucks, generators and water pumps. The expected electromagnetic emissions characterised by CISPR 12:2009 is shown in Figure 6.

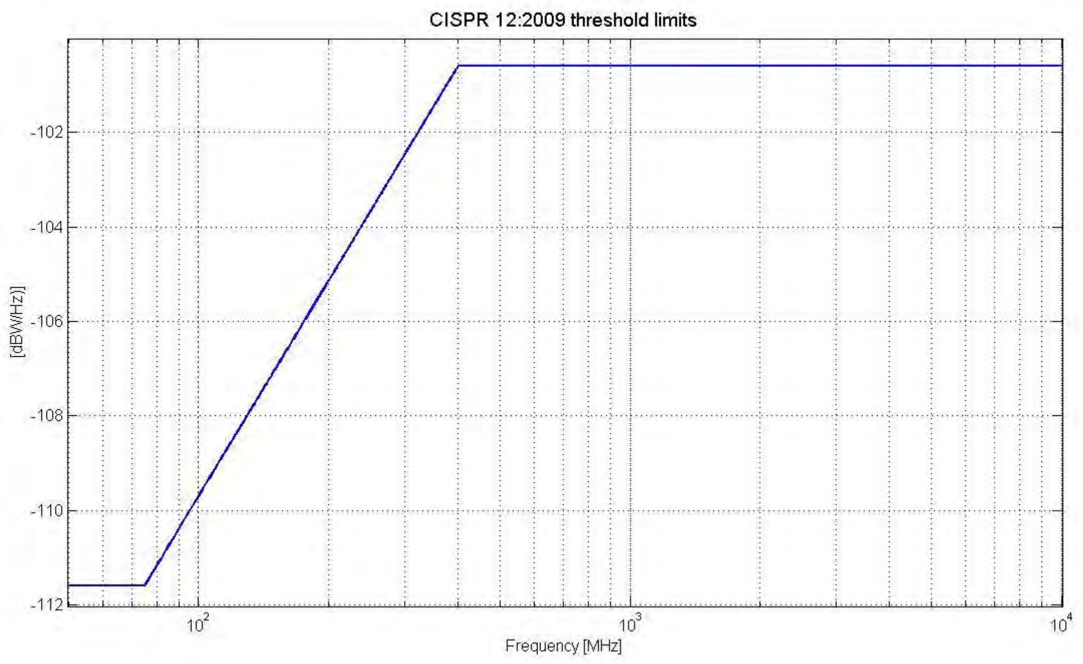

Figure 6: CISPR 12:2009 threshold limits.

6. Impact Analysis

This section considers the characteristic EMI profiles provided in Section 5 and determines the required attenuation, and hence geographic separation distance, in order to meet the protection threshold limits of radio astronomy. This attenuation can be achieved in other ways for particular sources of RFI. As this method is very specific on the technology being used, it will not be addressed in detail but instead will be commented on later in the report.

A detailed impact assessment should consider the operational scenario of the ‘fracking’ activity over installation, commissioning and operations. This will enable the development of a comprehensive EMI profile over time. By doing this, one may consider peak usage, and standard operations. Time constraints, and the lack of an operational model for the ‘fracking’ activity, did not allow for a full detailed assessment. However, references are made where the transient nature of the EMI source would require a modified assessment.

6.1. Modelling

Following the identification of sources of EMI, and obtaining either the relevant CISPR standards or measurement reports, the attenuation required to meet the radio astronomy protection threshold limits are calculated. In the case of the CISPR standards identified in Section 5, this is shown in Figure 7 as a function of frequency. For the purposes of this report, and as a result of the short timescales available, the relaxed protection threshold limits have been used.

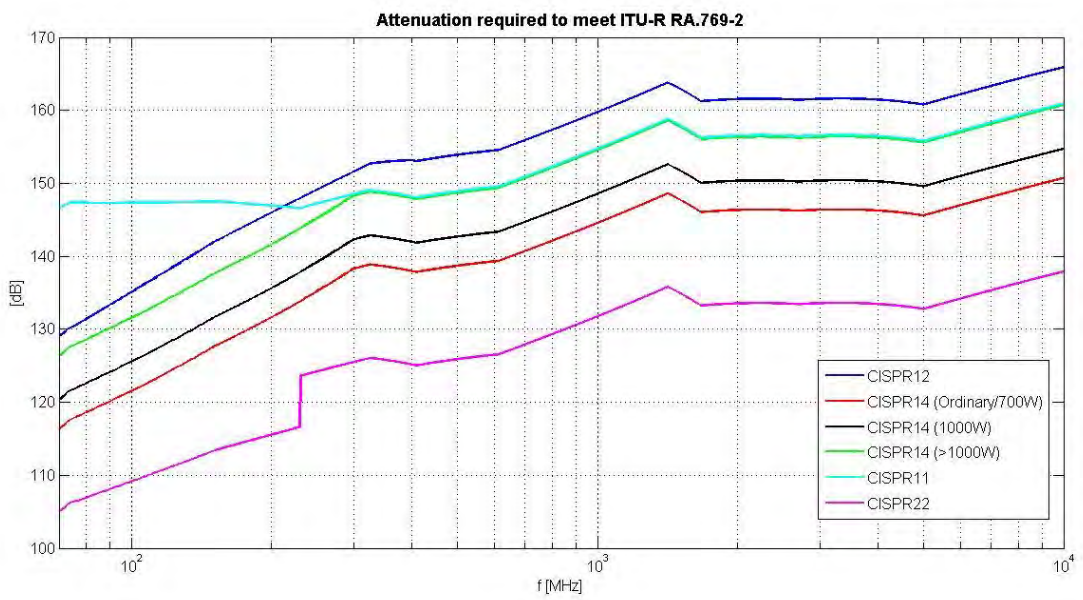

Figure 7: Attenuation required to meet the required radio astronomy protection threshold limits.

To perform the impact analysis, a path loss budget is developed. In order for the relevant sources of interference to be compliant with radio astronomy protection requirements, it should equal the total amount of attenuation required as shown in Figure 7. This path loss budet can be written as follows:

$$L(total) = L(free\ space) + L(topography) + L(other)$$

where *L(total)* is the total attenuation obtained, *L(free space)* is the attenuation due to free space propagation of the radio signal, *L(topography)* is the attenuation as a result of topographic shielding and other diffraction effects, and *L(other)* is attenuation due to other mitigation measures (discussed later). The analysis presented in the following sections only considers *L(free space)*, and a statistical component of *L(topography)*. What this means is that the model used to determine the attenuation as a result of propagation of the radio signal across terrain assumes a reasonably flat terrain with some variance of a couple meters. No large variations in topography are taken into account, and would need to be following the identification of exact geographic locations of 'fracking' sites. *L(other)* is taken to be zero at this stage. The results presented can therefore be seen as a guide to inform the reader, and cannot be taken as definitive in terms of separation distances at this stage.

6.2. Analysis

The radio frequency propagation model ITU Recommendation ITU-R P.1546-3 is used to determine the required separation distance between the sources of interference and radio astronomy receiver to meet the radio astronomy protection threshold limits. The model is highly dependent on the following:

i. Relative heights of the receiver and transmitter;
ii. Frequency of transmitter;
iii. Percentage of time that the radio signal power level exceeds that predicted.

As it is a statistical model, it is relatively insensitive to the actual topography in the surrounding area. It is recommended that in future a more detailed model is used that considers as input a high resolution digital elevation model. For the purposes of this analysis, an approximate height of 2m is assumed for the relevant transmitters. The receiver height is frequency dependent, due to the hybrid mix of receiver technologies used in the SKA. Conservatively, frequencies below 300 MHz will be received by aperture array stations, positioned 1m above the ground. Above 300 MHz, dishes will be used that have a maximum receive height of 15m. In all cases, the percentage of time allowed for which the radio signal exceeds the level predicted is 5%.

The analysis that follows considers two scenarios. Firstly, a scenario in which the sources of interference are present for more than 5% of the day. Note that this is an integrated effect ie. multiple arc welders, although individually used less than 5% of the day can result in greater than 5% if multiple arc welders are used, or other devices of the same CISPR class. The second scenario considers interference that is transient in nature – this could be as a result of the use profile of the equipment (only being used for a certain time period), or the fact that the source of interference is not in a fixed location but instead is moving.

6.2.1.Permanent and Semi-Permanent Sources of Interference

This subsection considers the separation distance required for equipment meeting CISPR recommendations to ensure protection of radio astronomy facilities. The separation distance as a function of frequency required to ensure protection from the use of arc welders, and other equipment meeting CISPR 11:2009 specifications, is indicated in Figure 8. The maximum separation distance of 20km is used as a specification.

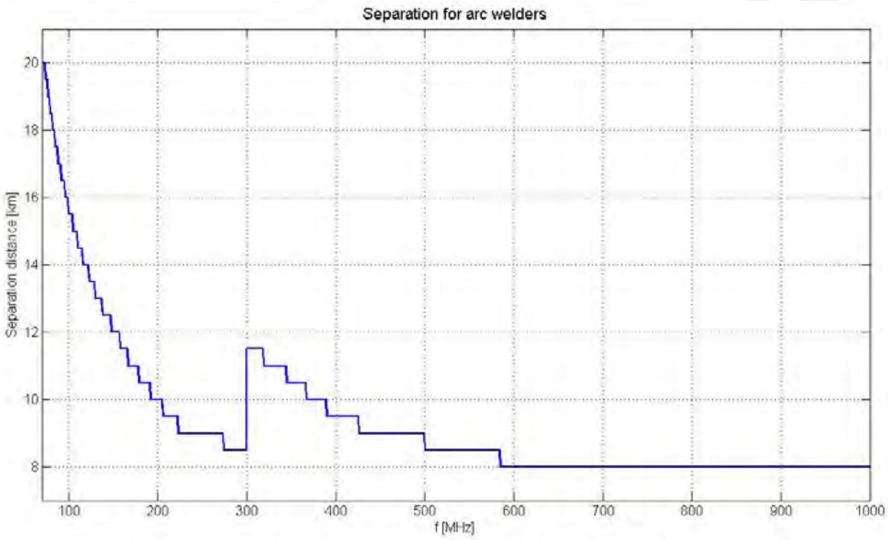

Figure 8: Required separation distance between devices meeting CISPR 11:2009 specifications, such as arc welders, and radio astronomy facility.

The required separation distance for ICT equipment meeting CISPR 22:2009 specifications is shown in Figure 9, with a maximum separation distance of 3.5km. A cautionary note – this result is for a single piece of ICT equipment. A large amount of ICT equipment would result in an integrated effect, and increase the required separation distance.

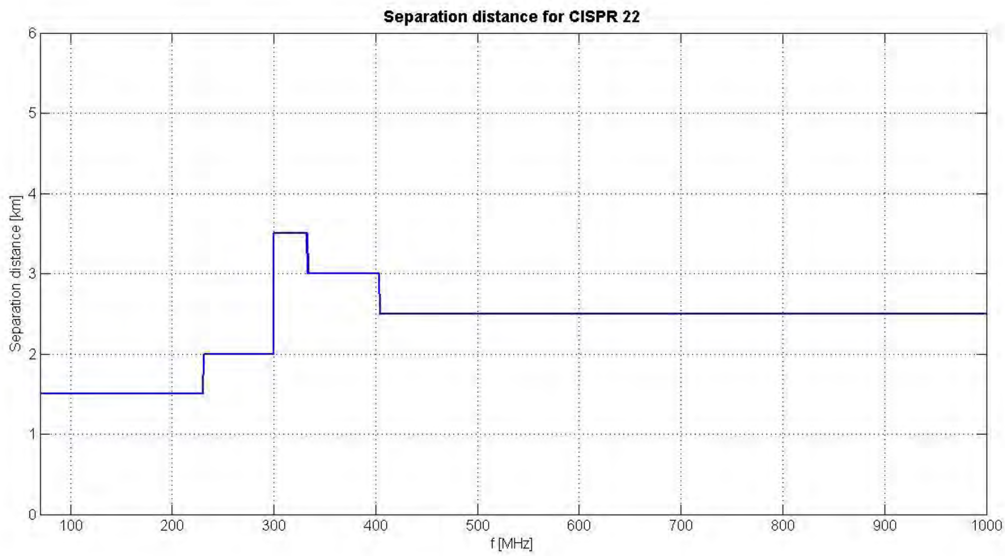

Figure 9: Required separation distance for ICT equipment meeting CISPR 22:2009 specifications.

If we consider equipment such as onsite vehicles, generators, water pumps and similar, all of which meets the CISPR 12:2009 specification, then the required separation distance has a maximum of 13.5km, as shown in Figure 10.

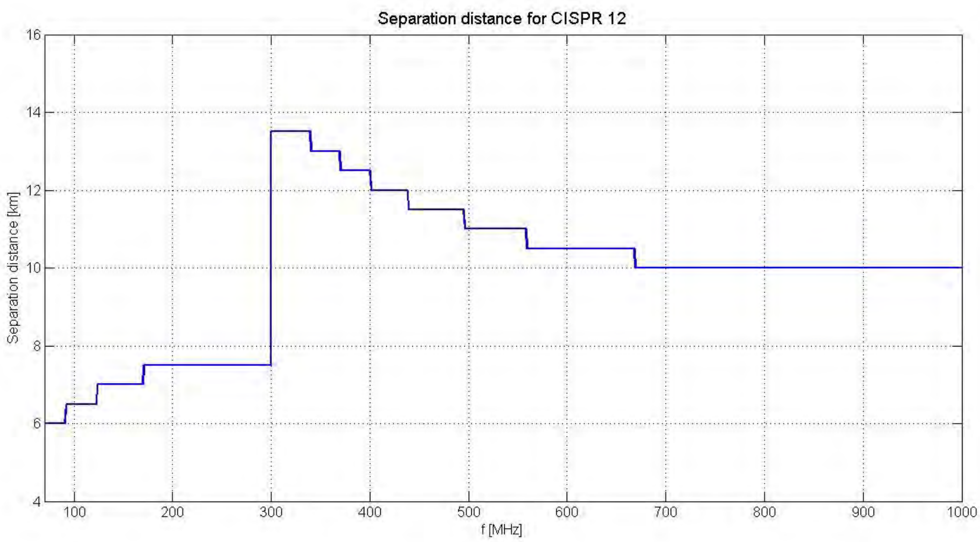

Figure 10: Required separation distance for equipment meeting CISPR 12:2009 specifications, such as vehicles, generators, water pumps and air compressors.

Finally, an operational mix of equipment is considered, shown in Figure 11. This mix includes an assortment of power tools, well maintained diesel vehicle, or generator, with no engine management systems. The required separation distance is of the order 13.5km.

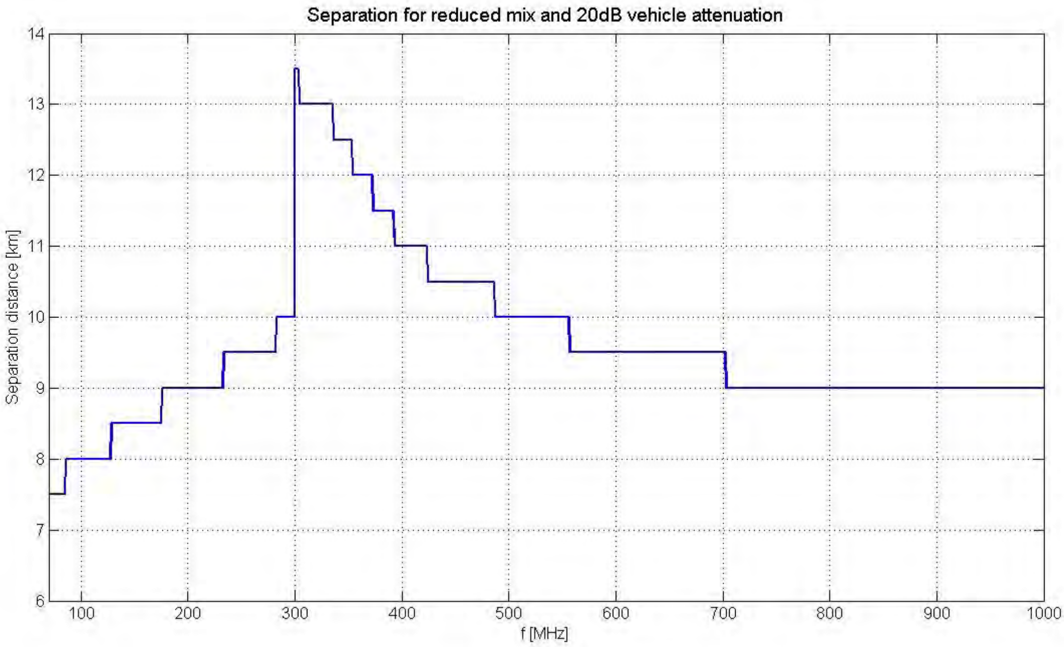

Figure 11: Separation distance for a typical operational unit, with well maintained diesel vehicle and some power tools.

6.2.2.Transient Sources of Interference

Transient sources of interference are sources that would result in a time dependant separation distance requirement. This would occur when either the equipment that that is producing the source of interference is operated for partial amounts of time, or the source of interference is moving (such as a vehicle). Both these scenarios are considered in the subsections that follow.

ITU Recommendation ITU-R RA.1513-1 (draft 2 in revision) considers the acceptable loss of data for a radio astronomy facility as a result of RFI. This is expressed as a percentage of time, with no single network of interference resulting in greater than 2% data loss, and a total data loss of no more than 5% tolerated for all sources.

Consider sources that are transient in time, taking 24 hours as a reasonable timescale for analysis. A full operations model is required in order to fully understand the EMI profile of a ‘fracking’ location with time. This would enable the accurate assessment of required separation distances as a statistical model. As this information is not yet known, or is unavailable, it is recommended that a study is undertaken on the full operational model of a ‘fracking’ site, to inform the detailed analysis.

The analysis of moving sources of interference takes into consideration the allowable time in which the source may be incompliant with the required separation distance, to ensure that data loss does not exceed the recommendations. The case of vehicles is used as a case study, which can be a complex modelling exercise. The primary input to this model is traffic volume, and we consider two cases: minor traffic, where each vehicle can be treated as an individual source of interference in time and space; and major traffic, where the density of vehicles is sufficient to treat as a constant source of interference.

The case of major traffic is dealt with as a permanent, or semi-permanent, source of interference as illustrated in Section 6.2.1. The case of minor traffic is dealt with below.

6.2.2.1. Minor Traffic

Figure 12 is a schematic that illustrates the case of travelling vehicles. We consider *n* vehicles per day, travelling at 100 km/hr. Each vehicle, meeting CISPR 12:2009 specifications, as a stationary source would result in a required separation distance of *r1* km. However, for sufficiently low vehicular volumes, a relaxation on *r1* can be accommodated, as defined by the equation:

$$r2 = \sqrt{r1^2 - \left(\frac{y}{2}\right)^2}$$

where *r1* is the separation distance required for a permanent device meeting CISPR 12:2009 specifications, *r2* is the relaxed separation distance, and *y* is the path length that a vehicle may be within the separation distance *r1*, as defined by the equation:

$$y = v \times t = v \times \frac{T}{n}$$

where *v* is the average velocity of the vehicle, *T* is the total allowable time in which data loss occurs, as defined by a percentage data loss over an acceptable timescale (nominally 24 hours), and *n* is the number of vehicles that pass by in the relevant time period.

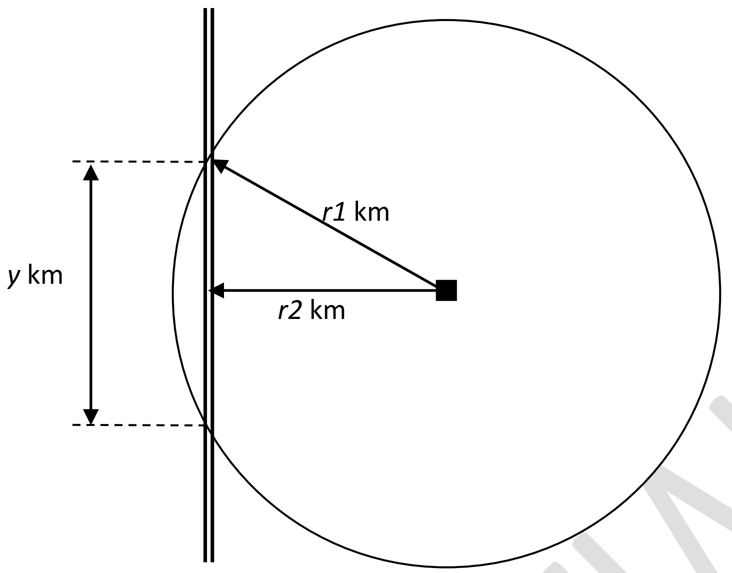

Figure 12: Schematic diagram for determination of separation distance for minor traffic.

Figure 13 describes the required separation distance for a road carrying 10 vehicles per day, travelling at an average of 100 km/hr.

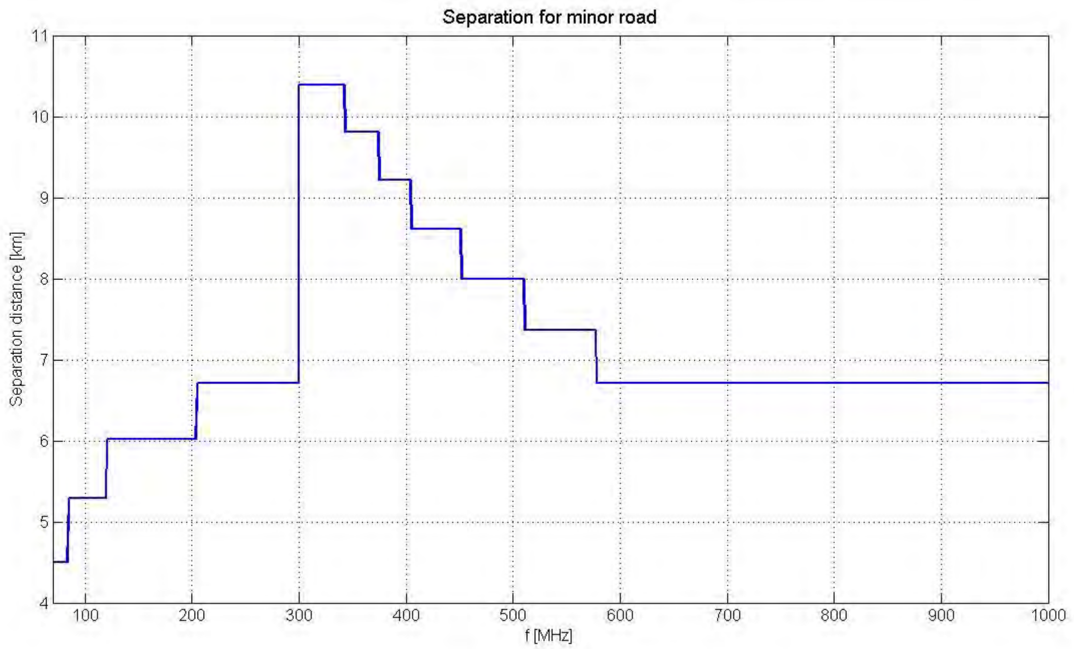

Figure 13: Separation distance for transport route carrying minor traffic, with a total volume of 10 vehicles per day, travelling at an average of 100 km/hr.

6.3. Impact on the SKA

The finalised SKA configuration is shown in Figure 14. This configuration has been developed together with the international SKA Program Development Office (SPDO), and is considered the final configuration to be submitted by South Africa for its proposal to host the SKA. A closeup of the configuration is shown in Figure 15. This figure not only shows the inner 180 km of the optimised configuration, it also shows the buffer zones that have been developed following a similar impact assessment as presented in this report. These buffer zones surround towns, mines, power infrastructure and transport routes deemed to be carrying sufficient vehicular traffic. An increase in vehicular traffic volumes on roads that do not currently have prescribed buffer zones would result in a major detrimental impact on the current optimised configuration, due to the resulting buffer zone requirement.

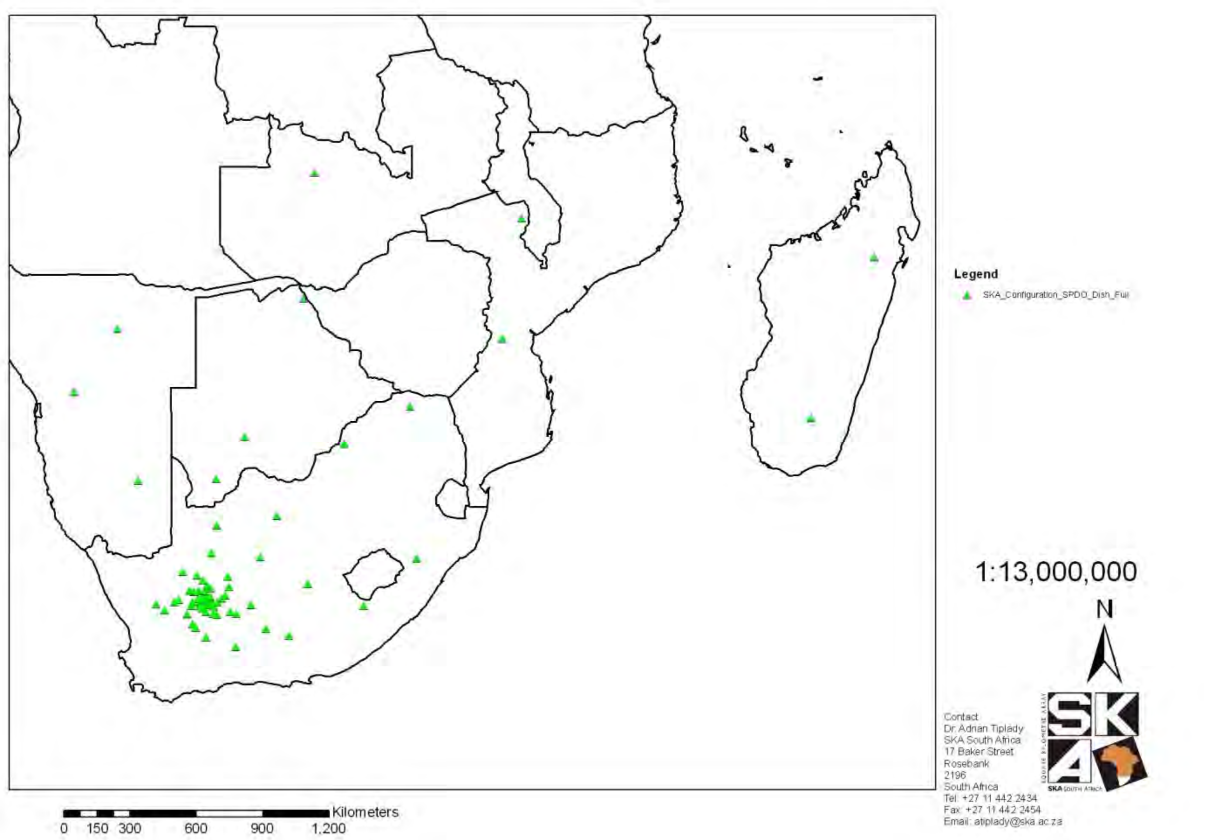

Figure 14: SKA configuration.

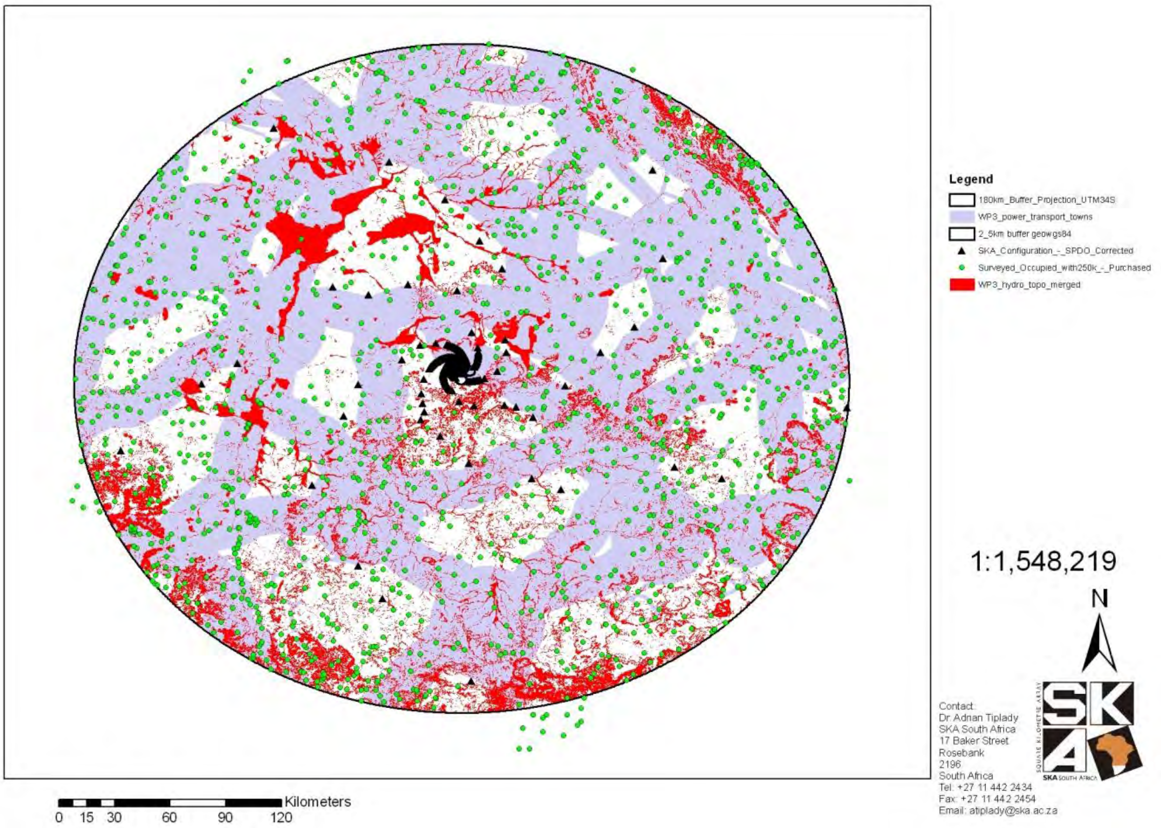

Figure 15: Closeup of SKA configuration, with buffer zones derived using a similar impact assessment as presented in this report. No SKA stations lie within existing buffer zones.

By way of illustration, the SKA configuration is illustrated in Figure 16. Each SKA station is surrounded by a 30 km buffer zone. Based on the analysis contained in this report, a conservative assessment would be that no ‘fracking’ activity takes places within the 30 km buffer zone, and that any locations within 50 kms of an SKA station be analysed with a detailed impact assessment prior to ‘fracking’ operations. Figure 17 shows a closeup of the SKA configuration in the Northern Cape Province. This area has been declared an Astronomy Advantage Area by the Minister of Science and Technology, in terms of the AGA Act. This area is most sensitive to ‘fracking activities’ due to the high density of stations.

The detailed coordinates for the SKA stations have been supplied to the Inter-Ministerial Task Team under conditions of non-disclosure.

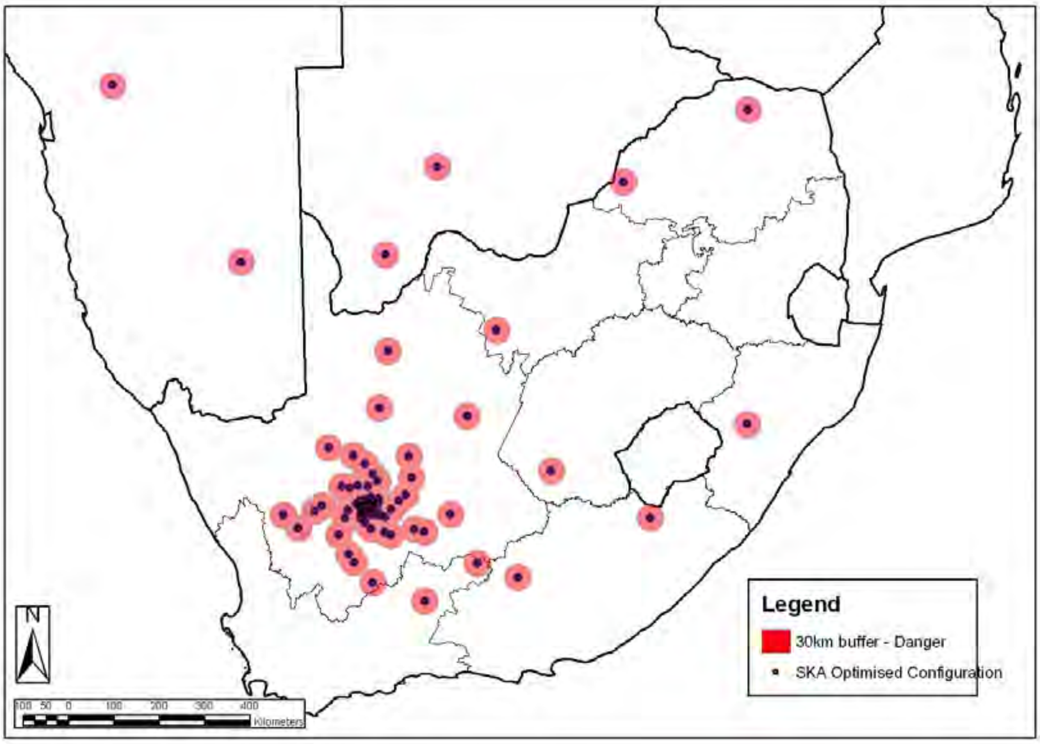

Figure 16: SKA Configuration, with each station surrounded by a 30km 'no-fracking' zone.

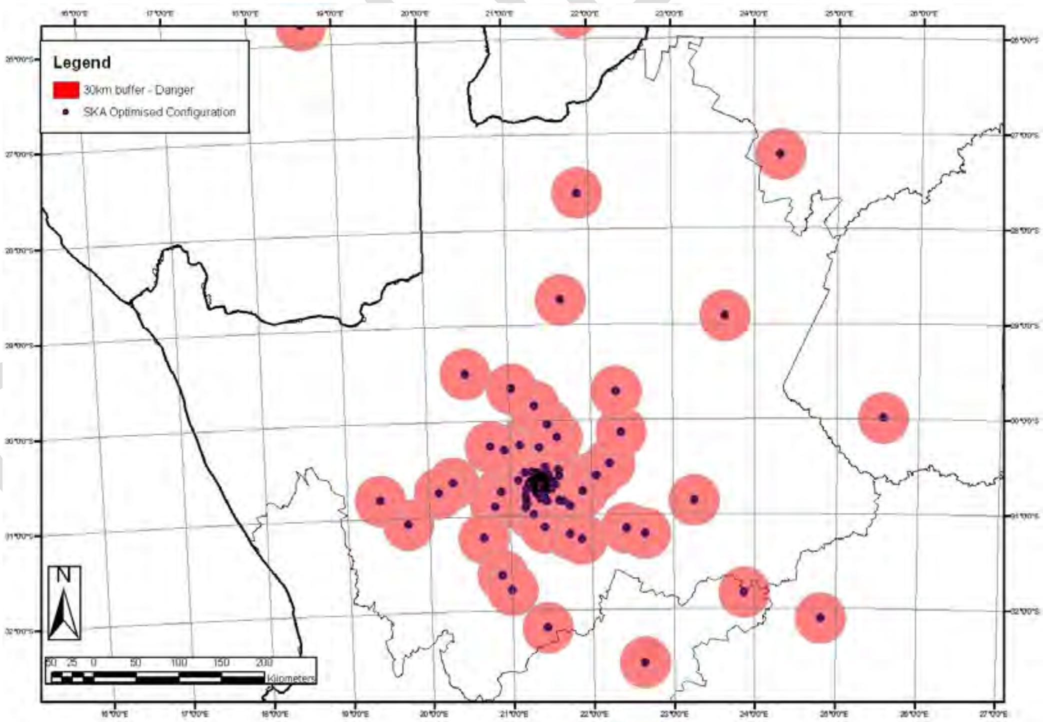

Figure 17: Closeup of the SKA Configuration in the Northern Cape Province, with each station surrounded by a 30km 'no-fracking' zone..

7. Mitigation Measures

The modelling undertaken in Section 6.1 assumes no further attenuation as a result of other mitigation measures, over and above that attenuation obtained from radio propagation loss. Various measures are available to increase the other attenuation, and thereby reduce the required separation distance. For example, the all onsite equipment at a radio astronomy facility is housed within a shielded environment, which produces up to 120 dB of attenuation of radio signals. The design of power lines ensures that any sparking on the power line, which produces EMI, is reduced to a minimum. Power filters are used on almost all equipment on site.

Various mitigation measures can be employed at 'fracking' sites to reduce required separation distances. However, a detailed technical analysis of all equipment, and operational model, is required before mitigation measures can be investigated. This technical analysis should not only include operations at the 'fracking' site, but also on supporting infrastructure such as regularly used transport routes.

8. Conclusion and Recommendations

This report considers a methodology to determine the potential impact of ‘fracking’ activities on the SKA. The methodology is based on sound, internationally accepted principles. The technical details assumed in the report have been used as a guide, and are not definitive, due to a lack of technical information on the ‘fracking’ activity. As a result, the author recommends that a more detailed study is commissioned over a period of 6-12 months. This study should consider the following:

i. Determination of the full range of equipment to be used in the commissioning and operation of ‘fracking’ sites by the various applicants. This list of equipment should be made available by the relevant applicants upon request;
ii. Field work study to characterise any relevant equipment in terms of its EMI characteristics if no appropriate national, or international standards exist. This may require field work at representative sites operated by the applicants;
iii. Determination of detailed operational scenario, including commissioning and operations;
iv. Determination of a detailed model to be used in analysing radio propagation;
v. Determination of a detailed impact assessment methodology, to be carried out once exact locations for ‘fracking’ activities are known.

Addendum to Report on Impact Analysis of Hydraulic Fracturing on the SKA:

Impact of SKA Site Decision of 25th May 2012

Dr. Adrian Tiplady

SKA South Africa

atiplady@ska.ac.za, +27 11 442 2434 (w), +27 72 372 0134

21-06-2012

Addendum compiled for the South African Task Team on Hydraulic Fracturing

Contents

1. Preamble

On the 25th May 2012, the international Square Kilometre Array (SKA) Board publically announced the outcome of the SKA Site Selection process. Following the recommendation of the SKA Site Advisory Committee (SSAC) to appoint South Africa and its African Partner Countries as the sole host of the SKA, the Board decided to maximise the investment made by both site proponents. In so doing, two of the three SKA receptor technologies (the high-frequency dish receptors, and the mid-frequency dense aperture array receptors) were to be built in Southern Africa, and the remaining receptor technology (sparse aperture array) was to be built in Western Australia.

This addendum to the *Report on Impact Analysis of Hydraulic Fracturing on the SKA* (referred to as the *Report* from hereon), submitted as part of the report by the Working Group of the Task Team on Hydraulic Fracturing, considers the implications of this 'split-site' decision on the analysis performed in the original *Report*.

2. Introduction

The SKA, although a single radio astronomy observatory, is based on the use of three receptor technologies. Each technology will receive and process radio signals in a different part of the radio frequency spectrum. The frequency ranges for each of the receptor technologies is currently defined by the international SKA Project Office (SPO) as follows:

- 70 MHz to 200 MHz – Sparse aperture array receptors at a height of 1m above ground level, located in a dense core and distributed along spiral arms out to 180km from the SKA core site;
- 200 MHz to 500 MHz – Dense aperture array receptors at a height of 1m above ground level, located in a dense core and distributed along spiral arms out to 180km from the SKA core site;
- 500 MHz to 10 GHz – Dish receptors at a height of 15m above ground level, located in a dense core and distributed along spiral arms out to 180km from the SKA core site, and a further 25 remote stations within South Africa and its eight African Partner Countries;

A low frequency limit of 300 MHz for the dish receptors has been used to determine required separation distances in the finalisation of the SKA configuration in Africa to ensure protection from electromagnetic interference generated from standard electrical appliances and equipment.

The *Report* shows that the required maximum separation distance to ensure the protection of the SKA from electromagnetic interference as a result of hydraulic fracturing operations and associated activities is largely dependent on the lowest operational frequency of the dish receptors (except for a small number of industrial devices). This is due to the increased receiver height over the aperture arrays (sparse and dense), where a higher receiver will be more sensitive to potential electromagnetic interference.

The *Report* also notes that any transmitters that are established to provide mobile telecommunication services would be required to comply with declarations and regulations governing use of the radio frequency spectrum, as promulgated in terms of the Astronomy Geographic Advantage Act.

3. Impact of SKA Site Decision on Results of the *Report*

The SKA site decision of May 2012 means that the receptor technologies, dense aperture arrays and high frequency dishes, to be established in Africa will operate from 200 MHz (minimum) up to 10 GHz (expandable). With a low frequency limit of 200 MHz, the key factor that determines the maximum required separation distance from hydraulic fracturing operations and associated activities is the low frequency limit of the dishes (300 MHz to 500 MHz [TBD]).

The SKA site decision will not result in a significant material change on the impact analysis in the *Report*. Determination of the maximum required separation distance in the *Report* adopted a minimum risk approach to ensure the complete protection of the SKA stations, using a 300 MHz low frequency limit for the dishes. An increase in this limit to 500 MHz may result in an overall decrease of 25% in the maximum required separation distance. However, this is still to be confirmed by the international SKA Project Office over the next 24-48 months during the Pre-construction Engineering Program (PEP).

Although the use of arc welders resulted in a large maximum separation distance requirement at frequencies below 200 MHz in the Report, it would not be appropriate to reduce the overall protection requirements as a result of the site decision at this stage. This is mainly as a result of the associated uncertainties as described in the impact analysis contained in the *Report*.

4. Conclusion and Recommendations

The Conclusions and Recommendations as provided in Section 8 of the Report still stand. The following recommendations should be considered in addendum, or over-riding where there is conflict, to the original Conclusions and Recommendations:

- A mandatory separation distance of 30km is to be adopted as a requirement around each SKA station. No hydraulic fracturing, or associated activities, should take place within this distance to an SKA station;
- The separation distance may be subject to detailed site specific impact assessments and measurements, on request to the relevant responsible coordinating body, following the use of site specific techniques and equipment that may be adopted by the persons responsible for hydraulic fracturing operations and associated activities in mitigation of potential detrimental effects;
- The establishment or use of any telecommunication service at a hydraulic fracturing site, if located within a Central Astronomy Advantage Area as declared in terms of the Astronomy Geographic Advantage Act, will be required to comply with the necessary declarations and regulations governing the restricted use of the radio frequency spectrum.

RECOMMENDATION ITU-R RA.769-2

Protection criteria used for radio astronomical measurements

(Question ITU-R 145/7)

(1992-1995-2003)

The ITU Radiocommunication Assembly,

considering

a) that many of the most fundamental astronomical advances made in the past five decades, (e.g. the discovery of radio galaxies, quasars, and pulsars, the direct measurement of neutral hydrogen, the direct measurement of distances of certain external galaxies, and establishment of a positional reference frame accurate to ~20 arc μs) have been made through radio astronomy, and that radio astronomical observations are expected to continue making fundamental contributions to our understanding of the Universe, and that they provide the only way to investigate some cosmic phenomena;

b) that the development of radio astronomy has also led to major technological advances, particularly in receiving and imaging techniques, and to improved knowledge of fundamental radio-noise limitations of great importance to radiocommunication, and promises further important results;

c) that radio astronomers have made useful astronomical observations from the Earth's surface in all available atmospheric windows ranging from 2 MHz to 1 000 GHz and above;

d) that the technique of space radio astronomy, which involves the use of radio telescopes on space platforms, provides access to the entire radio spectrum above about 10 kHz, including parts of the spectrum not accessible from the Earth due to absorption in atmosphere;

e) that protection from interference is essential to the advancement of radio astronomy and associated measurements;

f) that radio astronomical observations are mostly performed with high-gain antennas or arrays, to provide the highest possible angular resolution, and consequently main beam interference does not need to be considered in most situations, except when there is the possibility of receiver damage;

g) that most interference that leads to the degradation of astronomical data is received through the far side lobes of the telescope;

h) that the sensitivity of radio astronomical receiving equipment, which is still steadily improving, particularly at millimetre wavelengths, and that it greatly exceeds the sensitivity of communications and radar equipment;

j) that typical radio astronomical observations require integration times of the order of a few minutes to hours, but that sensitive observations, particularly of spectral lines, may require longer periods of recording, sometimes up to several days;

k) that some transmissions from spacecraft can introduce problems of interference to radio astronomy and that these cannot be avoided by choice of site for an observatory or by local protection;

l) that interference to radio astronomy can be caused by terrestrial transmissions reflected by the Moon, by aircraft, and possibly by artificial satellites;

m) that some types of high spatial-resolution interferometric observations require simultaneous reception, at the same radio frequency, by widely separated receiving systems that may be located in different countries, on different continents, or on space platforms;

n) that propagation conditions at frequencies below about 40 MHz are such that a transmitter operating anywhere on the Earth might cause interference detrimental to radio astronomy;

o) that some degree of protection can be achieved by appropriate frequency assignments on a national rather than an international basis;

p) that WRCs have made improved allocations for radio astronomy, particularly above 71 GHz, but that protection in many bands, particularly those shared with other radio services, may still need careful planning;

q) that technical criteria concerning interference detrimental to the radio astronomy service (RAS) have been developed, which are set out in Tables 1, 2, and 3,

recommends

1 that radio astronomers should be encouraged to choose sites as free as possible from interference;

2 that administrations should afford all practicable protection to the frequencies and sites used by radio astronomers in their own and neighbouring countries and when planning global systems, taking due account of the levels of interference given in Annex 1;

3 that administrations, in seeking to afford protection to particular radio astronomical observations, should take all practical steps to reduce all unwanted emissions falling within the band of the frequencies to be protected for radio astronomy to the absolute minimum. Particularly those emissions from aircraft, high altitude platform stations, spacecraft and balloons;

4 that when proposing frequency allocations, administrations take into account that it is very difficult for the RAS to share frequencies with any other service in which direct line-of-sight paths from the transmitters to the observatories are involved. Above about 40 MHz sharing may be practicable with services in which the transmitters are not in direct line-of-sight of the observatories, but coordination may be necessary, particularly if the transmitters are of high power.

Annex 1

Sensitivity of radio astronomy systems

1 General considerations and assumptions used in the calculation of interference levels

1.1 Detrimental-level interference criterion

The sensitivity of an observation in radio astronomy can be defined in terms of the smallest power level change ΔP in the power level P at the radiometer input that can be detected and measured. The sensitivity equation is:

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{\Delta f_0 t}} \tag{1}$$

where:

P and ΔP: power spectral density of the noise

Δf_0: bandwidth

t: integration time. P and ΔP in equation (1) can be expressed in temperature units through the Boltzmann's constant, k:

$$\Delta P = k\ \Delta T; \quad \text{also} \quad P = k\ T \tag{2}$$

Thus we may express the sensitivity equation as:

$$\Delta T = \frac{T}{\sqrt{\Delta f_0 t}} \tag{3}$$

where:

$$T = T_A + T_R$$

This result applies for one polarization of the radio telescope. T is the sum of T_A (the antenna noise temperature contribution from the cosmic background, the Earth's atmosphere and radiation from the Earth) and T_R, the receiver noise temperature. Equations (1) or (3) can be used to estimate the sensitivities and interference levels for radio astronomical observations. The results are listed in Tables 1 and 2. An observing (or integration) time, t, of 2 000 s is assumed, and interference threshold levels, ΔP_H, given in Tables 1 and 2 are expressed as the interference power within the bandwidth Δf that introduces an error of 10% in the measurement of ΔP (or ΔT), i.e.:

$$\Delta P_H = 0.1\, \Delta P\, \Delta f \tag{4}$$

In summary, the appropriate columns in Tables 1 and 2 may be calculated using the following methods:

– ΔT, using equation (3),

– ΔP, using equation (2),

– ΔP_H, using equation (4).

The interference can also be expressed in terms of the pfd incident at the antenna, either in the total bandwidth or as a spectral pfd, S_H, per 1 Hz of bandwidth. The values given are for an antenna having a gain, in the direction of arrival of the interference, equal to that of an isotropic antenna (which has an effective area of $c^2/4\pi f^2$, where c is the speed of the light and f the frequency). The gain of an isotropic radiator, 0 dBi, is used as a general representative value for the side-lobe level, as discussed under § 1.3.

Values of $S_H \Delta f$ (dB(W/m^2)), are derived from ΔP_H by adding:

$$20 \log f - 158.5 \qquad \text{dB} \tag{5}$$

where f (Hz). S_H is then derived by subtracting 10 log Δf (Hz) to allow for the bandwidth.

1.2 Integration time

The calculated sensitivities and interference levels presented in Tables 1 and 2 are based on assumed integration times of 2 000 s. Integration times actually used in astronomical observations cover a wide range of values. Continuum observations made with single-antenna telescopes (as distinct from interferometric arrays) are well represented by the integration time of 2 000 s, typical of good quality observations. On the other hand 2 000 s is less representative of spectral line observations. Improvements in receiver stability and the increased use of correlation spectrometers have allowed more frequent use of longer integration times required to observe weak spectral lines, and spectral line observations lasting several hours are quite common. A more representative integration time for these observations would be 10 h. For a 10 h integration, the threshold interference level is 6 dB more stringent than the values given in Table 2. There are also certain observations of time varying phenomena, e.g. observations of pulsars, stellar or solar bursts, and interplanetary scintillations for which much shorter time periods may be adequate.

1.3 Antenna response pattern

Interference to radio astronomy is almost always received through the antenna side lobes, so the main beam response to interference need not be considered.

The side-lobe model for large paraboloid antennas in the frequency range 2 to 30 GHz, given in Recommendation ITU-R SA.509 is a good approximation of the response of many radio astronomy antennas and is adopted throughout this Recommendation as the radio astronomy reference antenna. In this model, the side-lobe level decreases with angular distance (degrees) from the main beam axis and is equal to $32 - 25 \log \varphi$ (dBi) for $1° < \varphi < 48°$. The effect of an interfering signal clearly depends upon the angle of incidence relative to the main beam axis of the antenna, since the side-lobe gain, as represented by the model, varies from 32 to –10 dBi as a function of this angle. However, it is useful to calculate the threshold levels of interference strength for a particular value of side-lobe gain, that we choose as 0 dBi, and use in Tables 1 to 3. From the model, this side-lobe level occurs at an angle of 19.05° from the main beam axis. Then a signal at the detrimental threshold level defined for 0 dBi side-lobe gain will exceed the criterion for the detrimental level at the receiver input if it is incident at the antenna at an angle of less than 19.05°. The solid angle within a cone of angular radius 19.05° is 0.344 sr, which is equal to 5.5% of the 2π sr of the sky above the horizon that a radio telescope is able to observe at any given time. Thus if the probability of the angle of incidence of interference is uniformly distributed over the sky, about 5.5% of interfering signals would be incident within 19.05° of the main beam axis of an antenna pointed towards the sky. Note also that the 5.5% figure is in line with the recommended levels of data loss to radio astronomy observations in percentage of time, specified in Recommendation ITU-R RA.1513.

The particular case of non-GSO satellites presents a dynamic situation, that is, the positions of the satellites relative to the beam of the radio astronomy antenna show large changes within the time scale of the 2 000 s integration time. Analysis of interference in this case requires integrating the response over the varying side-lobe levels, for example, using the concept of epfd defined in No. 22.5C of the Radio Regulations (RR). In addition it is usually necessary to combine the responses to a number of satellites within a particular system. In such calculations it is suggested that the antenna response pattern for antennas of diameter greater than 100 λ in Recommendation ITU-R S.1428 be used to represent the radio astronomy antenna, until a model based specifically on radio astronomy antennas is available; see § 2.2 for further discussion.

1.4 Bandwidth

Equation (1) shows that observations of the highest sensitivity are obtained when radio astronomers make use of the widest possible bandwidth. Consequently, in Table 1 (continuum observations), Δf is assumed to be the width of the allocated radio astronomy bands for frequencies up to 71 GHz. Above 71 GHz a value of 8 GHz is used, which is a representative bandwidth generally used on radio astronomy receivers in this range. In Table 2 (spectral line observations) a channel bandwidth Δf equal to the Doppler shift corresponding to 3 km/s in velocity is used for entries below 71 GHz. This value represents a compromise between the desired high spectral resolution and the sensitivity. There are a very large number of astrophysically important lines above 71 GHz, as shown in Recommendation ITU-R RA.314 and only a few representative values for the detrimental levels are given in Table 2 for the range 71-275 GHz. The channel bandwidth used to compute the detrimental levels above 71 GHz is 1 000 kHz (1 MHz) in all cases. This value was chosen for practical reasons. While it is slightly wider than the spectral channel width customary in radio astronomy receivers at these frequencies, it is used as the standard reference bandwidth for space services above 15 GHz.

1.5 Receiver noise temperature and antenna temperature

The receiver noise temperatures in Tables 1 and 2 are representative of the systems in use in radio astronomy. For frequencies above 1 GHz these are cryogenically cooled amplifiers or mixers. The quantum effect places a theoretical lower limit of hf/k on the noise temperature of such devices, where h and k are Planck's and Boltzmann's constants, respectively. This limit becomes important at frequencies above 100 GHz, where it equals 4.8 K. Practical mixers and amplifiers for bands at 100 GHz and higher provide noise temperatures greater than hf/k by a factor of about four. Thus, for frequencies above 100 GHz, noise temperatures equal to $4hf/k$ are used in Tables 1 and 2.

The antenna temperatures in the Tables are also representative of practical systems in use in radio astronomy. They include the effects of the ionosphere or the neutral atmosphere, ground pickup in side lobes resulting from spillover or scattering, ohmic losses, and the cosmic microwave background. At frequencies above 100 GHz the atmospheric losses due to water vapour in the neutral atmosphere become very important. For these frequencies the values given are typical of the terrestrial sites used for major millimetric-wave radio astronomy facilities, such as Mauna Kea, Hawaii, or the Llano de Chajnantor at an elevation of 5 000 m in Chile, which is the site chosen for a major international radio astronomy array for frequencies in the range 30 GHz to 1 THz.

2 Special cases

The levels given in Tables 1 and 2 are applicable to terrestrial sources of interfering signals. The detrimental pfd and spectral pfd shown in Tables 1 and 2 assume that interference is received through a 0 dBi side lobe, and should be regarded as the general interference criteria for high sensitivity radio astronomy observations, when the interference does not enter the near side lobes.

2.1 Interference from GSO satellites

Interference from GSO satellites is a case of particular importance. Because the power levels in Tables 1 and 2 were calculated based on a 0 dBi antenna gain, interference detrimental to radio astronomy will be encountered when a reference antenna, such as described in Recommendation ITU-R SA.509, is pointed within 19.05° of a satellite radiating at levels in accordance with those listed in the Tables. A series of such transmitters located around the GSO would preclude radio astronomy observations with high sensitivity from a band of sky 38.1° wide and centred on the orbit. The loss of such a large area of sky would impose severe restrictions on radio astronomy observations.

In general, it would not be practical to suppress the unwanted emissions from satellites to below the detrimental level when the main beam of a radio telescope is pointed directly towards the satellite. A workable solution is suggested by observing the projection of the GSO in celestial coordinates as viewed from the latitudes of a number of major radio astronomy observations (see Recommendation ITU-R RA.517). If it were possible to point a radio telescope to within 5° of the GSO without encountering detrimental interference, then for that telescope a band of sky 10° wide would be unavailable for high-sensitivity observations. For a given observatory this would be a serious loss. However, for a combination of radio telescopes located at northern and southern latitudes, operating at the same frequencies, the entire sky would be accessible. A value of 5° should therefore be regarded as the requirement for minimum angular spacing between the main beam of a radio astronomy antenna and the GSO.

In the model antenna response of Recommendation ITU-R SA.509, the side-lobe level at an angle of 5° from the main beam is 15 dBi. Thus, to avoid interference detrimental to a radio telescope meeting the antenna side-lobe performance of Recommendation ITU-R SA.509, pointed to within 5° of the transmitter, it is desirable that the satellite emissions be reduced 15 dB below the pfd given in Tables 1 and 2. When satellites are spaced at intervals of only a few degrees along the GSO, the emission levels associated with the individual transmitters must be even lower to meet the requirement that the sum of the powers of all the interfering signals received should be 15 dB below ΔP_H in Tables 1 and 2.

It is recognized that the emission limitations discussed above cannot, in practice, be achieved so as to enable sharing of the same frequency band between radio astronomy and down-link transmissions from satellites to take place. The limitations are, however, applicable to unwanted emission from the satellite transmitters, which fall within the radio astronomy bands listed in Tables 1 and 2. These emission limitations have implications for the space services responsible for the interference, which require careful evaluation. Furthermore, the design of new radio astronomy antennas should strive to minimize the level of side-lobe gain near the main beam as an important means of reducing interference from transmitters in the GSO.

2.2 Interference from non-GSO satellites

In the case of non-GSO satellites, and in particular for low-Earth orbit satellites, the systems usually involve constellations of many individual satellites. Thus determination of interference levels requires analysis of the combined effect of many signals, most of which are received through far side lobes of the radio astronomy antenna. A more detailed side-lobe model than that of Recommendation ITU-R SA.509 is therefore desirable, and it is proposed that the model in Recommendation ITU-R S.1428 be used until such time as a more representative model for radio astronomy antennas is obtained. In using this proposed model the case for antennas with diameter greater than 100 λ is generally appropriate for radio astronomy applications. It should be noted that Note 1 of Recommendation ITU-R S.1428, which allows cross-polarized components to be ignored, cannot be applied since radio astronomy antennas generally receive signals in two orthogonal polarizations simultaneously. The motion of non-GSO satellites across the sky during a 2 000 s integration period requires that the interference level be averaged over this period, that is, the response to each satellite must be integrated as the satellite moves through the side-lobe pattern. One system of analysis that includes these requirements is the epfd method described in RR No. 22.5C. Values of epfd represent the pfd of a signal entering the antenna through the centre of the main beam that would produce an equivalent level of interference power. Since the threshold levels of detrimental interference in Tables 1 and 2 correspond to pfd received with an antenna gain of 0 dBi, it is necessary to compare them with values of ($epfd + G_{mb}$), where G_{mb} is the main beam gain, to determine whether the interference exceeds the detrimental level. Making use of the epfd method, Recommendation ITU-R S.1586 has recently been developed for interference calculations between radio astronomy telescopes and FSS non-GSO satellite systems. A similar Recommendation, Recommendation ITU-R M.1583 was developed for interference calculations between radio astronomy telescopes and MSS and radionavigation-satellite service non-GSO satellite systems. The applicability of the protection criteria given in Tables 1 and 2 is described in Recommendation ITU-R RA.1513.

2.3 The response of interferometers and arrays to radio interference

Two effects reduce the response to interference. These are related to the frequency of the fringe oscillations that are observed when the outputs of two antennas are combined, and to the fact that the components of the interfering signal received by different and widely-spaced antennas will suffer different relative time delays before they are recombined. The treatment of these effects is more complicated than that for single antennas in § 1. Broadly speaking, if the strength of the received interfering signal remains constant, the effect is reduced by a factor roughly equal to the mean time of one natural fringe oscillation divided by the data averaging time. This typically ranges from some seconds for a compact array with the longest projected spacing $L' \sim 10^3\ \lambda$, where λ is the wavelength, to less than 1 ms for intercontinental arrays with $L' \sim 10^7\ \lambda$. Thus, compared to a single radio telescope, the interferometer has a degree of immunity to interference which, under reasonable assumptions increases with the array size expressed in wavelengths.

The greatest immunity from interference occurs for interferometers and arrays in which the separation of the antennas is sufficiently great that the chance of occurrence of correlated interference is very small (e.g. for very long baseline interferometry (VLBI)). In this case, the above considerations do not apply. The tolerable interference level is determined by the requirement that the power level of the interfering signal should be no more than 1% of the receiver noise power to prevent serious errors in the measurement of the amplitude of the cosmic signals. The interference levels for typical VLBI observations are given in Table 3, based on the values of T_A and T_R given in Table 1.

It must be emphasized that the use of large interferometers and arrays is generally confined to studies of discrete, high-brightness sources, with angular dimensions no more than a few tenths of a second of arc for VLBI. For more general studies of radio sources, the results in Tables 1 and 2 apply and are thus appropriate for the general protection of radio astronomy.

TABLE 1

Threshold levels of interference detrimental to radio astronomy continuum observations

Centre frequency (1) f_c (MHz)	Assumed bandwidth Δf (MHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity(2) (noise fluctuations)		Threshold interference levels(2) (3)		
				Temperature ΔT (mK)	Power spectral density ΔP (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
13.385	0.05	50 000	60	5 000	–222	–185	–201	–248
25.610	0.12	15 000	60	972	–229	–188	–199	–249
73.8	1.6	750	60	14.3	–247	–195	–196	–258
151.525	2.95	150	60	2.73	–254	–199	–194	–259
325.3	6.6	40	60	0.87	–259	–201	–189	–258
408.05	3.9	25	60	0.96	–259	–203	–189	–255
611	6.0	20	60	0.73	–260	–202	–185	–253
1 413.5	27	12	10	0.095	–269	–205	–180	–255
1 665	10	12	10	0.16	–267	–207	–181	–251
2 695	10	12	10	0.16	–267	–207	–177	–247
4 995	10	12	10	0.16	–267	–207	–171	–241
10 650	100	12	10	0.049	–272	–202	–160	–240
15 375	50	15	15	0.095	–269	–202	–156	–233
22 355	290	35	30	0.085	–269	–195	–146	–231
23 800	400	15	30	0.050	–271	–195	–147	–233
31 550	500	18	65	0.083	–269	–192	–141	–228
43 000	1 000	25	65	0.064	–271	–191	–137	–227
89 000	8 000	12	30	0.011	–278	–189	–129	–228
150 000	8 000	14	30	0.011	–278	–189	–124	–223
224 000	8 000	20	43	0.016	–277	–188	–119	–218
270 000	8 000	25	50	0.019	–276	–187	–117	–216

(1) Calculation of interference levels is based on the centre frequency shown in this column although not all regions have the same allocations.

(2) An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, –1.3, –2.8, –4.8 or –6.3 dB respectively.

(3) The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels be adjusted by –15 dB, as explained in § 2.1.

TABLE 2*

Threshold levels of interference detrimental to radio astronomy spectral-line observations

frequency f (MHz)	Assumed spectral line channel bandwidth Δf (MHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity[2] (noise fluctuations)		Threshold interference levels[1] [2]		
				Temperature ΔT (mK)	Power spectral density ΔP_S (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
327	10	40	60	22.3	–245	–215	–204	–244
1 420	20	12	10	3.48	–253	–220	–196	–239
1 612	20	12	10	3.48	–253	–220	–194	–238
1 665	20	12	10	3.48	–253	–220	–194	–237
4 830	50	12	10	2.20	–255	–218	–183	–230
14 488	150	15	15	1.73	–256	–214	–169	–221
22 200	250	35	30	2.91	–254	–210	–162	–216
23 700	250	35	30	2.91	–254	–210	–161	–215
43 000	500	25	65	2.84	–254	–207	–153	–210
48 000	500	30	65	3.00	–254	–207	–152	–209
88 600	1 000	12	30	0.94	–259	–209	–148	–208
150 000	1 000	14	30	0.98	–259	–209	–144	–204
220 000	1 000	20	43	1.41	–257	–207	–139	–199
265 000	1 000	25	50	1.68	–256	–206	–137	–197

* This Table is not intended to give a complete list of spectral-line bands, but only representative examples throughout the spectrum.

(1) An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, –1.3, –2.8, –4.8 or –6.3 dB respectively.

(2) The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels need to be adjusted by –15 dB, as explained in § 2.1.

COLUMN DESCRIPTIONS FOR TABLES 1 AND 2

Column

(1) Centre frequency of the allocated radio astronomy band (Table 1) or nominal spectral line frequency (Table 2).

(2) Assumed or allocated bandwidth (Table 1) or assumed typical channel widths used for spectral line observations (Table 2).

(3) Minimum antenna noise temperature includes contributions from the ionosphere, the Earth's atmosphere and radiation from the Earth.

(4) Receiver noise temperature representative of a good radiometer system intended for use in high sensitivity radio astronomy observations.

(5) Total system sensitivity (mK) as calculated from equation (1) using the combined antenna and receiver noise temperatures, the listed bandwidth and an integration time of 2 000 s.

(6) Same as (5) above, but expressed in noise power spectral density using the equation $\Delta P = k\,\Delta T$, where $k = 1.38 \times 10^{-23}$ (J/K) (Boltzmann's constant). The actual numbers in the Table are the logarithmic expression of ΔP.

(7) Power level at the input of the receiver considered harmful to high sensitivity observations, ΔP_H. This is expressed as the interference level which introduces an error of not more than 10% in the measurement of ΔP; $\Delta P_H = 0.1\ \Delta P\ \Delta f$: the numbers in the Table are the logarithmic expression of ΔP_H.

(8) pfd in a spectral line channel needed to produce a power level of ΔP_H in the receiving system with an isotropic receiving antenna. The numbers in the Table are the logarithmic expression of $S_H\ \Delta f$.

(9) Spectral pfd needed to produce a power level ΔP_H in the receiving system with an isotropic receiving antenna. The numbers in the Table are the logarithmic expression of S_H. To obtain the corresponding power levels in a reference bandwidth of 4 kHz or 1 MHz add 36 dB or 60 dB, respectively.

TABLE 3

Threshold interference levels for VLBI observations

Centre frequency (MHz)	Threshold level (dB(W/m^2 · Hz))
325.3	–217
611	–212
1 413.5	–211
2 695	–205
4 995	–200
10 650	–193
15 375	–189
23 800	–183
43 000	–175
86 000	–172

No. R. 90 **10 February 2012**

REGULATIONS ON RADIO ASTRONOMY PROTECTION LEVELS IN ASTRONOMY ADVANTAGE AREAS DECLARED FOR THE PURPOSES OF RADIO ASTRONOMY

In terms of section 37, read with section 50, of the Astronomy Geographic Advantage Act, 2007 (Act No. 21 of 2007), I, Grace Naledi Mandisa Pandor, Minister of Science and Technology, having obtained the concurrence of the Independent Communications Authority of South Africa as required by the Act, hereby make regulations on radio astronomy protection levels in astronomy advantage areas declared for the purposes of radio astronomy, as set out in the Schedule.

MRS GNM PANDOR, MP

MINISTER OF SCIENCE AND TECHNOLOGY

SCHEDULE

1. Definitions

In these regulations any word or expression to which a meaning has been assigned in the Act has the meaning so assigned and, unless the context otherwise indicates –

"ITU" means the International Telecommunications Union;

"SPDF" means Spectral Power Flux Density;

"the Act" means the Astronomy Geographic Advantage Act, 2007 (Act No. 21 of 2007).

2. Protection levels

(1) The origin, derivation and references for the protection levels to be applied in astronomy advantage areas declared for the purposes of radio astronomy are as follows:

(a) The protection levels are derived using the methodology described in ITU Recommendation ITU-R RA.769.

(b) The technical assumptions made in the derivation are that receiver and sky temperatures are linearly interpolated from those values found in ITU-R RA.769, and that receiver bandwidth is assumed to be 1% of the observing frequency.

(c) Derived protection levels, which are equivalent to threshold levels of interference for new generation radio astronomy observatories and are based on the methodology outlined in ITU-R RA.769, are depicted in Figure 1.

(2) The protection levels to be applied in astronomy advantage areas declared for the purposes of radio astronomy shall be as follows:

(a) The values of the protection levels at the applicable frequencies are determined by means of a linearly piecewise function.

(b) The said function is described by the following equations, which are to be used to calculate the required protection level at any frequency in the spectrum from 70 MHz to 25,5 GHz:

SARAS [dBm / Hz] = - *17.2708* log_{10} *(f) – 192.0714 for f < 2 GHz.*

SARAS [dBm / Hz] = - *0.065676* log_{10} *(f) – 248.8661 for f ≥ 2 GHz.*

The values of (f) are to be in MHz.

(c) The function is designated as the South African Radio Astronomy Service ("SARAS") protection levels.

(d) The SARAS protection levels are reflected in Figure 1 below, together with the ITU interpolated continuum threshold levels of interference.

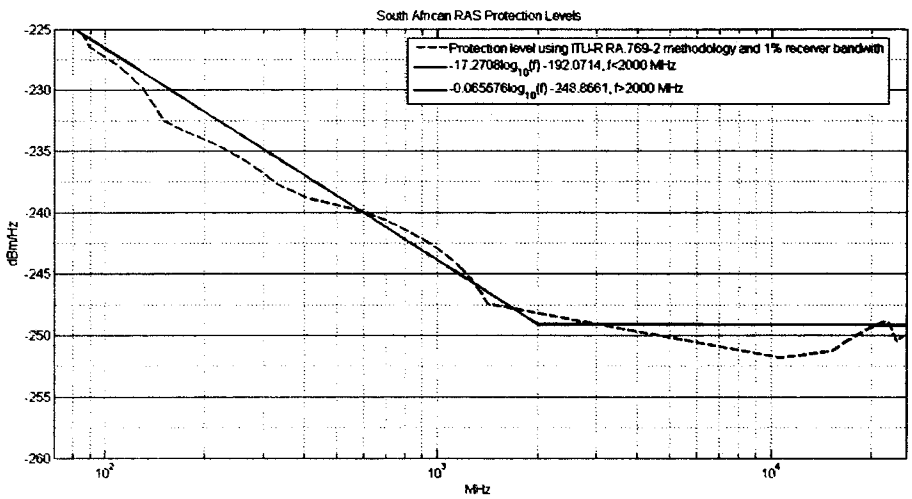

Figure 1. SARAS Protection Levels

(e) Owing to the variety of units used within the electronic communications sector, the following list of unit conversions is provided (assuming an isotropic radiator):

$$dB(W/m^2/Hz) \rightarrow dBm \quad : \quad SPFD - 20\log_{10}(f) + 10\log_{10}(\Delta f) + 188.5$$

$$dBm \rightarrow dBm/Hz \quad : \quad dBm - 10\log_{10}(\Delta f)$$

$$dBW \rightarrow dBm \quad : \quad dBW + 30$$

$$dBW \rightarrow dB(W/m^2) \quad : \quad dBW + 20\log_{10}(f) - 158.5$$

The values of "f" and "Δf" are to be in Hz.

3. Short title

These regulations are called the Radio Astronomy Protection Levels Regulations.

RFI and EMI Assessment Methodology

1. Preamble

The purpose of this document is to provide the mathematical framework to conduct an impact assessment of RFI and EMI on the risk of detrimental impact on radio astronomy receivers.

2. Generalised Assessment Methodology

In the generalised case to assess the risk of detrimental impact of radio interference at each frequency f_i on radio astronomy receivers, we require the following condition to be true:

$$\text{Compliance} \rightarrow Loss_{det} \geq Loss_{required}$$

where:

$$Loss_{required} = ProtectLevel - SPD$$

- SPD = spectral power density of transmitted RF signal [dB(W/Hz)]
- $ProtectLevel$ = Required protection threshold level. Unless otherwise determined, the default level shall be defined as
  - SARAS [dBm/Hz] = $-17.2708\ log10\ (f) - 192.0714$ for $f < 2\ GHz$,
    $-0.065676\ log10\ (f) - 248.8661$ for $f > 2\ GHz$

    where f is in MHz.

and where:

$$Loss_{det} = Path\ Loss + Shielding$$

- $Loss_{det}$ = total attenuation of transmitted RF signal [dB]
- $Path\ Loss$ = attenuation resulting from RF propagation, including free space loss and diffraction losses [dB]. These losses may be determined via the following methods, in order from most conservative to least conservative:
  - Free space loss;
  - Free space loss + diffraction model
  - Measurement;

- $Shielding =$ attenuation resulting from additional physical shielding [dB]

The spectral power density of the transmitted signal (*SPD*) can be determined either through transmitter specifications, where available, or via measurement. In the case that measurements of field strength are conducted, the *SPD* is calculated as follows:

$$SPD = EIRP - 10 \log_{10} BW$$

where

- $SPD =$ spectral power density [dB(W/Hz)]
- $BW =$ bandwidth of signal [Hz]

and

$$EIRP = E + 20 \log_{10} D - 74.8$$

where

- $EIRP =$ istropically radiated power [dB(W)]
- $E =$ electric field strength [dB(uV/m)]
- $D =$ measurement distance [km]

Minimum Attenuation Required			
Phase		**Frequency [MHz]**	**Predicted Attenuation [dB]**
On-Site (excl. Communication Service)			
Construction	Site Preparations	350	*155*
	Drilling Securing	350	*153*
Operations	Stimulation & Well Test	350	*149*
Decommissioning	Site Preparations	350	*155*
On-Site			
Construction	Site Preparations	350	*155*
	Drilling Securing	350	*155*
Operations	Stimulation & Well Test	350	*155*
Decommissioning	Site Preparations	350	*155*
On Road			
Construction	Site Preparations	350	*145*
	Drilling Securing	350	*143*
Operations	Stimulation & Well Test	350	*143*
Decommissioning	Site Preparations	350	*145*

Additional Shielding [dB]
0
0
0
0
61
61
61
61
0
0
0
0

Measured Results and Impact Analysis o			
Frequency [MHz]	**Max Radiated dB(W/Hz)**	**Min Radiated dB(W/Hz)**	**CISPR-22 Class B [dB(W/Hz)]**
			On-Site (excl. Com
350	*-111.3685744*	*-111.3685744*	*-135.6*
350	*-113.7190395*	*-113.7190395*	*-135.6*
350	*-117.8988769*	*-117.8988769*	*-128.6*
350	*-111.3685744*	*-111.3685744*	*-128.6*
			On-
350	*-50.59181246*	*-50.59181246*	*-135.6*
350	*-50.59181246*	*-50.59181246*	*-135.6*
350	*-50.59181246*	*-50.59181246*	*-128.6*
350	*-50.59181246*	*-50.59181246*	*-128.6*
			On I
350	*-121.6018953*	*-121.6018953*	*-135.6*
350	*-123.8205999*	*-123.8205999*	*-135.6*
350	*-123.8205999*	*-123.8205999*	*-128.6*
350	*-121.6018953*	*-121.6018953*	*-128.6*

›f Gemsbok PV1 on Nearest SKA Location		
SARAS [dB(W/Hz)]	Max Required Path Loss [dB]	Additional Mitigation [Required - Calculated Path Loss] [dB]
munication Service)		
-266.0094904	*154.640916*	*-0.359084049*
-266.0094904	*152.2904509*	*-0.709549117*
-266.0094904	*148.1106135*	*-0.889386499*
-266.0094904	*154.640916*	*-0.359084049*
-Site		
-266.0094904	*215.4176779*	*-0.58232208*
-266.0094904	*215.4176779*	*-0.58232208*
-266.0094904	*215.4176779*	*-0.58232208*
-266.0094904	*215.4176779*	*-0.58232208*
Road		
-266.0094904	*144.4075951*	*-0.5924049*
-266.0094904	*142.1888905*	*-0.811109533*
-266.0094904	*142.1888905*	*-0.811109533*
-266.0094904	*144.4075951*	*-0.5924049*

CHAPTER 18

Impacts on Integrated Spatial and Infrastructure Planning

CHAPTER 18: IMPACTS ON INTEGRATED SPATIAL AND INFRASTRUCTURE PLANNING

Integrating Author:	Elsona van Huyssteen[1], Cheri Green[1]
Contributing Authors:	Phil Paige-Green[2], Mark Oranje[3], Stephen Berrisford[4]
Corresponding Authors:	Dave McKelly[1]

1 Built Environment Department, Council for Scientific and Industrial Research (CSIR), Stellenbosch, 7660

2 Paige-Green Consulting (Pty) Ltd, Pretoria, 0181

3 University of Pretoria, Hatfield, 0028

4 Stephen Berrisford Consulting CC, Johannesburg, 2122

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Tables

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Executive Summary

Shale gas development (SGD) is expected to have the following impacts:

- Highly likely to be an incremental increase in the construction, upgrading and maintenance of road infrastructure with an associated increase in demand for scarce construction materials (including high quality gravel and water) and increased on-going road maintenance.

- Highly likely to be increased volumes of heavy vehicles on district and local roads, and a subsequent impact on major through routes (logistical corridors) in the wider region leading to 1) the deterioration of roads, and 2) necessitating higher levels of law enforcement and traffic management, to prevent vehicle overloading, traffic accidents and congestion.

- A high likelihood of formal and informal town growth and subsequent demand on housing, services and infrastructure in main towns, with resultant pressures on municipal capacity, financial viability resources and management, to ensure effective delivery.

- Site-specific land development will require the granting of land use and land development approvals in terms of the regulatory framework (being) put in place by the Spatial Planning and Land Use Management Act, 2013 (SPLUMA), the Western Cape Land Use Planning Act, 2014 (LUPA) (where applicable) and Municipal Land Use Planning Bylaws. The institutional governance capacity of municipalities and other organs of the state to consider land use and land development applications and provide inputs to applications in terms of other regulatory requirements where required will most likely need to be enhanced in order to plan for, guide and monitor SGD.

- The governance capacity of local and district municipalities in the region for coordinated, integrated, aligned and sequenced spatial and infrastructure investment planning and management is limited (see Western Cape Government, 2009; 2012; The Presidency, 2014). There is thus a high likelihood that these authorities will be challenged to successfully implement mitigation measures relating to any new activity in their individual and overlapping areas of jurisdiction.

- With the roll-out of the recently promulgated SPLUMA and the Western Cape LUPA, new institutions are being established and new procedures for spatial planning and land use management introduced, so there is high likelihood that even the slightest change in current land use will pose significant challenges in the context of land use regulation and spatial planning.

- While SGD might be beneficial for the relevant operators, and possibly the regional and national energy mix and the national fiscus, the indirect costs of the planned exploration and operation phases will most likely have the biggest impact on the already resource-constrained municipalities in the area, notwithstanding any potential municipal rates increase.

- The uncertainty of the outcomes of the exploration phase, the sustained incremental approach of the operation, and the ongoing exploration activities will require timeous and synchronised intergovernmental prioritisation, budgeting and implementation (within relevant integrated planning, spatial planning and infrastructure investment processes and frameworks), which will pose significant challenges to local, as well as provincial, spheres of government.

CHAPTER 18: IMPACTS ON INTEGRATED INFRASTRUCTURE AND SPATIAL PLANNING

18.1 Introduction and scope

18.1.1 Sustainable towns and infrastructure development as indispensable for shale gas development (SGD)

In this chapter the implications of shale gas development (SGD) in the Karoo are explored in the context of 1) local development realities, 2) legal requirements and associated development pressures related to land development and land-use change, 3) local and regional road infrastructure requirements, 4) settlement development, and 5) associated municipal service delivery and implications for spatial planning and land use management.

Short and longer-term implications, risks and possibilities for mitigation are outlined within the context of 1) the set development principles and priorities, as well as, 2) the institutional realities of the relevant provincial and national spatial planning and integrated development planning and transport planning governance system, which is primarily aimed at supporting intergovernmental alignment to facilitate effective service delivery, job creation, transformation of apartheid legacies and long term sustainability. While the latter represents a set of national challenges, merely escalated within the arid and semi-arid

Definitions

Regional infrastructure: This includes all national, provincial and district roads, railway lines used to access the area and passing through the area, as well as pipelines that could potentially be required for local and regional gas distribution.

Local access roads: These are any direct access roads (other than the above) used to access the wellpads and related service sites. It also includes any roads built in any formal settlements which are developed to accommodate workers, or to access informal settlements resulting from in-migration of aspirant job seekers.

Spatial planning: This is the term used to describe the planning for future patterns of development in an area, typically reflected in a municipal spatial development framework, but now also possible in provincial, regional and national Spatial Development Frameworks (SDFs) in terms of Spatial Planning and Land Use Management Act, 2013 (SPLUMA).

Land use management: This is the activity, typically carried out by a municipality, of regulating and facilitating land use change.

Sustainable settlement development: This term refers to the processes of planning for, investing in, and governing of human settlements in such a way that they are economically vibrant, spatially and socially integrated, self-generating, safe and overall good places to live in. It also includes the use of resources to achieve these characteristics that is cognisant of the cumulative needs of current and future generations.

Municipal service delivery: Delivery of housing, electricity and basic services such as water and sanitation, to which South African citizens have a constitutional right.

Karoo landscapes, resource-scarce municipalities and low-growth regional economies, it also represents challenges that form part of current initiatives in South Africa to support regional and local development through 1) large-scale catalytic investments, 2) the identification of alternative energy sources, and 3) a developmental ethos that requires national investment decisions to be rooted in local contextual and institutional realities.

In exploring the possible implications of SGD in the Karoo, it is important to recognise that land, infrastructure and settlement development often are merely the result and spatial footprint of complex socio-economic and socio-ecological systems. As such, the Chapter should be read in association with the chapters highlighting details regarding the social fabric and population and migration dynamics (Atkinson et al., 2016), economic development (Van Zyl et al., 2016), agriculture (Oettle et al., 2016) and tourism (Toerien et al., 2016). In terms of the implications SGD, it should also be noted that the Chapter addresses transportation implications in terms of road infrastructure and land-development implications in the context of the spatial planning and land-use management system and impacts on settlement development, while specific implications for water resources (Hobbs

Definitions

Integrated development. The planning instrument and process set in place by the Municipal Systems Act, 2000 (MSA), to enable coordinated service delivery and development between the three spheres of government and other role players within a municipal area, to 1) improve quality of life, 2) support sustainable development and transformation, and 3) facilitate democratic and multi-sector planning processes. The municipal Integrated Development Plan (IDP) addresses current and future societal needs within the context social and ecological systems in which they exist. All project and activities related to infrastructure, land development, service delivery, as well as land and environmental management within any area needs to form part of the relevant IDP and associated sector plans and infrastructure investment frameworks.

Regional Spatial Development Framework. SPLUMA makes provision for the establishment of a planning instrument to enable focused temporal and spatial coordination of governance and investment actions in and between different spheres of government, within areas with unique, but interrelated, attributes or development challenges that span more than one municipality and/or province.

Land development. SPLUMA defines land development as the erection of buildings or structures on land, or the change of use of land, including township establishment, the subdivision or consolidation of land or any deviation from the land use or uses permitted in terms of an applicable land use scheme.

Land use. SPLUMA defines land use as the purpose for which land is or may be used lawfully in terms of a land use scheme, existing scheme or in terms of any other authorisation, permit or consent issued by a competent authority, and includes any conditions related to such land use purposes. This could be related to "zoning" in the traditional sense of the word.

NOTE: No distinction is made between 'Land use application' and 'Land development application' in SPLUMA, however the Western Cape LUPA identifies conditions where land development applications would require provincial approval and SPLUMA makes provision for ministerial approval in cases where land development applications are deemed of national interest.

et al., 2016), transportation of hazardous waste (Oelofse et al., 2016) and all other biodiversity (Holness et al., 2016) and visual (Oberholzer et al., 2016) impacts are dealt with in a series of issue specific Chapters of this scientific assessment.

18.1.2 Pointers from international and regional infrastructure and town growth experiences

Risks associated with infrastructure and land development will most likely be central to opportunities and challenges associated with SGD in South Africa. Experience in the United States (US) points to how 1) the ability to source and access cheap and commoditised equipment and services, 2) the large scale availability of road and even pipeline infrastructure, as well as, 3) the private ownership of land and mineral rights assisted (amongst other things) in creating a set of specific circumstances that supported rapid commercial SGD in that country (Fakir, 2015).

Site visits to the Middle East and US have shown the geographically scattered patterns of on-surface infrastructure development associated with the establishments of wellpads for SGD, and the direct implications with regards to regional and local road infrastructure and settlement development that manifest as a result of it (Paige-Green, 2015; 2016).

Evidence from the Sultanate of Oman and Pennsylvania indicates that even before shale gas production phases, wellpad construction and use (for exploration as well as extraction) and associated activities result in significant stresses on the existing road network due to increased heavy vehicle traffic. While the stresses on road networks and infrastructure are primarily influenced by the mode of transport of the gas (i.e. pipeline or road) in the production phases, the preparation of wellpads and access roads, import of heavy equipment and transportation of construction materials during the exploration phases, as indicated in Burns et al. (2016), can also result in a significant increase in heavy traffic on regional road networks. Due to heavy vehicle loads of equipment and construction material, local roads also deteriorate rapidly and require significantly increased maintenance, if not severe rehabilitation or even total reconstruction. This is obviously more applicable to paved roads than unpaved roads, although deterioration of the latter and the need for re-gravelling does increase significantly (Paige-Green, 2015; 2016). The deterioration of unpaved roads is not only attributable to increased traffic, as climatic effects such as flash flooding can also play an enormous part in their deterioration. In the case of the less developed rural areas of the Sultanate of Oman (Paige-Green, 2016) where the inspections were carried out, unpaved roads make up a considerable proportion of the network. This necessitated an increase in the structural capacity of certain access roads in Oman, and significant resource-implications associated with the upgrading/improvement and maintenance of such roads. In the case of the unconventional gas exploration in the US (i.e. Pennsylvania), improving structural capacity for example required applying expensive asphalt overlays and new crushed stone bases on existing paved roads, with mitigation measures associated with the sustainability of the road infrastructure resulting in substantial resource implications related to construction, and the resultant introduction of concepts such as "bonded roads requiring exploration and extraction companies to maintain the road in at least as good a condition as they were at the start of gas extraction operations" (Paige-Green, 2015).

International experiences related to unconventional gas exploration seem to not only place significant focus on the benefits of unconventional gas as an energy resource, but also on implications for such large-scale regional investment to address unemployment and developmental challenges within regions and local towns, as in the case of Washington County Pennsylvania (Paige-Green, 2015; Williamson and Kolb, 2011), where unemployment in the region was said to have dropped to zero during the shale production phase. Settlement development in the case of Pennsylvania (as also projected in Burns et al. (2016) for the Karoo), was associated firstly, with the on-site provision of housing for security guards and engineers, and to support staff rotating for shifts (which are dependent on the range of activities within active periods of development); and, secondly, with temporary accommodation (i.e. construction camps) aimed at accommodation for construction workers and road labourers. In addition to providing housing on-site and in construction camps, more permanent/formal settlement provision is also required for the local or in-migrating set of largely high skilled staff supporting the activities related to the respective phases and scenarios of exploration and production.

While the experiences related to unconventional gas exploration and production internationally do not seem to highlight large scale in-migration of unsuccessful jobseekers into "host" regions and nearby towns, South African experiences of resource-related development and large scale infrastructure investment clearly highlight the implications and unintended consequences associated with the in-migration of unsuccessful jobseekers (Oranje, 2013a; 2013b; 2013c). Given the context of South Africa's large scale unemployment and highly mobile and dynamic population (Van Huyssteen, 2013; 2015), many examples exist of the implication of in-migration, i.e. "the Platinum Belt" (see Van Huyssteen et al., 2014) and of towns that have actually doubled in size in resource rich regions associated with new mining or extraction activities, i.e. Lephalale in Limpopo and Postmasburg in the Northern Cape (see Van Huyssteen et al, 2013b). Realities and implications of such in-migration and resultant boom and bust towns internationally (Argent, 2013; Jacquet, 2009; Jacquet et al. 2014) and locally (van der Berg et al., 2010) on already struggling local authorities (Oranje, 2013a; 2013b; 2013c), as well as on mining companies in terms of social responsibility and local investment (Oranje, 2013a; 2013b; 2013c) cannot be ignored in the case of considering the possible implications of unconventional gas exploration and production on settlement development and the pressures it could place on municipal service delivery. In the study area, possible developments (and even discussions about possible developments) related to shale gas, renewable energy and uranium mining will most likely have a cumulative impact on settlement development and associated pressures on governance capacity and service delivery.

18.1.3 The backbone of settlement and road infrastructure in the Karoo region

Given the above context, it is useful to note that the study area is largely characterised by the arid and sparsely populated Karoo landscape. For example, the area around Beaufort West that is likely to be the central logistical hub or production centre if full scale production is realised is a sparsely populated area. The Central Karoo District Municipality of which Beaufort West is the administrative centre had an estimated total population of just more than 70 000 people in 2011, of whom almost half (46%) lived in the town of Beaufort West (stepSA Regional Profiler, 2016). A more detailed description of urban development and spatial dynamics in the area, including a spatial representation of population distribution and concentration in the various towns in the study area is set out in Burns et al. (2016). Beaufort West is also the biggest and most accessible town in the region, providing a range of government and private sector services to the broader region. Unemployment in the region is exacerbated by the unavailability of jobs for school leavers and matriculants, and the fact that many of the jobs that are available, are actually of a temporary and seasonal nature (Western Cape Government, 2012).

With regards to existing settlement development, the area is characterised by an average population density (outside of towns) of less than 0.5 persons per km² (stepSA Regional Profiler, 2016). Settlement outside towns is limited (and 'discouraged') owing to a range of factors including 1) the Karoo's arid landscape and temperature extremes, 2) restrictions on the subdivision of farm land, 3) cost implications, and 4) the sustainability of service delivery. Within the wider study area, 475 319 people or 32% of the population, are concentrated in the towns of Queenstown, Graaff-Reinet, Cradock, Beaufort West, Fort Beaufort, Middelburg and Somerset East (stepSA Regional Profiler, 2016; stepSA Town Growth Profiler, 2015; Burns et al., 2016). The town of Murraysburg, at the centre of the possible 'sweet spot' for exploration, is a minor settlement of about 5 000 people (stepSA Town Growth Profiler, 2015).

In terms of regional connectivity and access to the area (see Figure 18.3), the N1 national road that bisects the Central Karoo is a key national transport corridor for road-based freight transport, passenger services and private vehicles. Running parallel to the N1 is the long-distance main railway line connecting Cape Town to Johannesburg and other main urban centres (see Figure 18.3) highlighting main regional routes to Port Elizabeth/Nelson Mandela Bay Metropolitan Municipality, Mossel Bay and George as well as the key internal routes N12, R61, R63, R75, R338 and R407 to Prince Albert, Murraysburg and Aberdeen. The routes to and from the coast traverse several scenic passes, some of which will need to have restrictions on use placed on them for heavy vehicle traffic, i.e. Swartberg, Montague (no-go gravel passes) and Robinson Pass (steep dangerous and misty), Meirings Poort and Outiniqua Pass (scenic, dangerous, but essential freight routes).

Road corridors, such as the N1 and N12, and important rail links which pass through the region are of critical importance to the country and must be maintained for the good of the economy of the country as a whole. However, the resultant heavy road traffic generated by SGD will significantly impact on local towns and regional roads. Minor roads currently provide access for individual farms, but are unlikely to be sufficient to support the establishment of the numerous wellpads required and more roads will need to be constructed for this purpose, mainly on private land.

The current coverage of the road network is considerable, given the sheer size of the Karoo. For example in the Central Karoo District there is 1 km of road per 5 km^2. Taking account of the low population total, the road network length per person is high and the maintenance of these roads presents an on-going problem; this is exacerbated by flash floods and dwindling local levels of the right quality of gravel to suitably maintain the unpaved roads and the import of construction material is already required. Capacity to maintain roads in the area is constrained (Theron, 2016).

18.1.4 Integrated spatial and development planning

Largely in response to Apartheid planning practices and outcomes, but also fuelled by similar sentiments in international planning circles, a primary objective of the post-1994 South African planning system has been the coordinated pursuit of shared development objectives in 1) the plans, 2) the budgets, and 3) the implementation of the plans of the three spheres of government and the sectors in each of these spheres (Pieterse, 2016; Oranje and Van Huyssteen, 2007; Oranje, 2013). Within the South African context, the importance of considering the spatial impact of development and spatial planning is not only strongly linked to current needs and priorities, but also to past legacies and challenges in creating a future for South Africans to thrive. Over the course of the last two decades, a range of plans and investment instruments have been put in place to guide development and bring about more effective intergovernmental and spatial alignment within the planning system, spearheaded initially by the Development Facilitation Act (1996) and embodied by the Intergovernmental Relations Framework Act, 2005 (IGRFA), and the SPLUMA.

Despite the necessity and desire for such an integrated and well-coordinated system of planning, budgeting and implementation in South Africa, its establishment has been a slow, uneven and arduous process (Pieterse et al., 2016; Oranje and Van Huyssteen, 2011; Western Cape Intra-Governmental Shale Gas Task Team, 2012). Within this context, the need for a new integrated approach to planning aimed at overcoming the challenges associated with distance, inaccessibility and lack of choice is perhaps greatest for 1) historically disadvantaged members of society who had lived in settlements marred by Apartheid planning in pre-1994 South Africa, 2) the more rural, less capacitated and lesser resourced municipalities where state expenditure in most cases is the key driver of the local economy, and 3) ecologically sensitive areas.

The region in which SGD may most likely take place, is exactly such a region - not only ecologically sensitive (Hobbs et al., 2016; Holness et al., 2016), but also a largely rural area characterised by high levels of socio-economic inequality and vulnerabilities (Van Zyl et al., 2016) and a diverse but significant number of under-capacitated and under-resourced municipalities (Department of Cooperative Governance and Traditional Affairs, 2009a; 2009 b; The Presidency, 2014; Van Wyk and Oranje, 2014). It is thus imperative that, irrespective of whether SGD is to take place in the area or not, careful, coordinated and integrated planning must take place.

The opportunities and challenges for coordinated inter-governmental planning becomes even more evident when considering the wide range of spatial and integrated development planning and governance instruments (see Figure 18.1), all requiring annual review, adaptation and alignment, relevant to the study area, i.e.:

- Spatial outcomes and principles as set out by SPLUMA and the National Development Plan (NDP) 2011, merely broadly defined and regional interpretation still to be defined;
- Integrated and strategic national, local and regional plans i.e. the NDP, the IDPs developed for every local and district municipality in the study area, and the Provincial Growth and Development Strategies (PGDSs) and equivalent plans within the Western Cape, Eastern Cape and Northern Cape Provinces;

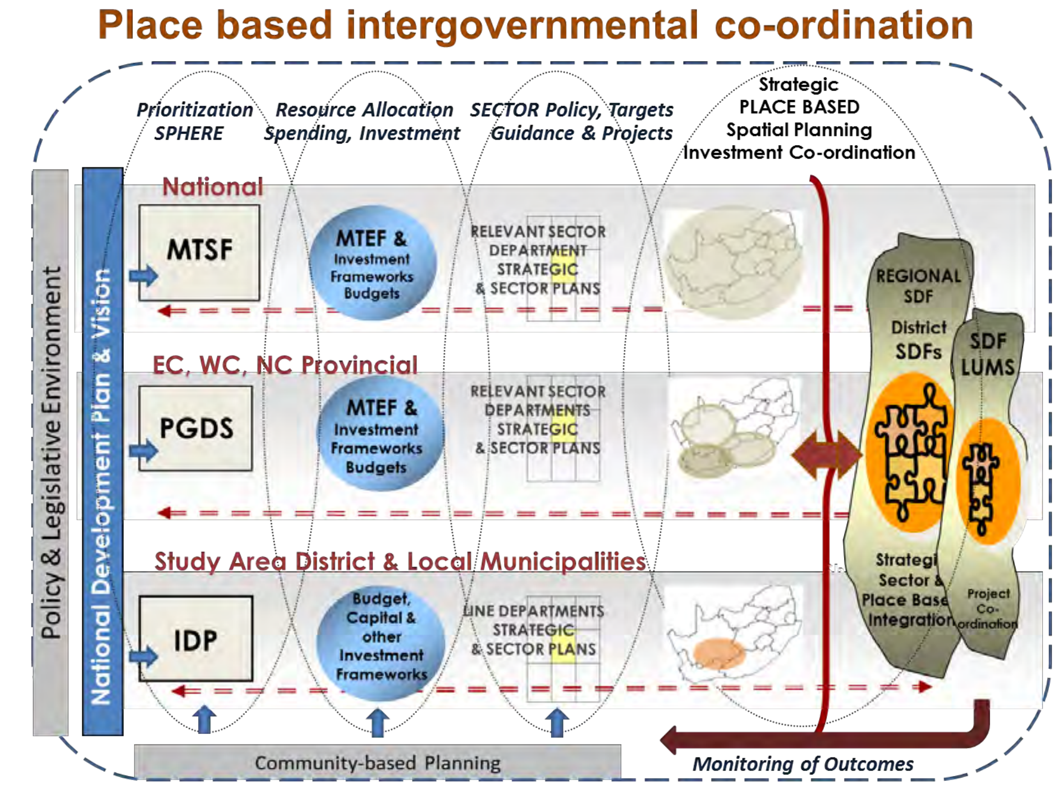

Figure 18.1: Overview of relevant integrated spatial and development planning instruments.

- Integrated Spatial Development Frameworks (SDFs) to guide spatial development within national, provincial, regional, local and precinct scales (see SPLUMA and the Department of Rural Development and Land Reform's (DRDLR) SDF Guidelines (2014), as well as the Western Cape LUPA). While plans are in place for all three provinces as well as relevant district and local municipalities (given that transitional requirements deem SDFs drafted in terms of the old legislation as SDFs in terms of new legislation), most of the local and district plans require an update to ensure that they can fulfil the functions and purposes as set out by recent legal developments and regulations;
- Integrated provincial and municipal sector plans i.e. integrated housing plans, integrated transportation plans and integrated disaster management plans;
- Integrated investment frameworks i.e. Integrated Infrastructure Investment Framework (provincial and municipal), Capital Investment Framework (municipal) and spatially targeted budgeting instruments introduced by National Treasury; and
- Land use management schemes which are largely in place for towns, and in most cases require support to develop for the full extent of the municipal area, need support to ensure alignment with SDFs and support with the preparation of relevant by-laws to guide

development. In the Western Cape, the Laingsburg, Prince Albert and Beaufort West Local Municipalities (amongst others) have all adopted municipal by-laws enabling LUPA.

Governance capacity of local and district municipalities in the Karoo region for coordinated and aligned spatial and infrastructure investment planning and management, including mitigation of any new activity in their areas of jurisdiction, is already limited, with high levels of differentiation between provinces in terms of legislative requirements and institutional readiness. This is worsened by the incremental approach often taken by mining companies in mining areas and towns which stands in stark contrast to the need for well-considered, multi-stakeholder planning (Oranje, 2013a; 2013b; 2013c). The complex institutional context for service delivery, and the associated roles and responsibilities, often negotiated at local and district municipal areas, adds a further challenge (Oranje & Berrisford, 2012) and requires dedicated capacity and support for relevant municipalities. With regards to the Western Cape Province, the Province for example plays an active role in the monitoring, support and regulating function within the Central Karoo District Municipality, as it is one of the least capacitated compared to the other district municipalities in the Province.

While it is both 1) legally mandated and 2) evident from the situation on the ground that government needs to create an enabling and guiding context for development and investment in the region through ensuring effective pro-active and coordinated planning, budgeting and targeted investment and governance, the risks and mitigations associated with the possible impact of SGD on land, infrastructure and settlements could in many respects also be addressed through such pro-active planning.

18.1.5 Regulatory and practice context for land development and land use management

The realisation, timelines, scale, location, cost and possible impacts of SGD (as outlined in Burns et al., 2016) are highly dependent on a complex regulatory framework and associated processes of obtainment of rights, the latter are addressed in this Chapter.

There are a wide range of development activities directly and indirectly related to SGD throughout the foreseen phases and possible scenarios that would potentially impact on existing land uses and future development of the area. A number of the proposed activities and developments directly related to SGD (Burns et al., 2016) will most likely require land use change and land development applications (See Figure 18.2) in terms of the relevant regulatory frameworks. While the focus of this Chapter is specifically in highlighting implications related to urban development, road infrastructure and spatial planning, the compatibility of SGD with respect to existing agriculture, mining, game farming, tourism and conservation remains a major consideration. The implications of SGD on these respective land uses are addressed in detail within the relevant Chapters of the study, including i.e. biodiversity and ecology (Holness et al., 2016); agriculture (Oettle et al., 2016); tourism (Toerien et al., 2016); economics (Van Zyl et al., 2016); human health (Genthe et al., 2016) and water resources, both on the surface and underground (Hobbs et al., 2016).

While the Environmental Authorisation (EA) issued by the provincial or national government in terms of the National Environmental Management Act (NEMA),, Act 107 of 1998 and prospecting or mining rights issued in terms of the Mineral and Petroleum Resources Development Act (MPRDA), Act 28 of 2002, are both legal determinants, they are issued in parallel to the relevant municipal applications for 1) changes in the applicable land use rights, and 2) land development required for both the exploration and production phases of SGD.

Since the advent of the SPLUMA in 2013, and in line with a series of pronouncements by the Constitutional Court since 2010, the locus of land use change approvals is the municipality. The decisions of other national or provincial departments may not overturn that of the municipality. Based on the above, it is emphasised that an applicant can only successfully commence with a development when all the required regulatory approvals has been granted.

Zoning for Agricultural Purposes

Historically, land use management in the study area was regulated through the provisions of the former Cape Province's Land Use Planning Ordinance, 15 of 1985 (commonly known as "LUPO"). With the division of the old Cape Province into the Eastern Cape, Northern Cape and Western Cape provinces in 1994, LUPO remained in place. Municipalities in these provinces all have zoning schemes approved in terms of LUPO, and these zoning schemes prescribe the extent of permissible land uses, particularly in the town/urban/built-up areas. Outside the built-up areas, and thus outside of the application of the zoning schemes, LUPO prescribed that the applicable land use would be deemed to be the most restrictive zoning that matched the current lawful land use. Thus, for most of the rural areas the land was deemed to be zoned for "agricultural purposes".

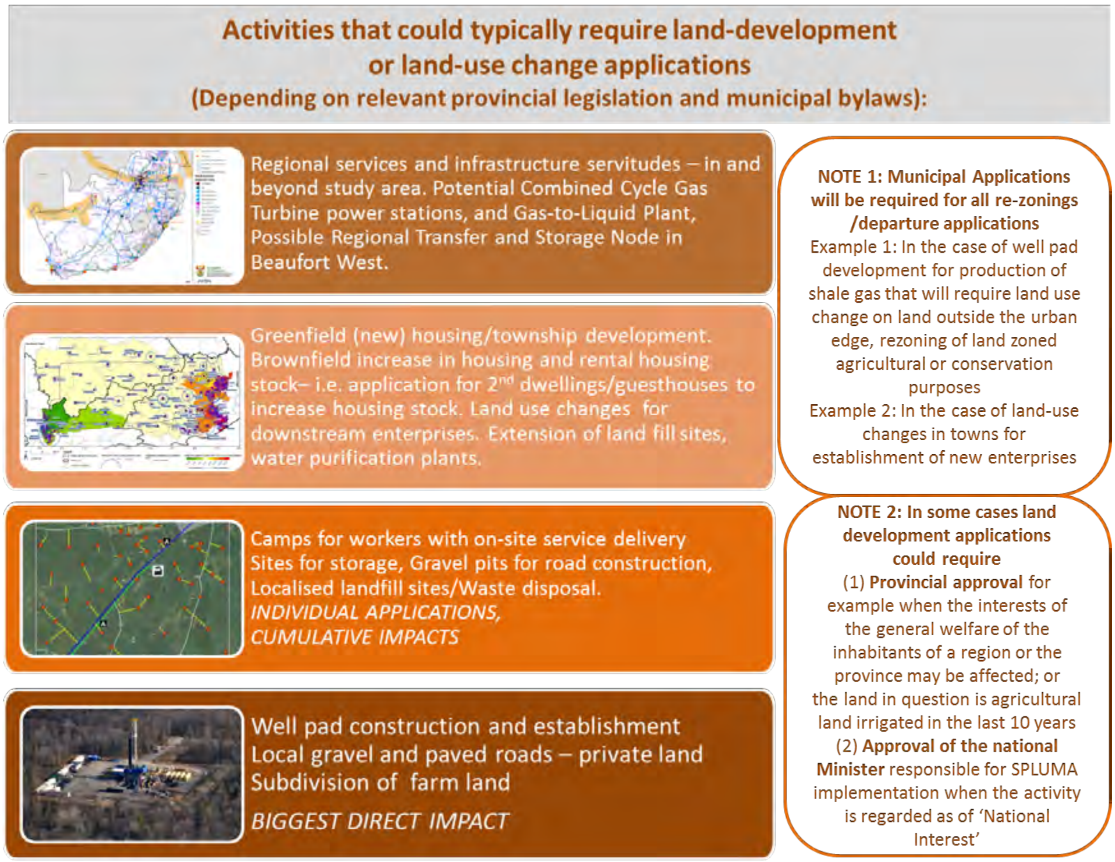

Figure 18.2: Activities that could typically require land development and land use change applications in the study area.

Prior to SPLUMA, the land use planning dispensation for the former Cape Province (now forming part of the Western, Northern and Eastern Cape) was governed by the Land Use Planning Ordinance, 15 of 1985 ('LUPO'). In the Northern Cape, the Northern Cape Planning and Development Act (NCPDA), Act 7 of 1998 was promulgated. The three affected provinces are, however, each at different stages in evolving from a legal position based on LUPO to one that is in line with SPLUMA. The Western Cape already has new legislation in place (LUPA and an accompanying set of Land Use Planning Regulations (2015)), while the Northern and Eastern Cape provinces have draft legislation that is being considered in each of the respective provinces. In the absence of new provincial legislation and until such time as the municipalities have municipal planning bylaws in place, the former LUPO-based (or NCPDA-based in the case of the Northern Cape) system stays in effect until repealed by provincial governments as set out in the Guideline on Transitional Measures (DRDLR, 2015). This results in significant challenges:

- Firstly, SPLUMA is a new act, which together with its set of regulations and guidelines, is still being rolled out, however effectuated differently between the provinces in the study area.

- Secondly, in order to extend Land Use Management Schemes (LUMS) required in terms of SPLUMA and LUPA beyond 'town/urban areas' (for which areas town planning schemes were originally developed for) large portions of 'rural land' in municipalities in the study area have 'inherited' a zoning for agricultural purposes. This implies that land use change applications will be required for any use outside agriculture zoning and existing provisions on such land portions, typically the portions on which SGD is envisaged.
- Thirdly, considerable support to municipalities with regards to capacity and resources are required to effectuate the institutional arrangements and processes to support municipal orientated land use decision-making required within SPLUMA, for example the appointment of Municipal Planning Tribunals in each municipality which are not yet in place.
- Fourthly, approval processes could be negatively impacted upon by the fact that SPLUMA is a new piece of legislation not yet tested and tried by courts. Legally, decisions taken in terms of this system, where SPLUMA and former Ordinances may in all likelihood have to be considered, are of dubious validity. A range of aspects, especially related to the lack of clarity regarding definitions and procedures related to a "land development application"; "land use application" and "land use of national interest" are also not clarified in SPLUMA, which

Interrelated Regulatory Context

It terms of NEMA, petroleum exploration and production activities trigger the need for an EA prior to the commencement of such activities. In terms of NEMA and the Environmental Impact Assessment (EIA) Regulations, 2014, the Minister of Mineral Resources is the competent authority for deciding on applications for EA, with the Minister of Environmental Affairs being the relevant authority to consider appeals against any EA granted/refused.

The statutes to be considered in this regard are: 1) the EIA Regulations 2014; 2) NEMA; 3) the Regulations for Petroleum Exploration and Production, 2015; 4) the Regulations pertaining to the financial provision for prospecting, exploration, mining or production operations, 2015, issued under NEMA; 6) the Regulations regarding the planning and management of residue stockpiles and residue deposits from a prospecting, mining, exploration or production operation, 2015, issued under the NEM: Waste Act; 7) the Disaster Management Act, 2002; 8) the National Heritage Act; and 9) the Hazardous Waste Act, 2008.

The Minister of Water and Sanitation also declared "The exploration and or production of onshore naturally occurring hydrocarbons that requires stimulation, including but not limited to hydraulic fracturing and or underground gasification, to extract, and any activity incidental thereto that may impact detrimentally on the water resource", to be a controlled activity (Government Gazette 39299, Notice 999, dated 16 Oct 2015). Following the declaration of the above-mentioned controlled activity, a water use licence for this particular category of activity is required under the National Water Act (NWA), 1998 (Act No. 36 of 1998. The Department of Water and Sanitation (DWS) is in the process of drafting water use licence application regulations, which will seek to align such applications in accordance with the so-called "One Environmental System".

could be problematic for application processes, as well as valid decision-making. These aspects are highlighted for timeous clarification as part of mitigation proposals in Section 18.4.

- Fifthly, a challenge to both SPLUMA and LUPA is that there are no precedents for land use approvals related to SGD in South Africa. The clarity provided in LUPA (thus Western Cape Province only at this stage) for land developments and uses related to unconventional SGD (Figure 18.2) might result in unintended consequences of potential exploration and production being initially focussed within the Western Cape Province's area of jurisdiction.
- Lastly, the challenges related to possible procedural uncertainties and capacity within the complex regulatory system is well recognised. While the relevant sector regulatory requirements are discussed in detail in the respective chapters of this scientific assessment, the cumulative need that these generate for integrated and coordinated planning and governance between different authorities, streamlined and aligned processes and the potential burden this places on human capacity and specific high-level expertise in already stretched municipalities is the focus of this discussion.

Most of the district and local municipalities in the Karoo Region have restricted financial, planning, technical (road construction/ maintenance) and administrative capacity (see study conducted by the Western Cape Intra-Governmental Shale Gas Task Team, 2012). Experience in the roll-out of renewable energy projects in this region has shown that municipal capacity is not up to the task of processing land use applications of this scale and impact, and thus it may even be necessary to create a 'shared capacity', which might include appointing the necessary experts and consultants to train officials and/or provide professional support to municipalities (Berrisford, 2015). The challenge implicit in gearing up these municipalities to be in a position to process the land use applications for SGD to fulfil their regulatory functions associated with these applications needs urgent attention. The need for municipalities to acquire additional capacity has been foreseen and can be facilitated through legislation, namely SPLUMA (Section 39(1)), or at a regional level through SPLUMA (Sections 18 and 19). The Infrastructure Development Act, Act 23 of 2014, could possibly strengthen integrated infrastructure development.

SPLUMA prescribes a system for municipal decision-making that is premised on the appointment of Municipal Planning Tribunals. Municipalities have relatively wide powers to elaborate on the provisions of SPLUMA (and LUPA in the case of the Western Cape), by adopting municipal planning by-laws. The authority for municipalities to adopt municipal planning bylaws lies in the provisions of the Constitution (see Section 156 (2)), which authority is reflected in the provisions of Section 2 of LUPA.

In addition to the need to enhance and strengthen the capacity to manage a system of land use approvals, municipalities will also have to gear up their development planning, financial management and infrastructure delivery capacities. This has to be done to provide the overall organisational capacity to anticipate and manage the increase in economic activity, infrastructure provision, population growth and related demographic shifts that will inevitably follow the scaling up of SGD.

18.2 Key potential impacts and their mitigation

The various exploration and production scenarios will have wide-ranging impacts on regional and local infrastructure (especially road infrastructure), land development, town growth and sustainable regional and settlement development in the area. In the next Section, 1) the key potential impact areas under the different scenarios are highlighted, 2) measures and limits of change are identified, and 3) high-level risks assessed (without and with mitigation). The Section is concluded with proposals around the most critical mitigation measures.

18.2.1 Local road construction and resource requirements

SGD will require significant road access. During exploration, seismic surveys are usually carried out by vehicles that travel off-road across local farmlands and do not impact significantly on the road infrastructure, other than to get to their points of departure for testing. The establishment of exploration wells (including those that involve the use of hydraulic fracturing (“fracking”)), however, require proper access, usually along unpaved access roads. During exploration movement (Paige-Green, 2015; 2016) activities include regular movement of staff, equipment, fuel and provisions and maintenance vehicles, generally requiring all-weather access for the most part (also see Burns et al. (2016) outlining the activities for the respective Scenarios). This is probably the busiest period in terms of road construction and utilisation. Once the wells are established, the intensity of vehicular movement will be linked to the respective campaigns. Access roads to wells that have been approved for production will require necessary upgrade and maintenance. It should be noted however, that while exploration and well development (for both exploration and production purposes) in a local area may be incremental it may also take place with increased intensity during the various phases and possible scenarios of SGD (see Burns et al. (2016) for estimated numbers of vehicles and time frames).

Exactly what percentage of the local access roads will need to be paved will be dependent on how the vehicle loading is distributed, and is highly dependent on how the drilling campaigns are distributed/ clustered. If the vehicle loading is distributed among a number of different roads, and if the total volume of vehicles on any single stretch of road does not exceed 60 heavy vehicles per day (acceptable industry standard), it may be possible to continue to use unpaved roads but these then have to be of a high standard. While the paving of roads may have some benefit for improved ride quality for the local community during and after production (decommissioning), and hold benefit for other industries in the area, i.e. agriculture and possibly tourism, the risk of having to maintain a greater length of paved roads into the future without the economic income stream, means that the paving of public roads should be limited as far as possible as it also holds additional costs implications for municipalities and a financial burden on government as a whole (Technical Recommendations for Highways (TRH) 20, 1999). Any paving of private access roads on farms will have resource implications. Their impact on the land owners will vary dependent on the length, nature of paving and the use the farmers can derive after decommissioning should they wish to maintain the road.

Although current local access roads provide a relatively good level of connectivity for current use when maintained, the current financial burden of road maintenance per capita is high (Central Karoo District Municipality, 2013) and can potentially increase with the advent of exploration. The development, maintenance and upgrading of roads requires significant resources in terms of materials and cost. The typical material usage on roads, based on a standard 8 m wide road is as follows:

- **Unpaved road:** Wearing course layer of about 1 200 m^3/km that needs to be replaced every seven to ten years; and
- **Paved roads:** At least two, sometimes three, layers of material each of about 1 200 m^3/km that should last 15 to 20 years. These also require routine (patching, crack-sealing, edge-break repair, etc.) and periodic maintenance (resealing).

The implications of increased traffic are difficult to estimate, and depend on existing traffic volumes. In the main, the heavy vehicle traffic volume is currently estimated to be below 25 heavy vehicles per day on the unpaved roads with an additional 25 vehicles per day for Scenarios 1: Exploration Only and 2: Small Gas over the whole network of roads and 160 heavy vehicles per day for Scenario 3: Big Gas, although this will be distributed among four separate campaigns and thus not on the same stretch of road (see Burns et al., 2016). Given that the vehicles are likely to be distributed over several different stretches of road it is thus estimated that not more than 40 additional vehicles a day will travel on any stretch of unpaved road. This is, however, highly dependent on the distribution of the campaigns and wellpads. The increase in traffic volume of heavy vehicles will not be assessed in terms of a percentage increase over existing traffic, but a fixed traffic volume. In other words, a local gravel road currently carrying 30 vehicles per day may experience an increase of 25 to 50 vehicles depending on 1) the scenario and 2) the distribution of traffic, which is difficult to predict. This will probably reduce the interval between re-gravelling from ten years to six years or less, the latter interval being relevant to the Big Gas scenario with less impact for the Exploration Only and Small Gas scenarios. The impact of the same increase of 30 to 50 vehicles on a road already carrying 200 vehicles per day may decrease the re-gravelling interval from six to perhaps four or five years. The 2012 traffic volume map (Central Karoo District Municipality, 2013) indicates that the majority of unpaved roads at that time carried less than 100 vehicles per day, but there is no information on the lower class roads, which probably carry less than 50 vehicles per day with the total usage unlikely to exceed 100 heavy vehicles per day even for the Big Gas scenario. An estimate of the increased traffic in each scenario and the impact on the maintenance costs are given in Table 18.1 and Table 18.2 below, based on the information as set out in Burns et al. (2016).

Not all of the unpaved roads will carry extra traffic, with the assumptions in the case of each scenario being as follows:

1. **Scenario 0** (**Reference Case):** No roads impacted. Routine and periodic maintenance with resealing every ten years and regravelling every seven to ten years continues at normal frequency - excludes any portion resealed as mitigation.
2. **Exploration Only:** All paved roads impacted (excluding the Fraserberg and Hofmeyer links) and 25% of all gravel roads in the 'sweet spot'. Routine and periodic maintenance of paved roads with resealing continues with increase in frequency to nine years – pro-rated for portion rehabilitated.
3. **Small Gas:** All paved roads impacted plus 50% of gravel roads in the 'sweet spot' and 12.5% of other gravel roads in immediate vicinity of the Fraserberg and Hofmeyer routes for campaigns identified in areas. Routine and periodic maintenance with resealing continues with increase in frequency to nine years – pro-rated for portion rehabilitated.
4. **Big Gas:** All paved roads impacted plus 100% of gravel roads in the 'sweet spot; and 25% of other gravel roads in the immediate vicinity of the Fraserberg and Hofmeyer routes. Routine and periodic maintenance with resealing continues with increase in frequency to seven years – pro-rated for portion rehabilitated

Extra traffic on unpaved roads will lead to more frequent grader blading and re-gravelling; depending on the increase in traffic (see Table 18.2 for changing frequency of re-gravelling). Extra traffic on paved roads will lead to additional routine maintenance (potholes, cracking and edge-break) and a small increase in resealing frequency.

Costs for maintenance are based on current costs (not adjusted for inflation as this is common to all of the roads), using the 2012 Central Karoo Integrated Transport Plan (Central Karoo District Municipality, 2013) as a bench mark.

Table 18.1: Traffic and network requirements for the four scenarios.

Road type	**Road length (km)**	**Percentage Roads Impacted**			
Paved roads		**Reference Case**	**Exploration Only**	**Small Gas**	**Big Gas**
Port Elizabeth - Victoria West	442	0	100	100	100
Victoria West - Three Sisters	61	0	100	100	100
Beaufort West (R61 via Aberdeen)- to Junction of R75 near Kleinpoort	288	0	100	100	100
Fraserburg - Beaufort West	30	0	0	100	100
Graaff-Reinet - Hofmeyer via R421	169	0	0	100	100
Unpaved roads					
Fraserburg - Beaufort West	120	0	0	100	100
Unpaved 'sweet spot" roads	1273.61	0	25	50	100
All roads in 30 km buffer of Beaufort West-Fraserburg (excluding main route above)	1624	0	0	12.5	25
All roads in 30 km buffer Graaff-Reinet -Hofmeyer (R421)	2512	0	0	12.5	25
Private access roads					
Exploration Only: 1 km road per wellpad for 30 wellpads	30	0	100	100	100
Small Gas: 0.5 km per wellpad for 55 wellpads	27.5			100	100
Big Gas: 0.5 km per wellpad for 410 wellpads	205				100

Indicative costs will depend on the exact extent of the network affected (see Table 18.2 for summary of likely increase in costs and gravel required and Digital Addendum 18A for guideline cost details per road segment).

Table 18.2: Summary of costs and additional gravel required for roads impacted.

Paved roads								
	Reference Case		**Exploration Only**		**Small Gas**		**Big Gas**	
Routine maintenance cost per km (Rand)	**R100 000.00**		**R 110 000.00**		**R 110 000.00**		**R 125 000.00**	
Reseal frequency in years	**10 years**		**9 years**		**9 years**		**7 years**	
Cost to rehabilitate to required base	**R 1.82 bn**							
Total annual maintenance cost	**R 150.1 mil**							
Additional annual cost: Paved roads			**R 12.2 mil**		**R 15.7 mil**		**R 49.8 mil**	
Unpaved roads								
	Routine	**Gravel/ m^3/year)**	**Routine**	**Gravel/ m^3/year)**	**Routine**	**Gravel/ m^3/year)**	**Routine**	**Gravel/ m^3/year)**
Periodic maintenance cost per km (Rand)	**R 300 000.00**		**R 300 000.00**		**R 300 000.00**		**R 300 000.00**	
Routine maintenance cost per km (Rand)	**R 750.00**		**R 825.00**		**R 825.00**		**R 1000.00**	
Regravel frequency	**7 years**		**6 years**		**6 years**		**4 years**	
Total annual maintenance cost	**R 241.1 mil**							
Additional annual cost: Unpaved roads			**R 3 mil**		**R 59.4 mil**		**R 177.6 mil**	
Total gravel lost per year (m^3)		**947 933**		**955 730**		**976 556**		**1 119 676**
Change in gravel lost (m^3/year)		**0**		**7 797**		**28 623**		**171 743**
Note: All costs exclude inflation and are based on current cost.								

Paved roads will typically require about 1200 m^3 of construction material per layer per kilometre of road. Depending on the existing site conditions, anything from one to three layers of material could be required for different areas of road. This would normally be expected to last 20 years before rehabilitation. Unpaved roads typically require re-gravelling with one wearing course layer on the existing pavement structure. Under normal operating conditions, this upper 150 mm of material would be lost as dust, eroded and whipped-off material, requiring a replacement every six to ten years.

The acquisition of this construction material is usually from borrow pits which 1) needs to provide access to appropriate quality material in close proximity to the road construction site, 2) has to go through the necessary regulatory approval processes, 3) has to be expropriated (if required), 4) have to be managed (including continuous rehabilitation), and 5) finally, be commissioned. It is already increasingly difficult to source the appropriate quality and quantity of construction materials within the region. The regulatory processes for commissioning new gravel pits requires effective project planning to avoid delays in the implementation of construction and maintenance programmes. In order to ensure longer lasting roads, better quality material increasingly needs to be sourced from further afield, resulting in significant project cost implications. For more than ten years, the access to gravel in the region has hampered maintenance on the gravel road network, due to the limited availability of (legally) approved gravel pits. For example, after several years, upgrading of the Swartberg Pass has recently commenced with material brought in at great expense from outside the district from commercial sources (Theron, 2016). The same challenges apply to paved roads, although the increased road width and the material quality requirements for the upper layers and bituminous surfacing is significantly higher (usually crushed stone), making the location of the materials more difficult, processing more expensive, the haulage somewhat longer and the actual cost of the materials significantly higher. One issue that is normally not considered adequately, especially in arid areas, is the availability of water for construction. Large quantities of water (especially during construction in dry and hot seasons) are required. These typically would be about 84 m^3 (i.e. 84 000ℓ) per layer per km. This water needs to be sourced and hauled to the construction site. The strength of local boreholes is likely to support construction of at least 1 km of road per well per week for the duration of construction (Hobs, 2016). Currently no additional import of water for this purpose is envisaged. In the following Sections, the demand for road maintenance is discussed in relation to each of the four scenarios:

Reference Case: Even if no SGD takes place, the demand for local access road maintenance is already high in the region (Central Karoo District Municipality, 2012) and thus, either with or without mitigation (using a better grade of gravel and/or water wise construction and a possible longer term switch to new/ alternative materials), there already is a relatively high demand on raw materials for road maintenance in the area. Given the lead time for such activities including licencing/approval of gravel pits, this needs to be planned and budgeted for, well in advance of the planned date for commencement of maintenance activities.

Exploration Only: Exploration-related activities will require expansion of the existing road network to enable drilling of wells and the establishment of wellpads and associated infrastructure in and around the SGD areas. The seismic surveys are usually carried out by vehicles that travel off-road across local farmlands and do not impact significantly on the road infrastructure, other than to get to their points of departure for testing. Exploration wells, on the other hand will require proper access, usually along unpaved access roads. During exploration activities, the regular movement of staff, equipment, fuel and provisions and maintenance vehicles occur, generally require road access of a quality to handle all weather conditions. This is probably the busiest period as once the wells have been established and ready (and approved) for production, access roads only require limited maintenance. While a concerted effort should be made to optimise the use of the existing road network, it is inevitable that new access roads will be required. Based on the assumption that new access roads will on average not exceed 0.5 km per well (see Burns et al., 2016) an additional 30 km, 27,5 km and 205 km of access roads will be required for the Exploration Only, Small- and Big Gas scenarios, respectively. The construction of these access roads is expected to be financed by the mining companies and to be constructed on private land. The main limitation will be the acquisition of gravel and other raw materials (Theron, 2016). There is a risk that severe pressure will be placed on local materials such as gravel and that steep price rises may price out the government-funded road sector. A strategy may be required to protect local gravel pits for the maintenance use of district and provincial managed and maintained roads. Although these new access roads will initially be used only for access to exploration areas and possibly later to production areas, their presence will invariably attract local traffic and most probably generate new traffic. For roads carrying less than about 150 to 200 vehicles per day, unpaved riding surfaces will usually be adequate, provided that the local materials are suitable, given current industry standards For roads carrying more traffic than this or more than about 60 heavy vehicles per day, paved roads are generally more appropriate and cost-effective and sustainable over the long term. These have much greater material requirements and higher environmental impact (TRH 20, 1990). Private roads are unlikely to ever be decommissioned; however, should the roads not be required for local use, such roads must at least be scarified to allow for recolonisation of the natural flora (See Holness et al., 2016).

Public access roads should however be restored to at least the same level as when exploration commenced. In order to ensure that this is achieved, the baseline monitoring must clearly define the condition of the various segments of road prior to any exploration-associated traffic using the road.

This must include photographic/video evidence of defects and poor quality sections as well as a full condition survey over the entire road, agreed on by the relevant road authority.

Small Gas: Given the approach of expanding exploration while production is under way, the biggest impact under the Big Gas scenario for local roads would be the establishment of additional exploration and extraction wells, with a resultant increase in the construction of local access roads (27.5 km additional road) and road use (i.e. traffic volumes). In this scenario, due to increased use of roads the demand for upgrading continues but as new access roads to the wells are built the demand for raw material for road making will increase significantly even with the use of better construction techniques and innovative materials. This will also result in an increase in regulatory applications associated with sourcing material from new gravel pits or the expansion of existing pits (NEMA, Regulations 765, Schedule 3). To improve the durability of roads, the use of better quality gravel and stone sourced from more distant pits may be required. An increase in construction will also result in an increase in the amount of water required to support construction (water could be just below potable level in terms of quality but cannot be too salty, with the salinity of the water wells in the area often being too high). Under this scenario the increased intensity of shale gas activities (related to both exploration and production) will increase the heavy vehicle load to approximately 25 heavy vehicles per day (see Burns et al. (2016) for total trips generated; where calculations are based on estimated total vehicle trip per scenario and estimated duration of scenario), placing greater strain on the roads and the maintenance thereof. This will in turn place limited resources (i.e. water, crushed stone, bitumen and the right quality of gravel), as well as existing strained institutional, financial and technical capabilities (e.g. the construction of new roads, expansion of existing roads, establishment of borrow pits, or expansion of existing pits will require increased project planning and management, as well as regulatory approval processes).

There are no specific actions required for decommissioning. Any new roads on private farms can either be left untended or continue to be used at the land owners discretion. Public access roads should be restored to at least the same level as when exploration commenced. This supports the importance of baseline monitoring from the outset.

Big Gas: With increased and full scale production, as well as the possible extension of wells, the impact of new ‘private’ road construction and heavy vehicle impact (increasing to 166 additional heavy vehicles per day – see Burns et al., 2016) on existing local access roads will become much more extensive with, firstly, paving of some local access roads to support increased activities in the production phase and, secondly, the specific need to ensure easy access to the local distribution and logistics hub (which will most probably be located in Beaufort West - see Burns et al., 2016). Due to uncertainty as to the scale and specific location of operations, no specific routes are identified for paving and any paving will be the responsibility of, and be financed by, the mining companies should this become necessary. This will have implication for gravel and other construction materials. Upgrading of unpaved roads to paved standard would have significant benefits in terms of road user costs, but these would accrue mostly to the exploration and production companies, as well as local road users, but would have no direct benefits to the local road authorities.

Paving of roads will be associated with even more planning, management, construction, tendering and project management requirements, with major implications for an increased demand for water and high quality construction material and their transport into the region. In addition to the above, side-effects of the sudden increases in traffic such as increased dust from unpaved roads, noise and vibration can have negative impacts on agriculture, tourism and even in the northern area on the Square Kilometre Array (SKA). Together with the increased heavy traffic volumes (i.e. those that damage the roads), there will be a corresponding, but larger, increase in light and medium traffic. This traffic, however, while having a negligible impact on the road performance, has implications in terms of traffic congestion, dust generation on unpaved roads and potential road safety.

As for the Small Gas scenario; there are no specific actions required for decommissioning. Any new roads on private farms can either be left untended or continue to be used at the land owners discretion. Public access roads should be restored to at least the same level as when exploration commenced. This supports the importance of baseline monitoring from the outset.

18.2.2 Pressures on regional road infrastructure and logistic networks

As the gas containing shale is at great depths (3 000 to 4 000 m in the Beaufort West area and deeper towards the east), large rigs will be required for the exploratory (and later production) drilling to such depths. These will comprise various components, some of which will definitely be abnormal loads, both in terms of dimensions and masses. The normal traffic ordinances will need to be followed during conveyance of these loads. The abnormal loads would have limited impact on the roads in comparison with the large numbers of other conventional heavy vehicles delivering the necessary provisions and resources (see vehicle trips as set out in Burns et al., 2016). Where possible, use should be made of the existing rail infrastructure to transport the abnormal loads (see Digital Addendum 18B). It should perhaps be noted that the size of loads carried by rail is limited by the height of the overhead power lines on electrified tracks as well as by the dimensions of bridges and tunnels. Any rail transport of material and equipment required for SGD will require a mode change in Beaufort West and distribution from that point to the wellpads by suitable trucks. This will imply the availability of suitable rigs to transport the equipment from rail head to the wellpads.

Any rapid economic or infrastructure development can place enormous challenges on existing road systems (pavements and bridges), as well as require significant investments in new systems. In addition to the traffic associated with SGD activities of gas fields (i.e. the transportation of heavy equipment, drilling rigs, etc.), other transportation issues must also be considered in the case of the Karoo. One of these is the importation of potable/fresh water and this is more fully considered in Hobbs et al. (2016). Based on local experience many of the local Karoo groundwater sources may have high salinities and may be unsuitable for the support of local staff and even for the fracking operations, or may not be able to provide the adequate quantities required for sustaining the operations (Hobbs et al., 2016). The current proposal is to identify suitable additional water sources outside the areas, e.g. desalinated water from Mossel Bay, and to transport it into the area.

The exact location and direction of travel has yet to be determined and traffic for this has not been factored in to the transport impact. However, should this become necessary, this will place significant extra stress on the existing regional road infrastructure. Similarly, the removal of wastes from the study area to either Port Elizabeth or Vissershoek (Cape Town) will add to the existing traffic volumes and will require attention (Oelofse et al., 2016). Many of these wastes (including waste water) could be hazardous or toxic, and this will involve special authorisation and the development of a fluid transportation management plan in terms of the regulations (Regulation 466; clause 117) under the MPRDA. Given the uncertainties regarding the exact volume and frequency, this is not covered in this part of the document. The re-use of material and construction of pipelines for transport of waste, use of rail, or even the establishment of a Hazardous Waste site in or close to the study area can be considered in mitigation. In addition to the impacts of the extra traffic, certain sections of road could be perilous to the movement of such heavy vehicles (slippery road surface, misty conditions, tight bends or steep grades) and could thus require improvement (re-alignment in some cases), avoidance strategies, especially of tourist-related routes or at least additional sign-posting and guard-railing.

The significant increase in traffic associated with SGD could have a severe impact on existing roads systems, especially ageing ones currently prevalent over most of South Africa. Figure 18.3 indicates local and regional roads in areas that will most probably be affected by the respective SGD scenarios as set out in Burns et al. (2016). The study area is already subject to flash flooding and extensive damage to key road infrastructure due to extreme rainfall patterns, increasingly associated with climate change, which is expected to get worse (Verhaege, 2016).

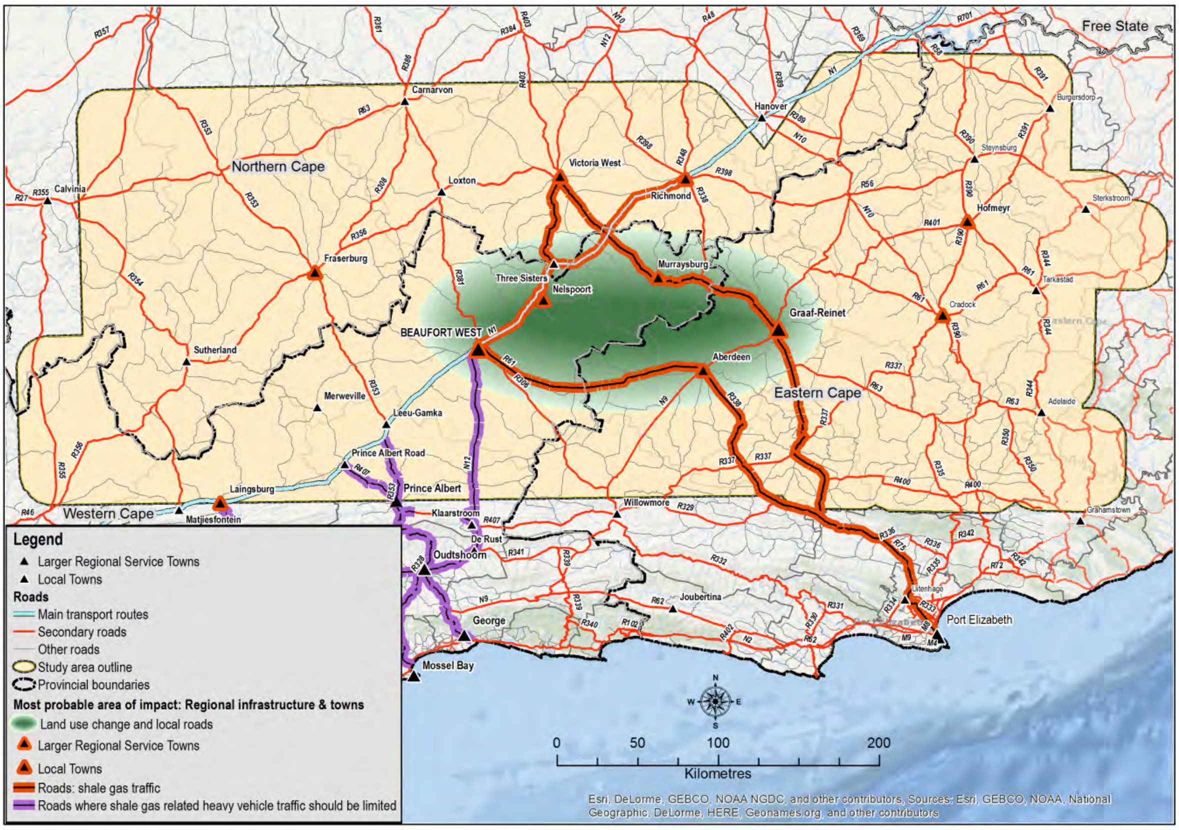

Figure 18.3: Towns and main routes likely to be impacted by potential SGD.

Reference Case: Currently, many of the roads in the area are already in a poor condition, although some of the key national and regional routes like the N1 have recently been upgraded. Many of the existing roads in the area are relatively old (more than 50 years) and nearly 30 years beyond their design lives. Existing demand for road maintenance is already high and either with or without mitigation (the former implying preventative rehabilitation and the use of higher grade gravel and other materials to extend road life, water-wise construction and application of new materials) there still is a high demand for raw materials (Central Karoo District Municipality, 2013; Theron, 2016). The application of new materials would be a more long-term option. Major implications related to the impact of regional and national corridors such as the N1 in the Karoo and surroundings, under the existing Reference Case can be summarised as heavy road freight traffic passing through the region (this currently makes up almost 40% of total traffic on the N1; see Central Karoo District Municipality, 2013). While such through-traffic, especially in Beaufort West, contributes significantly to high street traffic, but also to the local economy. This raises issues regarding ways to handle through-traffic, the need for better traffic controls, and emergency incident response by the local authorities, currently and in the future.

Exploration Only: While exploration and testing will result in the drilling of wells and establishment of wellpads and associated infrastructure and development in and around the exploration areas, the movement of equipment, materials and resources along the existing primary and secondary road networks (mostly national and provincial) into the area from ports of entry and major hubs can be expected to have a significant influence on the existing regional road networks as set out in the following Section. It is estimated that approximately 25 additional heavy vehicles per day will be traveling on the routes in question over a period of five years (Burns et al., 2016). The N1 especially is a key road freight route for South Africa, and the impact of large construction vehicles, equipment and the like on this road can increase the risk of accidents, spillage of hazardous materials, the deterioration of the road infrastructure and congestion. Likewise, the N12 is envisaged as a key route for the transport of water needed for fracking from Mossel Bay and is currently in a poor state of repair (more than half of the roads in the Eastern Cape are considered to be in a fair to very poor condition) (Kannemeyer, 2014). The R61 provides access between Beaufort West to Aberdeen/Graaff-Reinet, as well as Port Elizabeth Harbour/Coega and the inland areas of the Eastern Cape. This route will probably attract much of the equipment transport as Port Elizabeth is the nearest port to the area (this is also the most likely route for the transport of hazardous waste out of the area), with the N2 to Cape Town being the other alternative route likely to be used.

Construction material already has to be trucked in from outside the area (Theron, 2016). The ongoing identification and permitting of approved gravel pits will start to increase significantly during this stage. The road network provides a good level of connectivity when maintained. During this phase it is not expected that any significant deterioration of roads will be noticeable. However, to mitigate against any rapid decline in the subsequent phases, it is likely that greater emphasis will need to be placed on upgrading and the rehabilitation of specific routes, the N12 being of particular concern, as well as regular high quality maintenance of the existing road network (Central Karoo District Municipality, 2013). Demands on the prevention of overloading and general traffic enforcement are likely to increase in line with greater heavy vehicle traffic volumes.

Action required with respect to decommissioning will entail ensuring that roads are in at least the same or better state than in the Reference Case; pointing once again to the importance of baseline surveys to establish current state in order to apportion cost and responsibility for repair should roads be damaged. No additional regional roads are expected to be built.

Small Gas: As exploration is extended and more equipment is brought into the area, the heavy vehicle load will increase, increase somewhat with an estimated further 25 additional vehicles per day for a 35- 40 year period, thereby placing even greater strain on the roads, and with that an increased requirement for maintenance (see Burns et al. (2016) for estimated vehicle and trip volumes). This increased demand on financial resources, as well as natural resources in terms of water, crushed stone, concrete and asphalt and the right quality of natural gravel will require increased applications for new gravel pits and quarries. This process is already quite time consuming and expensive, leading to maintenance delays. As a key freight route for South Africa the impact of large construction vehicles and equipment on the N1 road can increase the risk of accidents, spillage of hazardous materials and congestion. A further concern is the pressure on key routes to the coast (Port Elizabeth, George, and Mossel Bay), especially so the pressure on several mountain passes with sharp bends and steep grades along the route. This will all contribute to rapid deterioration of the aging road infrastructure and increased congestion on the national and regional routes with limited opportunity to divert any freight to rail, due to the a) size of equipment, and b) the relatively poor location of the main rail lines in relation to the identified likely extraction areas.

Actions required with respect to decommissioning will be to ensure that roads are in at least the same or better state than in the Reference Case; pointing to the importance of baseline surveys to establish cost and responsibility for repair should roads be damaged. No additional regional roads are expected to be built (based on Burns et al., 2016).

Big Gas: With full SGD, the impact will continue to increase due to production phase requirements, together with the extension of wells and wellpads. It is expected that there will be an addition of 160 heavy vehicles per day on the regional network for the period of 35- 40 years (Burns et al., 2016). Regional roads will be under more pressure and deteriorate rapidly under these large increases in heavy traffic, requiring significant maintenance at best but, more likely, because of their ages, extensive rehabilitation and improvement. At this stage, the age of the road network will also become critical and substantial road reconstruction will be required. This will be associated with greater planning, management, construction, tendering and project management requirements, the majority of these being outsourced. This will also increase the demand for water and construction material. The development, maintenance and upgrading of roads to address increased traffic will also require increased financial and human resources. The more traffic generated, the shorter the lifespans of certain roads within the existing regional road network will become, and the more funding will need to be dedicated to maintenance and repairs. Invariably, as the major routes deteriorate and are not adequately maintained (commonly noted in South Africa as a result of constrained budgets), traffic will move to alternative (but longer) routes, enlarging the network that will suffer increased deterioration.

Actions required with respect to decommissioning entail that roads are left in at least the same or better state than in the Reference Case; pointing to the importance of baseline surveys to establish cost and responsibility for repair should roads be damaged. No additional regional roads are expected to be built.

18.2.3 Settlement development and service delivery implications

Within the study area, the towns of Beaufort West, Graaff-Reinet, Middelburg, Colesberg and Cradock provide different regional service functions in the broader study area, housing the bulk of the population (Burns et al., 2016; stepSA Town Growth Profiler, 2013) and acting as regional hubs in relation to retail, manufacturing, as well as community and government services economic activities (stepSA Town Growth Profiler, 2013; Burns et al., 2016) in the region. As in the rest of the country, these type of towns are also experiencing the impact of increased concentration of population in rural areas, marked with the highest growth rates in terms of population and households during the 1996-2011 era both due to natural growth, as well as townward movement – a trend which is most likely to continue (Van Huyssteen et al., 2013b). Given that more than one fifth of the population in these towns are households living in poverty and that these towns are facing 1) a relative decline in working age population, 2) a decline in formal economic production (stepSA Regional Profiler, 2016), 3) increased levels of socio-economic vulnerability (Atkinson et al., 2016), and 4) the constitutional provision of the right to municipal services, municipalities are under increasing pressure for sustainable basic and social service delivery while straddled with limited human and financial resources. While the average population growth rate for all towns in the area was quite low (calculated at a mere 1% between the 1996 and 2011 census years), the bigger towns in the area have experienced a 1.6% growth average during this time (stepSA Town Growth Profiler, 2016). While this growth is not high compared to the average population growth (1.8%) in similarly-sized towns in the country as a whole (Van Huyssteen et al., 2013b) it still has subsequent implications on the increase in demand for housing, access to water, electricity and sanitation, as well as resultant implications for local amenities (parks, sports and recreation), social services (health care, education, home affairs offices, etc.) and associated facilities.

Based on calculations in Burns et al. (2016), the estimation of staffing requirements and resultant potential population increase and settlement implications for households under various unconventional gas exploration and production scenarios is set out in Table 18.3. The required staffing includes local staff and estimates for construction and on-site security staff (Van Zyl et al., 2016).

Table 18.3: Estimated direct settlement implications associated with SGD in the study area/Karoo Region.

Scenario	**Highly Skilled Professionals (mostly non-local)**	***Skilled and Unskilled – Direct and Indirect (Construction, Security and other) (mostly national skilled and local unskilled)**	**** Associated Migration Pressures**	**Town-based settlement implications**	**On-site settlement implications**
Exploration Only 8 years	1 025 professionals (725 expat and 300 national experts estimated). Not necessarily permanent residents within the area, around 50% might commute in on weekly basis, on average small household sizes (single professionals, and or experienced expats not relocating families). Indirect job and enterprise opportunity could extend the number of professionals/highly skilled jobs.	675 direct jobs and a total of 1 100 direct and indirect jobs. Assuming that job opportunities will mostly be filled by existing residents and that provision for on-site and/or construction camp accommodation will be for certain percentage of local staff, while families and extended households of local staff will remain in existing housing in towns.	While jobs are highly limited and local job creation is prioritised, historic examples of in-migration associated with mining and other development (i.e. Saldanha Steel) in Northern and Western Cape towns, show that in-migration can be expected to increase the pressures on housing and service delivery especially in the so-called Service Towns (See Figure 18B(ii) in Digital Addendum).	High income households: Increase demand for rental accommodation in Service Towns. Limited high-income property development. Increased need for lower-income and subsidy housing. Increase bulk and basic service provision, which is primarily a municipal responsibility.	Construction of temporary and semi-temporary accommodation and sustainable on-site service provision. Largely a developer-responsibility.
Small Gas 25 Years	90 ore permanent residents within the area (60 expat and 30 national experts). Estimated that around 20% of the workers might commute in, on average small household sizes (single professionals, and or experienced expats not relocating families).	210 direct jobs and total of 420 direct and indirect jobs. Challenge will be the reduction in on-site and/or construction camp accommodation with resultant pressures on local towns. Families and extended households of local staff will remain in	While jobs are highly limited and local job creation is prioritised, the "word" of production and historic examples of in-migration associated with mining and other development (i.e. Saldanha Steel) in Northern and Western Cape towns, show	High income households: decrease demand for rental. Increase but limited high income property development (possible high security and alternative energy clusters for longer term accommodation need). Increased need for lower-income and subsidy housing	On-site development limited to staff required to stay on the wellpad i.e. security staff, or staff in temporary camp. Maintenance of temporary and semi-temporary accommodation, and sustainable on-site service provision.

Scenario	Highly Skilled Professionals (mostly non-local)	*Skilled and Unskilled – Direct and Indirect (Construction, Security and other) (mostly national skilled and local unskilled)	** Associated Migration Pressures	Town-based settlement implications	On-site settlement implications
	Indirect job and enterprise opportunity could extend the number of professionals/highly skilled jobs.	existing housing in towns and staff will most likely be sourced from existing residents in area.	that in-migration can be expected to increase the pressures on housing and service delivery especially in the so-called Service Towns (See Figure 18B(ii) in Digital Addendum).	with reduction in on-site housing. Increase bulk and basic service provision, which is primarily a municipal responsibility.	Largely developer-responsibility.
Big Gas 30 Years	600 more permanent residents within the area, (400 expat and 200 national experts). Around 20% might commute in, on average small household sizes (single professionals, and possible increase in higher income households in region). Travel modes might have impacted on ease of commuting.	1 400 direct jobs and total of 2 800 direct and indirect jobs. Challenge will be the reduction in on-site and/or construction camp accommodation with resultant pressures on local towns. Families and extended households of local staff will remain in existing residents in towns and staff sourced most likely from existing residents in area.	The increase in jobs and the "word" of more extensive production together with the network attraction of people already in the area in Northern and Western Cape Town show that in-migration can be expected to increase the pressures on housing and service delivery especially in the so-called Service Towns (See Figure 18B(ii) in Digital Addendum).	High income households: substantial increase demand for rental. Increased need for high income property development (possible high security and alternative energy clusters). Increased need for lower income and subsidy housing with reduction in on-site housing. Increase bulk and basic service provision. Largely municipal responsibility.	On-site development limited to staff required to stay on the wellpad i.e. security staff, or staff in temporary camp. Maintenance of temporary and semi-temporary accommodation, sustainable on-site service provision. Largely developer responsibility. Given higher levels of activity this could imply more temporary camps.

* Given the complexities regarding road maintenance and upgrading in the Karoo region as set out above, the number of construction related staff might be underestimated. It should be noted also that most road construction companies bring their own temporary construction crews.

** The table provides an estimation of direct need and does <u>not</u> include a calculation of possible in-migration.

Reference Case: Existing growth in towns will most probably continue with resultant increased demands on land, housing and municipal service delivery due to normal population growth. There might be fluctuations and an increase in in-migration to the area as experienced in many other towns in resource rich areas (Van Huyssteen et al., 2013b), even before exploration phases begin given the publicity and expectations with regard to possible unconventional shale gas and uranium mining and possible Green Energy Projects in the area (see indication of current green energy project applications across the country and concentrated in the region in Digital Addendum 18B).

Exploration Only: Land development associated with SGD will largely be associated with road construction, drilling wells and wellpad construction (Burns et al., 2016), with limited on-site housing provision, as well as housing for construction workers in temporary road-side construction camps, which is likely to move around the area. A limited number of people entering with high skills levels will most likely have options to reside in larger towns such as Graaff-Reinet or Beaufort West. A percentage of these might also opt to reside in nearby centres such as George/Mossel Bay, Nelson Mandela Bay Metropolitan Municipality, or even Cape Town – travelling in and out on a weekly basis to the area, an experience well noted in exploring regional town growth drivers in the Gamagara Mining Region in the Northern Cape (Van Huyssteen et al., 2014).

Even though low-skilled employment is expected to be limited to road and on-site construction as well as security and transport activities and exploration activities are expected to take place in an incremental way, expectations regarding possible opportunities will most probably give rise to influx to the area. Especially given the high levels of unemployment, increased mobility of the South African population (Mans et al, 2014; Maritz and Kok, 2014), as well as mine closures and job losses in other parts of the country. South African experience, i.e. in the case of in-migration being associated with developments in Saldanha and various mining towns in South Africa such as Kuruman and Lephalale (Van Huyssteen et al., 2013b) echoes experiences of the international boomtown phenomena (Jacquet, 2014). Implications of possible informal settlement and increased service demand could be expected in towns in the area. Given the proposed incremental approach to exploration, the number of people and households to accommodate in surrounding towns will most probably pick up over the exploration phase.

An increase (as well as an expected increase) in the demand for rental accommodation for specialists associated with SGD activities and/or associated services as in the cases of Lephalale (North West) and Postmasburg (Northern Cape) could give rise to an increase in property values, which in turn could lead to an increase in the conversion of existing housing stock to rental accommodation and guest houses. Given the uncertainty in the exploration phase; opportunities for ‘quick wins’ in the property market through gated community developments, land use changes or illegal sub-letting will probably arise. Associated with the above, an increase in land and other resources to cater for township extension and possible informal settlement upgrading, as well as timeous provision of social and basic services, and upgrading capacity of bulk services (especially considering water availability and land fill sites) can be expected.

While this scenario refers to a case of limited resource find and an exit after the exploration phase, it would most probably not have a huge effect on the highly skilled professionals and skilled (expat and national employment) workforce who would have been commuting and largely making use of rental accommodation. Many local employees and people that might have migrated to the area in the 'hope' of work will most probably not have alternative options. While town economies might experience fluctuation of growth and then decline during this time, the footprint of town growth (private sector and government), as well as the expected increase in the indigent population associated with migration will most likely remain. This scenario might entail that local economies and enterprises use the opportunity for growth and diversification, or that municipalities are left with an unsustainable service delivery and financial burden.

Small Gas: Growing demand for service delivery in service towns due to influx of job-seekers, a growth in formal activities, and an additional influx in Beaufort West which will most likely be developed as a local logistic hub to support operations. Expansion of wells, wellpads and thus on-site settlement could be expected. Continued exploration, as well as the increased need for higher quality road construction to address the needs within a production scenario, and the likely need for resurfacing, sealing and on-going maintenance will also sustain the need for construction related activities and camps in the area. While job creation in the construction sector and on-site on wellpads could contribute to local economic development, it is foreseen that large portions of households in towns will still be dependent on government grants and local economies will still be largely dependent on the government service sector, with subsequent spatial implications of growing informal settlements, coupled with an increased demands for social facilities and 'boomtown' characteristics without the market-related development that necessarily accompanies it. The prospect of dual economies in these towns of 1) grant-dependent and 2) shale and associated industry workers is likely. Given limited production activities in the Small Gas scenario and decommissioning without extensive production, the implication for small towns of 'losing' high skilled residents and experiencing a semi-permanent professional in-flux on a regular basis during the time period, and out-migration afterwards, might actually result in an over-supply of housing, rental accommodation and services, with severe implications for property prices and the municipal rates base.

Big Gas: Growing demand for service delivery in service towns due to an influx of job-seekers, a growth in formal activities and an additional influx in Beaufort West, which will most likely act as logistical hub in support of production is foreseen. This will have implications of informal settlement growth, service demand and associated unintended consequences, especially within larger service towns. The impact of demand for water and sanitation, landfill facilities, social facilities, etc. resulting from scattered settlement on the wellpads during the production phase will most likely continue. In this scenario, a larger impact on town growth can be expected with household growth and associated demand due to longer-term job opportunities for higher skilled workers and less uncertainty in the property market associated with production versus exploration phases. While job creation in the construction sector and on-site on wellpads could contribute to local economic development, it is foreseen that large portions of households in towns will still be dependent on government grants and local economies will still be largely dependent on the government service sector, with subsequent spatial implications of growing informal settlements, an increased demands for social facilities and ‘boomtown’ characteristics without the market-related development that necessarily accompanies it. The prospect of dual economies in these towns of 1) grant-dependent and 2) shale and associated industry workers is likely.

Given the extensive production activities in the Big Gas scenario and decommissioning taking place only after extensive production, the implication will most probably be severe. With decommissioning after the time period of extensive production it is quite probable that towns will be ‘losing’ highly skilled residents and semi-permanent professionals. Given the longevity of this scenario and the most likely influx of employed, entrepreneurs and job-seekers into the area during the time, as well as the establishment of a more diversified economy, the impact of decommissioning will most likely be felt not just locally, but also in direct and indirect ways in the regional economy. The cost of managing the towns and infrastructure will remain with the municipality (as also set out in the other scenarios), with mitigation only being possible in sustainable ongoing settlement development, which may be problematic should there be significant declines in the local economy

18.2.4 Spatial and development planning, land use management and governance implications

Integrated development planning and spatial coordination and alignment has proven difficult in South Africa, despite the Constitution and legislation such as the Municipal Systems Act 32, 2000, and SPLUMA expressly calling for it. The culmination of many small-scale and scattered land use applications, development and incremental operations will most likely have major impacts on towns and municipal governments. Municipalities and government as a whole needs to be prepared to consider and guide potential SGD and associated downstream developments.

The South African planning system provides for a range of planning instruments and processes to enable multi-agent coordinated prioritisation, budgeting and implementation in regional and municipal SDFs, IDPs as well as service delivery and infrastructure plans within the five year municipal planning cycles (Figure 18.4) and resultant annual investment and implementation priorities. The possibility of SGD, as well as other potential regional development activities such as uranium mining and renewable energy resource developments in the study area, would require timeous planning for various development scenarios within the range of relevant medium term spatial and integrated planning instruments. Such spatial planning instruments create the conditions conducive for municipal preparedness to consider formal private sector driven applications for land use change (i.e. by mining companies, and/or private land developers in towns) but also to be prepared to address potential increase in service demands due to increased traffic and activities in the area, and/or potential in-migration and increase in population numbers in towns and associated service delivery needs.

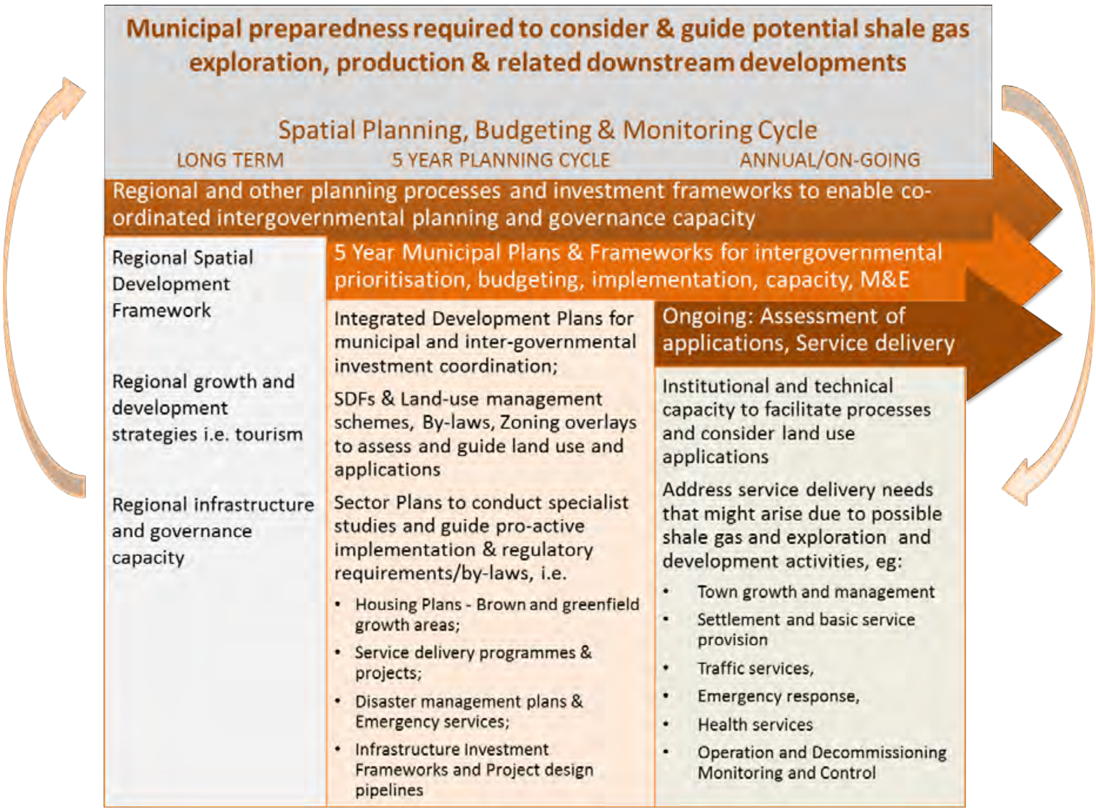

Figure 18.4: Municipal preparedness required to consider and guide land use applications and impacts related to potential SGD, and related downstream land developments and service needs.

While the envisaged SGD activities may have a positive impact on municipal and provincial financial viability and capacity and add money to the national fiscus, it will also have impact on investment, upgrading, expansion and maintenance service costs. An example of municipal services that are directly and indirectly impacted upon due to possible unconventional SGD campaigns under the respective scenarios would be investment, upgrading, expansion, maintenance and regulation of roads, and a need for expanded emergency services and environmental management (as noted in the Central Karoo Integrated Transport Plans of 2005, 2009 and again in 2013). The need for enforcement to enhance traffic safety especially on the N1 and reduce damage to roads through overloading has been identified as an issue in need of attention. While emergency incident response is critical and demands are far in excess of that required by the local population and locally generated traffic, the movement and parking of heavy freight vehicles passing-through towns, already creates traffic management demand in towns such as Beaufort West that largely act as a regional gateway. Development contributions related to impact on infrastructure and services will need to be considered.

In the same vein, the expected incremental but on-going land use and land development applications associated with well establishment through the different phases of SGD as represented by the respective scenarios for exploration and production will require additional resources and capacity in terms of the administration of regulatory processes – placing severe strain on authorities in all spheres of government.

In relation to each of the scenarios described below, it is important to recognise, as noted in Section 18.1.5 above, that the entire land use regulatory system is in a process of change, new laws are being developed, new institutions established and new regulatory instruments are being developed. Consequently, even the slightest change in current resource and land use patterns will pose significant challenges in the context of regulatory processes and environmental and spatial planning.

Exploration Only: The exploration activities will require various types of land use change applications. It will also require applications for mining to the Department of Minerals and Resources (DMR) after consultation with the competent authorities including the Department of Environmental Affairs (DEA). In the case of the applications for exploration infrastructure, primarily on farmland, this entails both a municipal decision to be taken by the Municipal Planning Tribunal regarding a land use within a land use zone that is probably zoned for "Agriculture". Decisions will also have to be taken around mining rights and environmental aspects in relation to mining and environmental legislation. Within the built-up areas, there may be some limited land use changes which are unlikely in this scenario to represent significant challenges. It is in the more rural areas where the capacity constraints in government are most deeply felt and where the deepest challenges lie. There might be difficulties in processing land use applications in a reasonable time period, as well as enforcing and monitoring decisions. The need to support municipalities in their adaptation to the new regulatory environment will be stronger in the Eastern and Northern Cape Provinces, given that LUPA provides more legal clarity in terms of land use and land development application processes, and that the Western Cape Province currently seem to have more capacity to support municipalities in this process.

With decommissioning, the relevant obtained land use rights will remain in place and wellpads will be rehabilitated as far as possible, adhering to relevant regulations pertaining to the sealing of drill heads (Burns et al., 2016). Unpaved and paved local access roads on private land will most probably just remain inactive as rehabilitation of road surfaces in the Karoo is problematic. Monitoring and control of sealed drill heads and wellpads (as in the case of derelict mining land) will require ongoing expertise and resources.

Small Gas: The intensity of the SGD activities described in relation to the Exploration Only scenario obviously increases in the Small Gas scenario. The pressures on municipal systems and processes become more pronounced. The processing of land use applications will very likely become complex and more challenging, with culminating implications of the incremental processes. While government has to respond to the needs of the private sector through policy development and the administration of regulatory processes (embedded), government must retain its independence (autonomy) and must not be captured by the vested interests of private sector. Care must therefore be taken in ensuring that governance systems assign accountability to decision-makers as required in terms of the relevant legislation and are open and transparent. The need for national and provincial government to support municipalities in their adaptation to the new regulatory environment will become stronger in this scenario.

With decommissioning, the relevant obtained land use rights will remain in place and wellpads will be rehabilitated as far as possible, adhering to relevant regulations pertaining to the sealing of drill heads (Burns et al., 2016). Unpaved and paved local access roads on private land will most probably just remain inactive as rehabilitation of road surfaces in arid regions such as the Karoo is problematic. Monitoring and control of sealed drill heads and wellpads (as in the case of derelict mining land) will require ongoing expertise and resources. Possible fluctuations in the economy might result in excess housing stock or out-migration of people and enterprises.

Big Gas: This scenario will be characterised by increased exploration activities (i.e. a higher intensity of exploration), the establishment of production wells and significant downstream developments. The intensification of these development activities will result in a significant increase in regulatory applications and demands for services (and service delivery) in all spheres of government. In particular, the ongoing and cumulative impact of increased land use and land development applications will put significant strain on the less capacitated municipalities (Department of Cooperative Governance and Traditional Affairs (CoGTA), 2014). Without the support from national and provincial authorities, it is anticipated that these under-capacitated local municipalities will struggle to adequately deal with the regulatory decision-making burden associated with this scenario. The challenge in this scenario lies in the work that the municipalities will need to do to scale up their overall planning and management capacity to guide and coordinate the development that will flow from the now significantly increased economic activity, and related social and environmental changes in their municipal areas.

It is expected that after the first five to eight years of exploration activities, in the course of this scenario, land use management within the Western, Eastern and Northern Cape Provinces will become aligned and that experience on the one hand, and more legal clarity in terms of land use and land development application processes on the other, will eventually support more streamlined approval processes. It will be critical in this scenario to plan for and manage the cumulative impact of site specific land developments and land uses associated with SGD. Given that the Big Gas scenario will result in a significant increase in regulatory applications it will require additional resources at all spheres of government.

With decommissioning, the relevant obtained land use rights will remain in place and wellpads will be rehabilitated as far as possible, adhering to relevant regulations pertaining to the sealing of drill heads (Burns et al., 2016). Unpaved and paved local access roads on private land will most probably just remain inactive as rehabilitation of road surfaces in the Karoo is problematic. Monitoring and control of sealed drill heads and wellpads (as in the case of derelict mining land) will require ongoing expertise and resources.

Possible fluctuations in the economy through or at the end of the production phase might at some stages result in excess housing stock or out-migration of people and enterprises. Evidence from the Northern Cape suggests the danger in complete 'draining' of population and enterprises in smaller local towns (Van Huyssteen et al., 2014) and the role of bigger towns in providing access to government services to communities that are dependent on government grants and faced with high rates of unemployment.

18.3 Risk assessment

Risks and opportunities are usually measured against a baseline or at least considering what is 'normal'. While some risks and opportunities are measurable to an extent, others might be more qualitative and probabilistic in nature. The wide range of aspects addressed in the Chapter on land, infrastructure and settlement development imply that key risks and opportunities are measured and explored in highly diverse ways, as summarised in Table 18.4 and set out in more detail for key impact areas below.

18.3.1 Measuring and highlighting key areas of risk

Table 18.4: Measures of risks, opportunities and limits of acceptable change.

Key risk area	Measuring risks	Limits of acceptable change
Local road construction and resource implication.	• Traffic volumes: Vehicle use per day. • Longevity – Intervals for upgrading/maintenance/reconstruction. • Construction material requirements and costs. • Maintenance requirements and costs. • Water requirements and standards regarding salinity.	Experience is that resources and capacity to maintain and build roads are currently constrained and thus any further increase in maintenance requirement would be unacceptable unless fully financed by the developers- the latter could be difficult to apportion fairly and must be negotiated prior to development. • Increase in normal maintenance cycle for a gravel or paved road to less than six to ten years (little water required here). Any change in this norm is the limit of acceptable change. • Increase in the maintenance costs beyond the existing cycle. • Reconstruction (significant water required here) occurs every 20-30 years and change in this norm is the limit of acceptable change. • More finance required than available in relative provincial and local budgets (through proportional contributions by developers).
Regional road infrastructure and networks.	• Freight volumes: Vehicle and tonnage per day. • Longevity – Intervals for upgrading/ maintenance/ reconstruction. • Distance to haul hazardous waste and fracking liquid. • Road safety.	• Increase in current maintenance budget requirement and cycle. • Increase in the maintenance costs beyond the existing cycle. • Reconstruction (significant water required here) occurs every 20-30 years and change in this norm is the limit of change since water is a scares resource in the area (Hobbs et al., 2016). • Any additional budget requirements as budgets are already constrained. • Increase in accidents and road deaths above current levels.
Settlement development and service delivery needs.	• Households in need of housing and free basic services (backlog). • Demand for (alternative) housing – rental, high income. • Resource availability: Sustainable service delivery (availability, cost, access to and resource	• Average town growth over last two census periods is the norm; an increase in town growth has major implications for land, service delivery and resources. • Increase in housing and service delivery backlog. • Above average growth in informal – green fields or 'backyard' settlement.

Key risk area	Measuring risks	Limits of acceptable change
	implications for water/sanitation/energy provision/spatial form & maintenance). • Capacity and accessibility to social and municipal services such as education, health, sport facilities, land fill sites, etc. respond to number and location of users. • Number of indigent population, and percentage of indigent population to total population. • Rates and taxes, service payments. • Increase in service delivery needs in the region. • Number and growth in enterprises, employment, GDP/capita, inequality. • Sustainable Development Goals (where relevant).	• Increase in operation and service cost, with increase in budget deficits (Increase in percentage indigent population within the municipality; increase in service delivery needs in the region; decrease in municipal revenue due to rates and taxes; limited access to grant and other funding; limited mitigation measures for alternative resourcing). • Increase in the demand for water and other bulk services beyond the planned delivery targets, or when the demand exceeds the projected resource availability and bulk infrastructure capacity. • Capacity and accessibility to social services and municipal services such as education, health social services and sport facilities, land fill sites, etc. respond to existing and projected demand. • Increase in inequality as measured by the average for the Gini-coefficient in the relevant regional and provincial context.
Spatial and development planning, land use management and governance capacity implications.	• Relevant and well capacitated role players involved in key planning processes. • Governance capacity for planning, implementation, monitoring, control. • Long term plans with scenarios, projections and alternative mitigation options. • National government project specific investment considering local realities and future. • Number and size of applications for land use change; EIAs, etc. • Capacity to facilitate administrative & decision-making processes.	• Forward planning (IDP/SDFs) – the existence of a credible SDF (based on existing growth rates) must be seen as the norm, and any anticipated demands for development and services not catered for in the SDF must be regarded as beyond the limits of acceptable change. • Regulatory framework and administration – legal certainty must be regarded as the acceptable norm (i.e. the existence of an appropriate regulatory regime and the capacity to implement it). The minimum municipal planning bylaws needed for most municipalities should be expected to be promulgated. • Consideration of projected and cumulative impact of separate but inter-related land use changes and developments should be standard practice at a regional level. • Skills development for municipalities must be seen as the norm, e.g. as required to fulfil their mandates, do long-term planning and give expression to their plans.

Local road construction and resource implications: The exact implications of increased traffic are difficult to estimate, as they depend on the level of existing traffic and base line traffic volumes are not available for all unpaved roads. It is unlikely that any predetermined limited can be set on the construction of infrastructure reconstruction volumes or indeed traffic volumes as it is always possible to maintain and build roads and increase road volume and safety features of a network in this sparse environment. It is currently not restricted by development or availability of undeveloped land for construction. The real limiting factors will be the availability of the financial and management resources available, as well as access to raw materials. The increase that will be measured will thus not be in terms of a percentage increase over existing traffic but a fixed traffic volume. In other words, as indicated in the previous Section, the traffic on a local gravel road currently carrying 30 heavy vehicles per day may increase by 30 to 50 heavy vehicles, probably reducing the interval between re-gravelling from ten years to six years. The impact of the same 30 to 50 vehicle increase on a road currently carrying 200 vehicles per day may decrease the re-gravelling interval from six years to perhaps four or five years.

It is essential that the status quo on the existing roads is identified, i.e. remaining life, problem areas, bridge conditions and problems, and that the status quo is maintained or improved. Any rapid deterioration of road quality above the current trend would not be acceptable. Neither would an increase in overloading, speeding or accidents be tolerated. Currently identification of the status quo of assets is a national requirement in terms of the Road Infrastructure Asset Management Policy that has been implemented down to provincial level, and is being implemented at local government level. This information will provide a base scenario (perhaps with some additional data collection related to specific areas or problems), which can be used to evaluate any accelerated deterioration, particularly if the assessment records extend back for a few years. Where pavement condition data is not available or up to date, this should be collected prior to initiation of any exploration or production.

Capacity and lifespan of regional through-routes/logistic corridors: The reduction in lifespan of any road by more than three to five years will significantly increase the demand on the national and provincial fiscus and burden the already over-burdened and onerous maintenance and upgrading programme.

The majority of damage to roads is done by vehicles with axle loads in excess of 80 kilonewtons (kN). However, there is evidence to indicate that this varies with the type of pavement structure – deep natural gravel pavements undergo less damage, for instance, than a shallow pavement with stabilised upper layers. The increase in legally loaded vehicles (i.e. those with individual single axle masses of less than 80 kN, the current legal axle limit is 90 kN, which results in 64% more damage than an 80 kN axle) will reduce the pavement life by approximately the same percentage as the increase in traffic, i.e. if the heavy traffic (in terms of number of standard axles) increases by 10%, the road life will be reduced by 10%. However, if the number of axles heavier than 90 KN increases by 10% the reduction in life is reduced by considerably more than 10% (typically the ratio of the actual mass to the standard design mass (80 kN) to the power 4.2).

Settlement development and service delivery needs: Growth and development of towns and settlements is a natural and generally progressive phenomenon which should not be limited unduly if well planned, executed and sustainable. Given the small size of towns and the current availability of vacant land, it would be difficult to set a limit on any well planned growth. The key limiting factor would to ensure that informal growth and development is limited and that township and settlement formation is restricted to areas directly adjacent to the current built-up area. The major restriction on development can only be seen to come in the form of the availability of the financial and management resources to develop and service new human settlements. Limits on available water supply to support increased settlement formation will need to be considered in implications on water resources.

Construction material and resources: Unpaved roads will typically require about 1 200 m^3 of construction material per layer per kilometre of road and depending on the existing site conditions, anything from one to three layers of material may be required for a new road. Under normal use the upper 150 mm of this material would require replacement every six to ten years. As long as raw materials can be sourced from local borrow pits, etc. at a reasonable cost, it is unlikely that any limits to change can be imposed.

The same applies to paved roads, where similar volumes and layers are required. However, the width is normally a little larger and the material quality in the upper layers and bituminous surfacing is significantly higher (usually crushed stone), making the location of the materials more difficult but not limiting, the haulage somewhat longer, and the actual cost of the materials significantly higher. Access to water for construction may be a limiting factor, as typically 84 m^3 (84 000ℓ) per layer per km will be required and needs to be sourced and hauled to site. Unpaved roads will typically cost about R 350 000 to R 500 000/km to construct and about R 40 000 to R 75 000 /km per year to maintain while paved roads are most likely to cost from R 2.5 million to about R 5 million/km to construct. The road authority would need to prepare budgets and procure funding for this. If the national and provincial budget allocations can be increased though, for example, taxes on shale gas, and loans, it would not pose a technical limitation.

Land use management regulatory bottlenecks: In the absence of comprehensive mitigation measures to develop land use management and spatial planning instruments, relevant institutional and municipal capacity (including for example Municipal Planning Tribunals) there will most likely be severe regulatory bottlenecks and challenges with effective assessment of applications.

Legal clarity and inter-governmental collaboration: SGD is new in South Africa. It was only recently that the courts pronounced on the legal channels that had to be followed and satisfied when applying for mining rights. In Maccsand (Pty) Ltd versus City of Cape Town and Others, Case No.: CCT 103/11 [2012] ZACC 7 (12 April 2012), the Constitutional Court made a clear distinction between 1) mining and 2) land use and spatial planning legislation, and ruled as follows: While the MPRDA is concerned with mining, the LUPO (1985) in the Western Cape Province (subsequently replaced by SPLUMA and LUPA) governs the control and regulation of the use of all land. These laws (mining-related on the one hand, and spatial planning and land-use related on the other) serve different purposes within the competence of the spheres of government charged with the responsibility of administering them: While the MPRDA governs mining, LUPO (now SPLUMA and LUPA) regulate(s) the use of land. However, the exercise of a mining right granted in terms of the MPRDA is subject to LUPO. An overlap between the two functions occurs due to the fact that mining takes place on land. This overlap does not constitute an impermissible intrusion by one sphere into the area of another, because spheres of government do not operate in sealed compartments.

There is nothing in the MPRDA suggesting that LUPO ceases to apply to land upon the granting of a mining right or permit. By contrast, Section 23(6) of the MPRDA proclaims that a mining right granted in terms of that Act is subject to it (i.e. LUPO) and other relevant laws. The implication of this pronouncement is that, while permission may be granted to mine, mining cannot take place until the land in question is appropriately rezoned. The South African constitutional order provides that one sphere of government or organ of state may take a decision whose implementation may not take place until consent is granted by another sphere of government or organ of state within whose area of jurisdiction the decision is to be executed. Each organ/actor and/or piece of legislation is concerned with different subject matter. If consent is refused in the case of a rezoning, it does not mean that the approval granted in the first decision (the granting of a mining right) is vetoed.

The authority from whom consent was sought would have exercised its power, which (power) does not extend to the power of the other functionary. This is the case, despite the fact that the effect of the refusal in those circumstances would be that the first decision cannot be put into operation. This difficulty may be resolved through cooperation between the two spheres of government or organs of state from the beginning of the desire to mine and lodge an application regarding the use of land. The option of course also exists to challenge the refusal through an appeal process or by taking it on review. The preferred option would of course be that of intergovernmental collaboration. In the second case, The Minister for Mineral Resources versus Swartland Municipality (12 April 2012), which was heard together with Maccsand versus The City of Cape Town, the judge concurred that a party who is granted a mining right or permit in terms of the MPRDA may start mining operations only if the zoning of the land in terms of LUPO permits it (Maccsand (Pty) Ltd versus City of Cape Town and Others [2012] ZACC 7, CCT 103/11). Whatever course of action is followed, functioning intergovernmental relations and/or time are required.

Clarity of legal and implementation practices with regards to land use application for SGD phases: Notwithstanding the ongoing development of regulations and guidelines to support the transition to a SPLUMA-based system for land use regulation, SPLUMA does not provide a clear picture of how exploration and production are to be dealt with in terms of land use and land development applications and no clear implementation practices have yet been established. In general, municipal planning by-laws or LUPO (where it is still in effect) will have to guide land use applications at municipal level, taking cognisance that municipalities' zoning schemes and definitions may differ. Two major aspects that pose risks are:

- Within the current legislative context as a general guide, SGD actions could possibly be covered by a temporary departure which may have a time limit of five years depending on the municipality's planning by-laws. When production is envisaged, suitable rezoning will have to be applied for, over and above other regulatory approvals. It has to be considered that other than other mining activities, in the case of SGD, the exploration phase is actually the phase that entails the most severe land use impact in terms of wellpad establishment, as well as all the activities associated with the process of fracking (Burns et al., 2016); and
- Clarification is required as SPLUMA defines land development as the erection of buildings or structures on land, or the change of use of land, including township establishment, the subdivision or consolidation of land or any deviation from the land use or uses permitted in terms of an applicable land use scheme. A land development application could thus be interpreted as a land use application in the traditional sense of the word. SPLUMA defines land use as the purpose for which land is or may be used lawfully in terms of a land use scheme, existing scheme or in terms of any other authorisation, permit or consent issued by a competent authority, and includes any conditions related to such land use purposes. This could be related to "zoning" in the traditional sense of the word. SPLUMA appears to be using the terms "land use application" or "land development application" indiscriminately. Whereas SPLUMA as framework legislation is not clear in its distinction between "land use" and "land development", clarity can however be provided in provincial planning legislation (as in the case of LUPA) and in municipal by-laws, which implies provincial capacity, intervention and collaboration in the study area.

Legal clarity is required in SPLUMA regarding matters of National Interest: SGD be an issue of national interest. Section 52 of SPLUMA requires that a land development application which impacts materially on matters within the exclusive functional area of the national sphere in terms of the Constitution; or strategic national policy objectives, principles or priorities, including food security, international relations and co-operation, defence and economic unity; or is a land use 1) of which the purpose may fall within the functional area of the national sphere of government; 2) may be prejudicial to the economic, health or security interests of one or more provinces or the Republic as a whole; or 3) may impede the effective performance of the functions by one or more municipalities or provinces relating to matters within their functional area of legislative competence, then it may be dealt with on national level.

- In such cases where the above applies, SPLUMA states that an application should be referred to the national Minister, should an applicant believe the above to be the case in relation to his/her application, or when the Municipal Planning Tribunal is of such an opinion. When this happens the Minister has two options, he/she can either join as a party to the application (thereby in subjecting him/herself to the municipal decision in this regard) or may direct that the application be referred to him/her to decide. There is no precedent of this yet and most likely implies that an additional process and decision is required to be taken.
- Lastly on SPLUMA and National Interest, before the Minister exercises a power in terms of Section 52 dealing with national interest, he/she must prescribe a set of criteria after public consultation. This has not yet been done and it is not known when this will be done. As a result of the involvement in the SPLUMA regulations process, it appears to be a matter for later regulation and not a matter that would need to be regulated for, as a prerequisite for SPLUMA implementation.
- The above aspects could have significant implications for municipal processes, institutional capacity and expertise and collaboration between the relevant organs of the state.

Spatial and development planning and governance capacity: In the area of sustainable development planning and settlement construction and management, there are a number of key risks associated with the lack of timeous planning and institutional readiness. Should processing of mining-related applications be slow and/or be seen as being inconsistent with the principles of fair administration (i.e. fair, open and transparent), there is an increased risk of decisions being challenged (and taken on review), or even unlawful commencement of development activities. The capacity constraints with regards to planning may result in the post-1994 ideals of integration and harmonisation not materialising, leading to social instability in the towns and social cohesion suffering. The lack of long-term environmental and development planning may also result in crises management becoming the norm in government, resulting in unsustainable development outcomes.

While effective environmental and development planning frameworks are essential, the risk of avoiding unsustainable outcomes can only be avoided if government has the capacity (i.e. funding, human resources, skills) to implement these strategic frameworks and the associated regulatory processes. To avoid unfavourable investment conditions especially for local economic development, long-term planning for shale and the after-shale phase will have to pro-actively consider land use needs and spatial planning implications of, for example, more heavy vehicle through traffic, as well as potential enterprises that are typically associated with SGD such as manufacturing, vehicle and equipment repair and services, and even guest house accommodation.

Mediation of benefits from mining rights and precedent for land applications: The regulation of mining rights, the mediation between mining and other economic, social, cultural and natural activities, and the process of ensuring that affected communities benefit from mining operations in post-Apartheid South Africa is still evolving. SGD steps into this 'still evolving and contested terrain' as both a generically labelled "extractive industry/activity", but also as a 'novel/new extractive industry/activity'. Officials and elected decision-makers that will be called upon to decide on 1) land use change and land development applications for SGD, 2) considering the implications of SGD on adjacent and nearby land uses, 3) the impacts on potential/future spatial development in surrounding areas, 4) the involvement by communities in mining operations, 5) contributions to be paid to municipalities for municipal services, and 6) the possible provision of bulk infrastructure etc. will not have local precedent to tap into, and will only have international experience to turn to. The relevance of such international precedent extends beyond the (more generic) technical experience, and extends into the locally-specific/unique aspects of spatial and land use planning legislation, powers and functions of organs of state, provision, maintenance and upgrading of infrastructure, etc.

Appeals processes: Under the pre-SPLUMA systems land use decisions of municipalities could be taken on appeal to the provincial government. This option has now fallen away and each municipality needs to design and implement its own system (to the extent that this is consistent with SPLUMA and LUPA in the Western Cape Province) for hearing appeals against the decisions of its Municipal Planning Tribunal. Municipalities in the Karoo region and especially towards the eastern parts of the area, in general, have technical and professional capacity constraints. The task in supporting these municipalities to be in a position to process the land use applications that will be needed for SGD is a challenge that must be addressed by provincial governments as a matter of priority. Experience in the roll-out of renewable energy projects in this region has shown that municipal capacity is not always up to the task of processing land use applications of this scale and impact (Berrisford, 2015).

18.3.2 Risk assessment summary

Table 18.5: Risk assessment matrix

Impact	Scenario	Location (See Figure 18.3)	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Local road construction and resource implications	Reference Case	Local access roads in the central Karoo area.	Low	Very likely	Low	Low	Very likely	Low
	Exploration Only	Most probable impact area.	Substantial	Very likely	Moderate	Moderate	Very likely	Moderate
	Small Gas	Most probable impact area with localised impact in medium probability area with likely access road linkages to Beaufort West as logistics hub.	Substantial	Very likely	Moderate	Moderate	Very likely	Moderate
	Big Gas	Most probable impact area with localised impact in medium probability area, with likely access road linkages to Beaufort West as logistics hub.	Severe	Very likely	High	Substantial	Very likely	Moderate
	Low – No additional increase in traffic and thus no additional maintenance required (See Table 18.3). Moderate – Increase in local road use, maintaining the frequency of maintenance at higher cost. With mitigation (i.e. better construction) the maintenance period can be maintained at the current level. Substantial – Substantial increase in traffic of heavy vehicles per day, resulting in more frequent maintenance and thus implies increased cost. Severe – In production scenario, increase in heavy traffic of up to 160 vehicles per day, increases the regularity and cost of maintenance.							

Impact	Scenario	Location (See Figure 18.3)	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Pressure on regional road infrastructure	Reference Case	Along major regional transport corridors with most probable impact.	Low	Very likely	Low	Low	Very likely	Low
	Exploration Only		Substantial	Very likely	Moderate	Moderate	Very likely	Moderate
	Small Gas		Substantial	Very likely	Moderate	Moderate	Very likely	Moderate
	Big Gas		Extreme	Very likely	Very high	Moderate	Very likely	Moderate
	Low – No additional increase in traffic and thus no additional maintenance required (See Table 18.3). Moderate – Increase in local road use, maintaining the frequency of maintenance at higher cost. With mitigation (i.e. better construction) the maintenance period can be maintained at the current level. Substantial – Substantial increase in traffic of heavy vehicles per day, resulting in more frequent maintenance and thus imply increased cost. Extreme – In production scenario, increase in heavy traffic of up to 160 vehicles per day concentrated on a few key roads which are currently in a poor condition, increases the regularity and cost of maintenance.							
Demand for new settlement development and associated local service delivery implications in towns and for on-site settlements	Reference Case	Existing larger regional service towns.	Low	Likely	Moderate	Low	Likely	Low
	Exploration Only	Larger regional service towns in area with most probable impact.	Moderate	Very likely	Moderate	Moderate	Very likely	Low
	Small Gas	Larger regional service towns in the area with most probable impact and Beaufort West as logistics hub. Scattered settlement impact.	Substantial	Very likely	Moderate	Moderate	Very likely	Moderate
	Big Gas	Larger regional service towns in the	Severe	Very likely	High	Moderate	Very likely	Moderate

<table>
<tr><th rowspan="2">Impact</th><th rowspan="2">Scenario</th><th rowspan="2">Location
(See Figure 18.3)</th><th colspan="3">Without mitigation</th><th colspan="3">With mitigation</th></tr>
<tr><th>Consequence</th><th>Likelihood</th><th>Risk</th><th>Consequence</th><th>Likelihood</th><th>Risk</th></tr>
<tr><td></td><td></td><td>most likely study area, with Beaufort West as logistics hub.
Scattered settlement impact.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="8">Reference Case: Low – Related to current growth rates and no SGD, the pressures on regional centres are low.
Exploration Only: Moderate – Increased migration and limited job growth will imply higher than normal growth rates of regional centre.
Small Gas: Substantial – Increased number of wellpads, construction related jobs and camps with increased in-migration expected will imply more scattered settlements through the area, increased direct and indirect activities related to SGD and associated logistics expected to impact growth in settlement and housing demand in Beaufort West specifically. Moderate with appropriate mitigation.
Big Gas: Severe – As above with increased indirect settlement and land use implications for housing, enterprise development and informal growth. Moderate with appropriate mitigation.</td></tr>
<tr><td rowspan="4">Spatial and development planning, land use management and governance capacity</td><td>Reference Case</td><td rowspan="4">Within all relevant municipalities, provinces and national departments in the study area</td><td>Moderate</td><td>Very likely</td><td>High</td><td>Low</td><td>Very likely</td><td>Low</td></tr>
<tr><td>Exploration Only</td><td>Extreme</td><td>Very likely</td><td>High</td><td>Moderate</td><td>Very likely</td><td>Moderate</td></tr>
<tr><td>Small Gas</td><td>Severe</td><td>Very likely</td><td>High</td><td>Moderate</td><td>Very likely</td><td>Moderate</td></tr>
<tr><td>Big Gas</td><td>Severe</td><td>Very likely</td><td>High</td><td>Moderate</td><td>Very likely</td><td>Moderate</td></tr>
<tr><td></td><td colspan="8">Reference Case: no additional pressure for land use applications, however given current lack of capacity the consequences are expected to be moderate without mitigation and low with mitigation applied.
Exploration Only: pressure for land use applications will increase, not only in terms of numbers, but also in terms of the complexity and the number of decision-makers involved. The consequences are expected to be extreme as there is no precedent, complexity of regulatory framework and current capacity constraints. The consequences are expected to be moderate with mitigation.
Small Gas: pressure for land use applications will also increase but given that the time period is longer, the larger numbers and complexity as above is expected but can benefit from lessons learned and adapting regulatory challenges. Thus, the consequences are expected to be severe. The consequences are expected to be moderate with mitigation.
Big Gas: the pressure for land use applications will increase exponentially due to production requirements, as well as expected land use change and growth in settlements. Thus, the consequences are expected to be severe. The consequences are expected to be moderate with mitigation.</td></tr>
</table>

18.4 Mitigation guidelines and monitoring requirements

18.4.1 Pro-active and integrated planning, prioritisation and budgeting

Inter-governmental Regional Planning: When considering the unique and cumulative (positive and negative) implications of the growing renewable energy market, the potential establishment of an uranium mine and SGD in the study area and the wider Karoo Region, it is proposed that the IGRFA, and the SPLUMA be used to enable the preparation of a Regional Spatial Development Framework (RSDF) for the area. It will also facilitate pro-active, coordinated intergovernmental planning between the respective local and district municipalities, provinces and relevant provincial, national sector departments, communities and business (including the Karoo Parliament), as well as other relevant institutions and state owned enterprises (such as ESKOM, the South African National Roads Agency Limited (SANRAL), SANRAIL, the South African National Biodiversity Institute (SANBI)) active in the area. Such an RSDF should 1) be aligned with the relevant Provincial Spatial Development Frameworks (PSDFs) and Municipal Spatial Development Frameworks (MSDFs), 2) systematically consider the status quo and existing guides and proposals for the area, as set out in relevant national, provincial and municipal plans, strategies, policies and frameworks, 3) make provision for a variety of futures, 4) craft a desirable future for the region, 5) allocate roles and responsibilities to the different spheres and sectors of government active in the area, and 6) be prepared in a consultative and collaborative manner under the auspices of the forum. It is expected that the forum will actively pursue continuous and meaningful engagement with civil society representatives, including representatives from existing and potential business interests in the area.

The RSDF and associated processes will address highly diverse, specialised and possible fluctuating governance, service delivery and capacity needs and challenges, as well as enable ‘inter-governmentally aligned’ responses from the magnitude of targets, plans, budgets, investment frameworks and projects driven by various sector departments and spheres of government in the area (see Figure 18.4). The development of a RSDF will provide a relevant medium term planning framework for five year municipal planning cycles, as well as timeous planning for projected demands and implications to ensure preparedness in terms of settlement, infrastructure and land development pipelines. In this way, government will be able to provide clear and consistent guidance and the required investment support to private sector and other development agents with regards to development for which very little if any president and/or capacity exist within the Karoo (and the rest of South Africa). The RSDF can inform national infrastructure investment and development spending programmes and schedules, the PSDFs of the affected provinces, and the MSDFs of the affected municipalities.

Essential long term spatial and integrated planning: The challenges and potential opportunities posed by activities related to potential SGD, as well as associated downstream development, clearly illustrate the need for sound IDP and SDF at municipal level. All spheres of government should participate in municipal IDP processes with SDFs providing guidance, as well as a spatial reflection on how, when and where all organs of state are to dispose of their budgets (i.e. planning led budgeting).

- Municipal IDPs and SDFs should be developed within the context of the RSDF, where the implications of demand modelling and projections of potential regional development, as well as likely town growth and decline and possible associated downstream development implications within the respective municipalities should be determined. For SDFs to play this role, it is critical that municipal SDFs be updated to cater for large scale development (such as SGD, uranium mining or expanded renewable electricity developments) and to inform the reprioritisation of budget allocations where and if required. In order to mitigate for this, provincial support to municipalities is essential. For coordinated spatial and delivery planning, local projects have to be planned in the context of regional and local SDFs and IDPs, as well as relevant sector plans (i.e. Plans for Housing; Disaster Management Plans; Integrated Transport Plans, etc.) to ensure timely provision for upgrading of the roads, as well as other infrastructure (rail and gas pipelines), housing, social services, etc. See also implications of potential SGD as identified within this assessment for example on tourism (Toerien et al., 2016), economic development (Van Zyl et al., 2016), enterprise development and social fabric (Atkinson et al., 2016).
- Given the infrastructure pipeline and associated time lines, the adaptation of sector plans is a crucial mitigation factor required for the planning, environmental clearance, land expropriation where necessary, design and procurement of new infrastructure, before construction starts. Examples include the need for applicants for unconventional shale gas exploration to develop a fluid transportation management plan to at least ensure planning to minimise fluid transport movements and distances, and the implementation of management procedures to address the risks associated with fluid transport – i.e. any transport of fluids must be in accordance with relevant legislation and national standards in a manner designed to prevent spillage.

18.4.2 Regional infrastructure network options

Mitigation and avoidance: One of the problems with road planning and maintenance in South Africa is that the jurisdiction over roads falls under several different authorities, each with its own competence, resources and prioritised budgets and implementation plans. For example, the N1 national route is managed by SANRAL, the N12 section within the Western Cape is managed by that province, R routes are managed by the respective provinces which they traverse, provincial authorities in various degrees provide support for local municipalities or even undertake road maintenance on their behalf especially of inter-town district and regional roads, district roads in the Western Cape are managed by the district municipalities' technical roads departments, and local roads are the responsibility of the respective local municipalities.

Railway: Continued use of a rehabilitated rail network, necessary rolling stock and improved logistics management for rail will be to benefit of the country as a whole (see Digital Addendum 18B). Given that size of loads carried by rail is limited by the height of the overhead power lines on electrified tracks as well as by the dimensions of bridges and tunnels rail transport of material and equipment required for SGD will require pro-active design, planning and implementation of a mode change and distribution facility in Beaufort West.

Pipelines: The potential use of pipelines for transport of gas for distribution or processing, for removal of waste and the import of fresh water will reduce the pressure on the road network. These pipelines can be developed alongside the road within the road reserve. After decommissioning pipelines can be flushed clean and used for alternative purpose. Pipeline use for transport of water can continue to be of use to the local community.

18.4.3 Maintenance of road infrastructure

Planning, resources and partnerships: One of the problems with determining the impact of the 'shale gas' heavy vehicles on the roads is to differentiate between the damage done by these vehicles and the normal deterioration that would have taken place without them. In most cases no historical rates of deterioration are available as a baseline for comparative purposes on specific roads. It may thus be necessary to identify similar roads in the area which do not carry any development vehicles and use these as a comparative basis. The alternative is to make use of the "social consciousness" of the developers to ensure that the local communities are constantly provided with high quality and well-maintained roads. It should be noted that, although road provision is expensive, the cost is infinitesimal compared with the overall cost of SGD and the presence of good roads has significant benefits in terms of reducing road user costs.

Baseline: To ensure efficient monitoring and checking of the impacts of the road traffic a baseline study to determine the current state of all roads is essential. A traffic count of heavy vehicles (together with their axle loadings) is also required in order to attribute responsibility for damage effectively if the shale gas companies are made responsible for maintaining roads in the current state. It is also expected that any critically poor roads be upgraded/rehabilitated or limitations placed on their use prior to being used for SGD activities.

Resources and materials: Mitigation of material loss from unpaved roads and high maintenance costs on paved roads requires careful road design and construction. For unpaved roads, selection of the best locally available material is essential to reduce maintenance and replacement costs. Although specifications for these materials are available, local materials may not always comply with these requirements and the corresponding performance will be poorer. It should be noted, however, that even with the best materials, construction must be of the highest quality to ensure good performance.

Similarly, with paved roads, the best available materials must be sourced and high construction standards (together with good drainage and overload control of vehicles) are essential. Because of the normal environmental requirements associated with the sourcing of the material required for road construction (often taking in excess of 18 months for a full approval by the Departments of Minerals and Energy (DME) and DEA), it is best that the initial material locations are identified and that such locations makes provision for sufficient material for replacement purposes as well.

One issue regarding resources is that natural gravels and construction materials are finite and their continued use is not sustainable. To mitigate this latter effect, more application/research is required with regard to less water-intensive building methods and the use of alternative materials. A possible alternative to consider is to locate and make use of industrial and mining wastes. Materials such as slag, fly-ash, bottom ash, waste foundry sands, etc. can often be used in roads, but these materials are probably only located in the Port Elizabeth area – there is little industrial or mining activity in the central Karoo areas. Haulage of these materials in the quantities required into the area under consideration would be both costly and time-consuming and would inevitably lead to additional deterioration of the regional road network. The use of local natural materials in the area, although neither environmentally nor socially sustainable, thus appears to be immutable. It can also be stated that it is possible to reduce water usage with careful construction practices, more expensive equipment, use of recycling machines and a skilled work force.

Partnerships for co-funding: In terms of local and regional roads, normal maintenance and construction procedures should be followed. It will be important, however, to identify which authorities are responsible for the various maintenance and upgrading operations. These could be national (SANRAL, Department of Transport or even Department of Public Works), provincial or municipal agencies. The relevant authorities need to be made aware of the possible developments that could affect their roads and their maintenance budgets. With regards to mitigating impact on roads, the concept of bonded roads has been set up in Pennsylvania where gas operators are required to maintain the road in at least as good a condition as they were at the start of SGD operations and maintain any damage induced by local traffic. Established best practice (similar to the concept of “bonded roads” used in Pennsylvania (Paige-Green, 2015)) in South African mining regions are partnerships where mining companies play a key role in maintaining municipal roads, i.e. in the case of Eskom in Ermelo (Hes, 2013). Given that extra traffic will lead to more frequent grader blading and re-gravelling on unpaved roads and to additional routine maintenance (potholes, cracking and edge-break) and a small increase in resealing frequency on paved roads necessary reconstruction will need to be negotiated with by SGD companies in a ‘maintenance co-funding agreement' similar to that between Mpumalanga Province and Eskom due to road damage from the transport of coal (SAnews.gov.za, 2013).

18.4.4 Monitoring and control of road use

In terms of mitigation, it will be essential to identify and document (with photographic evidence) the status quo of existing roads, including i.e. current traffic and road and bridge conditions, remaining life of roads, as well as problem areas, to be used as reference or datum points that can be used to allocate responsibility for any increased damage. This information will provide a base case scenario, which can be used to evaluate any accelerated deterioration, particularly if the assessment records extend back for a few years. Where pavement condition data is not available or up to date, this should be collected prior to initiation of any exploration or production, with photographs, videos and condition measurements (riding quality, pavement deflections, etc.) where appropriate. EIA requirements at the time of production will need to assess the specific impact on regional and local road and other infrastructure.

During the initial base line characterisation of the regional road infrastructure, certain roads may be in the latter stages of their effective lives and prone to rapid deterioration under the increased traffic. These will need to be identified and certain shale gas related traffic (say more than 3500 kg axle loads) excluded from using them (i.e. 'out of bounds'). The number of overloaded axles will need to be minimised and controlled – this is usually done by the need to obtain abnormal load permits for any vehicles with unusually heavy loads.

There is minimal overload control on non-SANRAL roads in South Africa. As the primary access to the area will be from the south on non-SANRAL roads, including the N12 which is already in an advanced state of deterioration, periodic checking of axle loads on these roads should be carried out. This should make use of at least Weigh-In-Motion (WIM) sensors but preferably portable scales or specially installed weighbridges. Portable scales are probably better as they can be procured from contractors on tender (not requiring much in-house capacity) and also can be randomly used on different roads to take into account intentional avoidance of routes with known overload control. WIM control is usually not sufficient to ensure effective prosecution, but requires the vehicles to be diverted to conventional weigh bridges. Calibrated portable weigh stations can usually be used for prosecution.

As indicated, tendering for vehicle-weighing systems requires minimal in-house capacity in the road authorities and is well within the ambits of the local road authorities. Prosecution of overloading offenders will require capacity among the traffic departments which probably exists already.

Weighbridges can be temporary/periodically implemented, especially when heavy equipment is coming in – possibly on the N12 somewhere and the R175.

Detailed evaluation of the risks of heavy vehicle traffic through the many mountain passes between the SGD area and coast at Mossel Bay and Port Elizabeth may be required and mitigation may include avoidance of certain passes and scenic routes which may be vulnerable.

18.4.5 Sustainable settlements and service delivery

Social services, facilities and bulk infrastructure: Given foreseen direct and possible migratory growth of towns, as well as foreseen growth in regional population and through-traffic, the demand for and access to social services (e.g. health, emergency services and education) and services amenities (sports and recreation facilities, education, libraries, home affairs offices) and utilities such as landfill sites, water treatment plants, energy and especially water resource demand will have to be considered over and above mere town extension. Projected growth of towns and regional service demands will be critical to support planning, budgeting, construction and/or upgrading of existing facilities and required service delivery. Implications of production on bulk infrastructure will need to be considered in relevant EIA closer to the time of production.

Sustainable on-site housing and service delivery: Minimising resource implications and risks with on-site development within the arid Karoo landscape will require making use of alternative technologies, environmentally sensitive and sustainable design of accommodation and buildings, utilisation of grey water and methodologies to enable sustainability, as well as on-site generation and use of renewable energy and food production where possible. EIA requirements will need to assess this in detail.

18.4.6 Effective and efficient land use management and regulatory environment

Regulatory uncertainty: Clarity and consistency of processes related to “land use applications” and “land use development applications” for SGD within the jurisdiction and legal contexts of the three affected provinces is critical and requires further legal input and assessment. As set out in Section 18.3 of this chapter, several risks with regards to the uncertainty of the regulatory framework to facilitate, guide and asses relevant land use change applications highlights the need to create regulatory certainty, which will imply setting in place the required institutional capacity (regulatory frameworks, strategies, human resources, skills, collaboration etc.). This particularly relates to the implementation of SPLUMA, especially at municipal level. It is proposed that an intergovernmental task team addresses this as a matter of urgency.

Municipal regulatory environment: The following steps will be needed to mitigate the risks arising out of the regulatory environment:

- It is proposed that the Northern and Eastern Cape Provincial Governments must take a leading role in rolling out municipal land use planning bylaws, and repealing old order provincial legislation (e.g. LUPO and the Northern Cape Planning and Development Act, Act 7 of 1998). They must also promulgate their own provincial planning and development legislation to ensure that SPLUMA can operate effectively.
- Support to provincial governments, especially in the Eastern and Northern Cape Provinces, to develop and/or model municipal planning bylaws that can be used to effectively regulate and manage land use change associated with potential SGD. This could possibly include the use of ‘zoning layers’ that can support municipal decision-making;
- Support to municipalities to establish Municipal Planning Tribunals, as required in terms of SPLUMA, either individually per municipality or jointly or at a district level (see Section 34 of SPLUMA). These tribunals can be set up to operate in more than one municipality, e.g. for a whole district, provided that the affected municipalities all agree to it;
- Support to municipalities to develop wall to wall land use management schemes (SPLUMA, Section 24(2)(a)), including land use zones that take into account the range of land uses likely to arise from SGD; and
- Support to municipalities to develop municipal spatial development frameworks (Section 20 of SPLUMA) and, where appropriate, regional spatial development frameworks (Sections 18 and 19 of SPLUMA).

In relation to each of the steps outlined above, coordinated capacity building and expansion of existing capacity (i.e. additional staff) will be needed (see Section18.4.7).

While government should understand the needs of the private sector and be responsible in terms of policy development and the administration regulatory processes (embedded), government must retain its independence and must not be captured by the vested interests of private sector. Care must therefore be taken in ensuring that governance systems assign accountability to decision-makers and are open and transparent.

18.4.7 Creating shared capacity to address regional service demands

The cost of improving the state of readiness of all spheres of government, especially municipalities, to deal with the implementation of potential SGD must be considered when evaluating the net economic impact of SGD on South Africa. It is anticipated that all spheres of government (especially municipalities) will struggle to handle the increased strategic planning and regulatory challenges without creating additional capacity. When referring to regulatory capacity, special mention should be made to the need for compliance monitoring and enforcement, as this will be one of the cornerstones for successful implementation of any SGD scenario. Unfortunately, local government in South Africa has a poor track record insofar as compliance monitoring and enforcement of legislation is concerned (See CoGTA, 2009a; 2009b). International best practice guidelines should be considered to address this challenge.

To achieve the above, it is recommended that 1) coordinated capacity building, and 2) the expansion of existing human recourse capacity (i.e. additional staff, shared skills and experience, capacity building) be addressed through the establishment of a 'shared services specialised unit'. Such a shared service unit is probably also more feasible given the anticipated extended timeframes and phased approach to potential SGD activities. An example of such a "shared specialised service" is the Planning Implementation Management Service (PIMS) centres that played a key role in providing a shared specialised service to support local and district municipalities with the development and institutionalisation of IDPs and IDP processes. Centres were staffed by consultants that reported to the former Department of Provincial and Local Government, or in some cases centres were hosted in district municipalities (Meiklejohn, 2003). Capacity building to support communities and local decision-makers to engage in relevant processes will be invaluable.

Figure 18.5: The critical role pro-active long term and regional planning instruments and capacity.

Managing increased traffic volumes and need for emergency services: Some of the critical key issues to be resolved are 1) how through traffic in towns such as Beaufort West will be addressed, i.e. by building a bypass or upgrading of internal roads; 2) the need to increase enforcement capacity to enhance traffic safety to improve safety especially on the N1 and to reduce damage to roads through overloading as well as to manage passing traffic within main towns; 3) the need to provide emergency incident response in the Karoo area, which is already far in excess of that required by the local population and locally generated traffic; 4) the need to further increase emergency response capacity in order to improve incident response capability to reduce fatalities at accident sites; and 5) the movement and parking of heavy freight vehicles passing, which is already creating traffic management demand in main towns such as Laingsburg, Beaufort West and Graaff-Reinet and which also requires the enhancement of local transport planning capacity to better serve existing community needs. Mechanisms such as development contributions to recover and mitigate for direct and indirect costs to municipalities will need to be considered, especially given the incremental approach within activities associated with the Exploration Only and Small Gas scenarios. International case examples and proposals are addressed in Van Zyl et al. (2016).

Capacity development, training and empowerment: One of the major mitigation factors critical to planning, implementation, monitoring and adaptation will be the capacity of the relevant settlement planning, service delivery, integrated planning and other authorities in the area. Building capacity and expanding numbers of planners in municipalities could address this, but this requires resources, may not be done to the extent to which it has to be due to funding constraints and skills availability, and takes time to ensure the desired results. In addition to this, data on shale activities and mining output is hard to come by, and will be need to be sourced, supplied and regularly updated. In order to deliver on this mandate, local planning officials will have to be capacitated and informed to provide the necessary enabling and regulatory services. The role and support of the South African Local Government Association (SALGA), Department of Cooperative Government and Traditional Affairs (DCOG), research councils, academia and local civil society led initiatives such as the Karoo Parliament can be solicited in support of the respective provincial governments. The important role of Non-profit Organisations (NPOs) in social collaboration initiatives in facilitating certain processes are dealt with in Atkinson et al. (2016) which outlines the social context and addresses the impacts on the social fabric. “Sister” agreements with municipalities that have experience of SGD could also be considered in support for municipal preparedness.

Regional specialist capacity: The following will be required:

- specialist support for baseline studies;

- specialist studies and dedicated capacity to support SDF and land use management scheme development, with possible appropriate zoning layers for multiple purposes (considering a variety of legal considerations);
- specialist studies and advice in considering land use applications. There is scope in terms of SPLUMA for a municipality to appoint technical advisers to a municipal or 'shared' planning tribunal to assist with more complex decision-making;
- special studies to determine relevant development contributions related to impact on infrastructure and services;
- specialist support with adaptation of sector plans and strategies;
- monitoring and control, which includes support and control of land use practices;
- processes to be followed with decommissioning; and
- the establishment of a dedicated task team.

Details regarding specialist capacity requirements should be provided for in relevant environmental impact assessment processes and management plans.

A regional specialist capacity can also be considered to provide specialist services that will be required to assess applications, assist with pro-active planning, monitoring and control of impacts on land uses and activities within areas to be effected by SGD, including for example specialists related to air quality (Winkler et al., 2016), waste planning and management (Oelofse et al., 2016), heritage (Orton et al., 2016), noise pollution (Wade et al., 2016).

Transportation of hazardous material: In addition to appropriate emergency services and the development of a fluid transport management plan, it will be critical that the general workforce, including drivers, must receive appropriate training and be equipped to respond to emergencies and implement clean-up measures, as required by-law (see MPRDA and relevant regulations regarding transportation of fluids). The possibility to make use of a regional landfill site instead of long distance hauling of fracking liquid could also be considered.

18.5 Gaps in knowledge

There is a need for a baseline study and set of findings regarding road conditions and impact. Baseline road condition data and on-going traffic volume studies are essential to attribute responsibility for negative road impacts. This may prove highly contentious if several different companies are granted mining rights in the area.

There are substantial information gaps as to the state of land use management instruments, such as land use management schemes, in the region. Similarly, there are few, if any, strategic environmental assessments on which decision-makers can rely for decision-making. The quality of many MSDFs is very weak, especially in the smaller municipalities. There is thus in general; 1) a shortage of information on which decision-makers can rely when making land use and spatial planning decisions, and 2) a lack of clarity regarding the regulatory implications of incremental exploration and associated wellpad development and local access road construction.

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18.8 Digital Addenda 18A – 18B

SEPARATE DIGITAL DOCUMENT

Digital Addendum 18A: Tabulated detailed information
Digital Addendum 18B: Maps

DIGITAL ADDENDA 18A – 18B

Digital Addendum 18A: Tabulated detailed information

Table 18A: Cost and gravel requirement for roads impacted.

Cost and gravel requirement for roads impacted

Road type		Scenario 0			Cost to rehabilitate to required base standard*	Scenario 1			Scenario 2			Scenario 3		
Paved roads														
Routine maintenace cost per km		**R 100 000**				**R 110 000**			**R 110 000**			**R 125 000**		
Reseal frequency in years			**10 years**				**9 years**			**9 years**			**7 years**	
	Road length													
			Cost R million				**Cost R million**			**Cost R million**			**Cost R million**	
		Routine	**Periodic**			**Routine**	**Periodic**		**Routine**	**Periodic**		**Routine**	**Periodic**	
Port Elizabeth - Victoria West	442	R 33.2	R 30.9		R1.1 bn	R 36.5	R 34.4		R 36.5	R 34.4		R 41.4	R 44.2	
Victoria West - Three Sisters	61	R 6.1	R 4.3			R 6.7	R 4.7		R 6.7	R 4.7		R 7.6	R 6.1	
Beaufort West (R61 via Aberdeen)- to Junction of R75 near Kleinpoort	288	R 21.6	R 20.2		R720m	R 23.8	R 22.4		R 23.8	R 22.4		R 27.0	R 28.8	
Fraserburg - Beaufort West	30	R 3.0	R 2.1			R 3.0	R 2.1		R 3.3	R 2.3		R 3.8	R 3.0	
Graaff Reinet - Hofmeyer via R421	169	R 16.9	R 11.8			R 16.9	R 11.8		R 18.6	R 13.1		R 21.1	R 16.9	
		R 80.8	R 69.3	R 150.1	**R 1.82 bn**	R 86.9	R 75.4	R 162.3	R 88.9	R 76.9	R 165.8	R 100.9	R 99.0	R 199.9
Additional annual cost: Paved roads								**R 12.2**			**R 15.7**			**R 49.8**
Unpaved roads														
		Routine	**Periodic**	**Gravel /m3/yr**		**Routine**	**Periodic**	**Gravel /m3/yr**	**Routine**	**Periodic**	**Gravel /m3/yr**	**Routine**	**Periodic**	**Gravel /m3/yr**
Routine maintenace cost per km (Rand)		**750**	**300 000**			**825**	**300 000**		**825**	**300 000**		**1 000**	**300 000**	
Regravel frequency				**7 years**				**6 years**			**6 years**			**4 years**
		Baseline (cost in R million)				**Additional (cost in R million)**			**Additional (cost in R million)**			**Additional (cost in R million)**		
Fraserburg - Beaufort West	120	R 0.090	R 5.143	20 571					R 0.099	R 6.000	23510	R 0.030	R 2.250	22775
Sweet Spot	1273.61	R 0.955	R 54.583	218 333		R 0.263	R 2.729	226 130	R 0.525	R 31.840	233928	R 1.274	R 95.521	311904
All roads in 30 km buffer of Beaufort West-Fraserburg (excl main route above)	1624	R 1.218	R 69.600	278 400					R 0.167	R 10.150	283371	R 0.406	R 30.450	308229
All roads in 30 km buffer Graaff Reinet -Hofmeyer (R421)	2512	R 1.884	R 107.657	430 629					R 0.259	R 15.700	438319	R 0.628	R 47.100	476768
Total routine and periodic		R 4.1	R 237.0			R 0.3	R 2.7		R 1.1	R 63.7		R 2.3	R 175.3	
Total maintenance costs			R 241.1				R 3.0			R 59.4			R 177.6	
Total gravel lost per year (m3)				947 933				955 730			976 556			1 119 676
Change in gravel lost (m3/year)				0				7 797			28 623			171 743

* Assumption: To maintain a reasonable routine and periodic maintenaince routine will require that roads are re-habilitated to a reasonable standards. Assumption is that 50% of road needs rehabilitaion at R 5m/ km. Typical state of paved roads in Eastern Cape

Note: All costs exclude inflation and are based on current cost

Roads Impacted

Scenario 0 : No roads impacted. Routine and periodic maintenace with resealing every 10 years continues at normal frequency excludes any portion resealed as mitigation.

Scenario 1: All paved roads (excluding the Fraserberg & Hofmeyer links & 25% of all gravel roads in sweet spot). Routine and periodic maintenace with resealing continues with increase in frequency to 9 years -excludes portion resealed.

Scenario 2: All paved roads plus 50% of gravel roads in sweet spot and about 12.5% of other gravel roads. Routine and periodic maintenace with resealing continues with increase in frequency to 9 years- excludes portion resealed.

Scenario 3: All paved roads plus 100 % of gravel roads in sweet spot and 25% of other gravel roads. Routine and periodic maintenace with resealing continues with increase in frequency to 7 years -excludes portion resealed.

Digital Addendum 18B: Maps

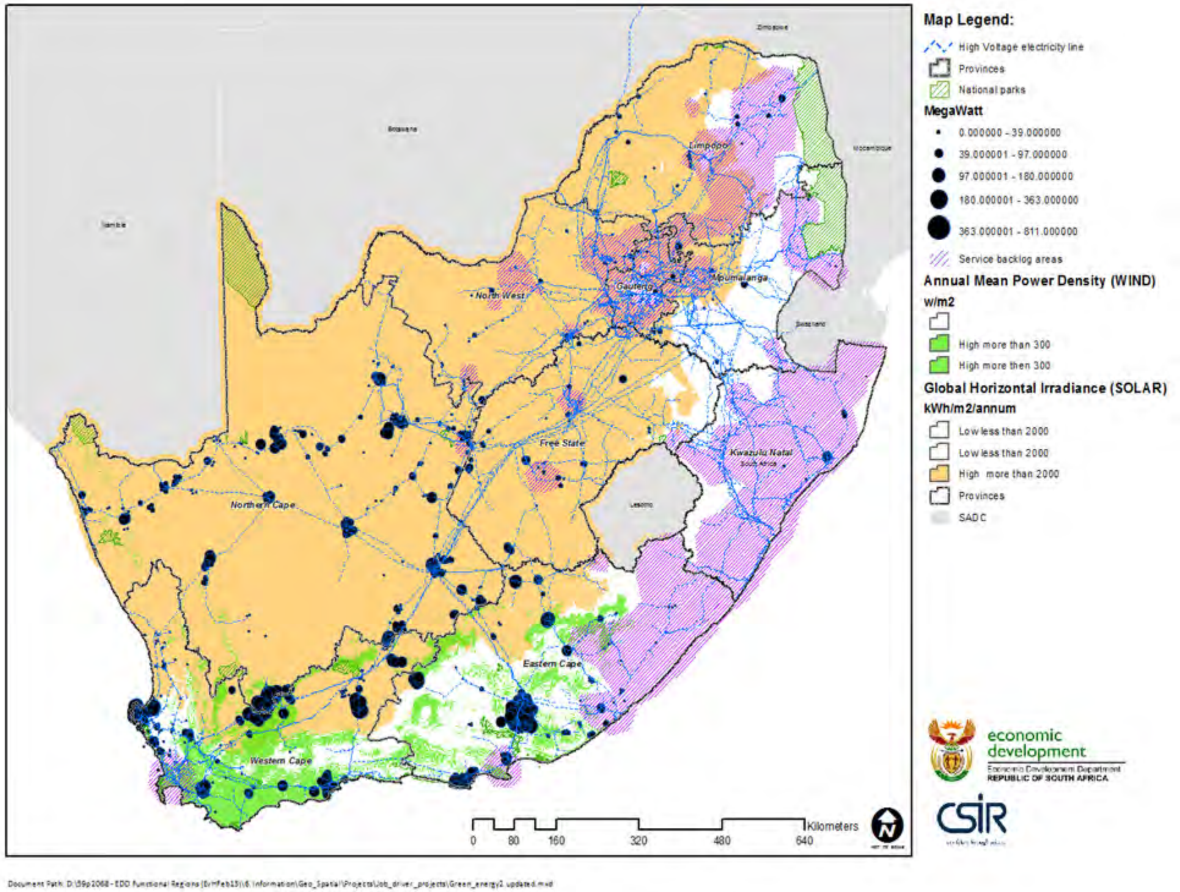

Figure 18B(i): Overview of Regional Green Energy Projects in the application pipeline (2014).
SOURCE: Van Huyssteen, E., Maritz, J. Oranje, M., Jordaan, A. Rogerson, C., Loots, A., Green, C. and McKelly, D. 2014. Resource Document: Towards Spatial Perspectives in support of the NGP. Unpublished working paper prepared for the Department of Economic Development, South Africa.

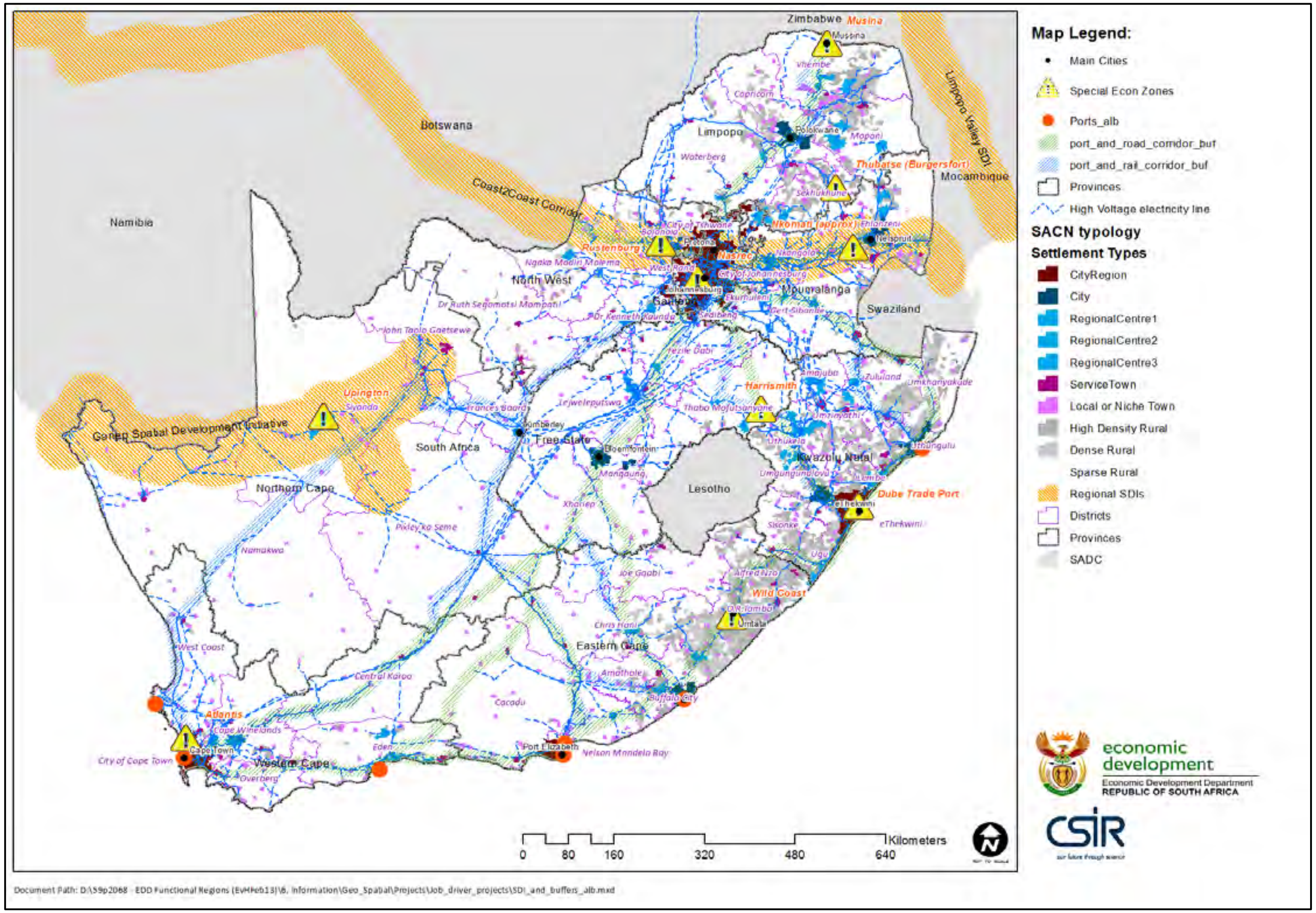

Figure 18B(ii): Overview of key national infrastructure corridors 2014.

SOURCE: Van Huyssteen, E., Maritz, J. Oranje, M., Jordaan, A. Rogerson, C., Loots, A., Green, C. and McKelly, D. 2014. Resource Document: Towards Spatial Perspectives in support of the NGP. Unpublished working paper prepared for the Department of Economic Development, South Africa.

APPENDIX 1

Glossary of Terms

Glossary	Explanation
Annulus	Empty space between the sidewall of a borehole or well and any material or equipment inserted into the bore. If the bore is fitted with casing, then it is the space between the natural sidewall of the bore and the outer surface of the casing. During drilling operations, it is the space between the drill string and the nearest inner surface of the hole being constructed. If the borehole is fitted with a pump or other instrumentation, it is the space between this equipment and the nearest inner surface of the borehole. The annular space, and in particular the space between the casing and the natural sidewall of the bore, may be filled with various types of material to serve specific purposes, e.g. with gravel to form a gravel pack or filter pack, or with cement grout to form a seal.
Additive (chemical)	A product composed of one or more chemical constituents that are added to a primary carrier fluid to modify its properties in order to form hydraulic fracturing fluid.
Aquifer	Part of a formation, a formation or a group of formations that in the natural environment is/are capable of both storing and transmitting groundwater, by virtue of possessing sufficient saturated and interconnected porous and/or permeable material, directly to a borehole, well or spring in sufficient quantities for an intended use. The porous and/or permeable material may comprise intergranular openings (pores), or one or a system of interconnected fissures, fractures and/or joints, or a combination of these features.
Base fluid	Any drilling fluid that must act as a mixing agent and carrier fluid during the process of hydraulic fracturing.
Baseflow	Portion of water flowing in a river or stream that derives from groundwater. It is generally best represented during the dry season when there is little or no rainfall and associated surface water runoff.
bbl	Barrel — 42 US gallons (approximately 160 litres).
Bcf	Billion cubic feet (approximately 28.3 million m^3).
Biocide	Also known as a "bactericide." An additive in the hydraulic fracturing fluid that kills bacteria.
Biome	A broad ecological unit representing major life zones of large natural areas defined mainly by vegetation structure, climate as well as major large-scale disturbance factors (such as fire).
Blowout	An uncontrolled flow of gas, oil or water from a well during drilling caused when high formation pressure is encountered.
Borehole	Typically a vertical hole usually made by drilling into rock formations to investigate various properties, such as whether the rock contains any groundwater and, if so, the quantity and quality of the water. Although the diameter may range from less than 50 mm to more than 400 mm, a typical water borehole is completed at a drilled diameter of 165 mm. Its depth may vary from only a few metres to hundreds of metres, the maximum depth generally being determined by such factors as the specific purpose of the borehole, the technical capacity of the drilling machinery and equipment, and the cost. Most commonly used for water supply purposes, other applications of a borehole include the monitoring of groundwater levels and quality in an environmental context, to serve as structures for artificial recharge purposes, and the exploration for minerals or other natural materials and substances.
Bossieveld	Local karoo term for arid shrubland consisting mostly of Asteraceae, Aizoaceae and grass
Brack water	South African term for saline water (TDS >1 000 mg/L)
Breaker	A chemical used to reduce the viscosity of a fluid (break it down) after the thickened fluid has finished the job it was designed for.

Glossary	Explanation
Brine	Water (either displaced from the geological formation or generated from the fracturing fluids used during hydraulic fracturing) which contains very high levels of dissolved solids (TDS >35 000 mg/L, i.e. more saline than sea water)
BTU	British Thermal Unit — equivalent to 1 055 joules.
Carrier fluid	The base fluid, such as water, into which additives are mixed to form the hydraulic fracturing fluid which transports proppant.
Casing	Pipe-like material used in the construction of a borehole or well to line the bore. As the purpose of fitting a bore with casing includes protection of the sidewall against collapse, the strength of the casing must be sufficient to withstand reasonable lateral pressure. Certain drilling methods may also require the casing to withstand vertical pressure exerted by downward (compressional) forces when inserting the casing and upward (tensional) forces when retrieving the casing. Although casing strength is determined mainly by the type of material (e.g. steel compared to uPVC), the thickness of the sidewall also contributes to the inherent strength of the casing, i.e. the greater the sidewall thickness, the stronger the casing.
CCGT	Combined-cycle Gas Turbine electric power station.
Cement / cementing	Material used to seal off formations and to stabilise the casing used in the well bore. Cement seals the annulus between the casing and the well bore sidewall, thus preventing the vertical migration of fluids in this space.
Ceramic proppant	A proppant (see proppant) that is composed of a ceramic material.
Chemical constituent	A discrete chemical with its own specific name or identity, such as a CAS Number, which is contained within an additive product.
Completion (well)	The activities and methods of preparing a well for extraction after it have been drilled to the target formation. This principally involves preparing the well to the required specifications; running in extraction tubing and its associated down hole tools, as well as perforating and stimulating the well by the use of hydraulic fracturing, as required.
Compressor	A facility which increases the pressure of natural gas to move it in pipelines or into storage.
Condensate	A low-density, high-gravity liquid hydrocarbon phase that generally occurs in association with natural gas. Its presence as a liquid phase depends on temperature and pressure conditions in the reservoir allowing condensation of liquid from vapour.
Contamination	Term used synonymously with pollution to describe the potential for activities associated with shale gas development to impact negatively on the environment in its broadest sense, i.e. whether aesthetically (visual disturbance, social disturbance, economic disturbance, etc.) or physically (atmospheric pollution, water pollution, noise pollution, etc.)
Conventional gas	In contrast to unconventional gas, conventional gas is trapped within a permeable rock reservoir, which in turn is overlain by a layer of impermeable rock (AfDB, 2013).
Corrosion inhibitor	Chemical agents that protect iron and steel from corrosive acid
Cross- linker	A compound, typically a metallic salt, mixed with a base-gel fluid, such as a guar-gel system, to create a viscous gel used in some stimulation or pipeline cleaning treatments. The crosslinker reacts with the multiple strand polymer to couple the molecules, creating a fluid of high viscosity.
Darcy	A unit of permeability. A medium with a permeability of 1 Darcy permits a flow of 1 cm^3/s of a fluid with viscosity 1 cP (1 mPa•s) under a pressure gradient of 1 atm/cm acting across an area of 1 cm.

Glossary	Explanation
Directional drilling	Deviation of a bore from the vertical during drilling so that it penetrates and follows a productive formation.
Distribution	Refers to the process whereby natural gas and associated products are conveyed to an end user through a local pipeline system; these pipelines are smaller in diameter in comparison to transmission pipelines (Branosky et al., 2012).
Drill bit	Tool at the leading (bottom) end of a drill string which cuts or crushes the rock in order to advance the depth (length) of the bore during drilling. The type of drill bit used, e.g. button bit, tricone bit or chisel bit, is dictated by the drilling method employed.
Drilling fluid	Describes any substance or mixture of substances applied during and used to facilitate the drilling process. Examples include the foam produced by mixing compressed air and “soapy” water (surfactant) in the case of rotary percussion drilling, and the mud-like substance produced by mixing certain chemicals with water in the case of rotary mud drilling. The drilling fluid serves five main functions, namely (1) to lubricate the drill bit, (2) to enhance the removal of drill cuttings from the borehole, (3) to support the borehole sidewall against collapse, (4) to combat the loss of fluid from the bore into the formation, and (5) to control the pressure in the bore during drilling.
Drilling mud	A thick viscous fluid normally prepared at the drill site by mixing water with materials (e.g. bentonite clay) and chemicals to enhance various characteristics of the fluid such as gel strength and density. This multipurpose mixture serves to lubricate the drill bit, block pores and minor fractures to minimise or prevent fluid loss from the bore and contamination of water resources, and prevent unexpected influxes of oil or gas from the formations penetrated.
Dry gas	Natural gas that occurs in the absence of condensate or liquid hydrocarbons, or gas that has had condensable hydrocarbons removed. Dry gas typically has a gas-to-oil ratio exceeding 100 000 scf/STB. The production of liquids from gas wells complicates the design and operation of surface process facilities required to handle and export the produced gas.
Dutch Disease	Economic term for over-strengthening of the exchange rate as a result of major natural resource discoveries and development
Ecological infrastructure	Ecological infrastructure means naturally functioning ecosystems that generate or deliver valuable services to people. It is the nature-based equivalent of built or hard infrastructure, and is just as important for providing services and underpinning socio-economic development. (SANBI, 2013)
Economically recoverable reserves	Technically recoverable petroleum for which the costs of discovery, development, extraction, and transport, including a return to capital, can be recovered at a given market price.
Ecosystem	A complex set of relationships of living organisms functioning as a unit and interacting with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire earth.
Endemic	A plant or animal species or a vegetation type which is naturally restricted to a particular, defined region.
Environmental impact assessment (EIA)	A public process by which the likely effects of a project on the environment are identified, assessed and then taken into account by the consenting authority in the decision-making process. This serves as a tool to facilitate sustainable development.

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Environmental impact assessment (EIA)	A public process by which the likely effects of a project on the environment are identified, assessed and then taken into account by the consenting authority in the decision-making process. This serves as a tool to facilitate sustainable development.
Estimated ultimate recovery	Estimated ultimate recovery refers to the expected cumulative output of a given unconventional gas well. Estimated ultimate recovery may differ between wells depending on the underlying geology, whether a well is located in a 'sweet spot' i.e. where output is particularly high, or the degree to which advanced technologies in drilling and completing wells have been applied (IEA, 2012).
Exploration	Exploration typically refers to activities to locate subsurface reservoirs of water, gas (conventional and unconventional) and/or oil. Exploration may involve seismic exploration, surface mapping and exploratory drilling, and the use of equipment such as magnetometers, seismic streamers and sound array guns or gravity meters (Branosky et al., 2012).
Exploration right	A right granted to the applicant in terms of section 80 of Mineral and Petroleum Resources Development Act 28 of 2008 (MPRDA) to reprocess the existing seismic data, acquisition and processing of new seismic data or any other related activity to define a trap to be tested by drilling, logging and testing, including extended well testing, of a well with the intention of locating a discovery.
Extraction	Extraction as used in this report refers to all types of unconventional oil and gas extraction, thus to both shale gas (regulated under petroleum resource exploitation (Chapter 6 of the MPRDA) as well as coalbed methane (regulated under mining (Chapter 4 of the MPRDA)).
Extraction	Extraction as used in this report refers to all types of unconventional oil and gas extraction, thus to both shale gas regulated under petroleum resource exploitation (Chapter 6 of the MPRDA) as well as coalbed methane regulated under mining (Chapter 4 of the MPRDA).
Fault	A fracture or fracture zone in a geological formation along which there has been displacement of the sides relative to each other.
Flare	The burning of excess or unwanted gas from a well.
Flaring	Flaring involves intentionally burning methane over an open flame as it is released, as this reduces the carbon content by converting the methane to carbon dioxide (Barcella et al., 2011).
Flowback	Fluid returned to the surface after hydraulic fracturing has occurred, but before the well is placed into production. It typically consists of returned fracturing fluids in the first few days following hydraulic fracturing which are progressively replaced by produced water.
Fold	A bend in geological rock strata.
Formation	A rock body distinguishable from other rock bodies and useful for geological mapping or description. Formations may be combined into groups or subdivided into members.
Fracking, fraccing or fracing	Informal terms for "Hydraulic Fracturing".
Freshwater aquifer	Groundwater resource that contains potable water and could potentially be used to supply drinking water.
Fugitive emissions	Fugitive emissions denote gas losses from the upstream natural gas system (i.e. losses as a result of equipment leaks, venting and flaring). In this report, the term does not cover those GHG emissions associated with fuel combustion during the shale gas life cycle. Another term for fugitive emissions is 'methane leakage'. This definition stems from Day et al. (2012).

Glossary	Explanation
Gas in place	Gas determined to occur in shale layers but of which the productive volumes have not been established by means of hydraulic fracturing.
Gathering lines	Small diameter pipelines that move gas from the production field to a transmission line.
Global Warming Potential	Global Warming Potential is a common metric used to quantify and communicate the relative and absolute contributions to climate change of certain substances by accounting for the respective radiative efficiencies of these substances and their lifetimes in the atmosphere, and providing values relative to those for the reference gas carbon dioxide (IPCC, 2013).
Green completions	Green completion is considered good practice during the flow back period. Green completion (also referred to as reduced emissions completion) refers to the process whereby hydrocarbons are separated from the flow back prior to being sold, as opposed to being flared or vented into the atmosphere, and remaining flow back fluid is collected for processing and recycling or disposal. The capture and sale of gas during the initial flow-back phase requires investment in gas separation and processing facilities (IEA, 2012).
Greenhouse gas	These are gases (including water vapour, carbon dioxide and methane) that trap energy radiated from the Earth's surface in the atmosphere to produce warming (the greenhouse effect).
Groundwater	Water contained in and completely saturating the interstices that occur below the ground surface in unconsolidated and consolidated rock formations. It excludes water that is in the process of moving downward (infiltrating) from the surface through the unsaturated zone. Most commonly derived from and associated with meteoric (atmospheric) water, it also includes juvenile water and connate water.
GTL	The process of converting natural gas into synthetic liquid hydrocarbons — Gas-To-Liquids.
Horizontal drilling	Deviation of a bore from the vertical to penetrate and follow sub-horizontal bedded strata.
Hydraulic conductivity	Describes the ability of saturated material to transmit a fluid (most commonly water) on the basis of both the nature of the saturated material and considering the influence of properties such as the density and dynamic viscosity of the fluid. It is typically expressed in the unit metres per day (m/d). Less commonly referred to as coefficient of permeability or seepage coefficient, terms typically used in the petroleum industry where the fluids of interest include oil and gas, it is not to be confused with the term permeability.
Hydraulic fracturing	The act of pumping hydraulic fracturing fluid under pressure into a formation to increase its permeability. Hydraulic fracturing has been used in the industry in various forms, for either stimulation of water boreholes to produce water, or for stimulation of oil and gas wells to produce oil and/or gas.
Hydraulic fracturing fluid	Fluid used to perform hydraulic fracturing; includes the primary carrier fluid, proppant material, and all applicable additives.
Hydrocarbon	A naturally occurring organic compound comprising hydrogen and carbon. Hydrocarbons can be as simple as methane [CH4], but many are highly complex molecules, and can occur as gases, liquids or solids. The molecules can have the shape of chains, branching chains, rings or other structures. Petroleum is a complex mixture of hydrocarbons. The most common hydrocarbons are natural gas, oil and coal.

Glossary	Explanation
Life cycle assessment	A Life Cycle Assessment (LCA) is the assessment of the consecutive and interlinked stages of a system from which a product is produced from the acquisition or generation of a given raw material to its end of life. In the case of an LCA pertaining to GHG emissions from hydraulic fracturing the assessment may include calculating emissions from the production and transportation of material involved in the well development activities; emissions from fuel consumption for powering the drilling and fracturing equipment; fugitive emissions and fuel combustion emissions associated with gas production, processing, transmission, distribution, and natural gas combustion (Bradbury et al., 2013; Branosky et al., 2012).
Life cycle assessment	A Life Cycle Assessment (LCA) is the assessment of the consecutive and interlinked stages of a system from which a product is produced from the acquisition or generation of a given raw material to its end of life. In the case of an LCA pertaining to GHG emissions from hydraulic fracturing the assessment may include calculating emissions from the production and transportation of material involved in the well development activities; emissions from fuel consumption for powering the drilling and fracturing equipment; fugitive emissions and fuel combustion emissions associated with gas production, processing, transmission, distribution, and natural gas combustion (Bradbury et al., 2013; Branosky et al., 2012).
Liquids unloading	Liquids which could slow well production in mature wells are removed from the wellbore either through the use of a down-hole pump or through a reduction of wellhead pressure (Branosky et al., 2012).
Methane	The simplest hydrocarbon molecule, consisting of four atoms of hydrogen bonded to a single atom of carbon expressed by the formula CH_4.
Natural gas	Hydrocarbon gas consisting primarily of methane and existing naturally in subsurface formations. Marsh gas is the equivalent in surface environments.
Naturally Occurring Radioactive Material	Radioactive material that occurs naturally in rock formations such as certain shales, and where human activity such as drilling may increase the chances of exposure from drill cuttings and other wastes from a well, compared with the unaltered situation.
Perforate (well casing)	To make holes through the casing to allow the oil or gas to flow into the well or to squeeze cement behind the casing.
Permeability	A measure of the ability of a fluid to move through pores, fractures or other openings in a rock. The unit for measurement is Darcy.
Plateau	An area of highland, usually consisting of relatively flat terrain.
Play	The prospective geographic area where oil and gas could potentially be commercially developed and extracted.
Plug	A temporary or permanent measure taken to seal off a portion of the well by plugging the bore or casing with material such as cement or steel, and which is pressure tested once installed to establish its integrity.
Pneumatic controllers	Pneumatic controllers are responsible for regulating gas flow and pressure, liquid levels and automatically operating valves in the separator, gas dehydrator, and compressor (Harvey et al., 2012).
Polymer	Chemical compound of unusually high molecular weight composed of numerous repeated, linked molecular units.
Porosity	Property describing the capacity of soil and rock containing interstices (pores) to store fluids, generally expressed as the volume of pore space per cent of the total bulk volume of the rock.

Glossary	Explanation
Prime mover	Refers to a device which transforms energy from thermal to electrical or vice versa, or pressure to/ from mechanical form. A prime mover is typically an engine or turbine that powers the drilling rig (Broderick, 2011; AEA, 2012).
Produced water	Fluids displaced from the geological formation, which can contain substances that are found in the formation, and may include dissolved solids, gases (e.g. methane, ethane), trace metals, naturally occurring radioactive elements (e.g. radium, uranium), and organic compounds.
Production	Production refers to the primary production phase, once wells have been connected to processing facilities. Hydrocarbons and waste streams are produced by wells during this phase.
Production casing	The final string of casing used to access the reservoir for extracting fluids. Production casing is placed inside other casings.
Production right	A right granted to the applicant in terms of section 84 of the MPRDA to the applicant to conduct any operation, activity or matter that relates to the exploration, appraisal, development and production of petroleum.
Production well	A well that is sunk for producing oil and gas.
Proppant or propping agent	Material, usually sand or ceramic particles, carried by the fracturing fluid into a fracture to keep it open when hydraulic pressure is released.
Proved reserves	The quantity of energy sources estimated with reasonable certainty, from the analysis of geologic and engineering data, to be recoverable from well-established or known reservoirs with the existing equipment and under the existing operating conditions.
PSI	Pounds per square inch — a unit of pressure (Imperial system).
Recharge	Process whereby some portion of the rainfall on a landscape infiltrates the subsurface to replenish groundwater resources. The quantity varies both spatially and temporally, depending on various factors such as vegetation cover, the nature of the soil profile and underlying geologic strata, the depth to water table, and the magnitude and intensity of rainfall. It is typically expressed as a per cent of the mean annual precipitation.
Reservoir (oil or gas)	A subsurface, porous, permeable or naturally fractured rock mass in which oil or gas has accumulated. A gas reservoir consists only of gas plus fresh water that condenses from the flow stream reservoir.
Reservoir pressure	The pressure within the reservoir rock.
Reservoir rock	A body or mass of rock that may contain oil or gas in appreciable quantity and that has sufficient porosity and permeability to store and transmit these products.
Reservoir stimulation	A class of activities intended to improve the productivity of oil and gas wells. This includes the injection of various chemicals (depending on the nature of the reservoir) at pressures below the fracture pressure of the rock to dissolve material that may be restricting flow from pore to pore, and as a separate subset, the fracturing of reservoirs to create new flow paths by the injection of fluids at pressures above the fracture pressure of the rock and at rates sufficient to sustain the propagation of the new fracture system (DMR, 2012).
Sandstone	A variously coloured sedimentary rock composed chiefly of sand-sized mineral grains (usually quartz) cemented by carbonate, silica, clay or other materials.
Scale inhibitor	A chemical substance which prevents the accumulation of a mineral deposit (for example, calcium carbonate) that precipitates out of water and adheres to the inside of pipes, heaters, and other equipment.

Glossary	Explanation
Sedimentary rock	Rock formed either from sediment transported in water (alluvial, fluvial), wind (aeolian) or ice (glacial) from its source and that accumulates by deposition and solidifies by cementation and compaction (e.g. sandstone, siltstone, mudstone), or from chemical precipitation of dissolved mineral constituents in water (e.g. limestone).
Seismic survey	A method of finding oil and natural gas by measuring the time it takes sound waves to travel through layers of the earth, reflect off of potential reservoir strata, and return to surface.
Shale	A fine-grained sedimentary rock composed mostly of compacted clay, silt or mud, and typically exhibits a laminated and cleavable appearance.
Shale gas	Natural gas that remains tightly trapped in shale and consists chiefly of methane, but with ethane, propane, butane and other organic compounds mixed in. It forms when black shale has been subjected to heat and pressure over millions of years, usually at depths of 1,500 to 4,500 metres below ground level.
Shale gas development	Refers to both exploration and production related activities; as well as downstream gas utilisation scenarios.
Siltstone	Rock in which the constituent particles are predominantly silt size.
Site remediation	Site remediation, i.e. efforts to restore the well site to its pre-drilling state, is performed after well closure (Branosky et al., 2012).
Square Kilometre Array (SKA)	Square Kilometre Array — internationally funded radio telescope to be constructed in the vicinity of Carnarvon, Northern Cape.
Stimulation	The act of increasing a well's productivity by artificial means such as hydraulic fracturing or acidizing.
Storage	Storage refers to the short- or long-term containment of natural gas either locally (in high pressure pipes and tanks), or underground in naturally occurring geological reservoirs which may include salt domes or depleted oil and gas fields (Branosky et al., 2012).
Storativity	The capacity of an aquifer to store water.
Stratigraphic well	A well that is sunk for determining the stratigraphy during oil and gas exploration.
Sustainable development	Generally defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable development is based on sociocultural development, political stability and decorum, economic growth and ecosystem protection, which all relate to disaster risk reduction. The National Environmental Management Act 107 of 1998 defines sustainable development as "the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations".
Target formation	The reservoir that the driller is trying to reach when drilling the well.
Tcf	Trillion cubic feet (approximately 28.3 x 10^9 m^3). A typical benchmark for initial assessments of the economic potential of a gas accumulation.
Technically recoverable reserves	The proportion of assessed in-place oil or gas that may be recoverable using current recovery technology, without regard to cost.
Thermal maturity	Of organic matter acting as source for the generation of hydrocarbons. Referenced to the reflectivity of particles of vitrinite amongst the organic matter. Progresses with time and temperature from immature to the 'oil window', then the 'gas window' to overmature. The 'windows' are named after the main type of hydrocarbon being generated. The boundaries/edges of the windows are gradational.
Tight reservoirs	Formations such as shales and some sandstones that do not have enough natural permeability to allow hydrocarbons to flow through the unstimulated rock mass.
Total dissolved solids	The quantity of dissolved material in a given volume of water.

Glossary	Explanation
(TDS)	
Transmission	The physical transferal of gas from single or multiple sources of supply, to single or multiple points of delivery (Branosky et al., 2012).
Transmissivity	Defines the rate of flow of water under a unit hydraulic gradient through a vertical strip of aquifer one unit wide and extending the full saturated thickness of the aquifer. The reporting unit is typically square metres per day (m^2/d). Increasingly smaller values represent increasingly impermeable conditions.
Unconventional gas	Unconventional gas refers to shale gas, tight gas and coalbed methane, which are gasses trapped in impermeable rock. These gasses are referred to as such due to the difficulty associated with extracting them and corresponding high production costs (IEA, 2012).
Upstream	Exploration for and extraction of oil and natural gas, and the construction and operation of the infrastructure necessary to deliver these hydrocarbons to the market or point of sale.
Venting	Venting denotes the process whereby methane is directly and intentionally released into the atmosphere (Barcella et al., 2011).
Vibroseis trucks	Trucks with mounted vibrator plates for acoustic measuring during seismic data acquisition.
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.
Wastewater	A collective term used to describe all fluids generated in the course of shale gas development activities; it includes spent fracturing fluids, flowback and produced water destined for disposal or treatment and re-use.
Well	Term used in this study to distinguish between a bore drilled for producing groundwater (a borehole) and that drilled for producing oil or gas.
Well closure	Once the supply of gas from a well is exhausted, the well is decommissioned, the wellbore plugged and the equipment is removed (Branosky et al., 2012).
Well completion	Well completion involves readying a well after drilling for production. This involves clearing the well by recovering the base fluid that has been injected into it (i.e. flowback) (Allen et al., 2013).
Wellpad	A site constructed, prepared, levelled and/or cleared in order to accommodate the equipment, materials and infrastructure necessary to drill one or more natural gas exploration or production wells.
Wellbore	The hole created by boring into the subsurface using a drilling rig to power a drill bit. The wellbore might be completely fitted with casing, left open (uncased), or comprise a combination of these.
Wellhead	The equipment installed at the surface of the wellbore. A wellhead includes such equipment as the casing head and tubing head.
Wet gas	Natural gas that contains less methane (typically less than 85% methane) and more heavy hydrocarbons such as ethane and other more complex hydrocarbons. Wet gas may also contain water.
Workover	Refers to operations undertaken to remediate producing wells in order to increase hydrocarbon output levels (Branosky et al., 2012).

APPENDIX 2

Abbreviations and Acronyms

Acronym	Explanation
ADE	Aquifer Dependent Ecosystem
AGA	Astronomy Geographic Advantage Act
AIDS	Acquired immune deficiency syndrome
AQ	Air quality
ARC	Agricultural Research Council
ATV	All-terrain vehicle
AU	Astronomical Unit
BAU	'Business-as-usual'
BCF	Billion cubic feet
BGG	Burial Grounds and Graves
BOD	Burden of Disease
BPG	Best Practice Guideline
Bq/L	Becquerel per litre
BTEX	Benzene, toluene, ethylbenzene, and xylene
CARA	Conservation of Agricultural Resources Act
CBA	Critical Biodiversity Area
CBD	Convention on Biological Diversity
CBER	Centre for Business and Economic Research
CCGT	Combined Cycle Gas Turbine
CCS	carbon capture and storage
CEAM	Cumulative Effects Assessment and Management
CFB	Cape Fold Belt
CGE	Computable general equilibrium
CGS	Council for Geoscience
CH_4	Methane
CI	Conservation Index
CIMERA	Centre of Excellence for Integrated Mineral and Energy Resource Analysis (a DST - NRF facility)
CISPR	Comité International Spécial des Perturbations Radioélectriques
cm	centimetre
cm^3/kg	cubic centimetre per kilogram
CO	Carbon monoxide
CO_2	Carbon dioxide
COC	Chain of custody
CRG	Community Reference Group
CSIR	Council for Scientific and Industrial Research
CSR	Corporate social responsibility
CTL	Coal-to-Liquid
DALY	Disability Adjusted Life Year
dB	Decibel
dBA	A-weighted decibel
DEA	Department of Environmental Affairs
DI	Degradation Index
DM	District Municipality
DMR	Department of Minerals and Energy

Acronym	Explanation
DMR	Department of Mineral Resources
DO	Dissolved Oxygen
DoE	Department of Energy
DPME	Department of Performance Monitoring and Evaluation
DST	Department of Science and Technology
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
E&P	Exploration & Production
EA	Environmental Authorisation
EC	electrical conductivity
ECO	Environmental Control Officer
ECPHRA	Eastern Cape Provincial Heritage Resources Authority
EDC	Endocrine disruptor chemical
EGS	Enhanced Geothermal System
EIA	Environmental Impact Assessment
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
EMP	Environmental Management Plan
EMPr	Environmental Management Programme
EPA	Environmental Protection Agency
EPWP	Expanded Public Works Programme
ESA	Early Stone Age
ESA	Ecological Support Area
EUR	estimated ultimate recovery
FAO	Food and Agriculture Organisation
FEPA	Freshwater Ecosystem Priority Area
FOD	First Order Draft
FOD	First Order Draft
FRAI	Fish Response Assessment Index
ft	Feet
g	gram
GA	General Authorization
GAI	Geomorphology Assessment Index
GCCA	Generation Capacity Connection Assessment
GCM	Global Climate Model
GDP	Gross Domestic Product
GE	Great Escarpment
GHG	Greenhouse Gas
GHz	Gigahertz
GJ	Gigajoule
GRAII	Groundwater Resource Assessment II
GSM	Global System for Mobile communication
GTL	Gas-to-Liquid
GTP	Gas-to-Power

Acronym	Explanation
GUMP	Gas Utilisation Master Plan
GVA	Gross value added
GW	Gigawatt
GWh	Gigawatt hour
GWP	Global warming potential
H	High
H_2S	Hydrogen sulfide
ha	hectare
HAI	Hydrology driver assessment index
HC	Hydrocarbon
HCl	Hydrochloric acid
HCS	Hazardous Chemical Substance
HDI	Human Development Index
HI	Hydrological index
HIA	Heritage impact assessment
HIV	Human immunodeficiency virus
HWC	Heritage Western Cape
I	Intensity
IARC	International Agency for Research on Cancer
ICT	Information and communications technology
IDP	Integrated Development Plan
IDP	Intensity Data Point
IEP	Integrated Energy Plan
IFC	International Finance Corporation
IGS	Institute for Groundwater Studies
IHI	Index of Habitat Integrity Method
INDC	Intended Nationally Determined Contribution
I-O	Input-Output
IPAP	Industrial Policy Action Plan
IPP	Independent Power Producer
IRP	Integrated Resources Plan
ISWG	Induced Seismicity Working Group
ITU	International Telecommunications Union
IUCN	International Union for Conservation of Nature
KARIN	Karoo research initiative
kg	kilogram
kg/t	kilogram per ton
km	kilometre
km^2	square kilometre
kN	kiloNewton
kW	kiloWatt
L	Low or litre
L/d	litre per day
L/s	litre per second
LADA	Land Degradation Assessment in Drylands
LCA	Life-cycle assessment

Acronym	Explanation
LED	Light-Emitting Diode
LM	Local Municipality
LNG	Liquefied Natural Gas
LPG	liquid petroleum gas
LSA	Late Stone Age
LSRWUA	Lower Sundays River Water User Association
LSU	large stock unit
LUPO	Land Use Planning Ordinance
LWD	logging while drilling
M	Medium
M	Magnitude
m	metre
m^3	cubic metre
m^3/a	cubic metre per annum
m^3/d	cubic metre per day
m^3/m	cubic metre per month
MAE	mean annual evaporation
MAP	mean annual precipitation
MAR	mean annual runoff
MCDA	Multiple Criteria Decision Analysis
mg	milligram
mg/L	milligram per litre
MHz	Megahertz
MIG	Municipality Infrastructure Grant
MIRAI	Macro-invertebrate Response Assessment Index
mm	millimetre
M_{max}	Maximum magnitude
MMBtu	Million British Thermal Units
MMI	Modified Mercalli Intensity
Mscf	Million standard cubic feet
MOOC	Massive Open On-line Course
MPa	MegaPascal
MPRDA	Mineral and Petroleum Resources Development Act
mS/m	milliSiemens per metre
MSA	Middle Stone Age
MTS	Main Transmission Substation
MW	MegaWatt
N_2O	Nitrous oxide
NAAQS	National ambient air quality standard
NBKB	Ngwao-Boswa Ya Kapa Bokoni
NBSAP	National Biodiversity Strategy and Action Plan
NCCRWP	National Climate Change Response White Paper
NCW	Not Conservation-Worthy
NDP	National Development Plan
NEMA	National Environmental Management Act

Acronym	Explanation
NEMAQA	National Environmental Management: Air Quality Act
NEMWA	National Environmental Management: Waste Act
NGI	National Geo-spatial Information
NGO	Non-Governmental Organisation
NGP	New Growth Path
NHRA	National Heritage Resources Act
NHS	National Heritage Site
NIOSH	National Institute for Occupational Safety and Health
NMR	Nuclear Magnetic Resonance
NNR	National Nuclear Regulator
NORM	Naturally occurring radioactive material
NOx	Nitrogen oxides
NOx	Mono-nitrogen oxide
NPC	National Planning Commission
NRF	National Research Foundation
NRM	Natural Resource Management
NSW	New South Wales
NWA	National Water Act
NWRS	National Water Resources Strategy
OCGT	Open Cycle Gas Turbine
ONPASA	Onshore Petroleum Association of South Africa
OSHA	Occupational Safety and Health Administration
PAI	Physico-chemical Driver Assessment Index
PASA	Petroleum Agency SA
PCG	Process Custodians Group
PEC	Project Executive Committee
PES	Present Ecological State
PGA	Peak ground acceleration
PHMC	Pennsylvania Historical & Museum Commission
PHRA	Provincial Heritage Resources Agencies
PHS	Provincial Heritage Site
PICC	Presidential Infrastructure Coordinating Commission
PJ	PetaJoule
PM	Particulate Matter
PPD	Peak-plateau-decline
PPE	Personal protective equipment
PSHA	Probabilistic seismic hazard assessment
PV	photovoltaic
RCP	Representative Concentration Pathway
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
RFI	Radio frequency interference
RfV	Reference Value
RHAM	Rapid Habitat Assessment Method
RSA	Republic of South Africa
RV	Recreational Vehicle
SAAO	South African Astronomical Observatory

Acronym	Explanation
SABS	South African Bureau of Standards
SADC	Southern African Development Community
SAHRA	South African Heritage Resources Agency
SAHRIS	South African Heritage Resources Information System
SAIAB	South African Institute for Aquatic Biodiversity
SALT	Southern African Large Telescope
SANBI	Southern African National Biodiversity Institute
SANParks	South African National Parks
SANRAL	South African National Roads Agency Limited
SANS	South African National Standard
SANSN	South African National Seismograph Network
SAR	Synthetic Aperture Radar
SARAS	South African Radio Astronomy Service
SAWS	South African Weather Service
SCLC	Southern Cape Land Committee
SDF	Spatial Development Framework
SEA	Strategic Environmental Assessment
SES	Social-ecological system
SG E&P	shale gas exploration and production
SGD	Shale gas development
SGP	Strategic Grid Plan
SIA	Social impact assessment
SIC	Standard Industry classification
SIMP	Social Impact Management Plan
SIP	Strategic Integrated Project
SIRT	single industry resource town
SKA	Square Kilometre Array (Internationally funded radio telescope observatory to be constructed in the vicinity of Carnarvon, Northern Cape.)
SLCFs	Short-lived climate forcers
SLO	social license to operate
SLP	Social and Labour Plan
SOD	Second Order Draft
SOEKOR	Southern Oil Exploration Corporation
SPLUMA	Spatial Planning and Land Use Management Act
SPM	Summary for Policy-Makers
SSU	small stock unit
TB	Tuberculosis
tcf	trillion cubic feet
TDP	Transmission Development Plan
TDS	Total dissolved solids
TPHs	Total petroleum hydrocarbons
TWA OEL-CL	Time weighted average occupational Exposure Limit – Control Limit
TWA OEL-RL	Time weighted average occupational Exposure Limit - Recommended Limit
TWh	Terawatt-hours
UFS	University of the Free State

Acronym	Explanation
UGEP	utilizable groundwater exploitation potential
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNGD	Unconventional natural gas development
UNGDP	Unconventional natural gas development and production
US EPA	United States Environmental Protection Agency
USA	Unites States of America
UV	Ultraviolet
UYF	Umsobomvu youth fund
VEGRAI	Vegetation Response Assessment Index
VFR	‘Visiting friends and relatives’
VH	Very high
VIA	Visual impact assessment
VOC	Volatile organic compound
vpd	vehicles per day
VRE	Variable renewables
WHO	World Health Organization
WIM	Weigh-In-Motion
WLAN	Wireless local area networks
WMA	Water Management Area
WSA	Water Services Act
WTW	Water treatment works
WWTW	Wastewater Treatment Works
YLD	Years lived with a disability
YLL	Years of life lost due to premature death
ZOD	Zero Order Draft

APPENDIX 3

Integrating and Contributing Author Biosketches

Preface

Authors	
Robert Scholes	Robert (Bob Scholes is a systems ecologist at the University of the Witwatersrand. He has led many assessments over the past 25 years, including parts of the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, the South african Assessment on Elephant Management, and the global Land Degradation and Restoration Assessments. Bob has co-led the shale gas development scientific assessment.
Paul Lochner	Paul Lochner is an environmental assessment practitioner at the CSIR in Stellenbosch, with over 25 years of experience in a wide range of environmental assessment and management studies. His particular experience is in the renewable energy, oil and gas, and industrial and port development sectors. He has been closely involved in the application of Strategic Environmental Assessment in South Africa. Paul has co-led the shale gas development scientific assessment.
Greg Schreiner	Greg Schreiner has worked at the CSIR for the past five years. He is interested in novel approaches to environmental assessment and social processes. He has a Masters Degree in Environment and Development from the University of Cambridge. He has for the past two years managed the day to day processes of the shale gas development scientific assessment.
Luanita Snyman-Van der Walt	Luanita Snyman-Van der Walt has worked at the CSIR for the past 3 years as an environmental assessment practitioner focussing on environmental assessment and Geographic Information System analyses. She has a Masters Degree in Environmental Science from North West University and assisted in managing the shale gas development scientific assessment.
Megan de Jager	Megan de Jager holds an MSc degree in Environmental Geography from the Nelson Mandela Metropolitan University. She is employed at the CSIR as an intern on the shale gas development scientific assessment and is currently undertaking a PhD on baseline monitoring of the Central Karoo.

Chapter 1: Scenarios and Activities

Integrating Author	
Mike Burns	Mike Burns, who is a Harvard University Research Fellow, is qualified in both ecology and environmental ethics. He understands human valuation of the environment and the often conflicting sustainability implications thereof. A capacity to understand the functioning of coupled social-ecological systems is the hallmark of his contribution to sustainability science. Mike has 20 years of consulting experience in Africa's oil and gas sector.
Contributing Authors	
Doreen Atkinson	Doreen Atkinson is a Research Associate at the University of the Free State, Bloemfontein. Her areas of research expertise include local government, community development, intergovernmental relations, policy analysis, governance, local economic development, small towns and rural development, land reform, sustainable livelihoods, project and programme evaluation, and regional development. Doreen has extensive research on Karoo tourism, and has organised five Karoo conferences since 2009.
Oliver Barker	Oliver Barker has an MSc from the University of the Witwatersrand, and is a registered natural scientist and member of numerous organisations, including AEG, SAIEG and the Ground Water Division of the GSSA. Oliver has consulted for large corporations and assessed geological risk in mining prospects. He has authored and co-authored numerous technical reports and published papers.
Claire Davis	Claire Davis is climate change impacts and adaptation specialist with a particular research interest in the field of biodiversity and conservation. She currently holds the position of Researcher in the Natural Resources and the Environment Unit (NRE) at CSIR. A key area of expertise is her skills in conducting vulnerability and adaptation assessments and producing tailor-made climate change projections for specific sectors.

Elizabeth (Liz) Day	Liz Day has over 20 years' experience in the field of freshwater ecosystems, mainly in the Western, Northern and Eastern Capes. Her particular interests include wetland and river water quality management, pollution abatement and protection strategies and understanding surface-groundwater interactions in wetlands. She has also been involved in wetland mapping and prioritisation projects for the CAPE fine-scale biodiversity planning project and for various local municipalities.
Surina Esterhuyse	Surina Esterhuyse is a researcher at the Centre for Environmental Management, University of the Free State. Recently, she has been extensively involved in work related to unconventional oil and gas extraction and led the project on the unconventional oil and gas interactive vulnerability map and monitoring framework development for the South African Water Research Commission.
Philip Hobbs	Philip Hobbs is a registered Professional Natural Scientist employed as a Senior Research Hydrogeologist in the NRE business unit. His ~35 years' experience includes the exploration and development of groundwater resources for water supply at all scales, the evaluation and assessment of land use activities (e.g. mining, industry and waste disposal) on groundwater, and the mapping of groundwater resource quantity and quality.
Ian McLachlan †	Ian McLachlan has a BSc Honours degree in Economic Geology from the University of the Witwatersrand, and is a Life Fellow of the GSSA. He worked for Soekor and Petroleum Agency SA where he gained wide experience in exploration operations in the Karoo and elsewhere. He also contributed to the compilation of the Minerals and Petroleum Resources Development Act of 2002 and associated Regulations.
Nigel Rossouw	Nigel Rossouw has more than 20 years' experience, working in different industry sectors and in a variety of roles, ranging from research, training, consulting, project implementation and corporate environmental planning. Nigel is the Environmental Planner for Shell South Africa Integrated Gas and is currently completing a PhD at UCT focusing on environmental governance of large engineering projects.
Simon Todd	Simon Todd has 18 years' experience as a terrestrial ecologist in arid systems. His primary focus includes examining the impacts of land use on biodiversity with the arid ecosystems of South Africa. Recent notable projects include specialist input for the Wind and Solar- and Eskom Grid Infrastructure Strategic Environmental Assessments, as well as on-going work related to the SKA.
Luanita Snyman-Van der Walt	Luanita Snyman-Van der Walt has worked at the CSIR for the past 3 years as an environmental assessment practitioner focussing on environmental assessment and Geographic Information System analyses. She has a Masters Degree in Environmental Science from North West University and assisted in managing the shale gas development scientific assessment.
Elsona van Huyssteen	Elsona van Huyssteen is a Principle Urban and Regional Planner at the CSIR and has over 20 years' experience in research, and policy development. She has lead collaborative multi-disciplinary initiatives in the urban and regional development planning field. Her interest focusses on innovative ways to engage collective futures through profiling spatial growth dynamics impacting cities, settlements and regions; transdisciplinary and multi-stakeholder initiatives, and action-orientated leadership.
Chapter 2: Energy	
Integrating Author	
Jarrad Wright	Jarrad Wright is a Principal Engineer at the CSIR Energy Centre, with an MScEng (Elec), working predominantly in energy system operations and planning. He has extensive power sector operations and planning experience in eleven African countries. Jarrad was appointed by the President of South Africa to the NPC in 2015 as a Commissioner for the period 2015-2020 to assist in the implementation of the NDP.
Contributing Authors	
Tobias Bischoff-Niemz	Tobias Bischof-Niemz is the Energy Centre Manager at the Council for Scientific and Industrial Research, prior to which, he was with the Energy Planning Unit at Eskom, as part of the team that developed the long-term power-capacity expansion plan (Integrated Resource Plan) for South Africa. Tobias is also a member of the

	Ministerial Advisory Council on Energy.
Clinton Carter-Brown	Clinton Carter-Brown has a PhD in Electrical Engineering from the University of Cape Town, and spent 18 years in Eskom, the later portion of which as a specialist in the Technology Division. He is lead author of over 15 conference and journal papers and has co-authored a number of contributions. Carter-Brown joined Aurecon's Tshwane Energy Unity as a Technical Director in 2014.
Owen Zinaman	Owen Zinaman is the Technical Lead for the 21st Century Power Partnership South Africa Programme, operated out of the United States National Renewable Energy Laboratory. He holds a dual appointment as a Research Analyst at the Joint Institute for Strategic Energy Analysis, where he leads and supports various research activities and technical writing efforts for the U.S. natural gas sector.

Chapter 3: Air Quality and Greenhouse Gas Emissions

Integrating Author	
Harald Winkler	Harald Winkler is Director of the Energy Research Centre, University of Cape Town. His research interests focus on energy, environment and climate change mitigation. Harald has co-authored a journal publication on GHG emissions from coal compared to shale gas for electricity in South Africa. Harald has been a lead author on the Intergovernmental Panel on Climate Change and serves on editorial boards of six journals.
Contributing Authors	
Katye Altieri	Katye Altieri is a senior researcher at the Energy Research Centre, University of Cape Town. She has extensive experience in atmospheric chemistry and air pollution, including building shale gas emissions inventories. Katye completed a PhD focused on atmospheric chemistry at Rutgers University, and a Masters in Public Policy focused on development and energy at Princeton University.
Simon Clarke	Simon Clarke has an MSc in Environment and Development and is founding Director of IBIS Consulting, where he is a sustainability and climate change specialist with 15 years' experience. His experience covers greenhouse gas reporting, energy and carbon reduction and physical climate change risk. He has led the development and verification of over 100 greenhouse gas inventories for corporate clients and governments across multiple sectors.
Rebecca Garland	Rebecca Garland holds a PhD from the University of Colorado and has been an atmospheric chemist at the CSIR since 2011. She has worked in the field of atmospheric science for 16 years. Her expertise is in atmospheric science, with a research focus on modeling atmospheric composition, the resultant impacts from poor air quality and a changing climate.
Gerrit Kornelius	Gerrit Kornelius is a chemical engineer specialising in air quality management and greenhouse gas policy for the past 30 years. He has worked in the hydrocarbon industry, academia and consulting practice. He was involved in drafting regulations under the Air Quality Act and was a participant in drafting of Long-term Mitigation Strategy that advised government on greenhouse gas reduction pathways.
Matthew Meas	Matthew Meas is currently undertaking a Masters in Sustainable Energy Engineering at the University of Cape Town. Matthew received a bronze medal for research involving sympathetic vibrations of musical instruments with strings at the Eskom Expo for Young Scientists National Competition in 2009. His interests include thermodynamics, sustainable energy technologies, mechanical engineering research and development, and energy policy.

Chapter 4: Earthquakes

Integrating Author	
Raymond Durrheim	Raymond Durrheim is the South African Research Chair of Exploration, Earthquake and Mining Seismology and holds joint appointments at the University of the Witwatersrand and CSIR. He is co-director of the AfricaArray research and capacity-building programme and was co-leader of the Japanese-South African collaborative

	project "Observational studies in South African mines to mitigate seismic risks" (2010-2015).
Contributing Authors	
Moctar Doucouré	C. Moctar Doucouré is an Associate-Professor of geophysics, Managing Director of AEON-Earth Stewardship Science Research Institute, and Manager of the Karoo Shale Gas Baseline Research Programme at the Nelson Mandela Metropolitan University, where he is responsible for geophysical research including airborne geophysics, deep subsurface geophysics, and micro-earthquakes. The programme involves 30 post-graduate students of which four are dedicated to geophysical operations and research in the Eastern Cape Karoo.
Vunganai Midzi	Vunganai Midzi has a PhD in Seismology from the University of Bergen, Norway. He is employed by the Council for Geoscience in Pretoria, South Africa, where he is mainly responsible for a team that carries out seismic hazard assessments for critical structures in South Africa and beyond. Vunganai also has experience in seismic monitoring and is well published.

Chapter 5: Water Resources

Integrating Authors	
Philip Hobbs	Philip Hobbs is a registered Professional Natural Scientist employed as a Senior Research Hydrogeologist in the NRE business unit. His ~35 years' experience includes the exploration and development of groundwater resources for water supply at all scales, the evaluation and assessment of land use activities (e.g. mining, industry and waste disposal) on groundwater, and the mapping of groundwater resource quantity and quality.
Elizabeth (Liz) Day	Liz Day has over 20 years' experience in the field of freshwater ecosystems, mainly in the Western, Northern and Eastern Capes. Her particular interests include wetland and river water quality management, pollution abatement and protection strategies and understanding surface-groundwater interactions in wetlands. She has also been involved in wetland mapping and prioritisation projects for the CAPE fine-scale biodiversity planning project and for various local municipalities.
Contributing Authors	
Peter Rosewarne	Peter's 40 years of experience includes geological mapping in the Merwerville/Fraserberg area, groundwater supply for municipalities, e.g. Beaufort West, hydrogeological studies for the proposed Ryst Kuil uranium mine near Beaufort West and assisting Shell with assessment of groundwater occurrence/risks related to shale gas. He has/currently sits on the Reference Groups of three groundwater projects related to Karoo shale gas for the Water Research Commission.
Surina Esterhuyse	Surina Esterhuyse is a researcher at the Centre for Environmental Management, University of the Free State. Recently, she has been extensively involved in work related to unconventional oil and gas extraction and led the project on the unconventional oil and gas interactive vulnerability map and monitoring framework development for the South African Water Research Commission.
Roland Schulze	Roland Schulze is Emeritus Professor, Fellow of the Royal Society of South Africa (FRSSAf), Member of the Academy of Science of South Africa, and is retired Professor of Hydrology at the University of KwaZulu-Natal. His research focus is currently on agro-hydrological modelling and mapping; impacts assessments of land use; and climate change impacts on the water and agricultural sectors.
Jenny Day	Jenny Day is an Emeritus Associate Professor Director of the Freshwater Research Unit at the University of Cape Town and is currently Honorary Professor at the Institute for Water Studies at the University of the Western Cape. Her particular interests include wetlands and their associated biotas; the effects of water chemistry on living organism, and the conservation and management of aquatic ecosystems.
Justine Ewart-Smith	Justine Ewart-Smith has 16 years of experience in the field of freshwater ecology, ranging from specialist input into biomonitoring, strategic environmental assessments and situation assessment surveys, to environmental flow studies both locally and abroad. Justine studied algal dynamics in Cape Rivers at the University of Cape Town and completed her PhD in Freshwater Ecology in 2012.

Marthie Kemp	Marthie Kemp is a plant ecologist at the Centre for Environmental Management, University of the Free State. Marthie has been involved in the development of an interactive vulnerability and monitoring framework to assess the potential environmental impact of unconventional oil and gas extraction and the development of a methodology to determine environmental water requirements for non-perennial rivers.
Nick Rivers-Moore	Nick Rivers-Moore is an aquatic ecologist with 15 years' professional experience. After completing a PhD in Hydrology at the University of Natal in 2003, he went on to a post-doctorate at the Institute for Water Research (Rhodes University). Nick is also a published regional expert on freshwater conservation planning, and successfully developed the first provincial freshwater conservation plan for KwaZulu-Natal, South Africa.
Henk Coetzee	Henk Coetzee has over 24 years' experience in Geophysics, and currently works at Council for Geoscience as a Specialist Scientist; Sustainable Resources and Environment Competency unit. His scientific experience includes radiometric surveying; remote sensing of mining environments; and research experience, specialising in the investigation, characterisation and rehabilitation of mining environments and abandoned mines and mine water, with a strong focus on acid mine.
Danita Hohne	Danita Hohne is a Scientific Technician with the Department of Water and Sanitation (Northern Cape), with 7 years' experience in groundwater management. Projects she has worked on include MeerKAT (SKA); renewable energy and thermal springs in Augrabies. With regards to hydraulic fracturing; Danita has been formulising baseline and monitoring concepts and assisting in writing the regulations for oil and gas exploration.
Ashton Maherry	Ashton Maherry has a BSc Honours degree from the University of the Free State, and is currently a full time Masters GISc student at UNIGIS International. Ashton has ~12 years' experience as a Geohydrologist at the Council for Scientific and Industrial Research, where he serves as a Senior Knowledge Applicator, GIS- and Groundwater specialist, and Project Manager.

Chapter 6: Impacts on Waste Planning and Management

Integrating Author	
Suzan Oelofse	Suzan Oelofse is a Principal Researcher and Research Group Leader at the CSIR, an Extra-ordinary Associate Professor in Environmental Sciences and Management at the North-West University and the President of the Institute of Waste Management of Southern Africa. Her expertise involves integrated waste management and water resource management; waste information and data; and reducing the environmental impacts of waste.
Contributing Author	
Johan Schoonraad	Johan Schoonraad is a professional chemist with EnviroServ Waste Management, where he interacts with a small dedicated team of professional scientists and engineers to find appropriate solutions to complex hazardous waste and chemical pollution problems. He is involved in on-going operational issues as well as providing input to the development of solutions to meet the strategic goals of the company.

Chapter 7: Biodiversity & Ecological Impacts: Landscape Processes, Ecosystems and Species

Integrating Authors	
Stephen Holness	Stephen Holness has 17 years' experience as a conservation planner, landscape ecologist and environmental GIS specialist. He is also an independent scientist associated with the Centre for African Conservation Ecology and the Coastal and Marine Research Institute at Nelson Mandela Metropolitan University. He specialises in systematic conservation planning in support of land use planning, marine spatial planning, protected area expansion and reserve management.

Amanda Driver	Amanda Driver is the Senior Biodiversity Policy Advisor at the South African National Biodiversity Institute (SANBI). Her work focuses on translating South Africa's biodiversity science into policy, legislation and practice. She led the National Biodiversity Assessment (2011), and has extensive experience in the application of spatial biodiversity information in a range of contexts at national and sub-national level.
Contributing Authors	
Simon Todd	Simon Todd has 18 years' experience as a terrestrial ecologist in arid systems. His primary focus includes examining the impacts of land use on biodiversity with the arid ecosystems of South Africa. Recent notable projects include specialist input for the Wind and Solar- and Eskom Grid Infrastructure Strategic Environmental Assessments, as well as on-going work related to the SKA.
Kate Snaddon	Kate Snaddon has 20 years of experience in the field of freshwater ecology (both as a researcher and consultant) and general environmental consulting. Her skills are in environmental impact assessment of infrastructure and development projects that impact on surface freshwater ecosystems. Recently, Kate has been lead consultant on two national strategic environmental assessments for wind and solar, and electricity transmission infrastructure.
Michelle Hamer	Michelle Hamer has a PhD from the University of KwaZulu-Natal. She has worked as a museum curator and academic, and is currently the Director for animal taxonomy at SANBI. She has led several large scale invertebrate surveys and participated in red listing and other conservation initiatives. She has published 70 scientific papers and contributed to six book chapters.
Domitilla Raimondo	Domitilla Raimondo is the Threatened Plant Programme Manager at the South African National Biodiversity Institute. Domitilla is the lead author of the "Red List of South African Plants" (2009), inter alia, and co-authored "Taxonomic research priorities for the conservation of the South African flora" (2013). She is also involved in the Custodians of Rare and Endangered Wildflowers (CREW) programme.
Fahiema Daniels	Fahiema Daniels plays a key role in supporting biodiversity planning in South Africa by leading spatial analyses for National-scale projects, such as the Electricity Grid Infrastructure Strategic Environmental Assessment. Additional projects include listing of threatened ecosystems; the terrestrial component of the National Biodiversity Assessment; and developing the spatial layers that feed into Department of Environmental Affairs Natural Resource Management Land User Incentive tool.

Chapter 8: Agriculture

Integrating Author	
Noel Oettlé	Noel Oettlé holds a Post Graduate Diploma in Agricultural Development from the University of London. He was founding Director of the Farmer Support Group at the University of KwaZulu-Natal, and is the Rural Programme Manager for the Environmental Monitoring Group. His work focuses on enabling small-scale farmers to adapt to climate change and enhance their livelihoods through the sustainable use of natural resources and improved market access.
Contributing Authors	
Lehman Lindeque	Lehman Lindeque is a Professional Natural Scientist in Agricultural Science with a Masters degree in Environmental Studies from the University of Newcastle, Australia. Lehman's field of expertise is the assessment and mapping of land degradation and sustainable land management. His knowledge and skills are also internationally recognised, as demonstrated by his involvement in training and consultation abroad.
Justin du Toit	Justin Du Toit is as an agricultural researcher in Middelburg, Eastern Cape. His research interests include long-term vegetation changes as influenced by fire, grazing and rainfall in the central to eastern Karoo; dealing with invasive plants in semi-arid areas, notably slangbos and satansbos; and rainfall patterns in semi-arid South Africa. He also teaches courses on planted pastures, environmental management, and rehabilitation/ restoration.

Igshaan Samuels	Igshaan Samuels is a research scientist working for the Agricultural Research Council. His current research focus involves assessing indigenous knowledge systems and its application in climate change adaptation in Namaqualand; assessing diet selection and resource use amongst different livestock species in semi-arid rangelands; and investigating and mapping livestock mobility patterns under variable socio-ecological conditions on the commons of Namaqualand.

Chapter 9: Impacts on Tourism in the Karoo

Integrating Author	
Daan Toerien	Daan Toerien had an early career as researcher/academic, specialising in ecological and water research, involvement in science management. A period at the Sloan Business School of M.I.T. prompted research and scientific publications on the similarities between natural ecosystems and enterprise development in South African towns. This enabled the development of predictive capabilities that extend to shale gas and the Karoo's tourism industry.
Contributing Authors	
Gerrie du Rand	Gerrie Du Rand is a Senior Lecturer and Head of the Foods and Nutrition Section at Department of Consumer Science, University of Pretoria. Her area of interest is Food Tourism and the use of Local foods in culinary mapping. She has received academic recognition nationally and internationally as a researcher and expert in the field of Food and Hospitality related consumer behaviour.
Caroline Gelderblom	Caroline Gelderblom has over 20 years' of experience in the environmental sector working with National and Provincial Agencies and at a municipal scale to strengthen institutions. She has a particular interest in public works programmes and sustainable land use planning, including the promotion of conservation, sustainable tourism and agriculture, which extend across South Africa into the Southern African Development Community.
Melville Saayman	Melville Saayman is the director of the Tourism Research in Economic Environs and Society (TREES) at the Potchefstroom Campus of the North-West University in South Africa. His field of research is tourism economics and management and he has published more than 160 scientific articles, 20 tourism books and more than 330 technical reports.

Chapter 10: Impacts on the Economics

Integrating Author	
Hugo van Zyl	Hugo van Zyl is the director of Independent Economic Researchers, focusing on economics impact assessment, project appraisal and applied environmental resource economics. He has 18 years' experience in providing specialist inputs to environmental authorisation and policy processes, including projects in the mining, oil and gas sectors. He was lead author of a 2012 WWF sponsored discussion document on financial provisions for mine closure in South African.
Contributing Authors	
Saliem Fakir	Saliem Fakir is the Head of the Policy and Futures Unit at the WWF-SA. His areas of focus include the economy, energy, climate and the food-water nexus. He has written on the economics of shale gas based on a study on framing the economics of shale gas. He is a regular columnist for Engineering News and other media outlets.
Anthony Leiman	Anthony Leiman is an associate professor at the School of Economics at the University of Cape Town. His expertise includes mining, fisheries, and project appraisal, particularly cost benefit analysis. Leiman co-authored a report on the sustainable management of natural resources focussing on Tanzania's new gas deposits in 2014 and helped formulate the WWF sponsored discussion document on financial provisions for mine closure in South Africa in 2012.

Barry Standish	Barry Standish is visiting Professor of Economics at the Rotterdam School of Management, Erasmus University in Rotterdam. He specialises in applied macroeconomics, and has written and consulted extensively on the analysis of energy and electricity. Barry is director and consultant at Stratecon, and while he has consulted in various capacities in the past; economic and financial modelling is his key specialisation.
Chapter 11: Impacts on Social Fabric	
Integrating Author	
Doreen Atkinson	Doreen Atkinson is a Research Associate at the University of the Free State, Bloemfontein. Her areas of research expertise include local government, community development, intergovernmental relations, policy analysis, governance, local economic development, small towns and rural development, land reform, sustainable livelihoods, project and programme evaluation, and regional development. Doreen has extensive research on Karoo tourism, and has organised five Karoo conferences since 2009.
Contributing Authors	
Catherine Schenk	Catherine Schenk has 34 years of teaching experience and 40 years of work experience, which includes rural social work in South Africa, involving the evaluation of the recruitment; and retention strategy of the Department of Social Development, which was commissioned by Chiastolite Professional Services (CPS). In 2015 the University of the Western Cape and University of Johannesburg provided funding for her research on the waste pickers in the Karoo.
Sethulego Matebesi	Sethulego Matebesi is a Senior Lecturer and Acting Academic Head of the Department of Sociology at the University of the Free State. Sethulego’s research focuses on community protests in South Africa, specifically the differential social organisation of communities and civic organisations in predominantly black and white neighbourhoods, as well as the effect of community trusts on protests in mining towns.
Karin Badenhorst	Karin Badenhorst founded the Footsteps Foundation and has over 25 years of research, consulting, business development and executive management experience in the large institutional environment. Her current research focuses on socio-economic and ecological entrepreneurship, sustainability, the renovation of selected economic, agricultural, natural, cultural and technological value chains for the benefit of small, distant, vulnerable, rural communities, with a particular focus on the Karoo.
Chapter 12: Impacts on Human Health	
Integrating Author	
Bettina Genthe	Bettina Genthe has over 30 years’ experience in the field of environmental health aspects and water quality. She has been a temporary advisor to the World Health Organisation and United States Environmental Protection Agency on Exposure Assessment. She has extensive experience in water-related human health risk assessments, water quality monitoring, risk communication, health interventions, and health and hygiene awareness creation and education.
Contributing Authors	
Ashton Maherry	Ashton Maherry has a BSc Honours degree from the University of the Free State, and is currently a full time Masters GISc student at UNIGIS International. Ashton has ~12 years’ experience as a Geohydrologist at the Council for Scientific and Industrial Research, where he serves as a Senior Knowledge Applicator, GIS- and Groundwater specialist, and Project Manager.
Maronel Steyn	Maronel Steyn has an M.Tech degree in Environmental Health from the Central University of Technology, and is a researcher within the CSIR’s Water Resources competency area. Her key competencies lie in environmental epidemiology, human health risk and burden of disease. Maronel’s areas of interest include drinking water treatment, wastewater treatment and reuse, water pollution microbiology, health

	economics and diseases.
Hanna- Andrea Rother	Hanna-Andrea Rother, PhD, is Associate Professor and Head of the Environmental Health Division in the School of Public Health and Family Medicine at the University of Cape Town. She has over 25 years' experience in research, policy analysis, capacity building and teaching related to chemical exposure risks, risk management and mitigation, as well as risk perceptions and risk communication.
Leslie London	Leslie London is a public health specialist and Professor at the School of Public Health and Family Medicine, University of Cape Town. He is actively involved in the Centre for Occupational and Environmental Health Research, and has served on many committees dealing with ethics and human rights. He has published over 150 articles and 15 books or book chapters.
Mieke Willems	Mieke Willems is employed as evaluator in a technical position as Assistant Director in the Western Cape Government Health's Impact Assessment Unit. She has a Master's in Public Heath from the University of Cape Town where her thesis related to risk perceptions surrounding fracking, specifically from a health perspective. Other research interests include environmental health, non-communicable diseases and diseases of lifestyle.

Chapter 13: Impacts on Sense of Place Values

Integrating Author	
Leanne Seeliger	Leanne Seeliger is an independent environmental ethics consultant. She completed a post-doctoral fellowship at the Economic Performance and Development Unit at the Human Sciences Research Council, and has lectured environmental philosophy at several tertiary institutions. She is an affiliate of the University of Stellenbosch's Unit for Environmental Ethics and the Environmental Education Programme. Her research interests are the green economy, adaptive governance, environmental ethics and environmental education.
Contributing Authors	
Michael de Jongh	Michael de Jongh is Professor Emeritus, Anthropology, at Unisa. He has published widely and presented scientific papers internationally. For some 25 years his research focus has been on the Karoo in particular. He has published over 20 articles and several books and research reports in the fields of prehistory, history and anthropology reflect his engagement with the region and its people.
David Morris	David Morris heads Archaeology at the McGregor Museum and is Extraordinary Professor at Sol Plaatje University in Kimberley. His main research interest in rock art was the focus of his PhD at the University of the Western Cape. He is involved in a wide cross-section of projects and publications in Northern Cape archaeology, including development of public archaeology sites.

Chapter 14: Visual, Aesthetic and Scenic Resources

Integrating Author	
Bernard Oberholzer	Bernard Oberholzer is a landscape architect and environmental planner with over 20 years' experience in visual assessments, particularly for wind and solar energy, as well as gas pipelines and powerlines. He authored the *Guideline for Involving Visual and Aesthetic Specialists in EIA Processes*, and co-authored a heritage and scenic resources study for the Provincial Government, Western Cape.
Contributing Authors	
Quinton Lawson	Quinton Lawson is a professional architect, with 15 years' experience in visual assessments. He is visiting lecturer for the University of Cape Town and serves on the Impact Assessment Committee of Heritage Western Cape for the Provincial Government Western Cape. Has been involved in numerous visual assessments, usually in association with BOLA, for solar and wind energy facilities, as well as gas pipelines and powerlines.

Menno Klapwijk	Menno Klapwijk has 33 years' experience as a SACLAP registered professional landscape architect, and is a founding and principal member of Bapela Cave Klapwijk, landscape architects and environmental planners. He has over 100 publications and reports dealing mostly with environmental planning, environmental rehabilitations and control specification, and environmental- and visual impact assessment. He also assisted in drafting 'A Guideline for Involving Visual and Aesthetic Specialists in EIA Processes'.
Graham Young	Graham Young is a registered landscape architect and visual impact assessment specialist. He was awarded an ILASA Merit Award for his work and helped develop the *Guideline for Involving Visual and Aesthetic Specialists in EIA Processes*. He authored a research document for Eskom, *The Visual Impacts of Power Lines*, and produced '*Guidelines for involving visual and aesthetic specialists'* for a World Heritage Site in Mauritius.

Chapter 15: Impacts on Heritage

Integrating Author	
Jayson Orton	Jayson Orton has conducted numerous heritage impact assessments for a wide range of project types throughout the western half of South Africa since 2004, often collaborating with other specialists. His research interest is in the Later Stone Age archaeology and rock art of South Africa's arid environments, especially Namaqualand; on which he has published widely.
Contributing Authors	
John Almond	John Almond is a Cape Town-based palaeontologist with almost 30 years' experience working on the geology and fossils of southern Africa. He worked for the Council for Geoscience for eight years, and has carried out numerous palaeontological impact assessments for developments and conservation areas in the Karoo, including strategic Impact Assessments for the SKA project and alternative energy developments.
Nicholas Clarke	Nicholas Clarke, a heritage architect, obtained his professional degree from the University of Pretoria, followed by a Masters Degree from Cambridge University. He has practiced as an architect and heritage advisor and lectured in built heritage studies at the University of Pretoria and Delft University of Technology. He is active in World Heritage, having undertaken numerous ICOMOS/UNESCO Missions.
Roger Fisher	Roger Fisher is Professor Emeritus, at the Department of Architecture, University of Pretoria. His research focuses on the South African built heritage, particularly as it serves sustainable communities. His expertise serves the public as advisor and committee member of various heritage bodies and committees and as practitioner acting as a heritage consultant.

Chapter 16: Noise generated by Shale Gas- related activities

Integrating Author	
Andrew Wade	Andrew Wade is the Managing Director of Sound Research Laboratories South Africa (SRL SA). He is a registered Chartered Engineer with the Engineering Council (UK), and is a member of the Institute of Acoustics (UK). He has significant experience in environmental noise and vibrations, building acoustics, industrial acoustics, acoustic modelling and Noise and Vibration Harshness (NVH).
Contributing Author	
Adrian Jongens	Adrian Jongens (M.Sc. Electrical Engineering) has trained undergraduate and postgraduate engineering students on the application of fundamental physical acoustical principles to noise and vibration control for 40 years. In parallel, he has provided a consulting service in all aspects relating to noise and vibration control, building and architectural acoustics, noise management policy formulation and environmental noise impact assessment and mitigation.

Chapter 17: Electromagnetic Interference

Integrating Author	
Adrian Tiplady	Adrian Tiplady has worked at SKA South Africa since 2005, and currently sits on the SKA Executive Committee as Head of Strategy. He has experience across a number of technical, scientific and strategic areas. Adrian was a member of the Working Group of the Task Team on Hydraulic Fracturing, and is involved in the environmental impact assessments of renewable energy projects in the Northern Cape Province.
Contributing Authors	
Paul van der Merwe	Paul van der Merwe, in his role as managing director of MESA Solutions, deals mainly with impact assessments of extensive engineering systems. MESA is involved in assessments of proposed large renewable energy developments in close proximity to the SKA project in the Northern Cape. MESA has assisted at least seven manufactures during various stages of their project proposal, including theoretical desktop investigation and field measurements of installed systems.
Braam Otto	Braam Otto has a Ph.D. in Electrical Engineering from the University of Stellenbosch. He works as a radio frequency engineer in the field of electromagnetic compatibility and radio frequency interference mitigation. He is actively involved in the South African Square Kilometre Array Project as EMC consultant, and has contributed to various environmental impact assessments in the renewable energy sector.

Chapter 18: Impacts on Integrated Spatial and Infrastructure Planning

Integrating Authors	
Elsona van Huyssteen	Elsona van Huyssteen is a Principle Urban and Regional Planner at the CSIR and has over 20 years' experience in research, and policy development. She has lead collaborative multi-disciplinary initiatives in the urban and regional development planning field. Her interest focusses on innovative ways to engage collective futures through profiling spatial growth dynamics impacting cities, settlements and regions; transdisciplinary and multi-stakeholder initiatives, and action-orientated leadership.
Cheri Green	Cheri Green has over 30 years' research experience in fields of accessibility, transportation planning, land use development, facility location planning (in urban and rural context), and social facility provision norms. She is a Registered Town & Regional Planner and Senior Researcher at the CSIR. She has been involved in several studies in the Karoo region since 2002, including the development of Integrated Transport Plans.
Contributing Authors	
Phil Paige-Green	Phil Paige-Green is an Extraordinary Professor at Tshwane University of Technology and has over 40 years' experience in research, dissemination and implementation related to aspects of roads and pavement engineering. His speciality includes the use of local materials and design and evaluation of unpaved and paved low-volume roads. He has authored or co-authored, inter alia, more than 135 refereed papers and 350 contract, research and unpublished internal reports.
Mark Oranje	Mark Oranje is Professor and Head of the Department of Town and Regional Planning at the University of Pretoria. His key areas of interest are planning policy, regional development, intergovernmental development planning and the interface between mining and settlement development. Mark has authored and co-authored numerous publications and consulted on a wide range of issue related to his above areas of interest.
Stephen Berrisford	Stephen Berrisford is an independent consultant working at the intersection between law and urban planning in Sub-Saharan Africa. Stephen is an Honorary Adjunct Associate Professor at the University of Cape Town's African Centre for Cities. His work focuses on legal and policy dimensions of land use and urban development. He holds degrees from the University of Cape Town and Cambridge University.