United Nations
Educational, Scientific and
Cultural Organization

International
Hydrological
Programme

Forest Management

and the impact on water resources: a review of 13 countries

IHP - VIII / Technical document Nº 37
Latin America and the Caribbean

United Nations Educational, Scientific, and Cultural Organization

International Hydrological Programme

International Sediment Initiative

Forest management and the impact on water resources: a review of 13 countries

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Published in 2017 by the United Nations Educational, Scientific and Cultural Organization, 7, place de Fontenoy, 75352 Paris 07 SP, France and UNESCO Regional Office for Sciences for Latin America and the Caribbean – UNESCO Montevideo

ISBN 978-92-3-100216-8

9 789231 002168

Cover photo: CC0 License
Graphic design: Leonardo Alvarez de Ron
Cover design: María Noel Pereyra
Typeset: Pablo García Chevesich
Edition: Miguel Doria, Soledad Benítez, Joaquín Jafif and Tatiana Másmela

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Executive summary

Trees have been around for more than 370 million years, and today there are about 80 thousand species of them, occupying 3.5 billion hectares worldwide, including 250 million ha of commercial plantations. While forests can provide tremendous environmental, social, and economic benefits to nations, they also affect the hydrologic cycle in different ways. As the demand for water grows and local precipitation patterns change due to global warming, plantation forestry has encountered an increasing number of water-related conflicts worldwide.

This document provides a country-by-country summary of the current state of knowledge on the relationship between forest management and water resources. Based on available research publications, the Editor-in-Chief of this document contacted local scientists from countries where the impact of forest management on water resources is an issue, inviting them to submit a chapter. Authors were instructed to use the following structure:

1. Introduction

Present a brief history of the country's native forests and forest plantations, describing the past and current natural and plantation forest distribution (map, area, main species), as well as main products produced (timber, pulp, furniture, etc.). Characterize the country's water resources and main water uses, discussing the key water resource issues. Finally, describe the forest & water issues that are relevant in the country.

2. Literature review

Write a brief review of water-related forest management studies. Include methods (e.g. paired watershed studies, precipitation/runoff relationship, water balance, hydrological modelling, sap flow meters, etc.) and results. End with a section on best management practices utilized or recommended by the country to increase water yield and/or improve water quality.

3. Politics

Discuss key environmental regulations, laws, and policies related to forestry and water, and evaluate how research results have interacted with politics and *vice versa*, i.e. the creation of new regulations, either enforced by the law, or simply applied by the private sector, to improve water yield and water quality. Also, discuss the role of forest certification systems in managing water quantity and quality.

4. Climate change and the future of forestry & forest research

Evaluate the effects of climate change in the country, especially on water resources, describing how the area occupied by forest plantations is increasing or decreasing, and where. End this section proposing future research and management practices that should be incorporated in the management of forest plantations to improve water quality and water yield.

An excellent group from 13 nations, representing almost half the World's population, submitted chapters (Argentina, Australia, Brazil, Chile, China, Republic of Congo, India, Malaysia, Peru,

Chapter 11. Forest management and water in the Republic of South Africa

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11.1 Introduction

South Africa is a semi-arid country with a very limited area of natural forest. The early colonial governments encouraged the establishment of plantations to supply wood for local uses, and South Africa consequently has a long history of plantation forestry. However, the growth of the man-made forests soon led to conflicts with downstream water users, mainly farmers. The simmering debate about the positive and negative effects of plantations of introduced tree species became a high-level political issue, and this led to the establishment of a large and intensive forest hydrological research program in 1936. The results of the research program were incorporated, between 1970 and 1995 into management policies for these plantations and the humid mountainous catchment areas (watersheds). One policy element was that the extent of the plantations was regulated, based on the estimated effects of the plantations on regional water resources. More recently, a new National Water Act (1998) has further restricted the forest industry, with the result that there has been a stagnation of timber planting over the last twenty years.

This chapter outlines the history of the forest industry and associated forest hydrology research in South Africa, and describes the measures that have been taken to control the forest industry because of its effects on water resources.

Water resources in South Africa.

South Africa is essentially a semi-arid country, with a mean annual precipitation (MAP) of roughly 460 mm (DWAF 2004), which is greatly exceeded by evaporative demand that ranges between 1400 and 3000 mm/year (Schulze, 2008). The distribution of precipitation though is highly variable, both in space and time, and there are small areas of the country with high rainfall (roughly 20% of the country has an MAP > 800 mm (Dye and Versfeld, 2007), which are largely responsible for sustaining much of the perennial streamflow. The high rainfall zones, known locally as mountain catchment areas, are responsible for 60% of the countries surface water production (Jacobson 2003). Groundwater resources are limited, so the country is dependent on surface water resources.

Within South Africa and the neighbouring mountain country of Lesotho, a large capacity to store water has been built to retain water for drier years, and there is a large reliance on inter-basin transfers of water. South Africa has a reservoir storage capacity of 32,412 million m^3, which is the equivalent of 66% of the Mean Annual Runoff (MAR) (DWAF 2004). Most water is used by agriculture, with irrigation accounting for 62% of utilizable water. The next biggest user is municipal water use (27%), for residential (urban and rural), commercial and light industrial purposes. Other uses are mining, bulk industrial and power generation, which jointly account for another 8% of utilizable water (DWAF 2004).

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Forest Resources

The humid parts of South Africa are scattered along the south and eastern seaboard and along the seaward escarpment that runs up the eastern part of the country. Within these well-watered regions there is a very small area of native forest, covering approximately 0.4% of the total land area (Figure 1). This restricted and scattered forest area produces a very small amount of high quality furniture wood, but the trees are slow-growing, the forests are difficult to regenerate, and the majority of the forest area is managed for conservation rather than production. The native forests are valued mostly for their aesthetic and ecological values, and they are not a significant part of the economy.

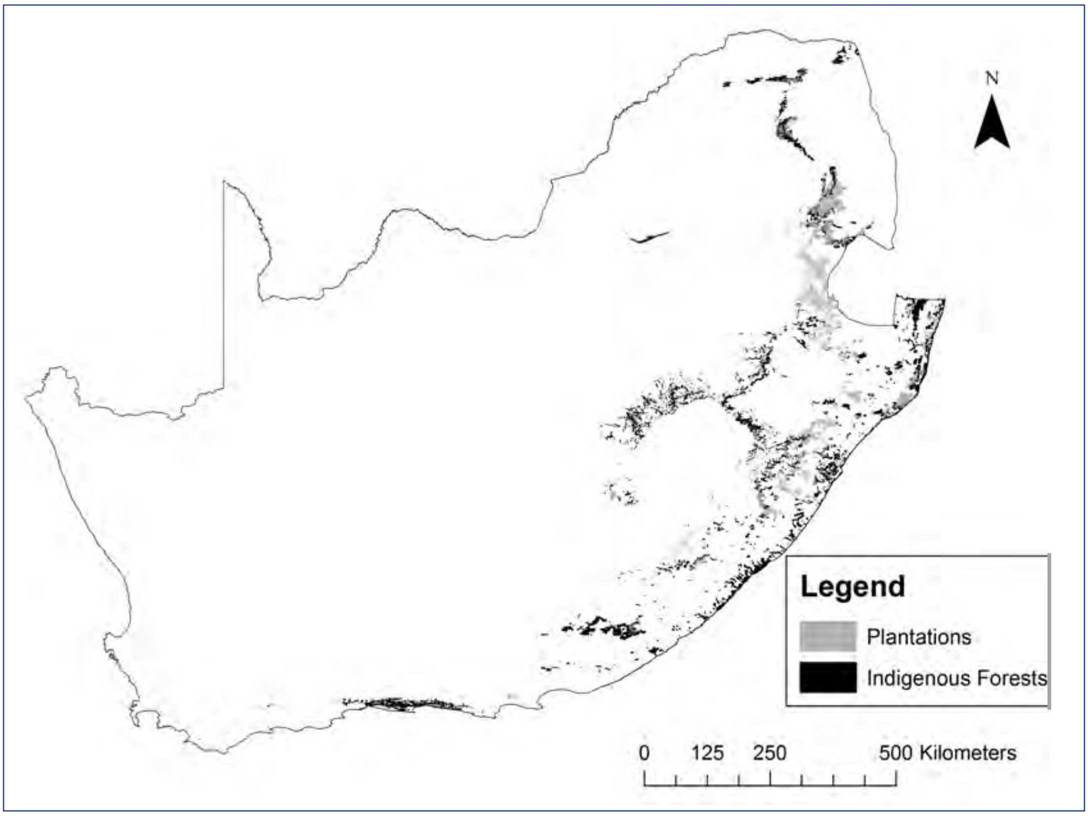

Figure 1. The distribution of native (indigenous) forest and timber plantations in the Republic of South Africa (GEOTERRAIMAGE, 2014).

Against this background of timber scarcity, the early governments in South Africa encouraged the planting of introduced tree species for timber, from as early as the late 19th Century (van der Zel, 1995; Kruger and Bennett, 2013). The earliest plantations were of eucalypts to supply fuelwood for trains and timber for railroad ties (sleepers). Another early crop was wattle, Australian *Acacia* species (mainly *A. mearnsii*), planted for the production of tannin from its bark. Mining became a major economic activity by the beginning of the 20th Century, and mining companies started planting introduced trees (mainly fast-growing eucalypts) to supply wood for mine props in the underground mines. Gradually, a saw-timber industry was developed based on plantations of pines that were thinned and pruned to produce a high quality timber.

Today, the country has a vibrant commercial plantation industry, based on approximately 1.27 million ha of plantations (Figure 2). These plantations are based on a limited number of pine, eucalypt and acacia species, but all are fast-growing, allowing for profitable production of forest products. Most of the saw timber comes from pine plantations which comprise 51% of the plantation area (mainly *Pinus patula*, followed by *P. elliottii, P. radiata* and *P. taeda*). A variety of eucalypt clones, mostly based on *Eucalyptus grandis*, are grown on short rotations (8-12 years), mostly for pulping and chipping (chips being exported to markets in the Far East are included in the pulpwood category in

Figure 3). These short-rotation eucalypts are also sawn for mining timber, though this market now makes up only 4% of production.

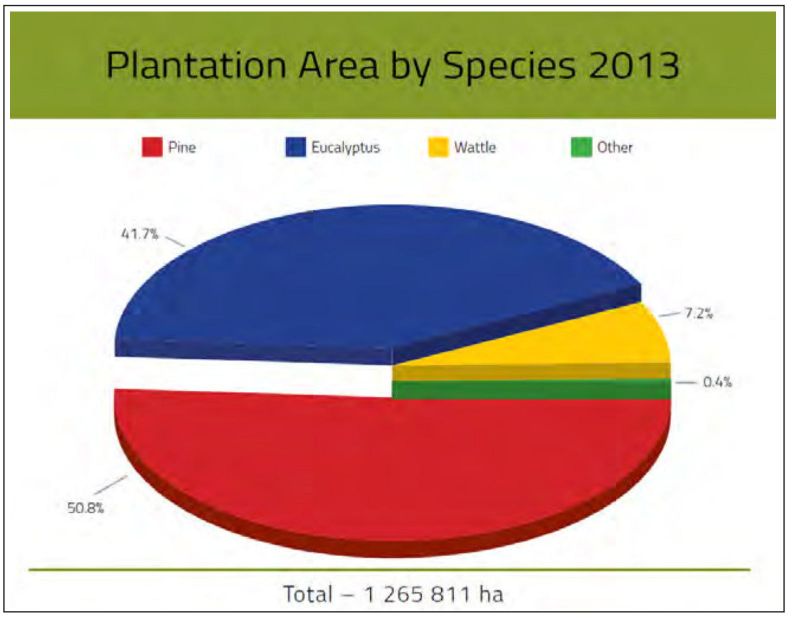

Figure 2. The area of South African plantations by tree type (FSA, 2014)

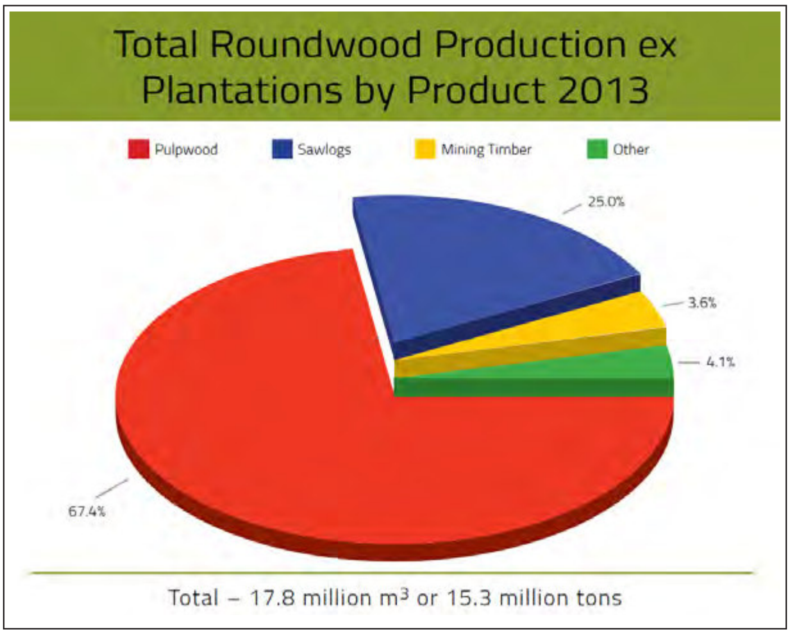

Figure 3. The main product categories of the South African forest industry (FSA, 2014)

The economic importance of the forest industry

The national forest inventory estimates that the annual sustainable production of timber from the plantations is 20 million tons, at an average growth rate of 15.8 ton/ha for the whole industry (DAFF 2014). Exports of forest products in 2013 amounted to US$1.7bn, which resulted in a positive trade balance with respect to wood products of $380m (DAFF 2014). Perhaps most significantly in South Africa, the industry as a whole (including processing) employs 170,000 people of which 66,000 are involved in forestry operations (DAFF 2014). The forest industry based on plantations of introduced timber species is therefore an important part of the South African economy, and projections indicate that it needs to grow in order to keep pace with future increases in demand for wood and fibre products.

11.2 Literature review

The commercial timber plantations are generally confined to areas where MAP exceeds 750 mm (van der Zel, 1995), and growth rates are generally positively related to rainfall. Although the current area of commercial timber plantations occupies only 1.04% of the land area, they are in the wetter parts of the country, and this lead to conflicts over their effects on water resources. As early as 1915 farmers were contesting the generally held view that forest cover would benefit the regional hydrology, and were complaining that their water supplies seemed to be negatively affected by upstream plantations (van der Zel, 1995). Forestry officials supported the spread of plantations for reasons of timber supply, control of erosion and for hydrological benefits, believing that trees would regulate flows and humidify their environment (Kruger & Bennett, 2013).

Figure 4. Plantation forests and water: A stream adjacent to a commercial pine plantation in the Magoebaskloof area, South Africa. (photo: M. Gush)

In 1935 the Empire Forestry Conference was held in South Africa. It brought the senior forest scientists from the British Empire together for an extended conference and tour of forestry sites in the country. At the time, South Africa had more plantations than any other country in the British Empire. Government ministers challenged the gathered foresters to advise them on the debate regarding the hydrological effects of plantations. As the then Minister for Agriculture and Forestry, Denys Reitz, said at the conference; “For more than a century we in South Africa have been planting trees, chiefly pines and eucalypts, under the impression that such plantations were valuable for the conservation of water. It has now been put to me that in this way we are decreasing the humidity and drying the soil.” (Bennett & Kruger, 2013). The conference recommended a serious scientific study to establish evidence of the hydrological influence of trees. In 1936, the Jonkershoek Forestry Research Station was established, under the direction of Dr CL Wicht, a forester with training from Germany and Oxford (Kruger & Bennett 2013). Additional gauged catchment studies that contrasted afforestation with introduced pines or eucalypts with a well-managed native vegetation, were added after the Second World War, at Cathedral Peak, Mokobulaan and Westfalia. As a result of the high political profile of the debate around plantations, there was strong government support for the research programme, which maintained its funding and was able to stick to an ambitious research plan for close to five decades.

Figure 5. A mosaic of indigenous forest, commercial plantations and grassland in a landscape typical of South Africa forest growing areas. (photo: M. Gush)

The research programme involved planting gauged catchments to pine or eucalypts that were used in that region of the country, and applying standard silvicultural treatments for saw-timber crops, which included thinnings and pruning of the trees at prescribed intervals. Standard planting was at 3 m by 3 m spacing, giving an initial stocking of roughly 1360 stems per hectare (spha). Periodic thinnings would have brought stocking to below 400 spha in most experiments. Over time the experiments were analysed by a series of researchers, starting with Wicht (1967) who analyzed the first experiments with *Pinus radiata* planted into the sclerophyllous scrub (fynbos) in Jonkershoek. Nanni (1970) analyzed the experiments with *P. patula* plantings into montane grasslands at Cathedral Peak showing that the same trend found in the Mediterranean-type climate of Jonkershoek also occurred in the mountainous summer rainfall region. Van Lill et al. (1980) analyzed the early results of the first experiment with *Eucalyptus grandis* planted at Mokobulaan, showing a sharper and earlier reduction in flows than observed under pines. Bosch (1979) did more work on the catchments at Cathedral Peak, including the first analysis that showed that dry season flows were impacted to a greater relative extent than annual runoff. Van Wyk (1987) extended the analysis of the replicated experiments at Jonkershoek, confirming the general trend of streamflow reductions caused by the planting of pines. Smith & Bosch (1989) and Bosch & Smith (1989) analyzed the second experiment with eucalypts in sub-tropical Westfalia, showing that when the fast-growing eucalypts replaced mature native forest, there was a highly significant reduction in streamflows within three years of planting. Scott et al. (2000) provide a background and review of the main experiments in the gauged catchment network.

Photo courtesy of Wood SA and Timber Times

Figure 6. View of typical pine & eucalypt plantation in South Africa (source: http://www.woodsa.co.za/2014/April/images/WaterUse3.jpg)

It had long been standard practice for the riparian zones (a 20 m wide strip either side of streams) within timber plantations to be exclusion zones. This was done on the basis of early work that showed that riparian vegetation had a direct effect on streamflow (Rycroft, 1955). Subsequently, several experiments have shown that the practice of keeping the riparian zones under a native vegetation cover is justified from a water conservation perspective (Prinsloo & Scott, 1999; Scott 1999; Everson et al., 2007). Van der Zel (1970) and Lesch and Scott (1997) looked at the influence of thinnings on water yield. Although thinnings may remove as much as half the trees, the remaining plantation trees soon occupy the whole site so that any savings in water are of short duration (<2 years). During the 1990's a series of process studies were undertaken in the plantations (many summarized by Dye 1996), which have provided insight into how and when the fast-growing introduced tree species use more than the native vegetation they have replaced.

Scott et al. (1998) used empirical models derived from the catchment experiment results to estimate the impacts of forest plantations on streamflow at regional and national scales. The forest plantations cover 1.2% of South Africa, but are concentrated in areas of higher rainfall, which produce a disproportionately large share of total streamflow. Thus, regional catchments in which some degree of afforestation has occurred comprise only 14% of the country, yet produce 53% of the mean annual streamflow and 70% of the mean annual low flows (Scott et al., 1999). Commercial plantations were estimated by Scott et al. (1998) to reduce mean annual streamflow by 3.2% (1417 X 10^6 m^3/year) but low flows by 7.8% (101 x 10^6 m^3/year). This translates into an annual average reduction of 98.6 mm/year for planted areas. In a more recent assessment, the ACRU model, a physically-based process model, was used to quantify the effects of afforestation across the country based on the difference in water use between native vegetation and plantations (Gush et al., 2002). From this study, reductions in streamflow caused by plantations in all quaternary (forth-order) catchments where commercial forestry was deemed to be viable (MAP>650mm) averaged a more modest 74 mm/year for eucalypts, 57 mm/year for pines and 57 mm/year for wattle (Acacia). However, as the study was only designed as an estimation of <u>potential</u> streamflow reductions across all viable forestry areas (including a large number of drier / marginal catchments where impacts would be lower in absolute terms), and not as a national water-use assessment, these estimates should not be considered representative of the average water use by the commercial forestry sector. Despite the differences between the outputs of different models, it is clear that forest plantations have a significant effect on the available water resources of South Africa.

11.3 Politics

Following droughts in the 1960's, two government committees looked into water matters and addressed the role of forestry in water supply (Malherbe et al., 1968; van der Zel, 1995). Consequently, the Forest Act was amended in 1972 to regulate further afforestation for water conservation purposes. The Act put the Afforestation Permit System in place (van der Zel, 1995), which was administered by the central government's Department of Forestry. Catchments (drainage basins) were placed into one of three categories that would determine whether further forestry was possible or not. Category I catchments were considered already fully allocated (because of existing water use demands) and no permits were granted within these. Category II catchments had sporadic water shortages and afforestation would be capped so as to use no more than an estimated further 5% of mean annual runoff (MAR). In Category III catchments, over the bulk of the country, afforestation would be permitted to the extent that would use an estimated additional 10% of MAR. The scientific basis for the policy came from the long-term gauged catchment studies, and the estimates needed in the permitting system, specifically, came from a summary model developed by Nänni (1970) and modified by van der Zel (1995).

A major revision of the water law was undertaken after the democratization of South Africa in the 1990's leading to the National Water Act of 1998. This innovative legislation changed the basis for the regulation of forestry. Forestry is now classified as a "streamflow reduction activity" (SFRA), on the basis of its estimated effects on streamflow, which requires that it be licensed. On the surface, this new Act opens the prospect of other land uses, for example, dry land sugarcane or bamboo, also being included. However, at this time there is no other land use that has been classified as a SFRA. The licensing procedure is time-consuming and complex, and the implications of the licensing are yet uncertain (Dye & Versfeld 2007). This, together with the fact that South Africa is rapidly approaching the point at which all of its easily accessible freshwater resources are fully utilized (NWRS, 2013), has resulted in very little expansion of the forest industry in South Africa in the fifteen years since the National Water Act came into effect (Kruger & Bennett 2013).

11.4 Climate change and the future of forestry & forest research

The effects of climate change on the southern African sub-continent are uncertain. However, the South African forestry industry is sensitive to climate, as only 1.5% of the country is suitable for tree crops under the current climate (Fairbanks and Scholes, 2005). In addition, the relatively long period between planting and harvest makes tree plantations vulnerable to environmental change. Warburton and Schulze (2008) modeled the potential effects of climate change on main species of pines & eucalypts in South Africa. There is a convergence of predictions by different global climate models regarding temperature as all indicate an increase in temperature over the forestry regions of the country. Regarding precipitation though, predictions are more divergent though a rise in precipitation seems more likely in the eastern forestry areas. Using known prescriptions for the climatic suitability of major forestry species, Warburton and Schulze (2008) assessed the potential effects of plausible climate change possibilities on the forest industry. As might be expected, declining rainfall concomitant with rising temperature will have an especially negative effect on total area of optimal growth, while an increase in rainfall will offset all negative impacts of temperature, and increase the total area of optimal conditions for both pines and eucalypts. These changes will necessitate the issuing of appropriate water use licences and have associated impacts on water resources. Other emerging issues in South Africa which have a forests and water link include: a growing demand for bio-energy products; impacts of plantation species exchanges (genus exchanges) on streamflow reductions;

water use by agroforestry systems; reforestation and expanded use of indigenous tree species. With regard to the latter, recent studies have investigated the water use, growth rates and resultant water use efficiencies (WUE) of indigenous tree species in South Africa compared to introduced plantation tree species (Dye, et al., 2008; Gush and Dye, 2009; WRC, 2010). Results are showing that while biomass production is much lower for indigenous tree species, they also use much less water than introduced plantation species. Resultant WUE estimates showed substantial variation, even within a particular species, but on average results indicated that indigenous tree species appear to exhibit similar bio-physical water use efficiencies to introduced plantation tree species (WRC, 2010). The relatively low water-use characteristics of indigenous tree species suggests that they are promising for reforestation and expanding indigenous tree production systems in South Africa, maximizing benefits (goods and services) while minimizing resource impacts (water-use).

Conclusions

In response to a shortage of native forest and an increasing need for timber, the early colonial governments encouraged the establishment of plantations to supply wood for local uses. South Africa thus has a long history of establishing and managing timber plantations using exotic tree species. However, the spread of the man-made forests soon led to conflicts with downstream water users, mainly farmers who claimed that, contrary to expectations, their stream water supplies seemed less reliable since the arrival of plantations. A simmering debate about the positive and negative effects of plantations of exotic tree species eventually became a high-level political issue, and this led to the establishment of a large and intensive forest hydrological research program in 1936. The research program was based on a series of paired catchment experiments around the timber growing areas of the country. These experiments produced unequivocal evidence that the fast-growing plantations had a negative effect on total and dry season streamflows. The results of the research program were incorporated into policy that regulated the extent and location of the plantations, based on their estimated effects on regional water resources. More recently, the National Water Act (1998) incorporated these restrictions by classifying commercial forestry as a streamflow reduction activity, and subject therefore to licensing and water use fees. As forestry is the only land use included under this restriction, and because of bureaucratic obstacles, the forest industry, despite its economic vitality and importance, is no longer expanding. The forest industry feels unreasonably disadvantaged by the fact that its hydrological effects are better understood than other land uses, and large forest corporations are now looking for growth opportunities in neighboring countries where investments in forest plantations are seen more favorably.

11.5 References

Bennett, BM and Kruger, FJ, 2013. Ecology, forestry and the debate over exotic trees in South Africa. *Journal of Historical Geography* 42: 100 - 109

Bosch, JM, 1979. Treatment effects on annual and dry period streamflow at Cathedral Peak. *South African Forestry Journal,* 108: 29.

Bosch, JM and Smith, RE, 1989. The effect of afforestation of indigenous scrub forest with Eucalyptus on streamflow from a small catchment in the Transvaal, South Africa. South African Forestry Journal 150:7-17.

Bosch, JM and von Gadow, K, 1990. Regulating afforestation for water conservation in South Africa. *South African Forestry Journal*, 153: 41 – 54.

DAFF, 2014. Report on commercial timber resources and primary roundwood processing in South Africa. Department of Agriculture, Forestry and Fisheries, Pretoria, South Africa.

DWAF, 2004. National Water Resource Strategy, first ed. Department of Water Affairs and Forestry, Pretoria, South Africa.

Dye, PJ, 1996. Climate, forest and streamflow relationships in Southern African afforested catchments. *Commonwealth Forestry Review*, 75: 31 – 38.

Dye, PJ and Versfeld, DB, 2007. Managing the hydrological impacts of South African plantation forests: An overview. *Forest Ecology and Management* 251: 121–128.

Dye, PJ, Gush, MB, Everson, CS, Jarmain, C, Clulow, A, Mengistu, M, Geldenhuys, CJ, Wise, R, Scholes, RJ, Archibald, S and Savage, MJ, 2008. Water-use in relation to biomass of indigenous tree species in woodland, forest and/or plantation conditions. WRC Report TT361/08, Water Research Commission, Pretoria, South Africa.

Everson, CS, Gush, MB, Moodley, M, Jarmain, C, Govender, M and Dye, PJ, 2007. Effective management of the riparian zone vegetation to significantly reduce the cost of catchment management and enable greater productivity of land resources. Report to the Water Research Commission. WRC Report No 1284/1/07 (ISBN: 978-1-77005-613-8).

Fairbanks, DHK and Scholes, RJ, 1999. South African country study on climate change: vulnerability and adaptation assessment for plantation forestry. CSIR Environmentek Report ENV/C/99. National Research Facility, Sustainable Development Program, Pretoria, South Africa.

FSA, 2013. Abstract of South African Forestry Facts for the year 2012/2013. Forestry South Africa, report to Dept. Water Affairs and Forestry. Available from [http://www.forestry.co.za].

GEOTERRAIMAGE, 2014. 2013 - 2014 South African National Land Cover Data. A commercial data product created by Geoterraimage for the Department of Environmental Affairs, South Africa.

Gush MB and Dye PJ. 2009. Water-use efficiency within a selection of indigenous and exotic tree species in South Africa as determined using sap flow and biomass measurements. Acta Horticulturae 846: 323-330.

Gush, M.B., Scott, D.F., Jewitt, G.P.W., Schulze, R.E., Hallowes, L.A., Görgens, A.H.M., 2002. A new approach to modelling streamflow reductions resulting from commercial afforestation in South Africa. *S. Afr. For. J.* 196, 27–36.

Kruger, FJ and Bennett, BM, 2013. Wood and water: an historical assessment of South Africa's past and present forestry policies as they relate to water conservation, *Transactions of the Royal Society of South Africa*, DOI: 10.1080/0035919X.2013.833144

Le Maitre, DC, van Wilgen, BW, Chapman, RA and McKelly, DH, 1996. Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. Journal of Applied Ecology, 33: 161-172

Lesch, W and Scott, DF, 1997. The response in water yield to the thinning of *Pinus radiata, Pinus patula* and *Eucalyptus grandis* plantations. *Forest Ecology and Management*, 99: 295-307.

Malherbe, HLW, 1968. Afforestation and Water Supplies in South Africa. Report of an Interdepartmental Committee, Department of Forestry, Pretoria, South Africa.

Nänni, UW, 1970. Trees, water and perspective. South African Forestry Journal, 75, 9–17.

NWRS, 2013. National Water Resource Strategy. Department of Water and Sanitation, South Africa. Available from www.dwa.gov.za/nwrs2013.

Prinsloo, FW and Scott, David F, 1999. Streamflow responses to the clearing of alien invasive trees from riparian zones at three sites in the Western Cape Province. Southern African Forestry Journal 185: 1-7.

Rycroft, HB, 1955. The effect of riparian vegetation on waterloss from an irrigation furrow at Jonkershoek. Journal of the South African Forestry Association, 26: 2-9.

Schulze, RE (Ed), 2008. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/08, Section 18.3.

Schulze, RE, 2010. Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective. Department of Agriculture, Forestry and Fisheries, Pretoria, South Africa. 391 pp.

Scott, DF, 1999. Managing riparian zone vegetation to sustain streamflow: results of paired catchment experiments in South Africa. *Canadian Journal of Forest Research*, 29(7): 1149-1157.

Scott, DF, Le Maitre, DC, Fairbanks, DHK, 1998. Forestry and streamflow reductions in South Africa: a reference system for assessing extent and distribution. Water SA 24, 187–199.

Scott, DF, Prinsloo, FW, Moses, G, Mehlomakulu, M, Simmers, ADA, 2000. A Re-analysis of the South African Catchment Afforestation Experimental Data. WRC Report No. 810/1/00, Water Research Commission, Pretoria, South Africa.

Smith, RE and Bosch, JM, 1989. A description of the Westfalia experiment to determine the influence of conversion of indigenous forest on water yield. South African Forestry Journal 151:26-31.

Van der Zel, DW, 1970. The effect of thinning on flow in a Jonkershoek stream. Forestry in South Africa, 11: 41-43.

Van der Zel, DW, 1995. Accomplishments and dynamics of the South African afforestation permit system. South African Forestry Journal, 172: 49 – 58.

Van Lill, WS, Kruger, FJ and Van Wyk, DB, 1980. The effect of afforestation with *Eucalyptus grandis* Hill ex Maiden and Pinus patula Schlecht. et Cham. on streamflow from experimental catchments at Mokobulaan, Transvaal. *Journal of Hydrology* 48:107-118

Warburton, ML and Schulze, RE, 2008. Potential impacts of climate change on the climatically suitable growth areas of Pinus and Eucalyptus: results from a sensitivity study in South Africa. *Southern Forests*, 70: 27–36.

Wicht, CL, 1949. Forestry and Water Supplies in South Africa. Department of Forestry, Union of South Africa. Pretoria, Government Printer, 58 pp.

Water Research Commission (WRC). 2010. Abridged Knowledge Review 2009/10 - Growing Knowledge for South Africa's Water Future. WRC, Pretoria. pp. 59-60.