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# Gold, Scorched Earth and Water: The Hydropolitics of Johannesburg

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ABSTRACT *Johannesburg is an unusual city because it is one of the few major cities of the world that does not lie on a river, a lake or a seafront. Since the discovery of gold in 1886, Johannesburg has grown from a dusty mining town to a major urban and industrial conurbation that houses and sustains a quarter of the total population of South Africa, accounting for 10% of the economic activity on the entire African continent. Water supply to Johannesburg is done by Rand Water, which is credited with sustaining the largest human concentration in the southern hemisphere that is not located on a river. This poses major challenges to engineers because the geology associated with the gold-bearing reef is also associated with the watershed between two major international river basins in Southern Africa, the Orange and the Limpopo. Having been classified as pivotal basins in the Southern African Hydropolitical Complex, these two river basins form the strategic backbone to the economies of the four most economically developed countries in the Southern African Development Community (SADC) region—South Africa, Botswana, Namibia and Zimbabwe. In order to sustain the urban and industrial complex in what is best described as the Greater Johannesburg Conurbation, massive Inter-Basin Transfers (IBTs) are necessary, posing a challenge to the notion of a river basin as a fundamental unit of management within the framework of Integrated Water Resource Management (IWRM), because in essence every river basin in South Africa is now hydraulically connected to every other river basin, with this pattern starting to cross international borders in an increasingly complex web of transfer schemes. This supports the notion that the management of water in transboundary river basins is now starting to impact on the political relations between states, which is the essence of the rationale behind the emerging Southern African Hydropolitical Complex.*

## Introduction

The City of Johannesburg in South Africa is an interesting story from a water resource management perspective for a number of reasons. Its existence in the first place is due to a geological factor in which gold-bearing reef was exposed on the surface through a series of ancient biological processes and tectonic events. This means that many of the logical factors that account for the existence of other major cities are simply absent in the case of Johannesburg. Known alternatively as *eGoli* or *Gauteng* (both meaning ‘the Place of Gold’ in *isiZulu* and *seTswana* respectively), the city of Johannesburg is one of the few great cities of the world that is not located on a river, a lake or a seashore. In fact Johannesburg straddles a major watershed, known as the Witwatersrand

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(translated literally as ‘Ridge of White Waters’), which divides the continent of Africa into rivers that flow into the Indian Ocean to the east, and rivers that flow into the Atlantic Ocean in the west. Located in the headwaters of two major international river basins, the Orange river and the Limpopo river, water supply challenges and water quality issues are but two of the major obstacles that confront the staff of Rand Water, the institution that is responsible for supplying the water that sustains, what is in effect, the economic engine of Africa. The significance of the Witwatersrand Ridge as a life support system relates to the large number of hominid fossils that occur, with some 40% of the world’s known hominid fossil deposits being associated with this geological feature. So while Johannesburg is a modern African city, it is also the Cradle of Humankind[1]. Today the Witwatersrand metropolitan area with a population of around 11 million people, largely dominated by Johannesburg and the many satellite towns and cities spawned by the gold mining activities of the last century, is said to be one of the largest concentrations of humans that has developed away from a sustainable water resource. Rand Water, the statutory body responsible for providing potable water to this sprawling urban conurbation, is one of the largest bulk water suppliers in the world today. Therefore, the story of water in Johannesburg is the story of Rand Water, which in turn is about sustaining a major urban conurbation that is far greater than the actual limits of this one city alone.

**Physical Aspects**

The City of Johannesburg is found at an altitude of some 6000 feet (1800 m) above sea level (Figure 1). It is located in an area that was originally a rolling grassland called the Highveld, which was devoid of any trees except for those found along the riparian zones of the many small rivers that are found there. The grassland is largely the result of the low and highly variable rainfall patterns, with a mean annual precipitation (MAP) of 600 mm. The Highveld covers a semi-arid area with evaporative losses of 1600 mm. The low MAP, combined with the high evaporative potential and variability in precipitation patterns, has resulted in the fact that rivers in South Africa have amongst the lowest conversion of mean annual precipitation to mean annual runoff (MAR) in the world (O’Keeffe *et al.*, 1992, p. 281). In fact, the total average runoff (that portion of rainfall that is not lost to evaporation that eventually finds its way into rivers) is only some 10% of total annual rainfall (Rabie & Day, 1992, p. 647) in South Africa as a whole. Of this relatively small runoff that eventually becomes streamflow, a mere 60% (Rabie & Day, 1992, p. 647) to 62% (O’Keeffe *et al.*, 1992, p. 278) can be economically exploited due in large to the extreme variability of the rainfall events. This hydrological reality has provided the stimulus for the construction of dams in an attempt to retain as much streamflow as possible (Turton & Earle, 2005), to the extent that South Africa is listed in the top 10 countries in the world by virtue of the number of large dams that have been constructed over time (WCD, 2000, p. 373; Turton, 2003b).

Cutting across the Highveld area is a geological feature that is the result of a series of tectonic events. This geological feature consists of recurring sedimentary cycles which have passed in phases of geological time, from deep sea marine to continental conditions (Werdmüller, 1986, p. 37). The gold-bearing reef within this geological feature has been described as being ‘typical lagoonal deposits’ that have been the subject of tectonic movements in which subsidence, uplift and subsidence has occurred, along with substantial weathering and erosion (Werdmüller, 1986, p. 37). More specifically, what is

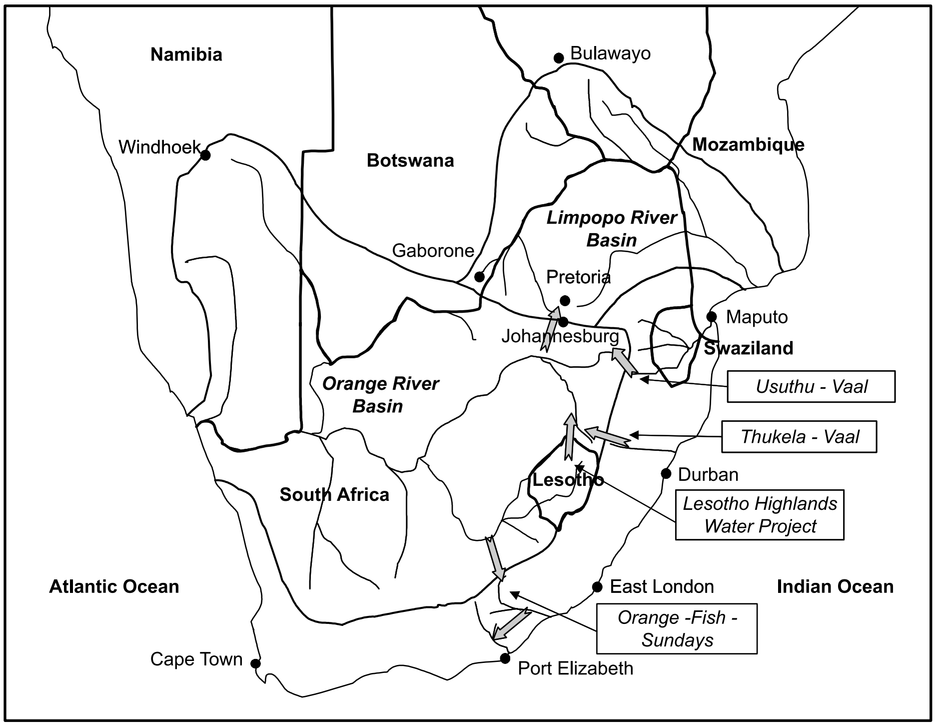


**Figure 1.** South Africa showing the Orange and Limpopo River Basins, with Johannesburg on the watershed and some of the strategic Inter-Basin Transfers

known as the Main Reef Leader is attributed to shore line pebble deposits in which gold and other heavy metals became concentrated during the gradual but relentless advance of an encroaching sea front (Werdmüller, 1986, p. 37). The inland sea that created these deposits dates back to periods of geological time between 3100 million years and 1900 million years ago (Werdmüller, 1986, p. 44). The entrapment of gold has been helped by the existence of primitive plants and algal-like material, which are preserved today as a thin band of carbon (Chapman *et al.*, 1986, p. 181) that is known as the Carbon Leader.

The Witwatersrand Ridge is important for five key reasons. First, the tectonic event that created it also created the major continental watershed, with rivers arising to the east flowing into the Indian Ocean through the Limpopo river basin, and rivers arising to the west flowing into the southern Atlantic Ocean through the Orange river basin. Both of these are strategically important to South Africa because of the high level of economic activity that they sustain.

Second, the tectonic event exposed gold-bearing reef to the surface, thereby making it relatively easy to discover once it was settled by farmers in the 1800s. The discovery of the Witwatersrand goldfields has probably exerted a greater influence on the evolution of South African history than any other single event (Cunningham, 1987, p. 7).

Third, the name 'Witwatersrand' gives an indication of the early pristine condition of the Highveld area. Translated literally as 'Ridge of White Waters', the name arose because of the myriad of small springs that rose along the geological feature, many of which cascaded across the different elements of the geological complex before starting their long journey as rivers down to the sea many thousands of kilometres away. The Witwatersrand is thus an important headwater for two major river basins, so pollution occurring there impacts a wide range of stakeholders downstream.

Fourth, the continental watershed created by the Witwatersrand, is part of a regional Hydropolitical Complex consisting of the four most economically developed states in the Southern African Development Community (SADC) region (South Africa, Namibia, Botswana and Zimbabwe), all of which have water scarcity constraints to their future economic growth potential (Turton, 2003a, 2003b, 2004; Turton & Earle, forthcoming; Turton *et al.*, 2004a, 2004b). Central to this complex are the Orange and Limpopo river basins, which are shared by these four riparian states, making these two basins pivotal in the sense that their strategic significance goes way beyond simply sustaining the socio-economic activities in the city of Johannesburg[2].

Finally, the Witwatersrand Ridge offered a safe haven for early hominid development. Providing high ground with a panoramic vista over the plains of Africa, early hominids could hunt the migrating herds of antelope. Significantly, the Highveld grassland biome has been described as sustaining the highest animal biomass of any similar ecosystems in pre-colonial Southern Africa (Mitchell, 2002, pp. 18–19). The underlying dolomite geology provided caves in which shelter could be found, the most notable of which is Sterkfontein Cave (translated literally as 'Strong Fountain Cave') in the Krugersdorp area of the West Rand. It was consequently along this watershed that human development was encouraged in pre-historic times, with fossil discoveries dating back to some of the oldest known hominid branches on the African continent. This is a World Heritage Site[3] today with the Cradle of Humankind as a component.

The significance of the combination of these key factors is that Johannesburg exists entirely as the result of the discovery of gold, is located on a watershed at high altitude, and lacks any of the other fundamental factors that are usually associated with the development of major cities elsewhere in the world. Johannesburg, in this sense, is very unique indeed, being one of the few cities in the world that is not located on a river, a lake or a harbour. However, more significantly Johannesburg straddles a major watershed that has strategic ramifications for four of the most economically developed states in the SADC region, all of which have reached a water-related limitation to their future economic growth potential. This combination of factors is the underlying driver of the many challenges that arise in the quest to manage the water resources that sustain the economic growth and development in and around the city.

## Driver of Growth

The geology associated with the Witwatersrand Ridge, exposed gold-bearing reef to the surface, thereby enabling gold to be discovered. It is here that the original driver of growth can be traced. In 1885 two wanderers, George Harrison and George Walker, arrived on the farm Wilgespruit (translated as 'Willow Stream') on the northern slopes of the Witwatersrand Ridge. Early in February 1886, Walker left Wilgespruit to join Harrison, who was building a house on the farm Langlaagte. En route to Langlaagte Harrison stumbled on an outcrop of rock, and after examining it, decided to crush and pan a piece of it. Having been a gold digger in Australia, he had the necessary skills to recognize the reef, and was surprised when he saw a tail of gold in the pan. He had inadvertently stumbled onto a weathered outcrop of what was to become known as the Main Reef (Werdmuller, 1986, p. 7). This was the start of the Gold Rush[4] that saw Johannesburg grow virtually overnight.

Similar discoveries soon followed with small mining towns springing up all along the Witwatersrand Ridge. The mining camps were generally sited according to the availability of water (Appelgryn, 1984, p. 14). The East Rand saw a cluster of mines starting to coalesce around what were to become future satellites of Johannesburg. Located at places like Springs (referring to the original freshwater springs that existed there), Brakpan (translated as 'Brackish Pond') and Benoni. In similar vein the West Rand spawned a plethora of mining towns in places like Roodepoort (a 'poort' is a natural ravine through a mountain caused by a river and often associated with a geological fault), Krugersdorp[5] (named after Paul Kruger, the President of the Zuid Afrikaanse Republiek when gold was discovered) and Randfontein (translated as 'Ridge Fountain'). The situation that arose shortly after the original discovery of gold was a typical gold rush bonanza, with the rapid influx of foreign diggers, capitalists and would-be prospectors. They settled in a series of tented and corrugated iron towns around each of these main discoveries, dotted all along the Witwatersrand Ridge. Over time these small settlements merged into one bigger conurbation, and on 4 October 1886 the City of Johannesburg was officially founded[6], subsequently accounting for some 40% of the global production of gold.

Politically this caused significant tensions. The Witwatersrand Ridge was located in an independent Boer Republic known at that time as the Zuid Afrikaanse Republiek (ZAR) with Paul Kruger as the President. The ZAR was one of two Boer Republics, which had arisen as the result of the Great Trek away from the British colonies of the Cape and Natal. Happy to settle the land and farm relatively free of foreign intervention, the Boer Republics were given a rude awakening when literally thousands of *Uitlanders* (translated as 'foreigners') descended upon them, all seeking wealth from the gold bonanza. This changed the politics almost overnight. Once it had been established that the gold discoveries were substantial, British interest was soon raised. The hidden wealth of the ZAR was to be coveted by the Crown[7]. A series of political interactions occurred, the most notable of which was the Jamieson Raid[8], in which the British raised a band of mercenaries who attempted to unseat Paul Kruger by force. In a series of skirmishes that saw the raid fail, Paul Kruger retained political control for a while. This was only a temporary respite however, as the subsequent Anglo-Boer War[9] eventually saw the ZAR being incorporated by military force into what became the Union of South Africa. Consisting of the two former British colonies of the Cape and Natal, along with the two vanquished Boer Republics of the Orange Free State and ZAR (also referred to as the Transvaal), the Union of South Africa was founded largely on the mining wealth arising from the original discovery of gold at Langlaagte, and diamonds[10] in the kimberlite pipes around the modern city of Kimberly.

## Recent History

At the time of the establishment of the Union of South Africa in 1910, the potentially promising gold-based economy was largely shattered. The Boers had been vanquished as the result of the scorched earth policy of the British, which saw large scale ransacking of the farms and the first recorded use of concentration camps[11] for women, children and other non-combatants on the African continent. Union was therefore a bitter affair for many Boers, who had become landless peasants without any modern skills, largely because of the perceived greed of other non-African citizens. However, the newly established mining houses created a demand for labour so there was a general influx of Afrikaners[12], many of whom who had been systematically dispossessed during the Anglo-Boer War. There was a demand for four distinct categories of worker on the rapidly developing mines—unskilled labourers, semi-skilled miners, specialists such as geologists and engineers, and entrepreneurs. These four categories had a specific impact on the development and growth of Johannesburg, and indeed the social fabric of South Africa as a whole.

The entrepreneurial class were all *Uiltanders*, mostly from Britain. This was so simply because the Boer Republics had not yet mobilized any financial capital or entrepreneurial skills needed to fund and manage the deep mining operations. The entrepreneurial class settled in a wealthy new suburb that was known as Doornfontein (translated as 'Thorn Fountain').

The skilled specialists such as geologists and engineers were also originally sourced from outside South Africa, coming mostly from the Universities of Britain (but also from other European countries). They generally spoke English.

The semi-skilled miners came mostly from the local Boer population. They spoke Afrikaans[13] and other indigenous African languages such as *isiZulu* and *seTswana*, which they had acquired in their earlier lives on the rural farms. As such they became a vital link in the management chain between the entrepreneurial class and skilled specialists that directed the mining operations and the unskilled labourers. They generally settled on the mine properties.

The unskilled labourers were all native Africans, speaking a variety of indigenous languages. They were used to wrestle the gold from the deep reefs which they followed relentlessly over time, eventually going thousands of metres into the earth in what were destined to become some of the deepest mines[14] in the world, often paying with their lives. These unskilled labourers were housed in hostels on the mine properties.

It was the need for labour on the mines that became one of the major drivers of the subsequent social fabric of South Africa that had two distinct components to it. Central to this was the notion of migrant labour, with men going to Johannesburg to earn wages to be remitted back to the rural areas all over the continent of Africa. This left the women back home, tilling the fields and raising a family in which men were hardly seen and thus increasingly irrelevant. The men on the other hand, away from home for 11 months of the year, lived in all-male hostels. The migrant labour system became deeply entrenched in the South African economy and society, with a range of debilitating features that were to become evident many decades later. These maladies manifest themselves as the social pathologies of the breakdown of the family unit, alcohol and substance abuse and prostitution. It was to these fertile soils of social disruption that the destructive seeds of HIV/AIDS were to be sown nearly a century later, by which time the social structure of South Africa had been so severely damaged that the pandemic could take root and spread. The first component of the South African social fabric thus consists of migrant labour, which has become so deeply entrenched today that it is impossible to understand Johannesburg without reference to this key factor.

The second component is the history of Apartheid, which also has its roots in the discovery of gold. The stratification of society that led eventually to the formal policies of Apartheid being launched in 1948 can be traced back to the social composition of the mining houses in the immediate post-Anglo-Boer War era. The landless Afrikaner white minority who had lost nearly everything because of the British scorched earth policy, found a new niche on the mines. Eager to protect their positions, and not yet ready to occupy the specialist categories through lack of appropriate tertiary education, and the entrepreneurial categories through the lack of capital, they began introducing legislation that came to be known as Job Reservation. Becoming a cornerstone of the subsequent Apartheid policies, Job Reservation saw every task being classified in terms of racial composition. Unskilled jobs were left to the Black majority, while Whites reserved jobs involving the management of mining machinery and explosives to themselves. In terms of this approach, Blacks were not allowed to handle explosives, or to handle machinery such as hoists. This became a cornerstone of Apartheid half a century later.

It was against this social backdrop that Johannesburg grew. As this occurred, the dust associated with the Highveld climate became a problem, especially when whipped off the growing mine dumps that were starting to dominate the landscape, so trees were planted (Figure 2). The first public park was established in 1887 in what is still known today as Joubert Park (Davie, 2003). As Doornfontein was outgrown by the magnates, new suburbs were developed in Victorian fashion, laid out with large formal gardens and complex public parks. The new posh suburbs to which the so-called Randlords migrated reflect this fact in their names—Park Town, Parkview and Forest Town (Davie, 2003). Trees were planted in vast numbers, with demand coming from two distinct sources. The first was the need to settle the dust by creating parks for recreational purposes. The second was the need for mine timbers to support the shafts and stopes that were being driven ever deeper into the Reef, following the Carbon Leader like an indelible pencil mark permanently etched on the rock face of geological time. This saw vast quantities of Eucalyptus trees from Australia being planted, which later became a major environmental problem as they choked the small rivers arising along the Witwatersrand Ridge desiccating the landscape.

Population growth became a major factor in the water management equation. From a sparsely populated rural setting before the discovery of gold in 1886, the population had grown to 100,000 a decade later, and to 150,000 by 1901. This had mushroomed to 420,700 by 1910, and to over 10 million by the 2000.[15]

## Role of Water in Sustaining the Greater Johannesburg Conurbation

Shortly after gold was first discovered, water for the small mining town was drawn from a spring called Fordsburgspruit (translated as 'Ford's Mountain Spring'), and a second fountain near the present Johannesburg General Hospital called Natalspruit. Prior to 1896 another source of supply was developed on the farm Weltevreden (translated as 'Very Satisfied') north of the mining operations in Roodepoort. When this failed to meet the demands, development turned to dolomite groundwater found on the farm Zuurbekom, with a pump station first erected there in 1899 that is still in operation today[16] providing high quality water that is not in need of any treatment before being mixed with other sources. The growing demand for water was driven by the accelerating need to process crushed ore[17], with about 2000 litres (2 tons of water) being needed to mill one ton of gold-bearing reef. In the early 1890s a new process of extraction was introduced. Called the McArthur Forester process, it used cyanide to coalesce the fine gold particles, thereby increasing the yield of recoverable gold from the milling process, but also resulting in a potential pollution hazard that still exists today.

The voracious demand for water saw the first major private concession being granted by the ZAR Government in 1887. Known as the Sievewright Concession, one of the

**Figure 2.** The modern Johannesburg skyline showing the large number of exotic trees. This is the largest man-made forest in the world registering on satellite images as a tropical rainforest, posing specific challenges to water supply engineers today. *Source:* Rand Water.

stipulations was a limitation on the price that could be charged for water. The source of water used for this was the Doornfontein springs and the concession gave rise to the Johannesburg Waterworks and Exploration Company. This company was purchased in 1889 by mining magnate Barney Barnato. By 1893 the demand for water was around 5.86 Ml/d, outstripping the supply capacity of the existing companies. In 1893 the Braamfontein[18] Water Company, supplying water to the newly-established upmarket suburb of Parktown, and the Vierfontein[19] Syndicate, supplying water of different quality to industrial and human users, were established. In 1889 the Vierfontein Gold Mining Company constructed the first pumping station in the Klip river valley, receiving its water from the Olifantsvlei[20] Farm near present day Turffontein. This grew over time into what became known as the Klip river scheme. This led naturally to the Vaal river, some 60 km away from the goldfields, being considered as a reliable strategic supply of water for what was by then being called ‘The Reef’ that was centred on Johannesburg. A concession was awarded to two engineers in 1889 to deliver water from the Vaal river. One of these engineers, F.C. Eloff, was the son-in-law of President Paul Kruger, so the first allegations of nepotism were raised in the water supply story of Johannesburg. These died out when in 1892 the Barnato brothers’ Johannesburg Waterworks and Exploration Company gained control over this scheme. This was the foundation of the linkage between water supply and economic wealth that is the cornerstone of the so-called Pipelines of Power thesis[21] (Turton, 2000) on which an explanation of the hydropolitical dimension of Apartheid is based. By the end of the Anglo-Boer War in 1902 there were three companies responsible for water supply in the Witwatersrand–Johannesburg area—the Johannesburg Waterworks Estate and Exploration Company, the Braamfontein Company and the Vierfontein Syndicate—sourcing water from the dolomites around Zuurbekom, the springs at Doornfontein (near modern day Ellis Park stadium), a well an spring at Natalspruit in central Johannesburg, a spring in Berea, a spring in Parktown and the Klip river valley pumping station in the south. It was becoming apparent that the availability of clean water at a high assurance of supply could become a limitation to the economic growth of Johannesburg, so additional sources were considered for strategic reasons.

Severe droughts occurred in the 1890s triggering a series of water crises. Water carts came into operation, selling exorbitantly priced water that was largely unaffordable to most of the non-industrial users. This coincided with the introduction of the McArthur Forester process of gold extraction, which saw the first cyanide contamination of rivers. The Klip river was polluted in 1894 resulting in the death of livestock drinking the water. A Commission of Enquiry was established, which reported that water in the Doornfontein Valley was also polluted by mine effluent. This was the birth of a substantial water resource management problem that persists to this day, a fact made worse because the rivers being polluted are the very headwaters of major river basins that cross international borders.

In 1901 the ZAR Military Government appointed the Witwatersrand Water Supply Commission. At the end of the Anglo-Boer War in 1902 the British had gained control over Johannesburg and they realized that stable local government had to be restored if future economic growth was to be realized. The Royal Engineers took initial control in investigating water supply and sanitation services. The Witwatersrand Water Supply Commission reported in 1902, making the recommendation that an institution to be called The Rand Water Board[22] should be established and given the responsibility of developing a secure water supply system. The Rand Water Board included members of the Johannesburg Town Council, the Chamber of Mines and representatives of other local authorities along the Witwatersrand Ridge. The formal establishment of the Rand Water Board[23] occurred through Incorporation Ordinance No. 32 in May 1903 with Lt. Gen. George Fowke as the Chairman. Representatives on the Board consisted of three nominated members from the Johannesburg Town Council, five members from the Chamber of Mines with other members coming from Boksburg and Germiston on the East Rand, and Krugersdorp and Roodepoort on the West Rand. This laid the formal foundation for stable bulk water supply to all of the key towns along the Witwatersrand Ridge that were to eventually grow into what can be described as the Greater Johannesburg Conurbation with no clear geographic distinction between the different components. Official talks[24] between Pretoria City Council and the Rand Water Board in 1928 paved the way for the incorporation of Pretoria into the water supply network being established.

Projections made by the Transvaal Chamber of Mines for the years 1915–1920 indicated that mining needs for water would range between 48 Ml/d–70 Ml/d. Domestic demand was projected to be in the order of 16 Ml/d–20 Ml/d. This meant that a combined demand of 90 Ml/d had to be planned for by Rand Water Board by 1920. Severe water shortages in 1913 focused attention on the need to secure the water supply if the full economic potential of the gold discovery was to be realized. This acted as a trigger event that changed the water management paradigm away from sourcing water from local springs and streams, to the Vaal river some 60 km away. In 1914 the Rand Water Board adopted the Vaal River Development Scheme based on a phased approach. The first phase consisted of the construction of the Barrage along with purification works and pumping stations in Vereeniging and a main pipeline to the Witwatersrand. As this scheme was being implemented the Great War broke out in Europe, placing a restriction on the possibility of raising funds. The Board sent a deputation to Europe and Egypt to investigate possible solutions. Investigations also included water supply planning from the Mississippi river in the USA. Construction of the Barrage was commenced in 1916 and completed in 1923. The security of water supply that this established meant for the first time that the full economic growth potential of the goldfields could be realized with confidence. Additional confidence arose when in 1934 the Vaal River Development Scheme Act was passed by Parliament, paving the way for the construction of the Vaal Dam, which was built during the Great Depression[25]. The yield of the Vaal Dam[26] was increased in 1955/6 to result in a capacity of 2330 million $m^3$, or more than twice its original volume.

In 1940 a critical water shortage in Pretoria saw the reopening of negotiations with the Rand Water Board. After protracted negotiations Pretoria was represented on the Board and the water supply area was officially increased to provide the foundation for industrial development in that city. This gave significant impetus to the development of an urban conurbation between Johannesburg and Pretoria, resulting in the fact that the two cities are for all intents and purposes one place today, despite the fact that they are managed by two different local authorities. Running concurrent with these negotiations was the need of Vereeniging to be included in the supply network. Both Vereeniging and Pretoria were officially incorporated into the Rand Water Board supply area simultaneously in 1944. This gave rise to the so-called PWV Triangle[27] in which the largest concentration of heavy industry and economic activity on the continent of Africa is based.

In 1960, roughly coinciding with the independence of South Africa and the ending of British colonial rule, the Rand Water Board increased its water supply area through the approval of the Eastern Transvaal Water Supply Scheme. This enabled the strategic oil-from-coal development to take place with the subsequent establishment of the SASOL plant at Secunda on the Far East Rand. This meant that the available supply was stretched to breaking point, so alternative strategic sources of water were investigated, leading to the Thukela–Vaal Augmentation Scheme[28] being launched in 1974. This was the first inter-basin transfer from a river basin outside of the normal catchment of the Vaal system. Running almost concurrently with the feasibility of the Thukela river as an alternative source of supply, investigations were launched into the possibility of taking water from the highlands of Lesotho. This gave rise ultimately to the Lesotho Highlands Water Project (LHWP) with the first water flowing into the Vaal Dam via the Ash river outfall on 8 January 1998. Details of current strategic supply via inter-basin transfers are shown in Figure 3, while the hydropolitical history timeline for Johannesburg is shown graphically in Figure 4.

## Role of Third Parties

The Johannesburg case study shows that third parties have not played a significant role in water resource management.

## Future Prospects

The Johannesburg case study suggests the existence of three strategic issues of contemporary relevance. These are issues of supply, issues of quality and issues arising from the fact that Rand water impacts on two pivotal basins in the Southern African Hydropolitical Complex. Each of these is discussed separately below.

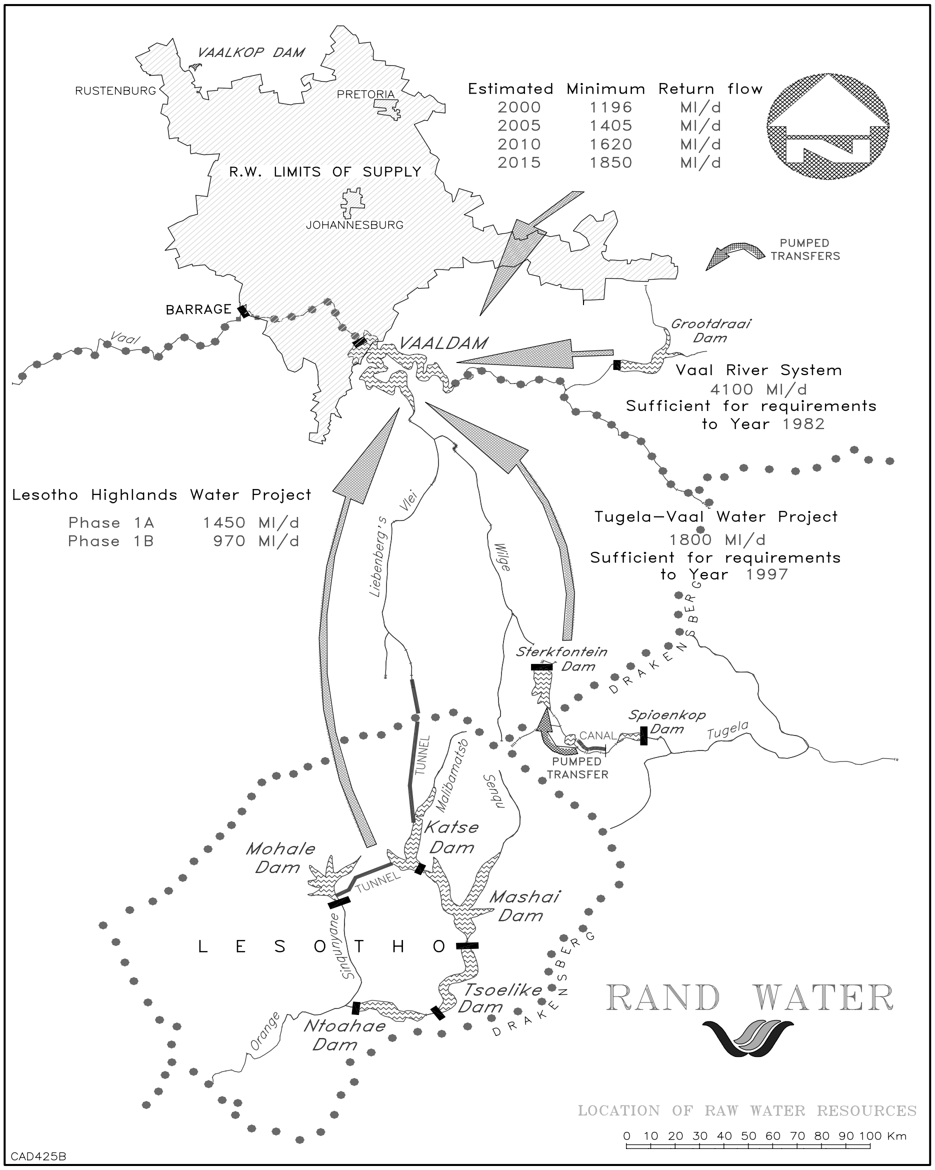


**Figure 3.** The Rand Water Supply Area showing some of the major inter-basin transfers needed to sustain the Greater Johannesburg Conurbation. *Source*: Reproduced with permission of Rand Water.

## *Issue of Supply*

The growth in real consumption and supply by Rand Water since 1903 is represented by the lower line in Figure 5. The upper line depicts the different supply schemes that were developed and built to be able to cope with the demand increase. It can be seen that from the 1980s onward, that engineering solutions, mostly in the form of inter-basin transfers from the Thukela river and the Lesotho Highlands Water Project, kept ahead of demand. This means

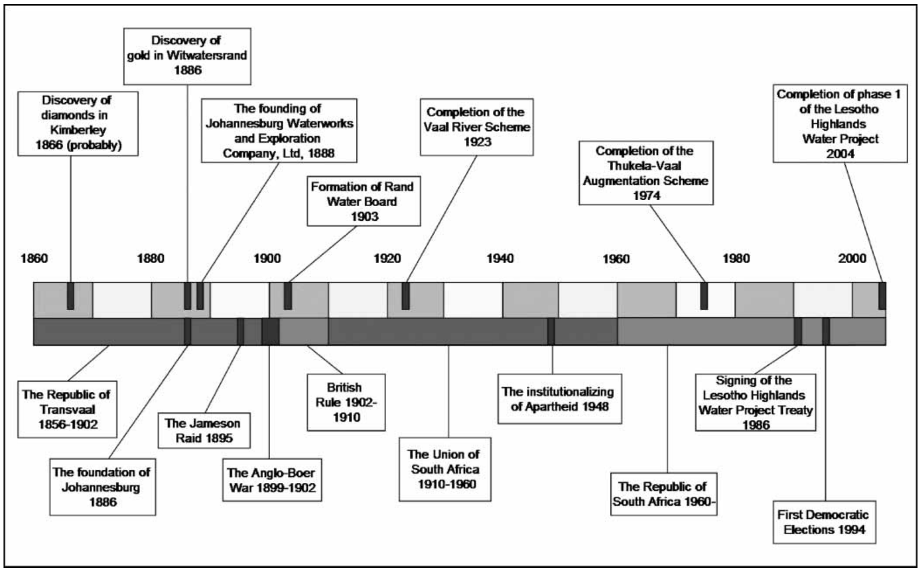


**Figure 4.** Hydropolitical history timeline for Johannesburg showing major events

that there is some overcapacity available in the supply system of Rand Water at the time of writing. The main cause for overcapacity is related to two distinct aspects. First, there were substantial droughts in the early 1980s, and again a decade later in the early 1990s, which resulted in the implementation of Water Conservation (WC) and Water Demand Management (WDM) strategies. These curbed the growth in demand. Second, the economy did not grow

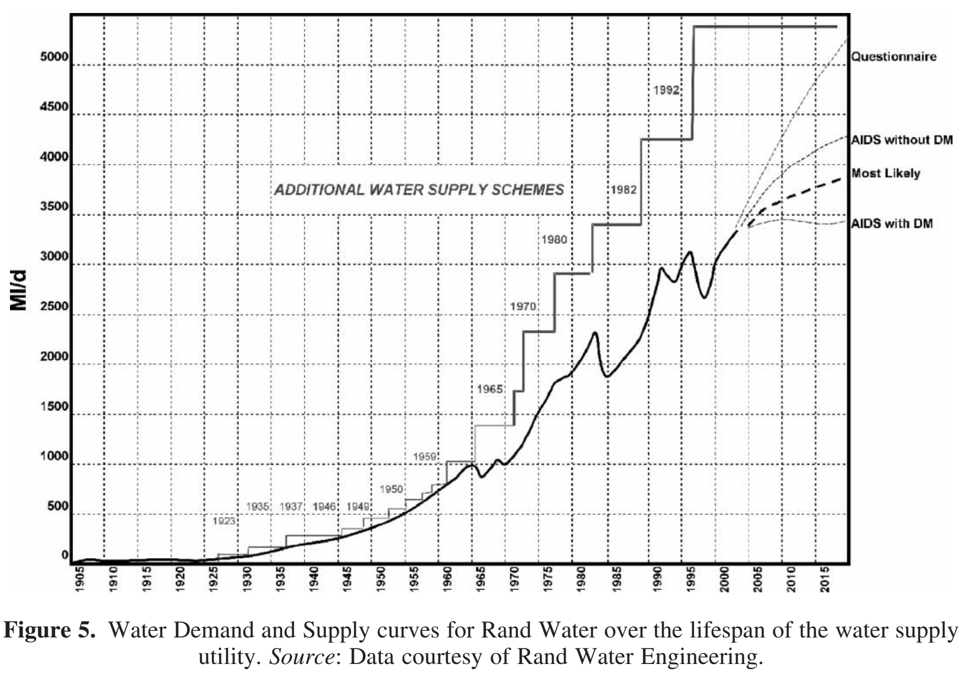


**Figure 5.** Water Demand and Supply curves for Rand Water over the lifespan of the water supply utility. *Source*: Data courtesy of Rand Water Engineering.

at the anticipated pace, possibly as a result of the uncertainty arising from the collapse of Apartheid and the transition to democracy in 1994, and also possibly as the result of the impact of HIV/AIDS on the economy as a whole. The exact nature of this has not yet been determined so this aspect remains the subject of some speculation today.

The future projections for water demand have been broken down into four possible scenarios by Rand Water. Scenario 1 is the most optimistic, based on strong economic growth and no HIV/AIDS impact. Scenario 2 factors in the impact of HIV/AIDS in so far as the pandemic has been quantified, but assumes no additional WDM measures will be implemented. Scenario 3 is also based on the best estimate of HIV/AIDS impact, combined with additional WDM strategies to curb consumption. Scenario 4 is the most likely trajectory based on the best available current knowledge about HIV/AIDS. This shows a growth in demand but at a reducing rate, suggesting that aggressive water supply augmentation is not likely in the mid-term future. This has already had an impact on the Lesotho Highlands Water Project, where Phase 2[29] has been placed on hold. This has reduced the income stream to Lesotho as royalty payments are based on water volumes delivered. The feasibility study[30] of using the existing infrastructure in the Thukela–Vaal Pumped Storage Scheme is currently underway. This provides a least-cost option should future demand in the Rand Water supply area need to be augmented. Should this option be followed, two new dams will be constructed on the Thukela river, Jana and Mielietun Dams, feeding into the existing Pumped Storage Scheme. This decision has other strategic considerations beyond mere water supply, as the Pumped Storage Scheme is an integral component of the national electricity grid, using surplus energy in off-peak periods to pump water across the Drakensburg Mountains, to recover some of that energy again when water is released into the Upper Vaal in order to meet peak energy demands. The additional volume of water will thus provide greater flexibility in managing the peaks in energy demand at the national level.

Central to Rand Water's planning is the need to understand the impact of HIV/AIDS. The Chief Engineer (Development) of Rand Water generated a document titled 'Rand Water's Integrated Least Cost Planning Model' in May 2000. In this document the problematique of HIV/AIDS is analyzed with respect to the provision of infrastructure (Figure 6). From this assessment, two key strategic issues arise:

- At the point of the peak demand prior to population reversal, the infrastructure could be under-utilized in the long term.
- At the point of minimum demand after population reversal, attempts to 'ride through' the peak demand by imposing water restrictions would offer the maximum utilization of infrastructure.

After careful consideration of these critical issues, the report concludes that both options have high-risk profiles for the Gauteng area. The first option raises the risk of financial crisis arising from excessive investment in infrastructure. The second option raises the risk of non-supply[31] at crucial periods of time. The report also suggests that regions with strong economic activity and high employment rates may not experience significant population reversal. This introduces some uncertainty into the overall water management regime for the Greater Johannesburg Conurbation.

One of the ramifications of this uncertainty suggests that even if infrastructure is provided to meet a growth in demand of 2.76% per annum, the infrastructure may be provided four to nine years earlier than necessary. Water restrictions may have to be used

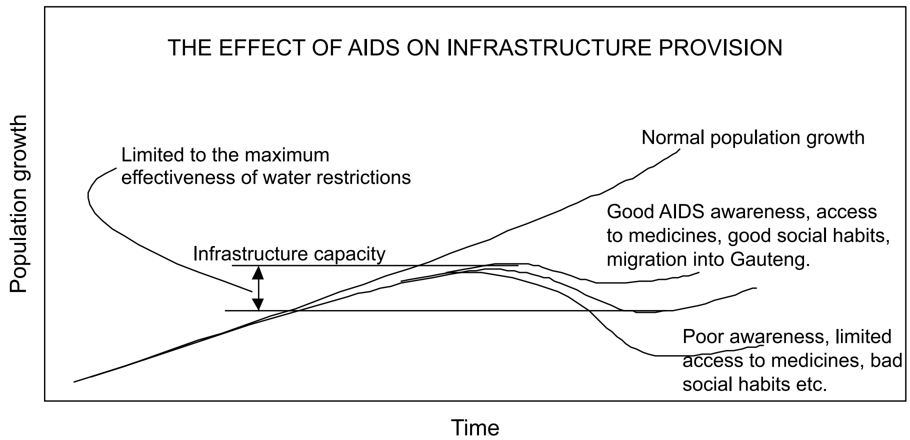


**Figure 6.** The effect of HIV/AIDS on infrastructure planning as envisaged by Rand Water

to 'ride through' the point of peak population. This is a complex decision as it would have to be based on the as yet unknown economic impact that HIV/AIDS has in the region, the financial impact that new infrastructure would have on a declining income-base and an understanding of which user groups would be mostly affected by HIV/AIDS. The reality is that there is currently insufficient information at a high enough level of confidence to make any strategic decisions about infrastructure provision based on the impact of HIV/AIDS in the Greater Johannesburg Conurbation.

Within this set of scenarios it is difficult to cater for WDM in the forecast. In the Greater Johannesburg Conurbation, the unaccounted-for-water figure is around 50%. During the anti-apartheid struggle, non-payment for services was used as a tool by disenfranchised township inhabitants to overthrow a repressive regime. With the birth of democracy in 1994, an era of unprecedented optimism was ushered into the political history of South Africa. However, within the context of water supply there were some unforeseen consequences that are still having a lasting impact on the development of sustainable water supply for the Greater Johannesburg Conurbation. Central to this is the culture of non-payment for services, which was such a central part of the so-called 'struggle'. Several studies done by the Data and Research Manager of Rand Water have shown that there are widely differing reasons given by respondents to non-payment for services, which includes unemployment, insufficient disposable income, deep-seated mistrust for government and the distance to pay points. This survey has also shown that when there is insufficient disposable income in a given household, payment goes towards electricity rather than to water, due partly to the fact that the latter is enshrined in the Constitution and may not summarily be cut off. Other causes include the entertainment factor in the use of electricity. However, this is not the sole cause for non-payment which include: the amount of disposable income being eroded by the use of cellular telephones; the burgeoning of gambling and the introduction of Lotto. The combination of these is a reduced income stream to Rand Water, which in turn has substantial ramifications in terms of future service delivery.

The need for reversing this trend is exacerbated by the massive water losses that occur in the area. Water wastage to the value of US$378 000 occurs daily in the Rand Water area of supply. Water wastage in this sense refers to potable water that runs into the ground from leaking

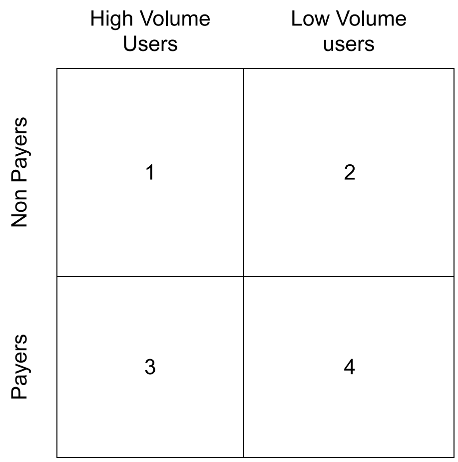


**Figure 7.** Matrix of Water Demand Management target group priorities used by Rand Water

reticulation networks of municipalities before being metered by a given consumer, or that runs out of leaking taps and toilet cisterns on private property after being metered. Recent work by Rand Water has shown that 80% of the wastage occurs on private property.

Rand Water recently completed an investigation into water losses and found in a township of 63 000 families that the mean daily average demand of the area was 3500 kilolitres per hour. Measurement of the demand showed that the Minimum Night Flow, that is the amount of water entering the area between 02:00 and 04:00 in the morning, amounted to 2700 kilolitres per hour. This shows a substantial loss in the reticulation system.

The Rand Water WDM strategy is based on a process of prioritization using the matrix shown in Figure 7. Non-paying users of high volumes of water are tackled first (Quadrant 1), followed by smaller non-paying users (Quadrant 2). The primary management objective of these two target groups is to bring them into the income stream of Rand Water, thereby securing the financial viability of the infrastructure as a whole, while using the price elasticity of water to reduce excessive demand. Next come high volume users that pay for their water (Quadrant 3), but herein lies a dilemma, because while these consumers are the ones that use water inefficiently, they also provide the income stream to cross-subsidize the losses in other parts of the system. For this reason Quadrant 3 will only be tackled under drought conditions, and then usually with retrofitting as an objective. Finally, smaller users that pay for their water are the last to be targeted, mostly with retrofitting and increased efficiency as an objective.

Experience on the ground is showing that WDM is a complex issue to manage and effectively implement. In the immediate post-apartheid era of service delivery, the focus is mainly on improving supply to the people that traditionally did not have access to water and sanitation. This also happens to be the poorest segment of society with the least capacity to pay. It is therefore seen as a political imperative that funds be spent on such service delivery. From purely a political perspective then, it looks good if, at the end of a project for the supply of water and sanitation, a grand opening can be launched where a tap is opened and another sector of the population has access to water and sanitation. The rewards are simply not the same for a WDM project, even if it has put back millions of litres of water into the system which otherwise would have been lost. There is no ribbon to cut in public at the end of the day, and WDM often comes at the price of punitive water bills or reduction in consumption. These are too closely related to hardship to translate into political kudos, so politicians seem to avoid such measures.

*Issue of Quality*

Water quality issues are becoming increasingly important for a variety of reasons. The first major cluster of issues in this regard relates to the chemistry of groundwater in mines (Ashton[32], personal communication). Given that the majority of the mining operations have occurred along the Witwatersrand Ridge, the water table has been substantially reduced due to mine dewatering activities. Water arising from mining operations tends to come into contact with the residue of the mining operation such as dust, exposed reef and waste rock.[33] Depending on the type of minerals being mined, this water dissolves chemical substances in that residue. When sulphite ores, particularly those containing pyrite (often associated with gold-bearing reef) come into contact with a combination of air and water, they give off sulphur dioxide and produce low pH waters with a high concentration of iron and sulphate. This process is accelerated by specific groups of bacteria that help to transform inert sulphides into acidic solutions. This problem is of a significant magnitude, particularly when mines reach the end of their useful lives and are closed, known as acid rock drainage. In the South African sector of the Limpopo river basin for example, there are over 1000 abandoned mining operations, though most of these are small gravel quarries and clay pits. The metal mines, mostly lead, tin and zinc, are small 1–10 man operations so their impact is negligible, but the larger coal, base metal (copper, lead, tin, zinc, chrome, vanadium) and precious metals (gold, platinum) tend to have an acid rock drainage problem (Ashton, personal communication).

Another different category of water quality problem relates to the effluent drainage from the Rand Water supply area. Associated with this are nitrogen (N) and phosphate (P), with the ratio of the two being a critical parameter (van Ginkel[34], personal communication). The N:P ratio is important for the community structure of phytoplankton, specifically with regards the relative competitive capabilities and biomass of cyanobacteria in epilimnetic phytoplankton communities (Figure 8). Low N:P ratios indicate the presence of cyanobacteria in phytoplankton communities. There is some debate over the exact dynamics of this, particularly with respect to the question as to whether the N:P ratio drives the dominance of cyanobacteria, or whether it is the result of the presence of cyanobacteria in the system. In this regard Wentzel (2001) has shown that cyanobacteria tend to be rare at N:P ratios of greater than 29. Van Ginkel (personal communication) has noted that this may be true for some species including *Microcystis*, but may not be true for all of the cyanobacterial species. Van Ginkel (personal communication) concludes that there is definitely some relationship between the N:P ratio and the development of specific phytoplankton species, but notes that care must be taken in interpreting the ratio without taking cognisance of the fact that blooms are multivariate in origin.

The significance of this is that nitrogen and phosphate tends to become concentrated in dams that receive effluent streams from sewage water treatment plants. For example, Hartebeespoort Dam is the first dam on the Crocodile river, a tributary of the Limpopo river, which receives treated effluent streams from both Johannesburg and Pretoria.

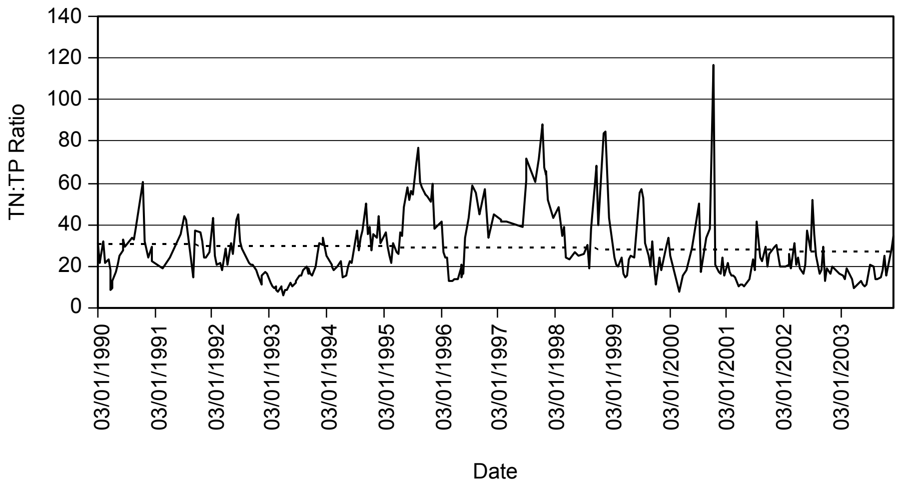


**Figure 8.** Time series of the N:P ratio for Hartebeespoort Dam. Low N:P ratios are associated with severe cyanobacterial blooms in South Africa

Studies of this dam[35] show that a low N:P ratio is associated with highly eutrophic systems dominated by cyanobacterial blooms. The most dominant bloom-forming cyanobacteria in South Africa is *Microcystis* (van Ginkel, personal communication). Venter (2004) notes that at least 20 tons of phosphate flows into the dam each year, so even if current treatment methods could reduce these levels at point source, they would not cater for the vast amounts of phosphate already trapped in the sediment of Hartebeespoort Dam, which is acting as a source for future releases downstream. This raises the huge technical problem of reducing the phosphate level at the dam from an average of 0.12 mg/l to less than 0.05 mg/l in order to significantly reduce future pollution loading of the headwaters of the Limpopo river basin. The cost of this technology is simply prohibitive for a developing country like South Africa, so it is unlikely to be introduced in the near future. This also illustrates the need for constant technical innovation in highly modified ecosystems.

### *Issues Arising from the Southern African Hydropolitical Complex*

Research work under-way at present suggests the existence of an emerging hydropolitical complex in Southern Africa (Turton, 2003a, 2003b, 2004; Turton *et al.*, 2004a, 2004b). Central to the rationale of this concept is the fact that water scarcity is reaching the point where four of the most developed countries in the SADC region—South Africa, Botswana, Namibia and Zimbabwe—are all reaching a point where future economic growth and hence political stability can be threatened. This makes the issue one of strategic importance. Within the so-called Southern African Hydropolitical Complex there is sufficient evidence to suggest that water scarcity constraints are becoming the trigger for co-operation rather than conflict, and are reaching sufficient magnitude to impact on the international political relations between the respective sovereign states in the region. Two international river basins of the most strategic importance within the Southern African Hydropolitical Complex are the Orange and the Limpopo, which have been called pivotal basins. With Johannesburg being located on the watershed between these two pivotal basins, the water supply imperatives link the two by way of IBTs and return flows. The reasons for the strategic significance of these two river basins are the facts that:

- both support substantial economic activity within each of the riparian states;
- both are shared by the four pivotal states in the Southern African Hydropolitical Complex (South Africa, Botswana, Namibia and Zimbabwe);
- both have reached the point where there is simply no more water left to be allocated to existing economic productive activities;
- both have significant water quality issues impacting on their future ecological sustainability.

Consequently, what happens in the future water resource management approach by Rand Water in sustaining the economical viability of the Greater Johannesburg Conurbation, will automatically cascade downstream and impact on the strategic options of the four pivotal states in the Southern African Hydropolitical Complex. This makes the Orange and Limpopo pivotal basins within the Hydropolitical Complex.

## Lessons Learned

The Johannesburg case study provides three valuable lessons learned.

The first major lesson is that complexity tends to breed further complexity. The initial complexity arising from the need to supply water to a city at high altitude straddling a watershed has placed considerable burden on the technical ingenuity of South African water engineers. The solutions have succeeded in keeping abreast of water demand in the Greater Johannesburg Conurbation, but at an increasingly high cost to the environment. The existence of substantial water quality problems has arisen directly as a result of the human technical ingenuity needed to wrestle vast wealth from the bowels of the earth, and is likely to become one of the single most important challenges in the mid-term future. This will place major strain on the so-called second-order resources of society, the social adaptive capacity, or the ability of a given social entity to cope with rapid changes to water supply over time (Ohlsson, 1999; Ohlsson & Turton, 1999; Turton & Ohlsson, 1999; Allan, 2000, pp. 322–325). The lesson learned in this case is that societies need to constantly generate two distinct types of ingenuity if they are to continue to survive under conditions of endemic water scarcity. Technical ingenuity, or the capacity to solve problems through technological innovation, and social ingenuity, or the ability to design markets and create incentives to stimulate an adequate flow of technical ingenuity in the first place (Homer-Dixon, 2000, p. 22) are flip sides of the same coin. This is important because it is in this context that issues such as the cash-flow crisis confronting Rand Water, and the unpredictable nature of the outcome of the HIV/AIDS pandemic can best be understood. Both are undermining the capacity of society to generate new innovative solutions to problems of an increasingly complex nature. An understanding of the dynamics of this are largely absent from the contemporary water resource management literature.

The second major lesson learned is that the sustained supply of water to the Greater Johannesburg Conurbation over time has created a massive dependency on the continued supply of that water over time. The fact that the Rand Water supply area today sustains one of the largest concentrations of human beings that exist away from a river, lake or natural waterfront, suggests that future strategic outcomes are not guaranteed. In fact, there is some evidence to suggest that the increased need to develop ever more complex water transfer schemes, will result in an increased level of vulnerability to rapid changes in the system that sustains those transfers. These IBTs are embedded in society on the one hand, and the ecological systems needed to sustain those supplies on the other hand. Thus, uncertainties associated with over-abstraction and ecological decline, global climate change, deteriorating water quality caused by the closure of mines in the headwaters, and the unknown trajectory of the HIV/AIDS pandemic, can all be potentially magnified through the heavy reliance on technical and social ingenuity. This will place a major burden on engineers and political systems in the future as sustainable solutions are sought. An understanding of this aspect is also largely absent from the contemporary water resource management literature.

The third major lesson that can be distilled relates to the emerging issue of environmental-induced conflict. The key question relates to the causal linkage between water scarcity and conflict. Will endemic water scarcity drive conflict or cooperation in future? The fact that water issues already feature at a level of interstate interaction to the extent that an immature Hydropolitical Complex can be detected in Southern Africa, suggests that this question has not yet been fully answered. Initial indications are that water scarcity is acting as a driver of co-operation, but the jury is still out on the future outcome of this vexing issue. In this regard water supply to the Greater Johannesburg Conurbation is a useful litmus test for the rest of the world.

### Conclusions

The water supply to a megacity like the Greater Johannesburg Conurbation is a study in complexity. The fact that Johannesburg exists at all has a lot to do with paleo-floodplain hydraulics, tectonic activities and the growth of primitive algal material that trapped the sediment and created the gold-bearing reef on which the city foundations rest. It is because of the existence of this gold, which has largely been mined out, that one of the largest human populations dependent on the ingenuity of water resource engineers exists in the Southern Hemisphere today. In the relatively short time-span of just over one century, the ecosystem around the Witwatersrand Ridge has been irreversible altered. In the wink of an eye in geological time, human ingenuity has transformed the Cradle of Humankind into a modern metropolis that is embedded in the largest man-made forest in the world. This raises serious questions about sustainability over time. More importantly it raises the issue of the link between second-order resources and social stability. Central to this is the emergence of the Southern African Hydropolitical Complex, with Johannesburg straddling the watershed between the two pivotal river basins in that Complex, the Orange and the Limpopo.

## Acknowledgements

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## Notes

1. See http://www.southafrica.net/heritage/heritage_places/cradle_1.cfm for more information.
2. A pivotal basin is one that is strategically important for the riparian states, which is reaching a point of closure where no more water is available for additional economic activities. See Turton (2003b, p. 79) for more information.
3. The Sterkfontein Heritage Site where the Cradle of Humankind is situated, is under threat from acid mine drainage entering the Tweefonteinspruit. This was first detected in 26 August 2002 and is now the focus of considerable environmental management concern. See Holtzhauzen (2004, p. 20) for more details.
4. For more background to the discovery of gold in Johannesburg, particularly with respect to the controversy about who was the first person to actually make the find, refer to Appelgryn (1984) and Cunningham (1987).
5. The first discovery of gold in what was to become Krugersdorp occurred in 1885 on the farm Kromdraai (translated as 'Crooked Bend' in a river). Krugersdorp has since been renamed as Mogale City.
6. When Johannesburg was officially founded, it was located on a piece of unaccounted for land (called Randjeslaagte) that had been left over when the original farms were demarcated (Appelgryn, 1984, p. 18). The reason for this was that there was no water on this land, making it useless for farming purposes. This saw a triangle of land some 240 hectares in extent being left over after farm delineation, to be taken over by the state. Significantly, this meant that when Johannesburg was first developed, a critical limiting factor became access to water. Associated with this was the pressing need for adequate sanitation. The first meeting of the Diggers Committee mandated Col. I.P. Ferreira, H.J. Morkel and Dr. H. Sauer to draw up a plan for sanitation (Appelgryn, 1984, p. 44). This saw the first comprehensive set of regulations being launched on 13 October 1887 (Appelgryn, 1984, p. 52).
7. Given that the currencies of the industrialized world at that time were based on the gold standard, with Britain as the leading industrial and economic power, this had strategic significance to the maintenance and expansion of the British Empire. For more background to this refer to Barber (1999, pp.11–12).
8. For more background to the Jamieson Raid see Seymour Fort (1908) and Longford (1982), both of which are considered to be authoritative.
9. The Anglo-Boer War was a resource war triggered by the British desire to gain control over the gold that had been discovered in the Zuid Afrikaanse Republiek (ZAR) (Barber, 1999, pp. 11–12). For more background see Farwell (1999), Nasson (1999) and Lee (2002).
10. Barber (1999, pp. 10–11) notes that despite the fact that there were two separate and independent Boer Republics in southern Africa at the time, the dominant belief in London was that this was firmly a British sphere of influence. So for example, when diamonds were discovered in Griqualand in the late 1860s, claims by the Boer Republics were quickly countered and the British absorbed the diamond-bearing territory into the Cape Colony. This laid the foundation to the belief that the subsequent Anglo-Boer War was a resource war.
11. The establishment of concentration camps in South Africa during the Anglo-Boer War was a direct result of Lord Roberts scorched earth policy (Van Rensburg, 1980, p. 37). This saw the removal of Boer women and children from the farms in the belief that this would prevent their support to the men who were out on Kommando fighting a guerrilla war (Evans, 1982). This thinking was based on earlier experiments with concentration camps in Cuba (Spies, 1977, p. 148), known as the Weyler Method (Spies, 1977, p.148; Van Rensburg, 1980, p. 38). For further accounts of the concentration camps see Farwell (1999), Nasson (1999), Raath (1999) and Lee (2002). For the linkage between concentration camps and imperialism, see Porch (2000).
12. For more background to the social stratification caused by the discovery of gold in Johannesburg, refer to Barber (1999, p. 12).
13. The Afrikaner is a much-misunderstood nation. The name Afrikaner literally means 'of Africa' or 'African' (Turton, 1999). They speak a language that was originally derived from Dutch, but which has been Africanized and is spoken on no continent other than Africa (with a small exception in Argentine where some Boer trekkers settled and established a small but non-viable Afrikaner community of herdsmen). The Afrikaner is an African in every sense of the word and regard themselves as the so-called White Tribe of Africa (Harrison, 1982), having engaged in an anti-imperial struggle during the Anglo-Boer War and therefore largely sympathetic to the anti-colonial aspirations of other African nations. Their 'Africaness'

is being given expression in post-Apartheid South Africa where they are taking their rightful place in what has become known as the Rainbow Nation.

14. The deepest mine is the Western Deep Levels, which is on the Witwatersrand complex in South Africa, with a depth in excess of 3500 metres. Planned operations are projected to take mining to a level of some 4117 metres, with research being conducted at the Council for Scientific and Industrial Research (CSIR) in South Africa attempting to go even beyond that depth (*Financial Times,* 1999).
15. The area supplied today by Rand Water has a population in excess of 11 million people, or a quarter of the total population of South Africa, who produce 34% of the country's GDP, or 10% of the GDP of the entire African continent (Gauteng Economic Development Agency, 2004).
16. The Zuurbekom dolomites yield high quality groundwater that does not need treatment before being entered into the overall supply system of present day Johannesburg. Yielding an annual average of 30.5Ml/d when first developed in 1899, this tapered off to 25 Ml/d in 1978 and 12Ml/d in 2003. This water is still of an exceptionally high quality.
17. By 1889 there were 711 crushers in operation. A year later this had grown to 6000 crushers. By 1898 some 7.3 million tons of ore was being milled, translating into a demand for water in the order of 14.6 tons of water.
18. The Braamfontein Spruit is one of the rivers that is now encased in the stormwater sewers of Johannesburg. A tributary of the Limpopo river basin, the Braamfontein Spruit discharges into the Hartebeespoort Dam, which is one of the most polluted dams on the continent of Africa today.
19. This is translated literally as 'Four Fountains'.
20. This is translated literally as 'Elephant Marsh', referring to the original wetlands of the area.
21. The Pipelines of Power thesis suggests that political power is derived from the development and control over water pipelines in semi-arid areas. This is based on the assumption that because water is scarce, it gives rise to economic privilege. Control over the supply of water thus translates to political power, leading to a degree of resource capture and ecological marginalization to use the concepts central to the work of Homer-Dixon (1991, 1994a, 1994b, 1995, 1996, 2000).
22. For a concise history of Rand Water see Tempelhoff (2003).
23. The Rand Water Board was modeled on the constitution of the Metropolitan Water Board of London, now known as Thames water, which was also formed in 1902.
24. These talks were driven by the desire to establish a large steel factory in Pretoria. Initial talks were stalled but again revived in 1934 when the Vaal Dam Project got underway.
25. There is a strong parallel here with the construction of the Hoover Dam during the Great Depression in the USA. Part of the New Deal, this thinking saw hydraulic infrastructure development as a sound hedge against the debilitating effects of economic recession. This thinking permeated the Hydraulic Mission of the western industrialized nations for the major portion of the 20th century. For more background see Reisner (1993) and Allan (2000).
26. For a more detailed assessment of this refer to Turton *et al.* (2004a).
27. This refers to the heavily industrialized triangle with Pretoria, Witwatersrand and Vereeniging on the respective corners.
28. This scheme took water from the Thukela river basin on the eastern escarpment, pumping it over the Drakensburg Mountains using surplus electricity from the national grid, and then reclaiming a significant portion of that energy when needed by gravity feeding the water into the upper reaches of the Vaal river. The first water was pumped into the Sterkfontein Dam in October 1974.
29. Phase 2 of the LHWP consists of the construction of the Mashai Dam shown in Fig 3 and associated water delivery infrastructure. Phase 3 consists of the construction of Tsoelike Dam and associated delivery infrastructure.
30. For more details of the feasibility study of the next phase of the Thukela Water Project see http://www.dwaf.gov.za/thukela/feasibility.htm (accessed 13 July 2004).
31. For a deeper understanding of the linkage between HIV/AIDS and water, refer to Ashton & Ramasar (2002). In addition to this, patients on anti-retroviral treatment need clean water if they are not to have their health compromised further. This is a problem that seems to receive surprisingly little attention in the contemporary water resource management literature.
32. Professor Peter Ashton is a water quality specialist at the Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa.
33. See Holtzhauzen (2004, pp. 18–20) for some indication of the nature of the problem.
34. Carin van Ginkel is a specialist scientist at Resource Quality Services in the South African Department of Water Affairs and Forestry (DWAF).

35. For example, see the study commissioned by the Department of Water Affairs and Forestry in 2003 that is being done by Southern Waters (DWAF, 2003a, 2003b). The final report is not yet available at the time of writing.

## References


Allan, J. A. (2000) *The Middle East Water Question: Hydropolitics and the Global Economy* (London: IB Tauris).

Appelgryn, M. S. (1984) *Johannesburg 1886–1889: Origins and Early Management* (Pretoria: University of South Africa).

Ashton, P. & Ramasar, V. (2002) Water and HIV/AIDS: some strategic considerations in Southern Africa, in: A. R. Turton & R. Henwood (Eds) *Hydropolitics in the Developing World: A Southern African Perspective*, pp. 217–235 (Pretoria: African Water Issues Research Unit (AWIRU)).

Barber, J. (1999) *South Africa in the Twentieth Century* (Oxford: Blackwell Publishers).

Chapman, K. M., Tucker, R. F. & Kidger, R. J. (1986) The Klerksdorp goldfield, in: E. S. A. Antrobus (Ed.) *Witwatersrand Gold—100 Years*, pp. 173–197 (Pretoria: The Geological Society of South Africa).

Cunningham, A. (1987) *The Strubens and Gold* (Johannesburg: Ad. Donker Ltd).

Davie, L. (2003) Joburg's First Trees. Available at http://www.joburg.org.za/2003/aug/aug25_trees.stm

DWAF (2003a) Hartebeespoort Dam Remediation Project (Phase 1), *Inception Report* (Pretoria: Department of Water Affairs and Forestry).

DWAF (2003b) Hartebeespoort Dam Remediation Project (Phase 1), *Deliverables Report: Task 1 (Literature Review)* (Pretoria: Department of Water Affairs and Forestry).

Evans, M. M. (1999) *The Boer War: South Africa 1899–1902. Osprey Military* (Mechanicsburg: Stackpole Books).

Farwell, B. (1999) *The Great Boer War* (London: Wordsworth Editions).

*Financial Times* (1999) Down, down, deeper and down, *Financial Times Weekend*, June 5. Available at http://deepmine.csir.co.za/Press%20Clips/clip02.htm (accessed 5 July 2004).

Gauteng Economic Development Agency (2004) Gauteng Overview. Available at http://www.geda.co.za (accessed 5 July 2004).

Harrison, D. (1982) *The White Tribe of Africa: South Africa in Perspective* (Berkeley: University of California Press).

Holtzhauzen, L. (2004) Decanting minewater: solving a 100-year-old problem, *Water, Sewage and Effluent*, 24(4), pp. 18–20.

Homer-Dixon, T. F. (1991) On the threshold: environmental changes as causes of acute conflict, *International Security*, 16(2), Fall, pp. 76–116.

Homer-Dixon, T. F. (1994a) Environmental changes as causes of acute conflict, in: R. K. Betts (Ed.) *Conflict after the Cold War: Arguments on Causes of War and Peace* (New York: Macmillan).

Homer-Dixon, T. F. (1994b) Environmental scarcities and violent conflict: evidence from cases, *International Security*, 19(1), pp. 5–40.

Homer-Dixon, T. F. (1995) The ingenuity gap: can poor countries adapt to resource scarcity?, *Population and Development*, 21(3), pp. 587–612.

Homer-Dixon, T. F. (1996) Environmental scarcity, mass violence and the limits to ingenuity, *Current History*, 95, pp. 359–365.

Homer-Dixon, T. F. (2000) *The Ingenuity Gap* (London: Jonathan Cape).

Lee, E. (2002) *To the Bitter End: A Photographic History of the Boer War 1899–1902* (Pretoria: Protea Book House).

Longford, E. (1982) *Jamieson's Raid: the Prelude to the Boer War* (London: Weidenfeld & Nicholson).

Mitchell, P. (2002) *The Archaeology of Southern Africa* (Cambridge: Cambridge University Press).

Nasson, B. (1999) *The South African War 1899–1902* (London: Arnold).

Ohlsson, L. (1999) *Environment, Scarcity and Conflict: A Study of Malthusian Concerns* (Göteborg: Department of Peace and Development Research, University of Göteborg).

Ohlsson, L. & Turton, A. R. (1999) The turning of a screw. Paper presented at the Plenary Session of the 9th Stockholm Water Symposium Urban Stability through. Integrated Water-Related Management, Stockholm International Water Institute (SIWI), Sweden, 9–12 August. Available as *MEWREW Occasional Paper No.19* at http://www.soas.ac.uk/Geography/WaterIssues/OccasionalPapers/home.html and from http://www.up.ac.za/academic/libarts/polsci/awiru

O'Keeffe, J., Uys, M. & Bruton, M. N. (1992) Freshwater systems, in: R. F. Fuggle & M. A. Rabie (Eds) *Environmental Management in South Africa* (Johannesburg: Juta & Co).

Porch, D. (2000) *Wars of Empire* (London: Cassell).

Raath, A. W. G. (1999) *The British Concentration Camps of the Anglo Boer War 1899–1902: Reports on the Camps* (Bloemfontein: The War Museum). Available from Thorrold's Africana Books.

Rabie, M. A. & Day, J. A. (1992) Rivers, in: R. F. Fuggle & M. A. Rabie (Eds) *Environmental Management in South Africa* (Johannesburg: Juta & Co).

Reisner, M. (1993) *Cadillac Desert: The American West and its Disappearing Water,* revised edn (New York: Penguin).

Seymour Fort, G. (1908) *Dr. Jamieson* (London: Hurst & Blackett Ltd).

Spies, S. B. (1977) *Methods of Barbarism: Roberts, Kitchener and Civilians in the Boer Republics January 1900–May 1902* (Cape Town: Human & Rousseau).

Tempelhoff, J. W. N. (2003) *The Substance of Ubiquity: Rand Water 1903–2003* (Vanderbijlpark: Kleio Publishers).

Turton, A. R. (1999) Statutory Instruments for the Maintenance of Ethnic Minority Interests in a Multi-Cultural Community: The Case of the Afrikaners in South Africa. (Translated into Russian as: Pravovye mery zashchity interesov etnicheskih menshinstv v mnogonatsionalnom obshchestve: afrikanery Yuzhnoy Afriki (Legal measures of defending interests of ethnic minorities in a multinational society: The Afrikaners of South Africa), in: N. I. Novikova & V. Tishkov (Eds) *Folk Law and Legal Pluralism*. Proceedings of the 11th International Congress on Folk Law and Legal Pluralism, August 1997, Moscow pp. 38–47 (Moscow: Institute of Ethnology and Anthropology).

Turton, A. R. (2000) Precipitation, people, pipelines and power: towards a political ecology discourse of water in Southern Africa, in: P. Stott & S. Sullivan (Eds) *Political Ecology: Science, Myth and Power* (London: Edward Arnold).

Turton, A. R. (2003a) An Introduction to the hydropolitical dynamics of the Orange river basin, in: M. Nakayama (Ed.) *International Waters in Southern Africa* (Tokyo: United Nations University Press).

Turton, A. R. (2003b) Environmental security: a Southern African perspective on transboundary water resource management, *Environmental Change and Security Project Report*. The Woodrow Wilson Centre, issue 9, Summer, pp. 75–87 (Washington, DC: Woodrow Wilson International Center for Scholars).

Turton, A. R. (2004) The evolution of water management institutions in select Southern African international river basins, in: C. Tortajada, O. Unver & A. K. Biswas (Eds) *Water as a Focus for Regional Development* (London: Oxford University Press).

Turton, A. R. & Earle, A. (2005) Post-apartheid institutional development in selected Southern African international river basins, in: C. Gopalakrishnan, C. Tortajada & A. K. Biswas (Eds) *Water Institutions: Policies, Performance & Prospects*, pp. 154–173 (Berlin: Springer).

Turton, A. R. & Ohlsson, L. (1999) Water scarcity and social adaptive capacity: towards an understanding of the social dynamics of managing water scarcity in developing countries. Paper presented at the Workshop No. 4: Water and Social Stability of the 9th Stockholm Water Symposium Urban Stability through Integrated Water-Related Management, Stockholm International Water Institute (SIWI), Sweden, 9–12 August. Available as *MEWREW Occasional Paper No. 18* at http://www.soas.ac.uk/Geography/WaterIssues/OccasionalPapers/home.html and http://www.up.ac.za/academic/libarts/polsci/awiru

Turton, A. R., Meissner, R., Mampane, P. M. & Seremo, O. (2004a) *A Hydropolitical History of South Africa's International River Basins*. Report to the Water Research Commission (Pretoria: Water Research Commission).

Turton, A. R., Ashton, P. J. & Cloete, T. E. (2004b) An introduction to the hydropolitical drivers in the Okavango river basin, in: A. R. Turton, P. J. Ashton & T. E. Cloete (Eds) *Transboundary Rivers, Sovereignty and Development: Hydropolitical Drivers in the Okavango River Basin*, pp. 9–30 (Pretoria and Geneva: African Water Issues Research Unit (AWIRU) and Green Cross International).

Van Rensburg, T. (1980) *Camp Diary of Henrietta E.C. Armstrong: Experiences of a Boer Nurse in the Irene Concentration Camp 6 April–11 October 1901* (Pretoria: Human Sciences Research Council) (HSRC)).

Venter, P. (2004) New hope for troubled waters: the Hartebeespoort dam test case, *The Water Wheel*, 3(1), January/ February, pp. 16–19.

WCD (2000) *Dams and Development: A New Framework for Decision-Making* (London: Earthscan).

Wentzel, R. G. (2001) *Limnology, Lake and River Ecosystems* (New York: Academic Press).

Werdmüller, V. W. (1986) The Central Rand, in: E. S. A. Antrobus (Ed.) *Witwatersrand Gold—100 Years*, pp. 7–47 (Pretoria: The Geological Society of South Africa).