A CSIR PERSPECTIVE
ON WATER IN SOUTH AFRICA
2010

our future through science

About the CSIR

The CSIR uses multidisciplinary research and technological innovation to foster industrial and scientific development to make a difference in our society, economy and environment. Our science, engineering and technology (SET) base positions the organisation to address challenges in a number of areas that are of particular importance to South Africa, such as better roads and houses; cleaner water; improved health; adequate nutrition; enhanced manufacturing approaches; a safer environment; access to renewable energy and a pristine environment – now and in future.

Because South Africa, like the rest of the world, is vulnerable to the impact of climate change and loss of biodiversity, a balanced approach is required. The CSIR works in support of this national priority, by focusing specifically on the wise use of our natural resources – water, vegetation, oceans. Some of the competences utilised in this regard include environmental sciences, mathematical modelling, geographical sciences, microbiology, ecology, hydrology, oceanography, climatology, sociology, economics, biochemistry, and remote sensing.

Citation: CSIR (2010) *A CSIR perspective on water in South Africa – 2010.*
CSIR Report No. CSIR/NRE/PW/IR/2011/0012/A
ISBN: 978-0-7988-5595-2

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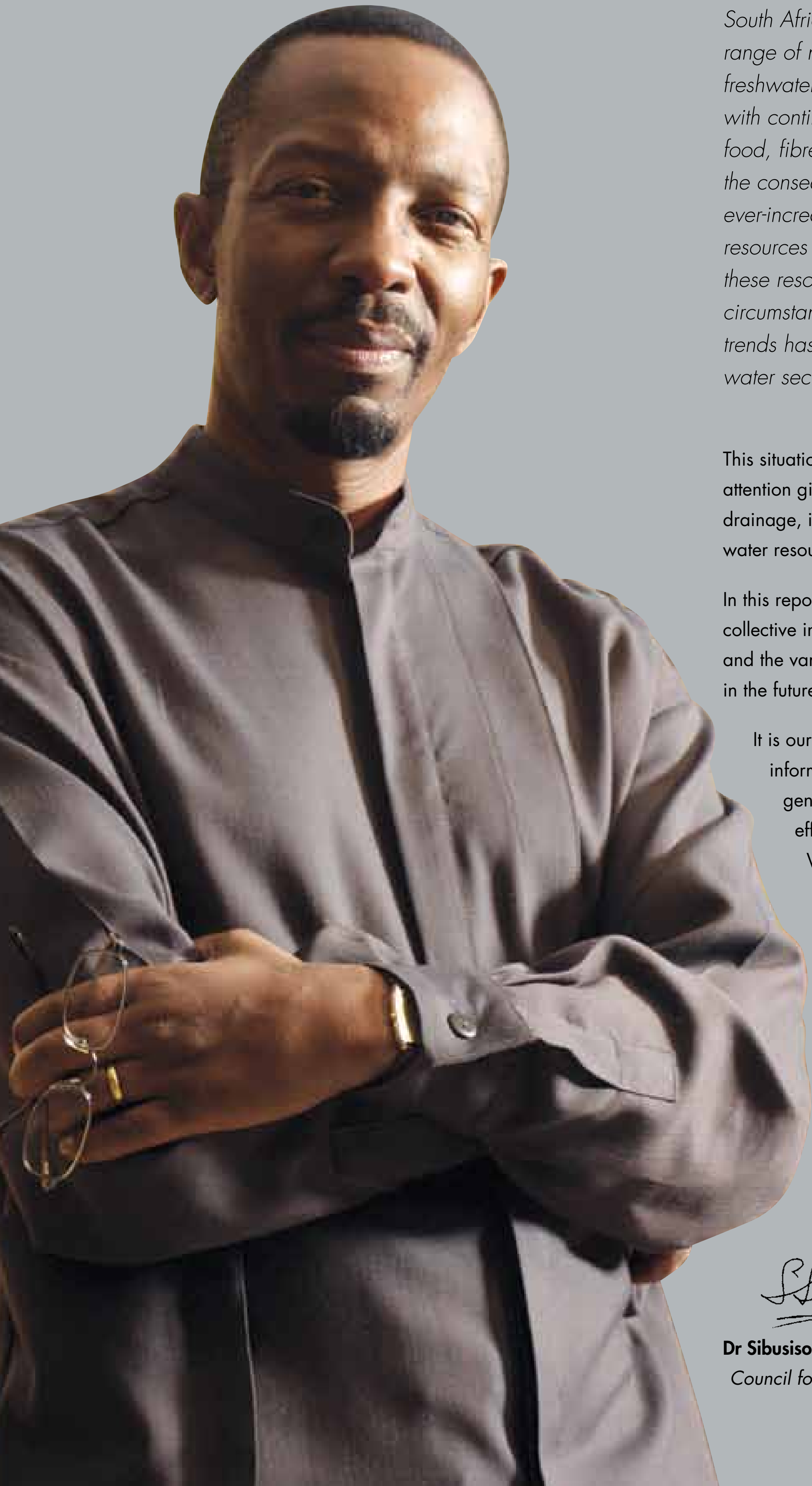

FOREWORD

South Africa has been richly endowed with an enormous range of natural resources, with one important exception: freshwater. Projected population increases – coupled with continuing efforts to meet growing demands for food, fibre, fuel and drinking water, while also redressing the consequences of past political inequities – place ever-increasing demands on the country's limited water resources and the institutions that are tasked with managing these resources. This combination of geographical circumstances, political imperatives and socioeconomic trends has crucially-important implications for the future water security of our country – and for our neighbours.

This situation has further been highlighted by the increased media attention given to particular cases of water shortages, acid mine drainage, inadequate service delivery, water pollution and poor water resource management.

In this report, CSIR scientists and engineers have combined their collective insights and understanding of South Africa's water situation and the variety of challenges and options that face us – now and in the future.

It is our hope that this broad, strategic overview will help to inform decision makers, water resource managers and the general public about the challenges that we face in our efforts to achieve the ideal epitomised by the Department of Water Affairs slogan: some for all forever.

This report also highlights the pressing need for all of us to adopt new, prudent and respectful ways of valuing, using and managing our fragile and vulnerable water resources for the greatest long-term good of our society and the southern African region as a whole.

I urge everyone who reads this document to take these messages to heart; to share the messages with others who may not have had an opportunity to read the document; and to help with the development of new, improved and effective ways of managing our country's vulnerable water resources.

Dr Sibusiso Sibisi
Council for Scientific and Industrial Research

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HOW MUCH WATER DO WE HAVE?

MARIUS CLAASSEN

The National Water Policy (1997) and the National Water Act (1998) are founded on Government's vision of a transformed society, in which every person has the opportunity to lead a dignified and healthy life and to participate in productive economic activity (DWAF, 2004a).

This bold national vision emphasises that water is central to human dignity and human health, as well as social and economic development (DWAF, 2004a). Considering the hierarchy of human needs, water is crucial for drinking, health, sanitation and agriculture. Thereafter, water is important for industry, power generation, mining operations and tourism.

South Africa is a dry country. Although some parts have higher rainfall than others, the country's average rainfall of 450 mm per annum is far below the global average of 860 mm per year (Figure 1). Thus, the reality is that South Africa has relatively little water available and several factors, such as climate change, water pollution and international obligations, limit the amount of water that we have at our disposal.

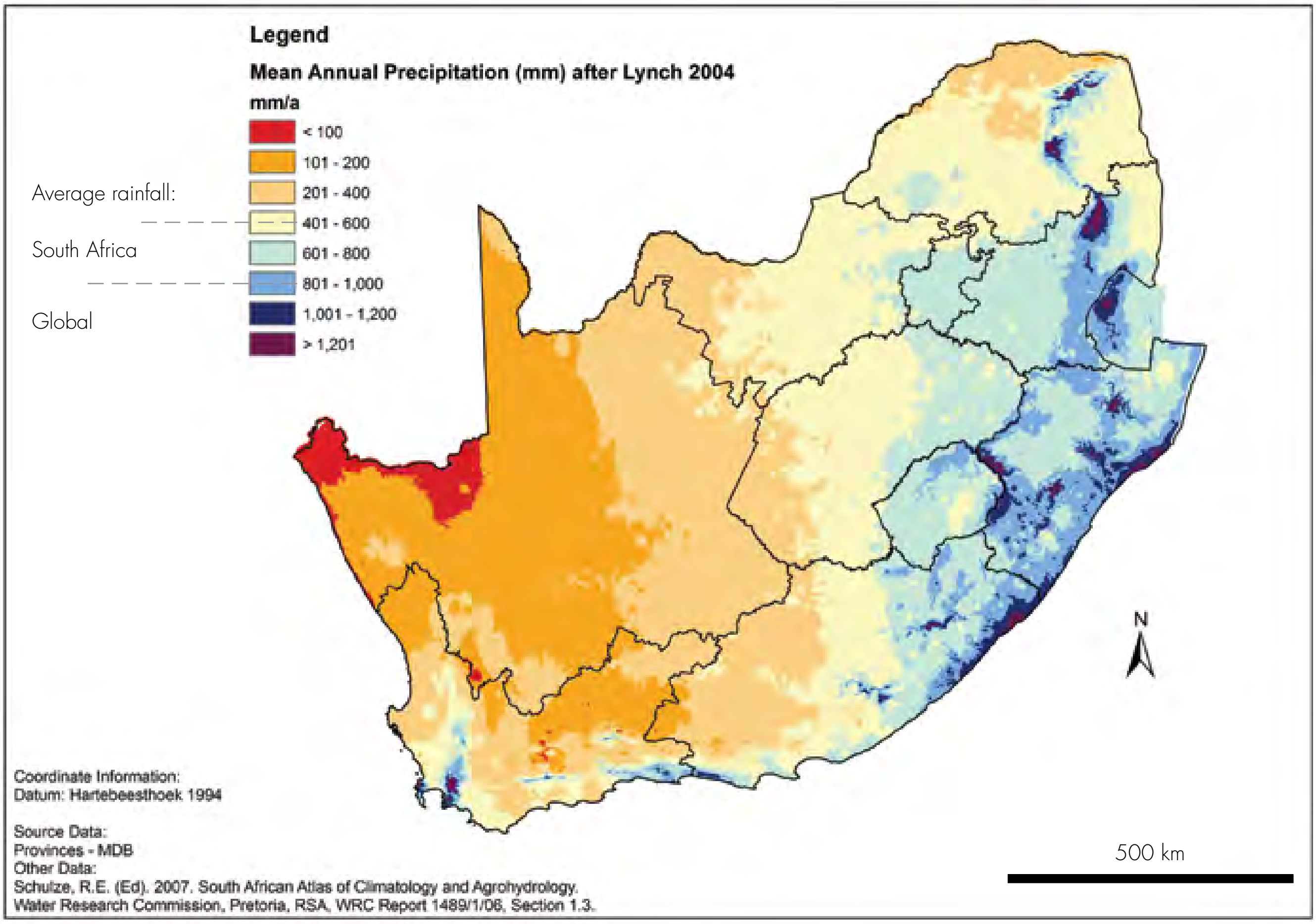
The comparison of South Africa's available water per capita (1 000 m^3/person/year) with neighbouring and other countries, emphasises the challenge we are facing. The available water per capita for neighbouring countries is higher, because they draw water from areas that have higher rainfall and/or lower populations (DWAF, 2008).

Careful calculations of runoff, yield and water use indicate that, at a national level, we have enough water to meet the nation's needs in the immediate future. While South Africa's estimated mean annual runoff is 43 500 million cubic metres per annum (excluding the runoff from Swaziland and Lesotho), the total available yield is 13 227 million m^3/a, and for the year 2000 the total water use requirements were 12 871 million m^3/a (DWAF, 2004a).

To meet South Africa's growing demand, surface water resources are well developed and supply the majority of the urban, industrial and irrigation needs. The 569 dams, with individual capacities exceeding one million cubic metres, have a total capacity of about 32 400 million cubic meters (m^3). All in all, the large dams capture about 70% of the total mean annual runoff.

The water balance for the 19 water management areas in the country shows that ten could not fulfil the demand for water in the year 2000 (DWAF, 2004a). One of the challenges is thus to bring the water to where it is needed. To do this, South Africa has many transfer schemes between rivers within the same catchment and between water management areas.

FIGURE 1: South Africa's average rainfall



This opens up the debate on how many more dams can be built and how much more water can be transferred between river basins to provide enough water for future needs. Economic activity and standard of living are the main drivers of increased water demand. While standard of living is also related to economic growth, the understanding of this relationship is beneficial to the management of water.

As the South African population increases, our water resources face greater pressure (DWAF, 2006a). Social, political and economic activities drive environmental change. Our modern day-to-day consumption patterns challenge and compromise our water resources. Examples are:

- Infrastructure (the many control structures, the dams and weirs that we need to secure water during low rainfall periods and supply to areas of high demand);
- Agriculture (securing the food supply for the nation); and
- Energy, industry and mining, all supplying jobs and commodities.

In some areas these impacts have resulted in severe degradation of the quality of water, and have impaired the integrity of aquatic life in rivers.

Water resource systems such as rivers and estuaries need water to sustain their functionality. This is very important because a river has the resilience to recover from stresses if its basic functions are not compromised. This is acknowledged through the setting of an ecological reserve – the proportion of water in the system to which natural ecosystems have adapted. In highly regulated systems, this becomes a trade-off because the little water that is left in the system may not meet these requirements and is then augmented from the yield. However, many of South Africa's dams are not designed to release sufficient water to meet the requirements of the reserve.

Pollution and water quality

Poor quality water not only limits its utilisation value; it also places an added economic burden on society through both the primary treatment costs and the secondary impacts on the economy:

- The more polluted the water resource, the higher the treatment costs;
- Human health (and the resultant loss in economic activity) is affected by poor water quality as it gives rise to waterborne diseases such as cholera, bacterial infections, heavy metal accumulation and endocrine disrupting substances; and
- Poor quality irrigation water has a ripple effect – for example, health inspectors may have to reject export fruit because of bacterial contamination or bioaccumulation of heavy metals.

The biggest threat to a sustainable water supply in South Africa is not a lack of storage, but the contamination of available water resources through pollution.

Economic growth implies industrialisation and urbanisation, which will result in further deterioration of our water resources. The National Water Resource Strategy (DWAF, 2004a) calls for "appropriate and timely corrective measures". Heavy utilisation of the nation's water resources and the limited availability of further supplies mean that sustainable use will require far more efficient water resource utilisation by all sectors. This would include revisiting both low and high benefit water users and arranging possible re-allocations between them.

The cost of treating water for human consumption increases as our water resources become more polluted. The difference or "gap" in the cost of treating polluted water resources and desalination of sea water is rapidly closing, opening up new options in the field of water management.

The challenge for South Africa lies in the efficient and balanced use of water, together with other natural resources, to create an environment conducive to social and economic well-being.

Runoff: Precipitation in the form of rain, fog, hail and snow that runs off the land surface to appear in streams and lakes, and infiltrates the soil to become groundwater.

Mean annual runoff: The average annual runoff originating from a certain geographic area.

Yield: The volume of water from a water resource system that people can reliably abstract at a certain rate over a specified period of time. Using a combination of surface and groundwater increases the usable yield.

Available water: The quantity of water available for use, including surface and groundwater, return flows and transferred water from other catchments. The reserve does not form part of the available water for other uses.

The reserve: The quantity and quality of water required to meet basic human needs (basic human needs reserve) and to protect aquatic ecosystems (ecological reserve). The latter is crucial to ensure "sufficient water of an acceptable quality for future use" and thus sustainable development.

DEFINITIONS

Groundwater

Wilma Strydom

Groundwater forms part of the natural water cycle and should not be seen as an additional water resource. Surface water filters into the soil and rocks, slowly replenishing the groundwater. The groundwater naturally overflows, feeding into rivers and wetlands (Figure 2). Where groundwater is over-abstracted or rainwater infiltration is reduced, these dependent ecosystems are negatively impacted (WRC, 2002).

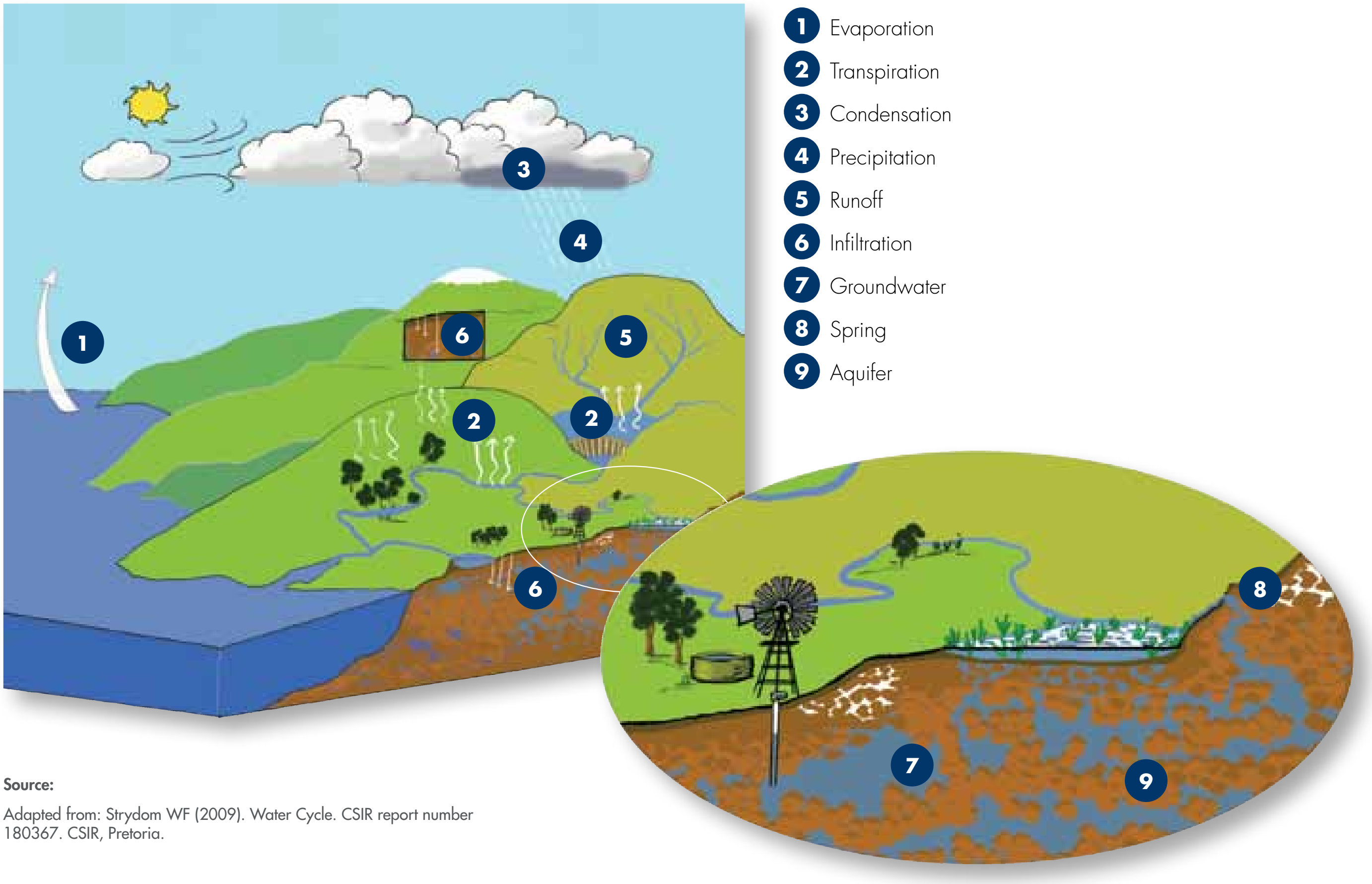
In 2004, the then Department of Water Affairs and Forestry (DWAF) estimated that groundwater provides 13.5% of the total volume of potable water used in South Africa (DWAF, 2004a,b). Small as this contribution may seem, it represents the only source of water for over 300 towns and 65% of South Africa's population (Woodford *et al.*, 2009). Total groundwater use was estimated at some 1 770 Mm^3/a, with 64% of that water being used for irrigation purposes in the agricultural sector.

Against this background, the under-utilisation of the country's groundwater resources is put in perspective by the estimated 19 000 Mm^3/a of potentially exploitable groundwater, of which an estimated 10 350 Mm^3/a is considered utilisable (Woodford *et al.*, 2009).

Further utilisation of groundwater needs to be managed carefully as we have few primary aquifers, of which most are in fractured rock with relatively low yields. Dolomitic aquifers are porous – infiltration into this groundwater resource is fast and has the potential to be easily contaminated.

Contamination of groundwater by viruses and bacteria has caused a number of disease outbreaks in South Africa, for example at Delmas in 2005 and 2006 (Griesel *et al.*, 2006).

FIGURE 2: Water cycle

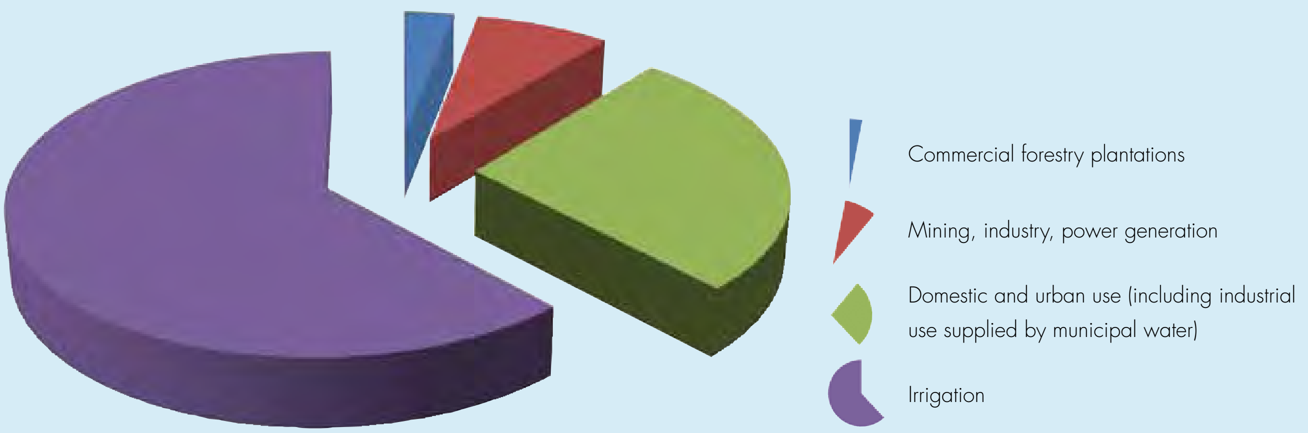


Source:

Adapted from: Strydom WF (2009). Water Cycle. CSIR report number 180367. CSIR, Pretoria.

FIGURE 3: Water use per sector

Water use in South Africa is dominated by irrigation, which accounts for around 62% of all water used in the country, with domestic and urban use (including water for industrial use supplied by water boards) accounting for 27% and mining, large industries and power generation accounting for 8%. Commercial forestry plantations account for a little less than 3% of water used by reducing runoff into rivers and streams (DWAF, 2004a). Agricultural activities also intercept rainfall and are not included in this breakdown.



THE CURRENT STATUS OF WATER QUALITY IN SOUTH AFRICA

PAUL OBERHOLSTER

The main factors contributing to the deterioration of water quality in South Africa are salinisation, eutrophication, disease-causing micro-organisms and acidification.

South Africa is facing a water supply crisis caused by a combination of low rainfall, high evaporation rates, an expanding economy and a growing population whose geographical demands for water do not conform to the distribution of exploitable water supplies.

In 2005, more than 95% of the country's freshwater resources had already been allocated. The water quality of these resources has also declined due to increased pollution caused by industry, urbanisation, afforestation, mining, agriculture and power generation (Ashton *et al.*, 2008). Exacerbating factors are South Africa's outdated and inadequate water treatment and sewage treatment plant infrastructure and unskilled operators (Rietveld *et al.*, 2009; Snyman *et al.*, 2006).

Of concern for human and ecosystem health are the occurrence, transport and fate of contaminants in the aquatic environment. The major problems are health-threatening microorganisms, numerous persistent and toxic metals and organic compounds. Contamination of groundwater by toxic and persistent compounds can cause irreversible pollution, influencing water users long after the original release to the environment has ceased.

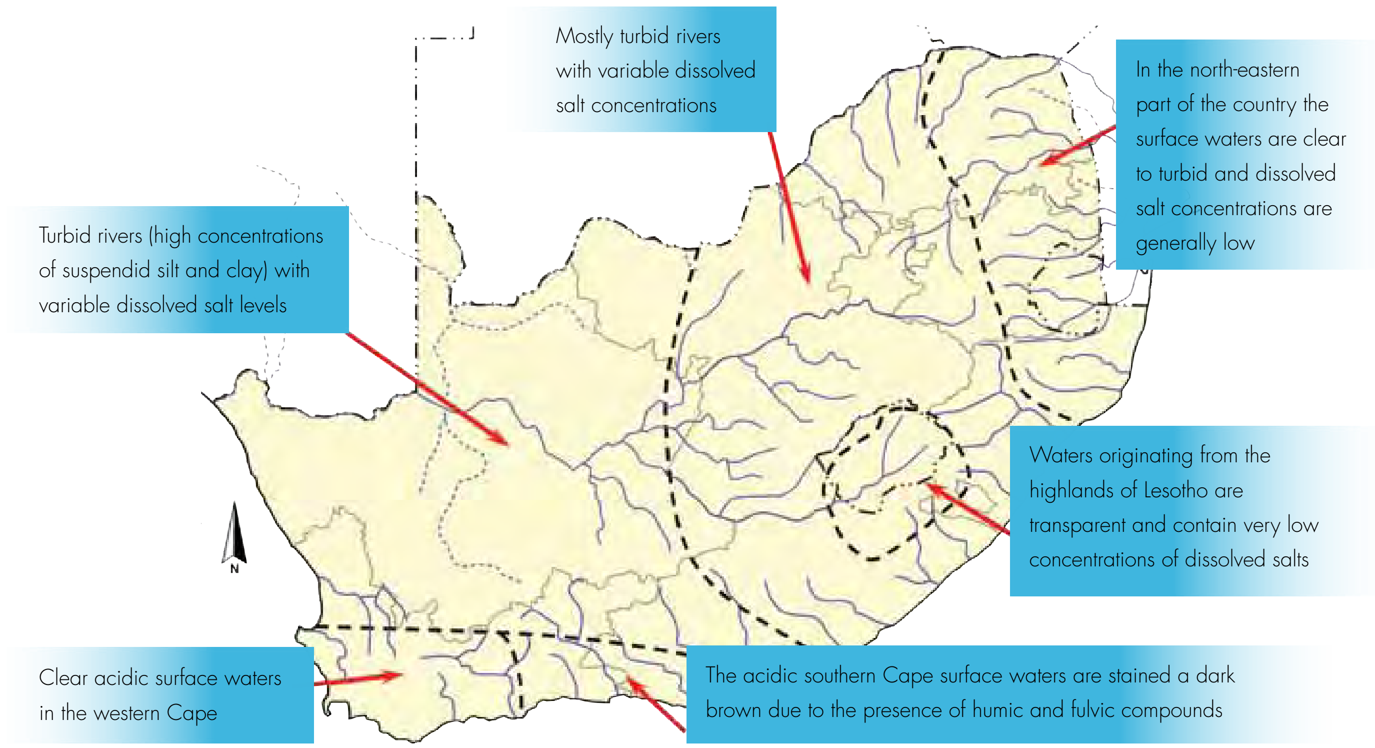
Given the current and anticipated future growth rates of the population and expected trends in socio-economic development, South Africa's water resources are unlikely to sustain current patterns of water use and waste discharge. Even with zero population growth in South Africa, pollutants will continue to accumulate in freshwater systems. Deteriorating water quality can adversely affect human health and the aquatic ecosystem and has economic implications for various sectors of the economy including agriculture and industry (Oberholster and Ashton, 2008). Water quality problems can lead to increased treatment costs of water used for human consumption and industrial processes, and decrease agricultural fruit and crop yields and quality. If the carrying capacity of the natural system is exceeded, problems associated with water quality can become exacerbated with disastrous consequences.

Human activities affect water quality

Most of South Africa's metropolitan areas are located on the watersheds of river catchments. The rivers draining away from these watersheds have the dual burden of providing water supplies and transporting waste material. Thus, the dams located downstream of urban and metropolitan areas have become progressively more contaminated during recent decades (Oberholster and Ashton, 2008). This has important implications for the quality of water supplies that are delivered to urban, industrial and agricultural water users. The combined effects of a wide variety of land use patterns and economic activities on water quality are superimposed on the natural background water quality types (Figure 4).

FIGURE 4: Natural background water quality ***Peter J Ashton***

The natural background water quality reflects the combined effects of climate (rainfall, evaporation and temperature), geology, soil type and vegetation patterns. Six basic water types can be recognised in South Africa (Figure adapted from Dallas & Day, 2004.25).



The effects of effluent discharges from urban and industrial areas, as well as seepage and discharges from areas that support mining and intensive agriculture, exert several important changes in water quality. In turn, these water quality changes have important consequences for all segments of society as well as the natural ecosystems that depend on the water resources. A large proportion of the sewage emanating from South African urban areas is not treated properly prior to discharge, because the sewer systems are incomplete or broken, or sewage treatment plants are overloaded and mismanaged. This is particularly true in small towns and in densely populated areas of the country.

Industrial development has also left its mark on our water resources. Many industrial processes produce waste products that contain hazardous chemicals, and these are sometimes discharged directly into sewers, rivers or wetlands. Even those waste products that are disposed of in landfills or slag heaps, for example, may release substances that eventually seep into nearby watercourses (Oberholster *et al.*, 2008). Modern agricultural practices add significantly to this environmental burden, with pesticides and fertilisers washing into rivers or leaching into groundwater (Walmsley, 2000).

Without a radical improvement in water quality management approaches and treatment technologies, progressive worsening of water quality will continue to decrease the benefits and increase the costs associated with use of the country's water resources.

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Salinisation

Salinisation is a persistent water quality problem in South Africa. Salinity refers to the amount of dissolved inorganic salts or compounds in the water and is measured as total dissolved solids (TDS). Salinisation refers to the natural or manmade processes that increase the salinity within a water system. Human induced causes of salinisation include:

- Discharge of municipal and industrial effluent;
- Irrigation return flows;
- Urban storm-water runoff;
- Surface mobilisation of pollutants from mining and industrial operations; and
- Seepage from waste disposal sites, mining and industrial operations.

Immediate increases in salt concentrations result from point sources of pollution such as waste water discharge by industries. Diffuse pollution, resulting from poorly managed urban settlements, waste disposal on land and mine residue deposits, can pose a larger problem than point source pollution, because the impact is more widely spread. It is also only detected in the water system after prolonged exposure and is difficult to monitor and control (Oberholster *et al.*, 2008). The effect of diffuse pollution on groundwater is also often difficult to reverse. Problems associated with salinisation include:

- Reduction in the yield and quality of crops and fruit;
- Increased scale formation and corrosion in domestic and industrial water conveyance systems;
- Increased requirement for pre-treatment of selected industrial water uses; and
- Changes in the community structure of aquatic biota present in the system.

Specific high-risk areas in South Africa are the lower Vaal River, starting at Bloemhof Dam downstream to the confluence with the Orange River (Van Rensburg *et al.*, 2008) , as well as the Breede, Crocodile and Olifants rivers.

High nitrate concentrations in groundwater pose elevated levels of risk of methaemoglobanaemia (so-called blue baby syndrome) to infants that drink formula feed made up with water drawn from these groundwater sources in certain areas of South Africa. High fluoride concentrations have caused bone and dental fluorosis (discoloration of the teeth) in children and adults in some parts of South Africa.

Eutrophication

Eutrophication is the process whereby excessive growth of algae and other aquatic plants is encouraged as a result of the enrichment of water with plant nutrients, particularly nitrogen and phosphate forms (NO_2, NO_3, NH_4 and PO_4). The accumulation of nutrients in excess of natural requirements results in nutrient enrichment – eutrophication – and this has important impacts on the composition and functioning of the natural aquatic biota (Oberholster *et al.*, 2009a,b).

South Africa's climatic conditions, combined with various factors, have resulted in large-scale changes to aquatic ecosystems and subsequent eutrophication of rivers and water storage reservoirs. The most important factors affecting water resources are:

- Discharge of treated and untreated sewage effluent;
- Excessive nutrient loads in return flows from agriculture;
- Modification of river flow regimes; and
- Changing land use or land cover patterns.

In most eutrophic reservoirs and rivers in South Africa the dominant phytoplankton genera are usually the cyanobacteria *Microcystis* and *Anabaena* (Van Ginkel, 2004). The excessive growth of toxic cyanobacteria ("blue-green algae") leads to problems in water purification due to the presence of toxic metabolites and taste- and odour-causing compounds. Because nutrients are present in sewage effluent, the problem is accentuated wherever there is a concentration of humans or animals.

Cyanobacteria produce some of the most potent known toxins, with no known antidotes available. These biotoxins fall into three categories, namely neurotoxins (poisonous to nerves), hepatotoxins (any toxin that affects the liver) and lipopolysaccharides (LPS)[1]. The biotoxins in the first two groups can cause severe reactions in animals and humans, while the third group appears to be less virulent (Oberholster *et al.*, 2006). The existence of gastrointestinal disorders linked to the ingestion of cyanobacterial biotoxins, as well as the chronic risks posed by hepatotoxins, make these toxins a serious threat to human health when present in drinking water supplies.

The biotoxin concentrations associated with cyanobacteria in major impoundments in Gauteng are so high that a regional crisis exists when compared to impoundments abroad. The presence of cyanobacteria in municipal water reservoirs involves extra costs for the removal of algal cells which may block filters. The excreted compounds of the algal cells also produce discolouration, odours and bad tastes, and, depending on environmental factors, can be highly toxic.

Filamentous toxic cyanobacteria such as *Oscillatoria, Planktothrix, Cylindrospermopsis* and *Anabaena* may position their long axes in the direction of the water flow during filtration stages enabling them to pass through filters. Large cyanobacterial blooms may rapidly clog filters and thus reduce filter time, because clogged filters must be taken out of service and backwashed. The conventional water treatment processes of flocculation, sedimentation and sand filtration, which are commonly used in South Africa, are inadequate to remove cyanobacterial biotoxins from water. In addition, this water treatment method can cause the breakage of cyanobacterial cells and result in the release of cyanobacterial biotoxins. Other cyanobacterial products, such as mucopolysaccharides, are able to chelate iron or aluminium added in water treatment and may thus inhibit flocculation. This also leads to high concentrations of metal ions in the potable water supply. The increase in soluble aluminium concentrations in drinking water supplies presents a health threat to humans as it has been linked with encephalopathy (any disorder or disease of the brain).

Heavy metal ions become bound to organic matter under certain pH conditions and may also cause problems for industrial uses such as in the production of carbonated soft drinks (Pitois *et al.*, 2000). Furthermore, treatment processes that use potassium permanganate or chlorine may release the biotoxins from the cyanobacteria, and the toxins may subsequently enter the domestic water supply. Specific high-risk reservoirs are:

- Roodeplaat and Rietvlei in Gauteng;
- Loskop Dam in Mpumalanga,
- Smith Dam in Kwa-Zulu Natal,
- Bridle Drift and Laing in the Eastern Cape;
- Voëlvlei Dam in the Western Cape; and
- Hartbeespoort and Klipvoor Dam in North West.

1 LPS form part of the cynobacterial cell wall and are thought to exert the toxic effect as endotoxins, eliciting an immune response in animals.

Observing water from space

As part of the Safe Water Earth Observation Systems (SWEOS) project, CSIR researchers developed a pencil buoy that is used for water observations. Design parameters were low cost, low weight and easy and fast to deploy. The buoy's electronics is a very low power design that can stay deployed for a long time without requiring maintenance. Solar panels are used to keep the buoy's battery topped up and data is collected at regular intervals. Data can be stored on board but can also be relayed via a GSM network to a central server.

The buoy can be used for both ocean and inland water monitoring, and initial trials were held at Hartbeespoort Dam in September 2010 with a prototype assembly. After further mechanical, electronic and software work, the buoy underwent sea trials at the end of February 2011. During these trials algae blooms were monitored which have a detrimental effect on fisheries.

Acidification

The pH of natural waters is predominantly determined by geological, soil and atmospheric influences. Freshwater resources in South Africa are relatively well buffered. However, human-induced acidification – from industrial effluents, mine drainage and acid rain – can cause a lowering of the pH over time, resulting in a deterioration of water quality and mobilisation of elements such as iron, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc, which may accumulate in fruits and crops (Oberholster *et al.*, 2010).

The Witwatersrand region in South Africa is famous for its gold production. The groundwater within the mining district is heavily contaminated, has elevated concentrations of heavy metals and is acidified as a result of oxidation of pyrite (FeS_2) contained in waste rock and tailings dumps. The polluted groundwater is discharging into streams in the area and contributes up to 20% of total stream discharge, causing a lowering of pH in the stream water while most of the metal load is precipitated.

South Africa's coal mining industry is the second largest mining sector after gold, with sales contributing 16% of export revenue in 2003. Together with its southerly neighbours, the Highveld and Ermelo coal fields, the Witbank coal field represents the largest conterminous area of active coal mining in South Africa. These coal fields produce coal for power generation and support 48% of the country's total power generating capacity (Tshwete *et al.*, 2006).

Environmental risks from these coal fields include surface and groundwater pollution in the form of heavy metal uptake in the environment, the degradation of soil quality and the harming of aquatic fauna (Oberholster *et al.*, 2010). Acid mine drainage (AMD) has been linked with several health-related consequences. Groundwater contaminated with AMD might be consumed by individuals without them being aware of it, with treatment often ineffective by the time that the effects materialise (USEPA, 1994, 1999; Adler and Rascher, 2007). A number of defunct and flooded underground coal mines, such as the Middelburg Colliery to the west and northwest of Witbank, commenced decanting in the mid-1990s, contributing to pollution of water resources in the upper Olifants River catchment upstream of Loskop Dam.

Disease causing micro-organisms

The microbial content of water represents one of the primary determinants of fitness for use. Human settlements, inadequate sanitation and waste removal practices, storm water wash-off and sewage spills are the major sources of deteriorating microbiological water quality in South Africa.

The spread of diseases such as cryptosporidiosis, dysentery, cholera and typhoid is caused by the use of water that is contaminated by faecal matter (Momba *et al.*, 2004). Micro-organisms derived from faecal matter can also end up on fruit and crops through contaminated irrigation water. After HIV/Aids and low birth weight, diarrhoea is the third highest cause of death among children under five years of age and represents 10% of all deaths in this age group in South Africa (Bradshaw *et al.*, 2003).

The World Health Organization estimates that 94% of diarrhoea cases are preventable by increasing the availability of clean water, and improving sanitation and hygiene (WHO, 2007a). South Africa is one of only 12 countries in which mortality rates for children have increased since the baseline for the Millennium Development Goals (MDGs) was set in 1990 (South Africa Every Death Counts Writing Group. 2008). In South Africa, almost 2 000 children die annually before they reach one month, and an additional 51 300 die between 29 days and five years. The main causes are HIV/Aids, pneumonia and sepsis, diarrhoea and malnutrition (Chopra *et al.*, 2009).

Surface and drinking water quality, in peri-urban and rural areas, is further compromised by unskilled plant operators, old and inadequate infrastructure and poor maintenance. Interruptions in the water supply and provision of poor quality water are common in these areas. The 2008-cholera outbreak in Limpopo is just one deadly example of poor water quality management.

An estimated R3.5 billion is spent in South Africa every year as a direct result of diarrhoea (Pegram *et al.*, 1998). Some of the highest potential health risk areas of surface water due to faecal pollution are the towns and surrounding areas of:

- Klein Letaba, Elands River (Mpumalanga);
- Kokstad, Newcastle, Dundee, Ulundi Esigodini, Nsikazi River, Matsulu and Ngnodini (KwaZulu-Natal);
- Tolwane, Makapanstad, Mafikeng (North West);
- Matatiele, Maclear, Port St Johns, Buffels River (Eastern Cape);
- Phuthaditjhaba (Free State);
- Pholokwane, Lebowakgomo (Limpopo); and
- Garankuwa, Tshwane, and the Olifants, Elands and Apies rivers (Gauteng).

The health risk in these areas is caused by high population densities, a shortage of proper sanitation infrastructure and a shortage of purified water for domestic use (NMMP, 2000).

Future challenges

- Water quality: There are clear indications from the relatively scanty water quality monitoring data available that the water quality of most South African river and reservoir systems has deteriorated over the last twenty years. In some areas – such as the upper and middle reaches of the Vaal River system, the Mgeni River system, the Crocodile River (West) system and the upper and lower reaches of the Olifants River system – the water quality poses serious health risks to humans and livestock that drink the water over many years. With a growing population and increased urbanisation, coupled with the apparent inability of most local authorities to effectively treat urban and industrial effluents to the promulgated effluent standards, the situation will continue to worsen.

- **Global and climate change:** Given the predictions associated with global and climate change and the down-scaled forecasts of increased temperatures across South Africa, a rise in air temperature of 2 degrees Celsius will likely have far-reaching effects on the quality of water in river systems and water storage reservoirs. In particular, higher water temperatures will alter water-gas equilibria and increase the rates of microbial processes; these will in turn accelerate nitrification, denitrification, respiration and methanogenesis (the generation of methane by anaerobic bacteria). Higher water temperatures will lead to increased rates of evaporation, thereby reducing the volumes of water needed for a growing population.
- **Increased treatment costs:** Increased loads of discharged effluents will increase the costs associated with purifying water for domestic consumption.
- **Acid mine drainage (AMD):** If left unchecked, AMD will continue to contribute increased concentrations of dissolved salts, metal ions and, in some instances, radionuclides to the already stressed river and reservoir systems. Low pH values in AMD will increase the solubility of trace metals locked up in sediments and release these into the overlying water.

Overall, water quality will progressively deteriorate unless corrective management actions are implemented effectively and continuously.

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Conclusions

Human activities have had a series of progressively worsening effects on South Africa's scarce water resources – these effects have accelerated during the last few decades as the population grew rapidly and the economy expanded. The natural ability of rivers and reservoirs to trap toxic chemicals and nutrients in their sediments has enabled these systems to accumulate these and other contaminants, which are then available for uptake by nuisance algae and aquatic plants.

These substances pose frequent – and often severe – health risks to humans, livestock and wildlife that use these contaminated waters.

A visible consequence of South Africa's social and economic development has been the progressive increase in the loads of harmful micro-organisms, nutrients, salts, metal ions, toxic chemicals, radionuclides (can emit radiation) and suspended sediments entering the country's river systems and water supply reservoirs. This has been accompanied by an increase in the incidence of nuisance blooms of toxic cyanobacteria, especially *Microcystis aeruginosa*, with numerous instances where livestock and game animals have died. Toxic cyanobacteria present a range of risks to human health, depending on the type of algal toxin produced and the type of water use. Conventional water treatment technologies do not remove algal toxins; carbon filtration and other forms of tertiary treatment are needed to achieve removal and inactivation.

Despite the promulgation of the effluent phosphate standard, the water quality in South Africa's rivers and reservoirs has deteriorated rapidly – fuelled by increased effluent loads discharged to rivers and the inability of water resource managers to ensure strict compliance with water quality standards at all sewage treatment works.

The available predictions linked to patterns of global and climate change, as they apply to South Africa, indicate that increased water temperatures will contribute to the worsening of the water quality situation.

If current water quality management efforts continue in the same vein, without drastic improvements to counter the worsening water quality situation, then the position will continue to deteriorate into the future. This has the potential to pose great social, economic and environmental risks for the country as a whole and cannot be allowed to happen.

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South Africa's water supplies and eutrophication *Peter J Ashton*

The importance and current extent of eutrophication in South African water bodies has been highlighted in recent reports and also by the development of an implementation manual for the National Eutrophication Monitoring Programme (DWAF, 2002). However, the benefits of these efforts have yet to be realised.

South Africa's natural lakes are few and mostly small. River flows are seasonal and highly variable, so water storage reservoirs are the major sources of freshwater for human use.

South Africa has 569 large dams, each with a capacity in excess of one million cubic metres. The water quality in the larger reservoirs and also in the smaller dams and impoundments reflects the interacting effects of physical processes (runoff patterns, light penetration, temperature profiles, gas equilibria, wind mixing); chemical processes (adsorption and desorption of salts and nutrients on clay particles, ionic equilibria, chemical interactions) and biological processes (e.g., photosynthesis, respiration, nitrification and denitrification).

South Africa's freshwater resources are excessively enriched and are considered to be moderately to highly eutrophic. Large areas of South Africa are arid to semi-arid and experience erratic and unpredictable extremes of drought and floods. Where point source nutrient inputs are combined with reduced flows, rapid rates of eutrophication occur.

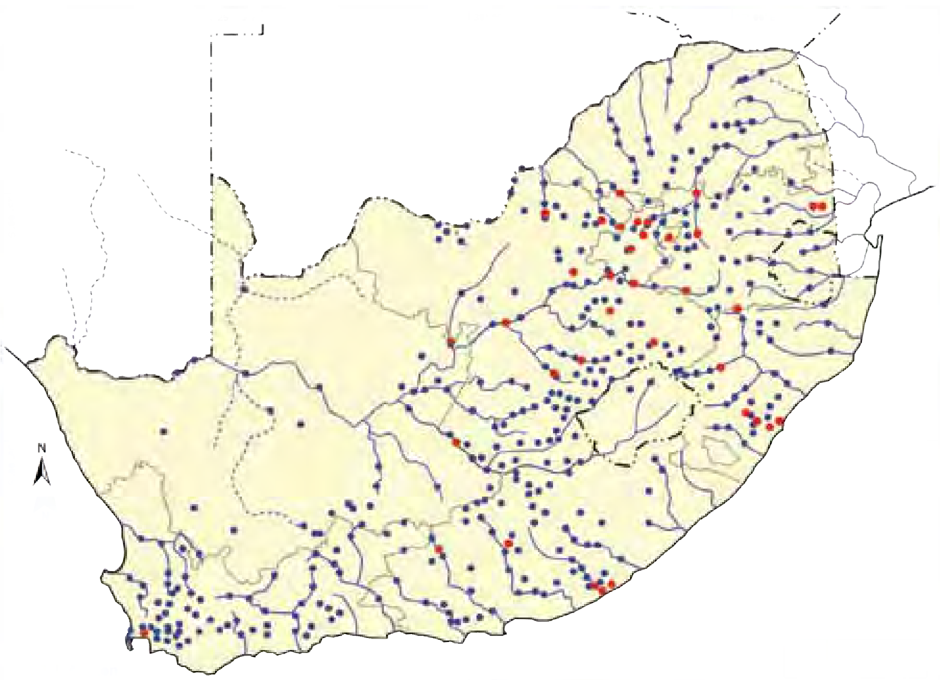
Large proportions of the inflowing nutrient loads are retained within waterbodies, favouring cyanobacterial blooms (NIWR, 1985). Eutrophication is generally indicated by the accumulation of metabolic products (e.g., hydrogen sulphide in deep waters); discolouration or turbidity of water (resulting in low or poor light penetration); deterioration in the taste of water; depletion of dissolved oxygen; and an enhanced occurrence of bloom-forming species of cyanobacteria (Figure 5).

A large amount of work has been carried out on eutrophication in dams and lakes. However, our collective understanding of eutrophication in rivers remains relatively limited. Most South African river systems are turbid – containing high concentrations of suspended silts and clays – due to catchment mismanagement, erosion, siltation, unstable riverbeds and loss of in-stream fauna that feed on planktonic algae. High suspended sediment concentrations exert an adverse effect by generating underwater light conditions that favour toxic cyanobacteria such as *Microcystis aeruginosa* (Hart, 2006).

Rivers that are located downstream of eutrophic lakes are likely to show a prevalence of cyanobacteria due to the large numbers of cyanobacteria that are discharged in the outflow from these lakes. However, these cyanobacteria will only continue to show measurable growth in slow-flowing rivers that have a long retention time. In fast-flowing, turbulent rivers with a short retention time, the cyanobacteria that are discharged from a water-storage reservoir will add to the total turbidity of the river water, but the cyanobacterial population will not increase significantly by growth during their transit of the river.

FIGURE 5: Map of South Africa showing the locations of the largest reservoirs

Map showing the locations of the largest reservoirs (blue dot symbols). Red dots show where toxic cyanobacterial blooms have been recorded and include some of the smaller reservoirs. Source: Department of Water Affairs and NRE, CSIR.



Information from previous surveys of South African river systems that are classed as eutrophic or having the potential to become eutrophic soon because of their poor water quality, indicates that the most important river systems are the:

- Olifants, Vaal, Jukskei/Crocodile (Gauteng);
- uMngeni (Kwazulu-Natal);
- Orange (forms the border between South Africa and Namibia);
- Modder (forms part of the border between Northern Cape and Free State); and
- Buffalo river system (Allanson and Jackson, 1983; Breen, 1983; O'Keeffe, 1986; O'Keeffe, 1988; Walmsley, 2003; Pieterse and Janse van Vuuren, 1997).

The most important driving forces that cause degradation of water quality in these river systems are the dense rural population and extensive urban informal housing developments that dominate land use patterns in these catchments, which have no access to effective sanitation systems. Other contributing factors are contaminated surface run-off from rural and urban areas; discharges of raw or partially treated sewage from overloaded sewage treatment plants; poor agriculture management practices and solid waste dumps located on or close to river banks.

Although eutrophication is a natural, slow, ageing process of lakes, it can be greatly accelerated and modified to benefit nuisance algae by human intervention in the natural biogeochemical cycling of nutrients within a watershed (Rast and Thornton, 1996).

Until the mid-1980s, South Africa was recognised as a world-leader in eutrophication research. Unfortunately, this advantage was lost because eutrophication management in South Africa focussed on the implementation of an inappropriately high phosphorus concentration (1 mg/litre as P) for all effluents discharged from sewage treatment plants to surface water systems in designated sensitive catchments, and what appears to be progressive incapacitation due to an inability to transform policy into practice (Oberholster and Ashton, 2008).

In common with many other developing countries, eutrophication has a relatively low priority in South Africa (Harding and Paxton, 2001).

Thankfully, however, the importance and current extent of eutrophication in South African water bodies has been highlighted in recent reports (Van Ginkel, 2004; Van Ginkel *et al.*, 2001) and also by the development of an implementation manual for the National Eutrophication Monitoring Programme (DWAF, 2002). However, the benefits of these efforts have yet to be realised.

Agriculture and the water quality reality

Suzan Oelofse

Agriculture, especially irrigated agriculture, contributes to the degradation of water quality. At the same time, successful irrigation requires water of good quality.

A study conducted in Zimbabwe (Muchuweti *et al.*, 2006) showed that the accumulation of heavy metals in agricultural soils results in environmental contamination and elevated uptake of heavy metals by plants. Irrigating crops with sewage effluent has led to crops being heavily contaminated with the four regulated elements, namely cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn).

Analysis of edible plants indicated that while most plants appeared to be healthy and grew well, the accumulated heavy metal concentrations exceeded the permissible levels set in the European Union (EU) Standards (2001) and the United Kingdom (UK) Guidelines (1989).

Implications for South Africa

Crops irrigated with water contaminated by sewage, or other sources of pollution, pose a potential human health risk.

The current poor state of wastewater treatment plants in South Africa poses an increasing risk to agricultural crops because of the general deterioration in the quality of water available for irrigation. If South African grown export crops become contaminated with metals as in Zimbabwe, this will result in potentially disastrous impacts on export markets, not to mention the potential health impacts on consumers.

Heavy metals and human health

Trace metals such as copper, manganese and selenium are essential in the human diet. Some metals are needed in biochemical processes: zinc is needed for several enzymatic reactions; vitamin B-12 has a cobalt atom at its core; and haemoglobin contains iron. Other metals such as lead, mercury, and cadmium are examples of "toxic metals".

Heavy metals are basic elements and cannot be broken down. While organic pollutants slowly degrade to carbon dioxide and water, heavy metals tend to bio-accumulate, especially in lake, estuarine or marine sediments – they persist in the environment, moving from one place to another. Human symptoms and level of toxicity depend on the specific metal in question, the dose absorbed, as well as whether or not the exposure was acute or chronic.

Water quality and human health

Martella du Preez

All life is dependent – directly or indirectly – on the healthy functioning of aquatic ecosystems. Globally, unsafe water, inadequate sanitation and poor hygiene are rated among the top ten risks to health.

Human health and water in South Africa

The World Health Organization's (WHO) Constitution defines health as "a state of complete mental and social wellbeing and not merely the absence of disease or infirmity" (WHO, 2004a). Globally, unsafe water, inadequate sanitation and poor hygiene are rated among the top ten risks to health (WHO, 2002).

Legislation in South Africa prescribes management options favourable to human health. However, despite all the acts, bills, white papers and policies, a significant percentage of South Africa's population is still compromised due to non-implementation.

A comprehensive understanding of the interrelationships between water and human health is essential for the sustainable management of water quality, so as to attain optimum human health gains.

Protection of water resources and sustainable development

Within the context of human health and water quality, several aspects or principles of sustainable development related to water should be taken into account. Ecological, socio-economic and political factors are interdependent and growth is not possible without development.

Simultaneously, all life is dependent – directly or indirectly – on the healthy functioning of aquatic ecosystems. The capacity of ecosystems to supply services is limited, so the demand for goods and benefits often exceeds the supply. This is aggravated by the fact that most kinds of water use have negative, and often irreversible, impacts on the health of ecosystems. Although ecosystems show some degree of resilience to negative impacts, their ability to recover has limits.

Water resources are under threat of over utilisation for excessive short-term benefits, which will compromise their ability to sustain the provision of these benefits. Thus, sustainable development of South Africa's water resources is non-negotiable for the improvement of quality of life and more specifically human health.

Waterborne and water-related pathogens

About 25% of all deaths worldwide are the result of infectious diseases caused by pathogenic micro-organisms (UNEP, 2006). Scientists have identified about 1 400 species of micro-organisms that can cause ill health, including bacteria, protozoa, protozoan parasites, parasitic worms, fungi and viruses.

Water is both a source and transport agent for many of these pathogens, which typically emerge when environments are conducive to their growth and development. Releases of pathogens, for example, occur when sewage treatment plants overflow. Where water treatment

Integrating environmental modelling and earth observation for decision making

Water-related human health, and in particular the health impact of water-related infectious diseases, cannot be addressed in isolation any longer. CSIR researchers are integrating domains such as human health, remote sensing, earth observation and modelling to provide an increasingly deeper and holistic understanding of the complex interactions and links between the environment and water-related human health.

With the help of remote sensing and earth observation data, microbiologists are starting to understand how changes in the environment drive the spatial and temporal behaviour and spread of organisms, ultimately impacting on the physical well-being of humans. It ultimately will aid microbiologists to remotely track water-related infectious diseases without having to sample and test for the responsible pathogens on a continuous basis and over large areas

With the aid of funding from the European Union, CSIR researchers are working on the integration of these domains to demonstrate how it can underpin sound decision making for environmental health control and mitigation options. The main objective is to contribute to a better understanding of the complex relationships between human induced environmental changes and human health.

facilities malfunction or do not exist, pathogens can be released into drinking water (UNEP, 2006).

Medicines such as antibiotics and anti-parasite drugs, as well as insecticides, can encourage the development of resistant pathogens. Several man-made systems such as hot water tanks sustain water temperatures and nutrient levels that favour pathogen growth and harbour films of microbes (biofilms) that can protect these organisms from disinfectants (WHO, 2004b; Vaerewijck *et al.*, 2005).

A number of emerging and re-emerging diseases have been recognised. The Mycobacterium Avium Complex (MAC), for example, are bacteria living in biofilms of water distribution systems and shower heads. MAC organisms pose a specific and significant threat to highly immune-compromised individuals. They have been identified as the third most common opportunistic infection causing death in HIV-infected individuals (Bonnet *et al.*, 2005).

Cholera is also re-emerging in Africa. The devastating effects of this disease are well known. For example, a total of 131 943 cases and 2 272 deaths were reported to the World Health Organization in 2005 with Africa accounting for 58% of the global total (WHO, 2006). In more recent outbreaks in Angola, 82 204 cases and 3 092 deaths were reported in May 2007. In Zimbabwe, 88 834 cases were reported by 7 March 2009 (WHO, 2009; Mintz and Guerrant, 2009).

In 2009, the African region accounted for over 90% of the total cases of cholera reported to the World Health Organization (WHO, 2007a).

Chemical contaminants

Industrial, agricultural and medical improvements have introduced many "new" chemicals from the petrochemical and pharmaceutical industries into our environment (UNDP). These chemicals enter the environment through, for example, pesticide applications, as by-products of industrial processes and as household waste such as cleansers and pharmaceuticals. Knowledge of the prevalence, distribution, and ultimate fate of many of these compounds and their breakdown products is limited and these substances "persist to a greater extent than initially anticipated" (UNDP). These substances can be grouped into endocrine disrupters and pharmaceutical/personal care products.

Socio-economic enhancement and human health

Human activities affect water quality. In turn, the quality of water has an impact on human health and livelihoods. The Millennium Development Goals encompass the provision of safe and secure water to people around the globe, as well as the sustainable use of water resources (UNDP).

Internationally, the interdependencies between the health of ecosystems, the water they provide, and the health and well-being of humans are recognised, especially as expanding human populations, and changing weather patterns place enormous pressures on our natural environment (UNEP, 2006).

Improved health levels decrease morbidity and mortality. Healthy people are more productive, which is a fundamental requirement for skills development and wealth creation.

SOUTH AFRICA'S INTERNATIONAL OBLIGATIONS
– *LEGAL AND ETHICAL ISSUES* INGA JACOBS

Sharing a critical and strategic resource requires strong and robust institutions, sound legislation, and implementation of suitable legislation to ensure harmony and alignment between states.

The strategic and shared nature of water is pervasive throughout southern Africa. South Africa shares six river basins and at least seven aquifer systems with six neighbouring countries. Rivers form the international borders between South Africa and Namibia, Botswana and Zimbabwe, while Swaziland and Mozambique are situated downstream of South Africa (Figure 6).

A large proportion of the South African population, as well as industrial, mining, power generation and agricultural activities, are dependent on water from the four main shared rivers: the Incomati, Maputo, Orange-Senqu and Limpopo (Turton and Ashton, 2008). These basins are considered to be reaching closure, which implies that all available and utilisable water from these basins has already been allocated for use, leaving little water for allocation to new developments (Svendsen *et al.*, 2001).

Sharing a critical and strategic resource requires strong and robust institutions, as well as sound legislation to ensure harmony and alignment between states. But, more importantly, it requires effective implementation of jurisdiction. South Africa's international obligations regarding water quantity and quality management are influenced by a hierarchical framework of environmental legislation, spanning from the national to the international level (Figure 7):

- **National level:** The Constitution of the Republic of South Africa (Act No.108 of 1996) constitutes the supreme law of the country and guarantees the rights of all people in South Africa. Additionally, an environmental legislation framework exists that includes the National Environmental Management Act (No.107 of 1998), which was principally promulgated to enact Sections 24 (environmental rights) and 41 (containing provisions on co-operative governance) of the Constitution. Secondly, in terms of sectoral environmental legislation, the National Water Act (No.36 of 1998); and the Water Services Act (No.108 of 1997); supported by the Strategic Framework for Water Services (2003); Water Services Regulations; and the National Water Resources Strategy are the most prominent examples.
- **Regional level:** The SADC Regional Strategic Action Plan for Water Resource Management and the 2000 SADC Revised Protocol on Shared Watercourses of SADC provides the regional perspective.

FIGURE 6: Potential boundaries of conflict, with transboundary aquifer types indicated in red, yellow and brown.

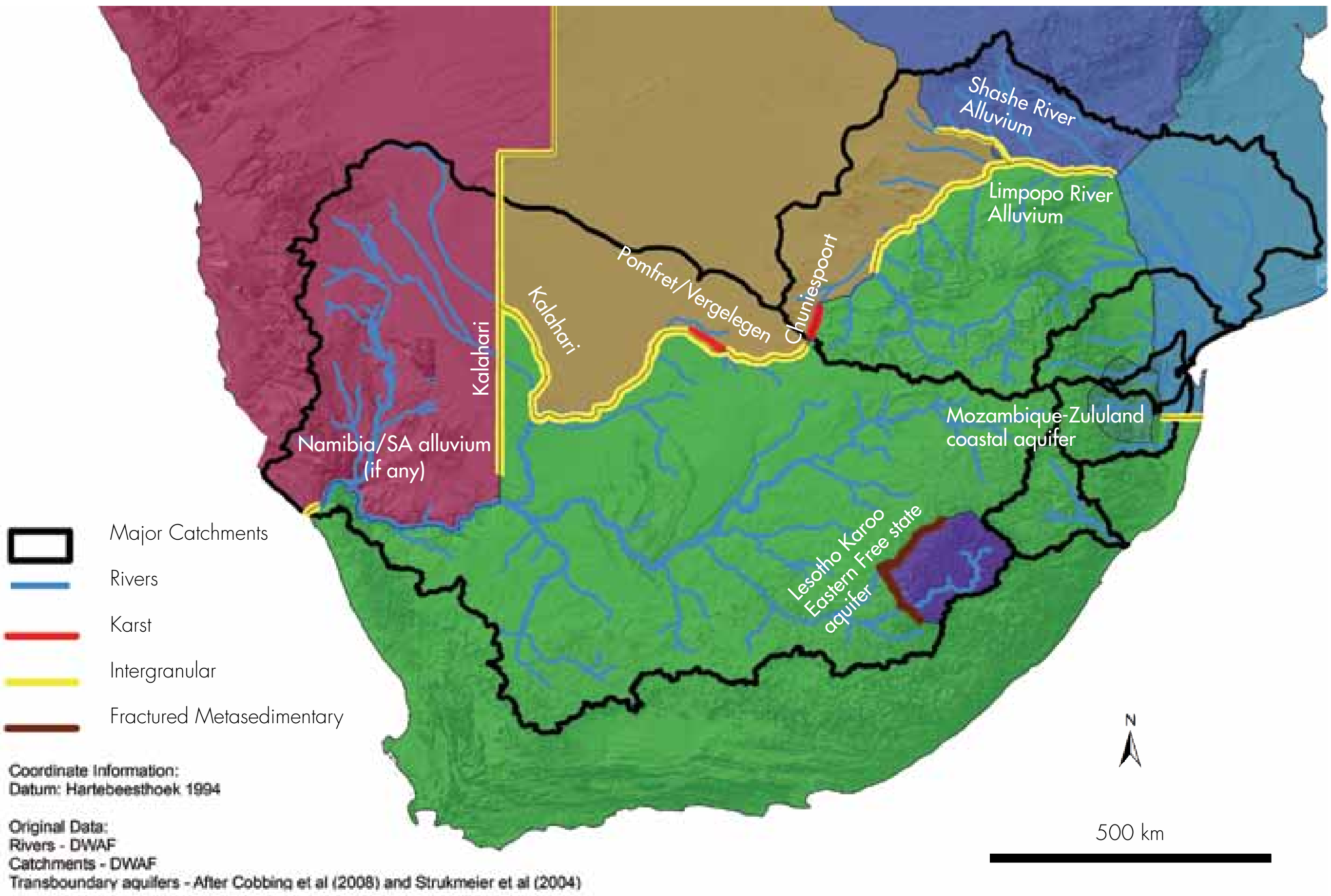
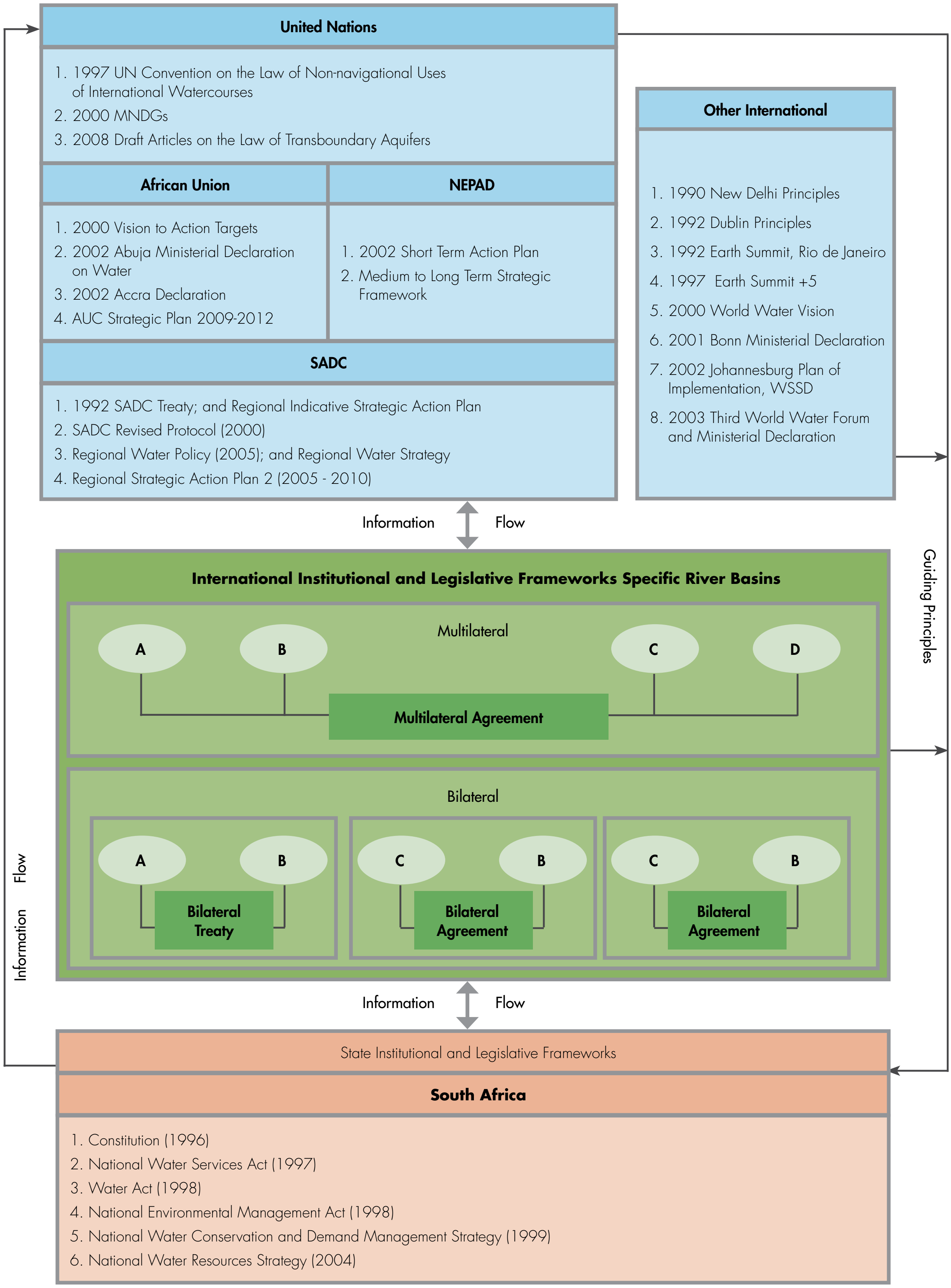


FIGURE 7: Hierarchical framework of environmental legislation (water quality and quantity)



The latter contains general principles such as equitable and reasonable utilisation as well as the obligation not to cause significant harm to co-riparian states (Article 3); as well as specific provisions including planned measures (information exchange, notification and consultation); environmental protection and preservation (control of pollution); management of shared watercourses; prevention and mitigation of harmful conditions; and emergencies. The Regional Water Policy (2005) and the Regional Water Strategy give greater specification to these principles.

- International level: Reflected in South Africa's legal commitment to and recognition of Agenda 21; the 1997 UN Convention on the Non-navigational Uses of International Watercourses; 1990 New Delhi Principles; 1992 Dublin Principles; 1992 Earth Summit, Rio de Janeiro; 1997 Earth Summit + 5; 2000 World Water Vision; 2001 Bonn Ministerial Declaration; 2002 Johannesburg Plan of Implementation, WSSD; 2000 Vision to Action Targets; 2002 Abuja Ministerial Declaration on Water; 2002 Accra Declaration; 2003 Third World Water Forum and Ministerial Declaration.

Since 1910 South Africa has entered into 101 international water-related treaties and agreements. Sixty-one treaties and agreements deal with shared water resources, while 25 specifically concern South Africa's shared river systems (Kistin *et al.*, 2009).

International obligations

The 1997 UN Convention on the Non-navigational Uses of International Watercourses is the only international treaty governing shared freshwater resources that is universally applicable (McCaffrey, 2001a,b). Although not yet in force, it offers much value as a guiding framework because it shows which countries have committed themselves in theory to the principles of transboundary cooperation, such as equitable and reasonable utilisation and no harm. The UN Convention has also been influential in the negotiation of international agreements and in the review of existing agreements such as the Revised SADC Protocol. The Convention was passed by the UN General Assembly on 21 May 1976 by a 103 vote with three against (Eckstein, 2002; Thompson, 2006; United Nations, 1997a). South Africa has both signed and ratified the Convention. South Africa and Namibia are the only African countries to have done so (UNEP, 2002). The UN Convention will, however, only enter into force and become legally binding after 35 states have ratified it (as such it requires an additional 15 ratifications).

The principle of "equitable and reasonable utilisation" is a cornerstone of international water law and is enshrined in the International Labour Organization's (ILO) Helsinki Rules of 1966 and in the UN Convention and the Revised Water Protocol (SADC, 2000).

In their need to be globally applicable, international freshwater agreements are often silent on water allocation specification (Kistin *et al.*, 2009). This is left up to regional, basin and national legal frameworks to provide greater context-specific detail.

Regional trends in water allocation and water quality

Agreements relevant to South Africa where water allocation is mentioned include:

- The 2002 Tripartite Interim Agreement (Tripartite Interim Agreement, 2002), which establishes a comprehensive flow regime for the Incomati and Maputo Rivers (Kistin *et al.*, 2009);
- The 1989 Memorandum of Understanding (MOU) signed between South Africa and Botswana (MOU, 1989), which divides the waters of the Limpopo River (forming the border between the two states) equally (estimated at roughly 116.67 Mm^3 per state, per year) (Kistin *et al.*, 2009); and
- The Treaty on the Development and Utilisation of the Water Resources of the Komati River Basin between Swaziland and South Africa, March 1992 (the Komati River Treaty), also provides for water allocations.

With these exceptions, most of South Africa's freshwater agreements are project-related and were established before South Africa's transition to democracy in 1994.

TABLE 1: A summary of allocation agreements and their specifications by transboundary river basin

Basin	Year	Water Allocation Specifications
Incomati	1991	South Africa is required to release 2 m^3/s averaged over a cycle of 3 days
	1992	Swaziland: 15.1 Mm^3 at High Assurance; 260.2 Mm^3 at Low Assurance; 46 Mm^3 for afforestation South Africa: 157.8 Mm^3 at High Assurance; 381.0 Mm^3 at Low Assurance; 99 Mm^3 for afforestation
	2002	South Africa: 336.6 Mm^3/year (First priority supplies); 786 Mm^3/year (irrigation supplies); 475 Mm^3/year (Afforestation) Swaziland: 22 Mm^3/year (First priority supplies); 261 Mm^3/year (irrigation supplies); 46 Mm^3/year (Afforestation) Mozambique: 19 Mm^3/year—with up to 87.6 Mm^3/year reserved (First priority supplies); 280 Mm^3/year (irrigation supplies); 25 Mm^3/year (Afforestation)
Maputo	1980	South Africa is required to supply 5 cusecs (142 ℓ/s) of water from the Pongolopoort Dam to Swaziland for irrigation and rural use at Lavumisa, in addition to the construction of storage reservoir near Lavumisa. One cusec (28 ℓ/s) is used by the Swaziland Water Services Corporation to provide municipal water services to Lavumisa town. The other 4 cusecs (114 ℓ/s) were made available for economic development.
	2002	South Africa: 242 Mm^3/year (First priority supplies); 532 Mm^3/year (Irrigation supplies); 198 million Mm^3/year (Afforestation) Swaziland: 44 Mm^3/year (First priority supplies); 413 Mm^3/year (class 1), 114 (class 2) (irrigation supplies); 82 Mm^3/year (Afforestation) Mozambique: 6.0 Mm^3/year – with up to 87.6 Mm^3/year reserved (First priority supplies); 60 Mm^3/year (Irrigation supplies); 0 Mm^3/year (Afforestation)
Orange-Senqu	1986	Annex 2 of the Treaty on the Lesotho Highlands Water Project specifies the amount of water to be delivered annually from Lesotho to South Africa between 1995 and 2020. South Africa: from 57 Mm^3/year in 1995 to 2 208 Mm^3/year after 2020. Lesotho: hydropower and capital payment from project
	1992	20 Mm^3/year is allocated for the Vioolsdrift and Noordoewer Joint Irrigation Scheme, with 11 Mm^3/year designated for farmers on the South Africa side and 9 Mm^3/year for those in Namibia
Limpopo	1988	Department of Water Affairs (Republic of Bophuthatswana): 5.0 Mm^3/year (primary purposes); 20.6 Mm^3/year Water Utilities Corporation (Botswana): 7.3 Mm^3/year (primary purposes) Department of Water Affairs (South Africa): 10.6 Mm^3/year (irrigation)
	1989	Flows in the Ngotwane, Marico and Limpopo rivers where they constitute the border shall be shared equally between states with an estimated quantity of roughly 116.67 Mm^3/year for Botswana and South Africa

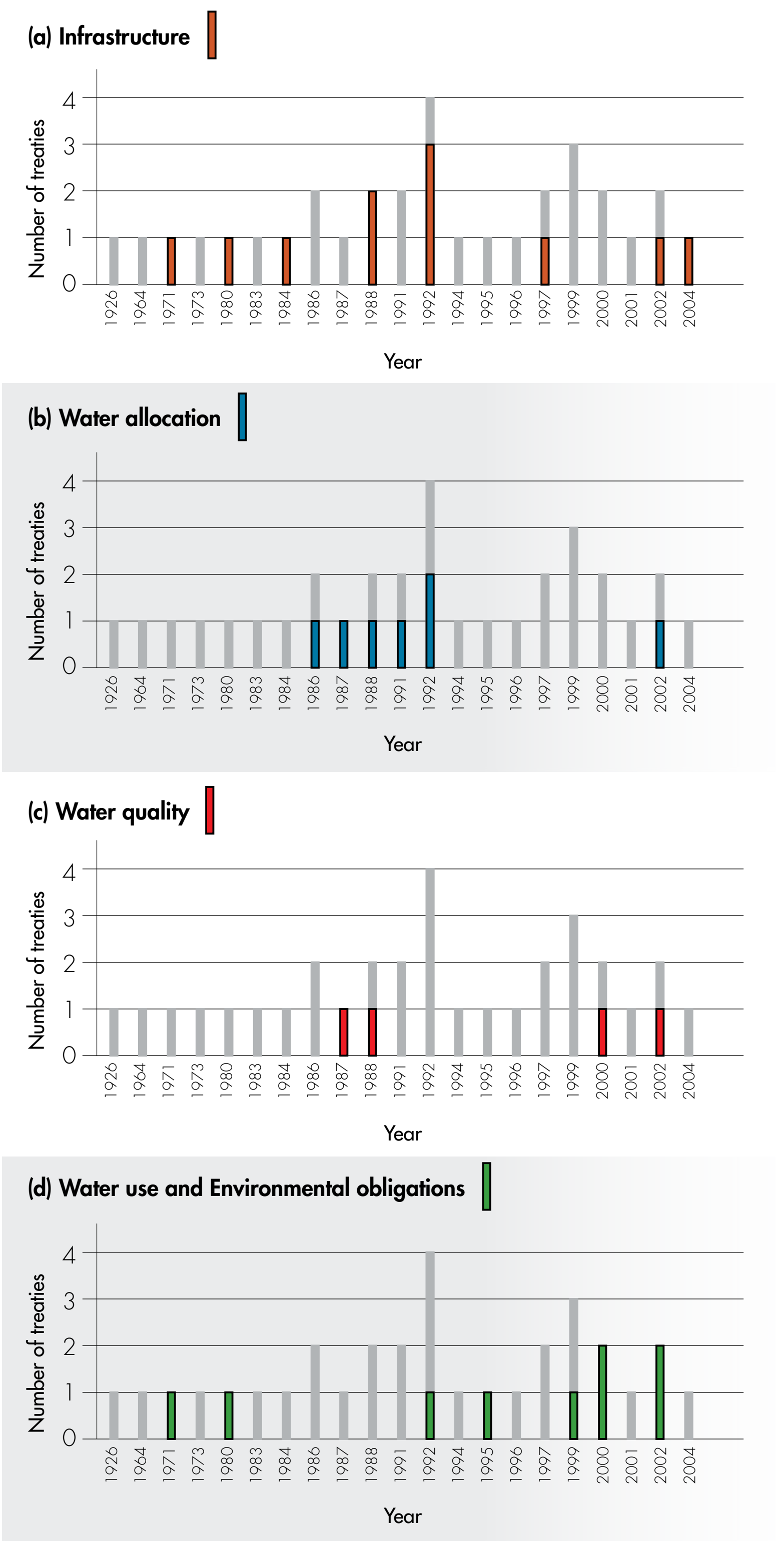
More than thirty bilateral and multilateral agreements signed between South Africa and neighbouring states (Kistin *et al.*, 2009) have given priority to supply-driven infrastructure with more specific provisions made in this area, and with constant representation over time (from the 1970s to 2000s). Provisions for water quality are particularly under-represented, with only four agreements making mention of water quality from 1987 to 2004 (Figure 8).

Additionally, there is a global shift in focus away from water allocation to resource management and protection which is also reflected in global and continent-wide trends over the past few decades (Lautze and Giordano, 2007). This trend is reflected in South African agreements, which have seen an increase in provisions that make specific mention of water use and environmental obligations. In developed countries, this trend has been attributed to increased water and economic development and evolving views of environmental values (Lautze and Giordano, 2007). In developing countries, a similar trend has been attributed to being the product of external influences such as donor institutions and international NGOs (Kistin *et al.*, 2009). Another justification lies in power asymmetries that characterise basins where powerful countries secure a desirable quantity of water (either through previous allocation treaties or prior use) and are seldom willing to reopen this debate (Zeitoun and Warner, 2006).

Management strategies and allocations may however require adjustment based on climatic, demographic and socio-economic changes in the affected river basins (Nkomo and Van der Zaag, 2004; Dlamini *et al.*, 2007). The potential need for adjusting water allocations in response to changes in water availability, demand or technology, can for example be found in the treaty establishing the Lesotho Highlands Water Project (LHWP, 1986a). It includes a delivery schedule designed to increase gradually in parallel with successive phases of the project and is subject to modification based on South Africa's level of demand (Kistin *et al.*, 2009).

Other agreements, such as the Vioolsdrift/Noordoewer Joint Irrigation Scheme (VNJIS, 1992), provide water managers with no specific guidelines for adjusting the specified allocations to each country over time (Kistin *et al.*, 2009). Instead, it leaves the issue to the two bilateral institutions — the Joint Irrigation Authority (JIA) and the Permanent Water Commission (PWC) — for investigation, negotiation and recommendation to parties (Kistin and Ashton, 2008).

FIGURE 8: Agreements signed between South Africa and neighbouring states that contain provisions on: *Infrastructure, Water allocation, Water quality and Water use and Environmental obligations*



As previously noted, specific provisions regarding water quality are not often mentioned in agreements, despite their contentious nature. However, two exceptions, which do make reference to the impacts of poor water quality on allocations, are the Lesotho Highlands Water Project (LHWP, 1986a) and the project agreement on water transfer from South Africa to Botswana (South Africa-Botswana, 1988; Kistin *et al.*, 2009).

The 1988 Agreement relating to the supply of water from the Molatedi Dam on the Marico River, between South Africa and Botswana, specified that the delivery of poor quality water would be treated as the delivery of no water at all (South Africa-Botswana, 1988; Kistin *et al.*, 2009). As concerns about water quality and ecological health increase, SADC Member states have started to investigate and legislate in-stream flow requirements (Kistin *et al.*, 2009). That said, however, the Tripartite Interim Agreement (Tripartite Interim Agreement, 2002), which establishes a comprehensive flow regime for the Incomati and Maputo Rivers, is the only multilateral international agreement in southern Africa that formalises a specific environmental requirement at the basin level and, as such, is considered to be a benchmark for inter-state water quality standards.

South Africa's international obligations as reflected in national legislation

The 1998 National Water Act stipulates that "meeting international obligations" is one of its primary purposes (South Africa, Government of, 1998) and that "international rights and obligations" must be provided for in the National Water Resources Strategy (DWAF, 2004a). In terms of water allocation it provides generalised licensing requirements regarding water abstractions and waste disposal into water bodies. Specifically, it subjects all licensing to pre-grant scrutiny and to post-grant monitoring in order to protect the water resource, and stipulates that international obligations must be met in preparing water allocation schedules for abstraction licensing (DWAF, 2004a). With regard to water quality, international obligations must be considered in issuing authorisations and licences for abstraction, and for waste disposal purposes (DWAF, 2004a). Additionally, international obligations take precedence in times of shortage, and licences can be adjusted downwards as a result (DWAF, 2004a).

These considerations of international obligations as reflected in South Africa's National Water Act are instrumental in facilitating inter-state cooperative management of water sharing schemes and water pollution control programmes agreed under the bilateral and trilateral agreements South Africa has entered into with its neighbours. This legislative and institutional infrastructure ensures compliance with regional obligations.

CLIMATE CHANGE AND WATER

EMMA ARCHER

Climate change is likely to have an effect on water supply, water quality, agriculture, biodiversity and poor communities.

Water supply and quality

Different sub-regions of South Africa have shown, and are likely to continue to show, distinct climate changes. Scientists agree that by 2050 the coast is likely to warm around 1°C and the interior around 3°C (DEA, 2010). By 2100, the temperature increase is likely to approach 3°C on the coast and 5°C in the northern interior. While rainfall intensity is likely to increase, it does not necessarily indicate an increase in total rainfall.

Any projected increases in rainfall may be offset by projected future increased temperature and evapotranspiration. More extreme run-off is possible if rainfall intensity increases. Further, projected warming and lower flows may result in compromised water quality, which may lead to increased cost of water treatment and further risks to human health (DEA, 2010).

Agriculture

The increase in temperature and changes in the timing, amount and frequency of rainfall may have severe effects on all agricultural systems in South Africa (DEA, 2010).

Increasing evaporation and reduced water availability is likely to compromise dry land and irrigated agriculture in terms of water supply and water quality. While there might be some positive effects of higher temperatures, such as a reduction in frost incidence, these are not well quantified – and should comprise a focus of further work.

Livestock farming will be affected in terms of greater stock water requirements and livestock heat stress (Archer and Tadross 2008). The link between rainfall, land use and degradation is important in rangelands, since climate change can modify the magnitude of desertification processes and the frequency with which thresholds are exceeded. Climate change may accentuate potential desertification due to overgrazing (Archer and Tadross 2009).

The impacts of climate change on pests and disease vectors are poorly known, and require future consideration due to their important implications and adaptation potential. Climate change may also trigger new and emerging infection epidemics and environmental toxins. This is even more significant in the light of pests and pathogens affecting key agricultural industries and forestry.

Lastly, the potential benefits of rising atmospheric carbon dioxide (CO_2) on crop and rangeland production are still poorly understood in the South African context.

Biodiversity

Significant implications of climate change for biodiversity are projected in the winter rainfall biomes, the Fynbos and Succulent Karoo (DEA, 2010). The integrated stresses of climate change, wildfire frequency and alien invasive species, as well as land use and habitat transformation, may make the sector increasingly vulnerable to climate change over time.

Poverty and climate change

Poverty is the determining factor for vulnerability to climate change. Settlement populations with an existing high exposure to extreme events and a poorly developed infrastructure, coupled with a high disease burden, are especially vulnerable to the impact of climate change.

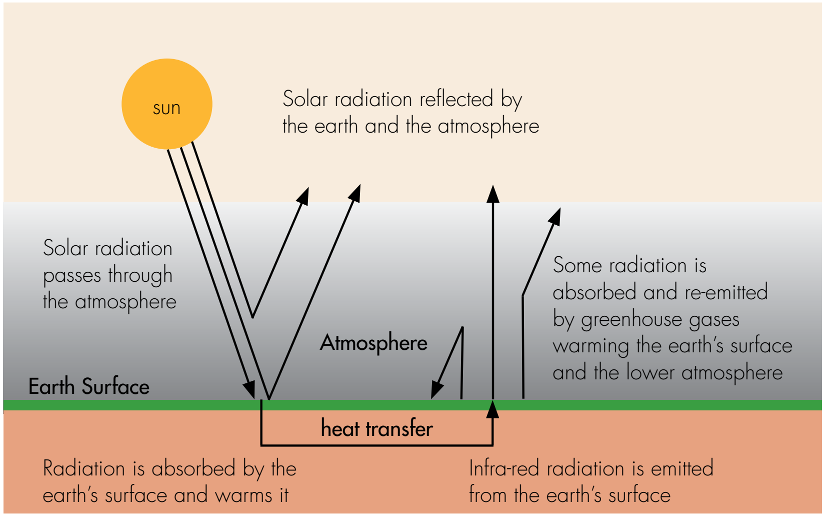
Climate change impacts may make agriculture and other land uses such as agro-forestry increasingly unfeasible as a livelihood strategy for the rural poor. This will be particularly important in developing policy and strategy for emerging farmers in the agriculture sector.

The projected climate change impacts are likely to complicate the efforts of land reform beneficiaries and the emerging agricultural sector in rangelands. Strategies and policies supporting this sector should integrate such considerations (DEA, 2010).

FIGURE 9: What is causing climate change?

Similar to the manner in which heat is trapped in a greenhouse, greenhouse gasses trap the longer-wave heat (infrared) radiation reflected from the earth's surface. This trapped radiation warms the earth's atmosphere and heat is re-radiated to the earth surface. This effect is explained in the diagram on the right.

Diagram adapted from IPCC (1990). Climate change: The IPCC Scientific Assessment. Houghton, Jenkins, and Ephraums, eds. Cambridge, UK, Cambridge University Press, pp. xiv.



Poverty is the determining factor for vulnerability to climate change.

Adapting to climate change

Adaptive responses are ways for extending current efforts to respond to present climate risk, and as supporting strategic efforts to adapt to longer-term but more gradual climatic changes. Selected adaptive responses (DEA, 2010) include:

- Water: Strategic adaptations to longer-term climate changes include enhanced water storage capacity and increased water supply for the water sector, as well as improved catchment management (e.g., removal of invasive alien species).
- Healthcare: Adequate and reasonable healthcare delivery services that satisfy all aspects of South Africa's complex health requirements. Interventions in vulnerable communities should focus on reducing the risk of water-borne diseases, exposure to indoor pollution and supporting existing public health infrastructure and planning.
- Agriculture and agro-forestry: Improved management practices should include a move to intensive yet environmentally sustainable livestock production, sustainable rangeland production and forestry practices, more efficient water use, carbon sequestration and reduction in greenhouse gas emissions.
- Forestry: Targeted response to potentially increased fire risk, as well as specific programmes to match possible shifts in suitable growth areas.
- Biodiversity: A range of adaptation responses are available within the biodiversity sector, including the establishment of partnerships to enable effective management of areas not under formal protection, as well as using climate change as one of a range of objectives in expanding the formal protected area network.

A "multiple benefits approach" in responding to climate change

To sum up, South Africa has existing vulnerabilities that may exacerbate the effects of climate change in many sectors, and compromise effective responses if inappropriately managed.

A "multiple benefits approach", simultaneously addressing a range of objectives such as adopting to climate change; carbon sequestration and the mitigation of greenhouse gas emissions; conservation of biodiversity and sustainable livelihoods should guide strategy, with particular attention paid to cross-sectoral strategies (DEA, 2010).

Modelling climate change

Key groups in South Africa involved in atmospheric modelling and climate change modelling include the Climate System Analysis Group (CSAG) at the University of Cape Town, the University of Pretoria, climate variability-oriented work at the South African Weather Service (SAWS), and the emerging work of the CSIR Atmospheric Modelling Focus.

Climate change data was traditionally available at quite a coarse spatial resolution, not necessarily as useful to decision makers as it could be. Downscaling, undertaken at the universities of Cape Town and Pretoria, SAWS and the CSIR, provides climate change scenarios at improved spatial resolution. Such information may be accessed through CSAG's spatial portal (www.csag.uct.ac.za); and through the Risk and Vulnerability Atlas website (www.rvatlas.org).

Understanding the impact of climate change on the cultivation of rooibos

Climate change scientists have been working in the Suid Bokkeveld in partnership with small-scale rooibos farmers and key civil society initiatives to investigate the potential impacts of climate change on rooibos cultivation; and to consider actions that might create an enabling environment for improved adaptation to climate change.

The team found that certain climate parameters currently of concern to rooibos farmers may worsen under climate change. Using an action research approach, the team focused on empowering farmers in the research and adaptation support process, including participatory monitoring and analysis, as well as regular "climate preparedness" meetings with farmers. Of interest in the work is its early emphasis on linking adaptation strategies to what is currently being done by small-scale farmers to manage climate variability, and by its emphasis on "multiple benefits strategies" (Archer *et al.*, 2008).

SUSTAINABLE WATER ECOSYSTEMS

JEANNE NEL

South Africa's geography and climate is complex, with a diverse range of ecosystems and associated biodiversity with high levels of endemism.

South Africa is a semi-arid country, characterised by an uneven, poorly predictable and highly seasonal rainfall, while potential evapotranspiration rates exceed rainfall in most parts of the country. The availability of water is one of the most limiting factors affecting future social and economic growth in South Africa. The country has almost exhausted its use of available surface water, and is running out of suitable sites for new dams (Turton and Ashton, 2008; DWAF, 2009a).

As with many developing countries, water demand is likely to increase with improved wealth of the nation, and one estimate puts the water deficit at 1.7% by 2025 (DWAF, 2004a), with many catchments facing severe water stress. Compounding this current situation, climate change models predict changes to both rainfall and temperature in southern Africa, which may reduce available water in some regions (DWAF, 2009a).

Key pressures on freshwater ecosystems

Five of the six key global threats to freshwater biodiversity (Dudgeon *et al.*, 2006) are pertinent to South Africa, namely flow modification; water pollution; destruction or degradation of habitat; invasion by exotic species and climate change. South Africa is a prime example of the phenomenon that flow modification tends to be most pronounced in regions of variable flow (Dudgeon *et al.*, 2006).

Most large rivers are heavily utilised and regulated to improve water security, with 70% of the total annual runoff being stored in dams across the country, and many water transfer schemes bring water to areas where demands exceed the natural supply. The cumulative effect of small farm dams on the quality and quantity of waters in South African rivers (Mantel *et al.*, 2010) threatens the sustainability and longevity of large dams within the associated catchments (Foster *et al.*, 2009).

Water pollution is a growing problem in South Africa, especially as failing water treatment infrastructure battles to cope with the increasing domestic and industrial effluent from towns and cities. Pollution from irrigated agriculture return flows and acid mine drainage are also major problems, exacerbated by decreased dilution capacities and the destruction of the filtering system provided by healthy riparian zones.

Destruction or degradation of habitat include both direct (e.g., bulldozing and planting in channels) and indirect modification (e.g., catchment clearing resulting in increased sediment loads and erosion). Wetland ecosystems have been particularly hard hit: in agricultural areas they have been dammed or drained for cultivation, and in the more urban areas they are frequently completely transformed by infrastructure development (Snaddon *et al.*, 2008).

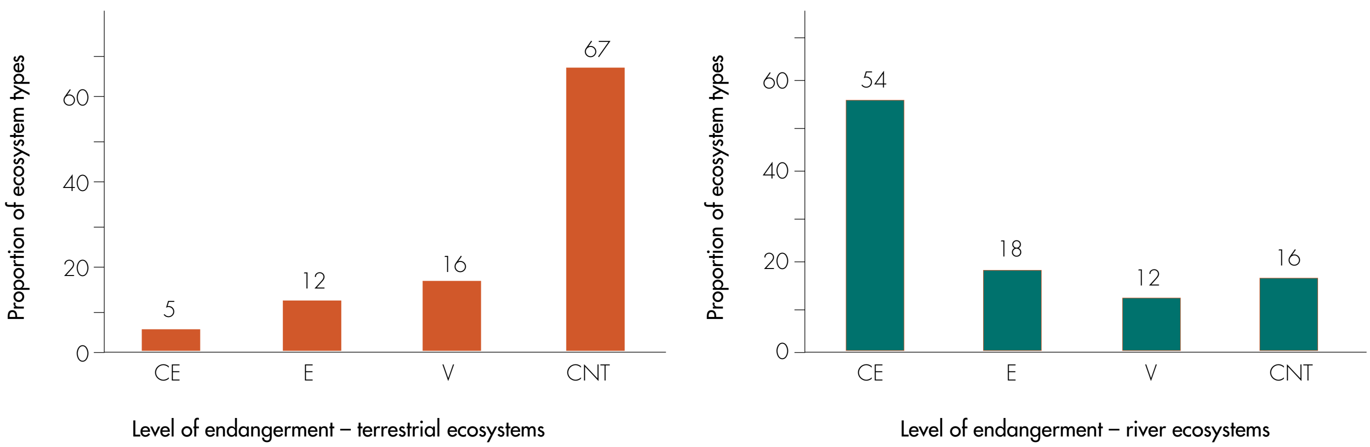
Alien invasive fish are widespread in most large rivers and their presence has caused local extinctions of indigenous species. Alien invasive plant species have a substantial impact on water yield, consuming an estimated 6.7% of the total annual runoff, and are also associated with the loss of invertebrates such as dragonflies.

Predicted impacts on and adaptations to climate change also threaten freshwater ecosystems. Changes in rainfall and temperature are likely to influence the survival of sensitive species. Adaptation responses to climate change are also likely to result in increased water-engineering responses to reduce flood and drought frequency.

Conservation status

The combination of these threats and socio-economic trends holds crucial implications for the conservation of South Africa's freshwater ecosystems and their associated biodiversity features. In a global context, seven of

FIGURE 10: Comparative levels of endangerment for terrestrial and river ecosystems



Comparative levels of endangerment for (a) terrestrial and (b) river ecosystems in South Africa, where CE = critically endangered; E = endangered; V = vulnerable and CNT = currently not threatened. Proportion of ecosystems is expressed as a percentage of the total number of ecosystems in each endangerment category. Total number of terrestrial and river ecosystem types is 438 and 112, respectively.

the 93 African eco-regions (Thieme *et al.*, 2007) occur in SA, and all of these eco-regions are threatened.

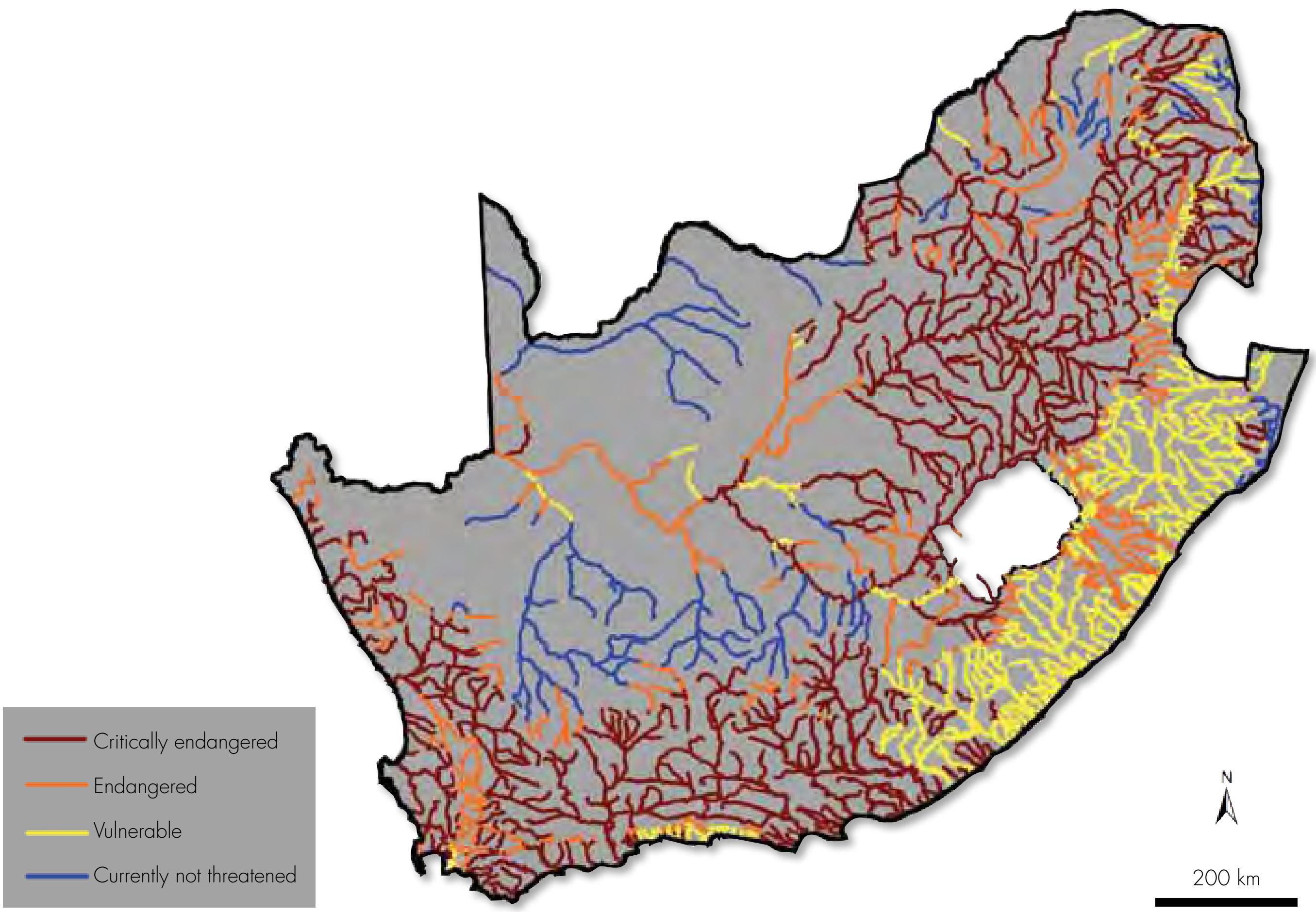
At a finer level of resolution, a recent conservation assessment revealed that the state of ecosystems associated with large rivers in South Africa is dire, far worse than for terrestrial ecosystems (Figure 10): 84% of the 112 unique river ecosystem types assessed were threatened, with a disturbing 54% critically endangered, 18% endangered and 12% vulnerable (Figure 11). A similar country-wide assessment of estuary ecosystem types found that 77% are threatened and 23% are critically endangered. The overall picture is less dramatic than for river ecosystems, but worse than for terrestrial ecosystems.

A country-wide assessment of estuary ecosystem types found that 77% are threatened and 23% are critically endangered.

High levels of threat are also documented for freshwater fauna: an estimated 31% of freshwater fish indigenous to South Africa are threatened (Skelton *et al.*, 1995). A recent southern African study on the conservation status of major freshwater-dependent taxonomic groups (fishes, molluscs, dragonflies, crabs and vascular plants) reported far higher levels of threat in South Africa than in the rest of the region (Darwal *et al.*, 2009).

South Africa's system of protected areas leaves significant gaps in conserving freshwater ecosystems, and less than 15% of the river ecosystems assessed are moderately to well represented within protected areas. Moreover, inclusion in protected areas does not guarantee conservation: almost half of the large river systems that are incorporated into protected areas have been degraded by upstream human activities before entering the protected area. Despite these deficiencies in protection levels, rivers inside protected areas are in a better condition than those outside. This emphasises the positive effect that protected areas can have through appropriate land management strategies.

FIGURE 11: Conservation status of South Africa's freshwater ecosystems



Protecting freshwater ecosystems

Improving the way in which protected areas are designated and managed in the future will help to conserve freshwater biodiversity. This would include:

- Represent freshwater biodiversity within protected areas;
- Avoid the use of rivers as boundaries of protected areas;
- Maximise hydrological connectivity; and
- Use alternative management strategies in combination with existing protected areas to protect rivers before they enter the protected area.

The CSIR has recently incorporated these principles into the spatial component of South Africa's National Protected Area Expansion Strategy (NPAES) for the Department of Environmental Affairs. The strategy provides a common set of targets and spatial priorities to guide efforts and strengthen coordination among the many role players involved in expanding and consolidating South Africa's protected area network.

Another initiative, the National Freshwater Ecosystem Priority Areas (NFEPA) project, responds to the reported global degradation of freshwater ecosystems. It uses systematic conservation planning to identify priorities for conserving South Africa's freshwater biodiversity, within the constraints of equitable social and economic development.

The project has three inter-related components:

- A technical component aimed at identifying a national network of freshwater ecosystem priority areas, using systematic conservation planning;
- A national governance component aimed at aligning different conservation policy mechanisms and tools; and
- A sub-national governance and management component that aims to demonstrate how outcomes can influence land- and water-resource decision making in a number of case studies.

So far, work has focused on the technical component, developing criteria and assembling data sets to identify priority areas. Key national spatial input data developed include: a river layer classifying the river ecosystem types across the country along with their ecological condition, proposed planning units, wetland delineations and ecosystem types, free-flowing rivers, high water yield areas, and fish sanctuaries for all threatened freshwater fish indigenous to South Africa.

Three of the 19 Water Management Areas (the Inkomati, Breede-Overberg and Crocodile (West) and Marico) have been selected as case studies. These will be used to test concepts and illustrate how the products can be used to encourage equitable and sustainable allocation of water at a catchment level.

The results of this project are directly applicable to the National Water Act and the National Environmental Management: Biodiversity Act, and will be packaged so that they can inform key policy processes that form part of a comprehensive approach to the sustainable development of South Africa's scarce water resources.

Lastly, the National Environmental Management: Biodiversity Act allows for the listing of threatened ecosystems that must be reviewed every five years. The purpose of listing threatened ecosystems is primarily to reduce the rate of ecosystem loss and species extinction, preventing further degradation and loss of structure, function and composition of these ecosystems. This enables or facilitates proactive management of these ecosystems.

The CSIR is currently working with the Department of Environmental Affairs, the Department of Water Affairs and the South African National Biodiversity Institute to develop criteria for *Listing of Threatened River Ecosystems* and translating these criteria into spatially explicit identification of ecosystems. The results will be packaged for the process of public comment and signing off by the Minister of Water and Environmental Affairs.

ESTUARIES ARE INVALUABLE TO COASTAL DEVELOPMENT AND BIODIVERSITY

LARA VAN NIEKERK AND SUSAN TALJAARD

The 290 estuaries along the 3 000 kilometers of South Africa's coastline represent most of the sheltered marine habitat along the coast, playing an essential role in ecosystem functioning and biodiversity conservation. These environments are also focus areas for coastal development. However, inappropriate development poses serious threats to these sensitive systems and requires proper planning and management (Van Niekerk and Turpie, 2011).

TABLE 2: Summary of the goods and services estuaries provide

Category	Goods and Services	Examples of opportunities and activities
Ecological	Biological control	Maintaining the balance and diversity of plants and animals
	Refugia/Migratory Corridors	Fish and crustacean nurseries and roost for migratory birds
	Sediment supply	Creation and maintenance of beaches, sand bars and sand banks
	Erosion control	Estuary vegetation prevents soil loss, reeds and mangroves capture soil
	Soil formation	Accumulation of sediment and organic material on floodplains and in mangroves
	Nutrient supply and cycling	Nutrient supply, nitrogen fixation and nutrient cycling through food chains
	Genetic Resources	Genes for mariculture, ornamental species and fibre
	Disturbance regulation	Flood control, drought recovery and refuges from natural and human induced catastrophic events, such as oil spills
Subsistence	Food	Line fishing, inter-tidal collecting, beach and seine netting
	Raw material	Harvesting of craftwork and house-building materials
Recreational and Tourism	Nature appreciation	Providing access to estuaries and associated wildlife for viewing and walking
	Scenic views	Resorts, residential houses, housing complexes and offices with scenic views
	Culture	Aesthetic, educational, research, spiritual, intrinsic and scientific values
	Sports fishing	Estuary flyfishing, estuary and inshore conventional fishing
	Water sports	Water sports: swimming, sailing, canoeing, skiing and kayaking
Commercial and Industrial	Waste treatment	Breaking down of waste and detoxifying pollution
	Water supply and regulation	Water supply to marine environment and water for mariculture
	Mariculture	Production (natural and cultivated) of fish, crustaceans and worms
	Food production	Fishing
	Raw material	Diamond and titanium mining
	Transport services	Ports, harbours, marinas and skiboat launching sites

Socio-economic value

Estuary ecosystems provide ecological, subsistence, recreational or commercial goods and services, for example (Van Niekerk and Taljaard, 2004; Costanza *et al.*, 1997; Mander, 2001; Mander *et al.*, 2001):

- The estimated subsistence value of estuaries range between zero and R800 000 per estuary, with an average of R70 000 per annum (Turpie and Clark, 2007; Clark *et al.*, 2002);
- The majority of estuaries have a nursery value in the range of R100 000 to R10 million per annum as they contribute to marine fishery production by providing nursery areas for commercially or recreationally valuable species (Lamberth and Turpie, 2003); and
- Most of the estuaries also have a tourism value of between R10 000 and R1 million per annum; and an estimated property value, based on willingness to pay, ranging from R1 million to R2 billion per estuary.

Further, society is willing to pay in monetary terms for existence value – the sense of satisfaction that people feel for knowing that estuaries exist. Based on mainly the scenic beauty and biodiversity importance of South African estuaries, the overall willingness to pay has been suggested as R90 million (Turpie and Clark, 2007).

Biodiversity importance

Estuaries provide important nursery areas for a number of marine species (Whitfield, 1998). South Africa's intertidal estuarine areas are very important over-wintering habitats for many migrant bird species. Should these habitats be severely degraded or destroyed, a drastic reduction in the numbers of these fish and bird species could occur which could contribute to their eventual extinction. In the longer term, sea level rise due to global warming could eliminate many intertidal areas, particularly estuarine habitats, as these become constricted between the rising water level and existing developments and structures (Van Niekerk and Turpie, 2011; Clark *et al.*, 2002).

The *South Africa Outlook* (DEA, 2006) reported that there is little information on the status of estuarine species, a serious gap in the overall conservation database. However, existing knowledge, albeit limited, already confirm large biological diversity in our estuaries, spanning three biogeographical zones, namely the cold temperate (west coast), warm temperate (south coast) and subtropical (east coast) zones. Loss of this biodiversity is already reflected in four South African estuarine fish species listed on the IUCN Red Data List as critically endangered, namely the doublesash butterflyfish *(Chaetodon marleyi)*; Knysna seahorse *(Hippocampus capensis)*; St Lucia mullet *(Liza luciae)*; and estuarine pipefish *(Sygnathus watermeyeri)* due to human pressures.

Three of South Africa's estuaries: the Klein Brak (top), Mthatha (middle) and the Buffalo River estuary (bottom).

ESTUARIES ARE INVALUABLE TO COASTAL DEVELOPMENT AND BIODIVERSITY continued…

Status of our estuaries

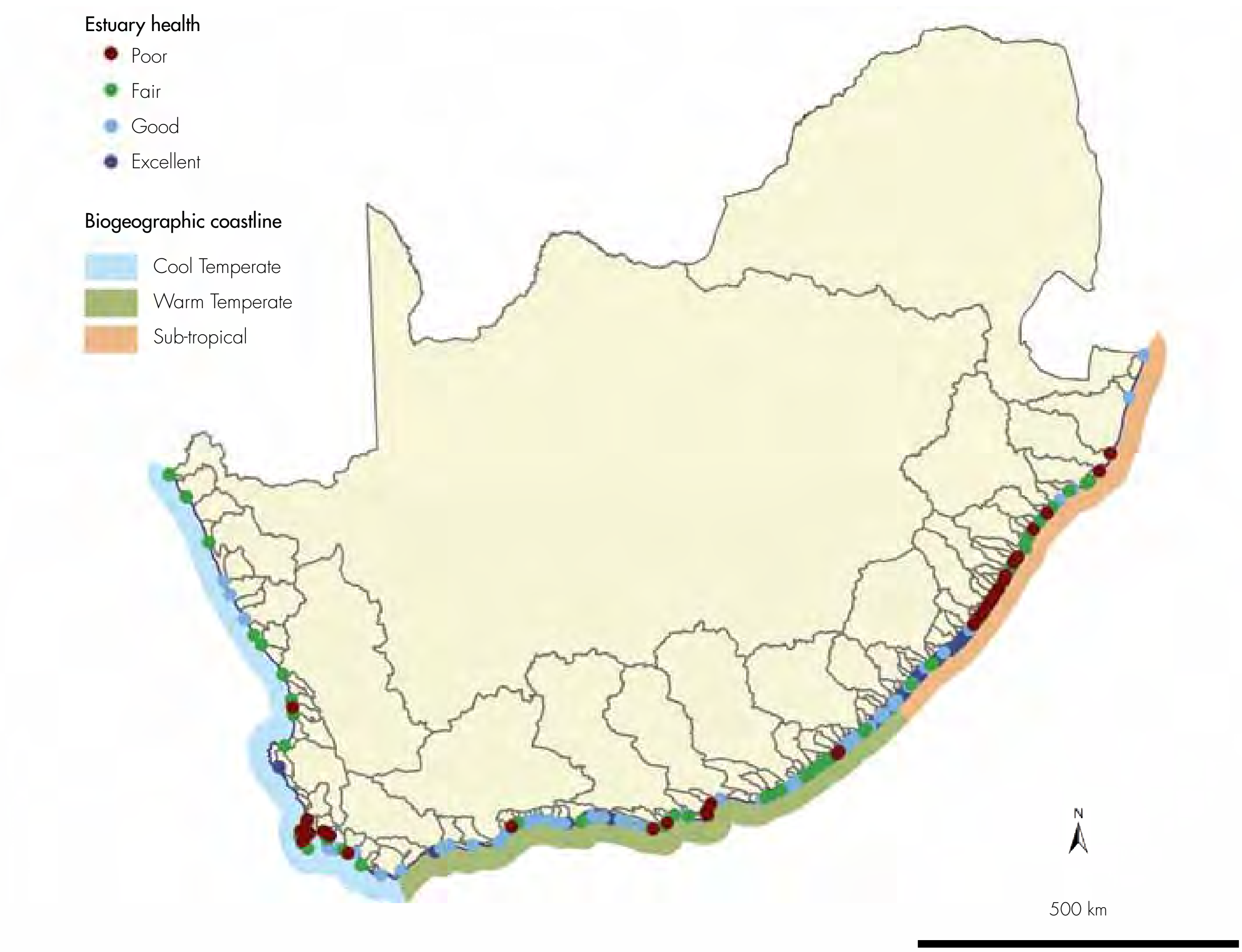
International biodiversity obligations require South Africa to report on our ecosystem status every five years. A national health assessment was undertaken to assess the status of South African estuaries, updating the previous national biodiversity assessment conducted in 2004 (Turpie, 2004; DEAT, 2008; Van Niekerk and Turpie, 2011).

The recent assessment revealed that, while a large number of South African estuaries are still in an "excellent" or "good" condition, these are mainly the very small systems. Our larger systems, which comprise most of the estuarine area in the country and are the most important nursery grounds, are predominantly in a "fair" or "poor" condition – considered to be one of the reasons for the slow stock recovery of our line fish species (Figure 12).

The severe deterioration in the health of estuaries close to urban areas is mostly related to habitat destruction, artificial breaching and pollution. Estuaries in rural areas suffer mainly from reduction in freshwater inflows and pollution from agriculture activities. Here nutrient input from catchments cause excessive weed growth or phytoplankton blooms in estuaries. This is particularly evident during low flow periods (dry seasons) when the river water containing high concentrations of nutrients (for example, due to irrigation return flows) have longer residence times within the estuaries. Overexploitation of living resources is especially significant in the large permanently open systems and estuarine bays and lakes which in a number of systems severally compromised their nursery function.

The most pristine estuaries in the country occur along the Wild Coast with their most pressing threat caused by increased turbidity and sedimentation from severely degraded catchments.

FIGURE 12: The health status of South African estuaries



Mitigating the impact

Government's primary response in mitigating the deterioration of South Africa's estuaries is manifested in two pieces of legislation, namely the National Water Act (No. 36 of 1998) (NWA) and the National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICMA).

The NWA recognises the right to water for aquatic ecosystems, second to the right to water for basic human needs. As part of the country's Water Resource Management Strategy, a standard approach for determining the water requirements of aquatic ecosystems, including estuaries, has been developed. While the method has been used to determine the ecological water requirements from a number of estuaries rolled out to all our estuaries, effective implementation of the strategy remains a major challenge.

The CMA focuses on the planning and management aspects and requires the establishment of a national estuarine management protocol, as well as individual estuarine management plans for South Africa. Because our country's estuaries have a diverse range of management requirements, often unique to individual systems, a flexible, but legally defensible protocol is required to guide the development of local, site-specific management plans. While a draft national protocol has been proposed, this still needs to be officially adopted by government (Van Niekerk and Taljaard, 2003). In terms of local estuarine management planning, government in collaboration with the CAPE (Cape Action Plan for the Environment and the People) Regional Estuarine Management Programme, developed a generic framework for local estuarine management planning (Van Niekerk and Taljaard, 2007; Taljaard and Van Niekerk, 2009).

This framework is currently being pilot tested in selected estuaries, exploring appropriate avenues to integrate these estuarine resource plans into broader management programmes such as integrative development plans, water resource plans and biodiversity conservation plans.

Threats to estuaries

Inappropriate coastal development poses a serious threat to the goods and services provided by estuaries (Van Niekerk and Taljaard, 2004; Turpie *et al.*, 2002; Breen and McKenzie, 2001; Boyd *et al.*, 2000; Morant and Quinn, 1999; Smith and Cullinan, 2000; Glazewski, 2000; Prochazka and Griffiths, 2000).

These threats are typically categorised into:

- Land use and infrastructure development (e.g. low-lying developments, bridges and mining);
- Water quantity and quality (e.g. water abstraction, contaminated stormwater and agricultural runoff and sewage disposal); and
- Over-exploitation of living resources (e.g. overfishing and poaching).

The fragmentation and lack of coordination of management responsibilities among national, provincial and local government agencies is a fundamental obstacle in the effective management of activities and developments that affect estuaries. This is further fuelled by inadequate knowledge of estuarine functioning and a lack of political will to enforce legislation.

Socio-economic issues that contribute to problems encountered in estuaries include the migration to coastal areas due to rising unemployment and poverty, the externalisation of costs incurred through inappropriate development, for example low-lying developments in floodplains, stakeholder fatigue and conflicting interests of the different interest groups.

Rapidly increasing coastal development and growing water demand, remain major threats to estuaries in future, particularly along the KZN and the south and south-western Cape coasts where demands on water supplies are growing rapidly (Van Niekerk and Turpie, 2011).

WATER INFRASTRUCTURE FOR HUMAN AND ECONOMIC DEVELOPMENT

KEVIN WALL

South Africa is rightly proud of the water services infrastructure rolled out since 1994, and the increasing proportion of the population that now has access to infrastructure that permits first-hand experience of "water is life, sanitation is dignity". However, many challenges remain.

"Water problems in South Africa are symptomatic of an emerging gap between national policies and implementation of such policies. For instance, recently the reliability and quality of water supply by municipalities has been receiving attention, with some experts warning that South Africa has serious challenges. Some of these challenges include a lack of qualified staff and insufficient investments in water infrastructure for both capital and maintenance. The drive to achieve universal access for water and sanitation is compounding the challenge" (Financial and Fiscal Commission, 2009).

Water services

Water services infrastructure supports quality of life and the economy if it delivers accessible and reliable services that individuals and institutions need. An accessible and reliable water service, such as sanitation, requires infrastructure that is effectively operated and maintained.

Responsibility for the treatment and distribution of water and sanitation is allocated to the statutory water services authorities (municipalities or groupings thereof) and the water boards. Arrangements differ from place to place. For example, where the water boards are responsible for water and wastewater treatment, the water services authorities are responsible for water supply storage and distribution.

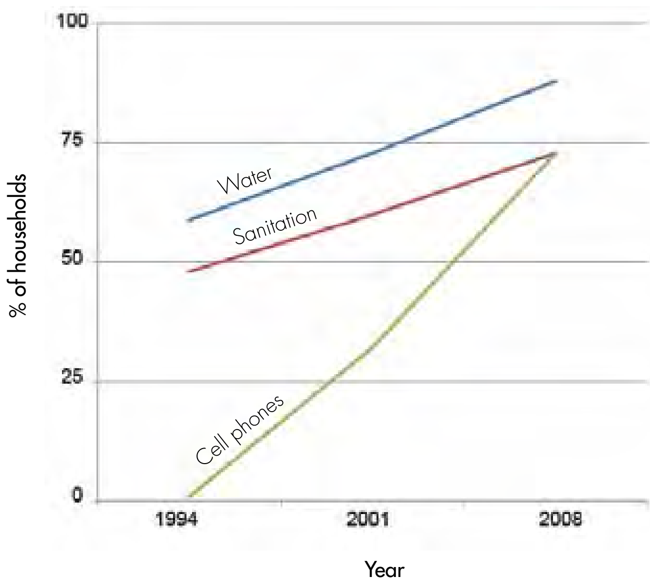
History and backlogs

In 1994, the democratically-elected government evaluated the imbalance in infrastructure that characterised the nation, and embarked on an ambitious plan to put matters right by addressing the backlog. Since then the government has invested significantly in providing water to 17 million people. Other infrastructure provided at the same time, such as sanitation and road infrastructure, has further improved the quality of life of South Africans. Government remains committed to increasing levels of infrastructure investment at national, provincial and local government level as a foundation for service delivery, economic growth and social development.

Almost 60% of the South African population of 39 million in 1994 had access to basic levels of water service. Since then, basic service levels were raised to 88% of the estimated population of 48.7 million in 2008. This implies that 5.7 million people are still lacking access to safe water in South Africa.

Access to basic sanitation services increased from 48% in 1994 to 73% in 2008 (DWAF, 2009a). However, the biggest constraints to addressing expectations for new infrastructure in terms of government's own stated targets are the capacity (skills and finance) to operate and maintain the infrastructure to be built.

FIGURE 13: Percentage of households with access to water, sanitation and cell phones. Source: Department of Water Affairs.



Investment

The estimated current replacement cost of municipal water services capital stock is R169 billion (R103 billion for water and R66 billion for sanitation) (National Treasury and World Bank, 2009) of a total municipal infrastructure stock with a current replacement value of R685 billion. The estimated current replacement value of the 15 water boards' infrastructure was R60 billion in 2006 (CSIR and CIDB, 2006).

Much of this infrastructure is not in a fit state to continue delivering high quality and reliable water services. Without proper operation and maintenance the infrastructure service will not be sustainable.

Despite the widely held belief that water service "backlogs" consist mostly of serving the previously unserviced South Africans, other needs far surpass these, namely:

- Rehabilitation or replacement of neglected infrastructure; and
- Provision of infrastructure for population growth and new household formation due to the gradual reduction in average household size, immigrants from beyond our borders, and migration within South Africa (National Treasury and World Bank, 2009).

The largest proportion of previously unserviced people lives in small towns and rural areas. In metros and larger towns, the bigger problem is growth and rehabilitation or replacement of infrastructure.

WATER INFRASTRUCTURE FOR HUMAN AND ECONOMIC DEVELOPMENT continued…

It is estimated that the capital requirements to address infrastructure backlogs for the previously unserviced comprise 17% of total infrastructure requirements. Infrastructure for growth and migration will require 34%, and rehabilitation or replacement of neglected infrastructure a staggering 49% (National Treasury and World Bank, 2009).

The challenge is to supplement current infrastructure to address the backlogs from the past, while at the same time also focusing on the maintenance of both new and old infrastructure, and upgrading or replacing infrastructure that is in disrepair, overloaded or obsolescent.

Sustainable and free basic service

The Municipal Systems Act requires municipalities to ensure the delivery of sustainable services. Despite the payment to municipalities by national government of equitable share and other transfers, many municipalities are in practice unable to cover the costs of the services that they are obliged to provide.

Compounding this difficulty is the requirement to provide a free basic quantity of service to indigent households – the cost of which should be covered from equitable share and from cross-subsidy by the municipality's customers who can pay for that service. Insufficient covering of cost results in an unsustainable service with the inevitable decline in quality and reliability of the service. The reason for insufficient covering of the cost is one or a combination of the following:

- There are not enough customers who can pay;
- Customers that should pay, do not; and
- Customers who are eligible for the free basic service take more than their allocation, and do not pay for the additional amount.

People who do not have access to piped water services are not benefiting from the free basic water policy. Therefore, until government physically brings about universal access to piped water – extremely difficult if not impossible – the policy will not assist many of the poorest people, those whom it was most intended to help.

Service delivery

The "delivery" of infrastructure does not end with the commissioning of the infrastructure asset. Once the infrastructure has been constructed, various operation and maintenance activities must be carried out regularly to ensure that it continues to perform, such as the allocation of necessary budgets and the employment of staff to run the service for the whole design life of the asset (CSIR and CIDB, 2006; DWAF, 2005).

All spheres of government face the challenge of operating and maintaining infrastructure, although to varying extents. Some public sector institutions maintain their infrastructure at a high standard. Budgets are adequate (even if barely so), skilled staff are in place, leadership is committed, and policies support sound infrastructure maintenance practices. Other institutions have lagged behind, but the risks of this are recognised, and in some instances maintenance needs are being addressed by targeted programmes.

Wastewater treatment works are of particular concern. Other sectors of concern include water treatment works, water and sewer reticulation, and on-site sanitation. Ultimately, unless maintenance is improved in these sectors, funds to address the cost of repairs and unplanned replacements (as opposed to planned, preventative measures) will have to be found from capital budgets, which will severely limit the programme for expanding service delivery.

From an accrual accounting perspective, there is no real saving in reducing maintenance budgets, because the resulting reduction in asset values is invariably greater than the saving in maintenance. Furthermore, there are other significant costs associated with inadequate maintenance and consequent breakdowns – including loss of production – which can cause serious economic loss; in some cases health risks, injury or loss of life; and the cost of alternative emergency measures needed during breakdowns.

Despite its age, the 2006 infrastructure assessment "report card" by SAICE (SAICE, 2006) still gives a valid broad overview of the state of infrastructure. Water quality, for example, is excellent in the metropolitan areas, but water losses are sometimes high and it can be a problem to ensure a reliable supply at all times. In many rural areas, including small towns, both drinking water quality and waste water effluent quality are frequently below the standards laid down (SAICE, 2006; DWAF, 2006b; DWAF, 2009b).

Many health problems are the direct result of the collapse of existing sanitation systems and difficulties encountered in the siting of informal settlements and the provision and maintenance of essential services. In some areas short-sighted planning has resulted in bucket eradication schemes actually causing deterioration in service provision. For example, in some Free State settlements, replacement of bucket sanitation systems with waterborne systems left residents with no sanitation at all since the water supply was insufficient to flush their toilets. In other instances, the large increases in sewage inflow volume led to overloading of wastewater treatment works and pollution of downstream river systems.

The failure of many municipalities to deliver a reliable, sustainable service is mainly due to poor leadership, inadequate budgets, and inadequate skills and experience. Municipalities find it relatively easy to obtain funding from national government for capital expenditure. However, operational budgets for service delivery and funding to maintain the current infrastructure are often inadequate. Where municipalities have taken on additional infrastructure, they have seldom taken on the corresponding skills to manage it. Few if any municipalities have had an increase in technical staff from before the demarcation change in 2000, yet they are required to deliver, operate and maintain services over far larger areas than before, with population, and length of roads and pipes, having doubled or more – up to five times more in some instances.

The shortage of skilled staff is inhibiting sustainable service delivery. Specific issues include:

- High turnover of staff;
- Loss of skills and of institutional memory following the departure of experienced staff;
- Little or no career path planning and succession planning;
- Shortage of experienced supervisors and mentors;
- Loss of not only the most highly trained staff, but also of the middle order – in particular of those who had originally qualified as artisans, and who had worked their way up through the ranks to supervisor positions;
- Appointment of non-technical personnel to management positions requiring technical experience; and
- Shortage of trained and experienced engineering and financial staff in the job market.

Recommendations to address the issues affecting water services that most need attention are:

- Ensure municipal financial sustainability: Review the viability of municipalities and of measures for improving their revenue, including appropriate external financial support, and recovery of revenue due for service delivery;
- Prioritise strategic infrastructure: Introduce a regulatory requirement that municipalities must annually identify their key strategic infrastructure (for example water and wastewater treatment works, key arterial roads, etc.) and specifically budget for the adequate operation and maintenance of this strategic infrastructure – and report performance;
- Build up the skills base: Build capacity at every level in the infrastructure sector generally and in the water sector in particular. Not just in engineering skills, but in other key areas, particularly financial. Also, every effort must be made to impress on the two national departments of education the urgent need to overhaul mathematics and science education in secondary schools for learners to realise their full potential;
- Capacity audits and skills development: Carry out regular national audits of the available and required public and private sector capacity to operate and maintain municipal infrastructure – including

budgets, financial capacity, and prioritisation of resources, systems and equipment – to provide a base for structured interventions and ongoing monitoring. Develop strategies to promote the retention of skilled staff, recruitment of experienced people in key posts, and training and mentoring of staff who are inappropriately skilled, or are skilled but inexperienced. Capacitate political decision-makers so that they will be more knowledgeable of and sympathetic to the needs of infrastructure;

- Introduce new delivery models: Develop and promote alternative delivery models and delivery agents for infrastructure maintenance. These could include, for example, the outsourcing to the private sector of discrete tasks to be completed within specific contract periods; ongoing maintenance of infrastructure by public-public partnerships and public-private partnerships (including partnerships along franchising principles and community-based responsibility, for reward); and improvement of procurement models;
- Establish norms and standards and appropriate practice guidelines: Develop and promote appropriate practice guidelines and norms and standards for the maintenance of infrastructure – covering both financial and technical aspects. Ensure that levels of service and technology choice are determined by what is appropriate to the circumstances;
- Legislation enhancement and enforcement: Review and amend relevant national legislation, regulation and codes where necessary in order to more effectively guide municipalities to improved water services performance with appropriate budgets for sound infrastructure maintenance. Also enhance monitoring of its observance, and enhancing its enforcement;
- Conditional infrastructure investment: Develop mechanisms to make capital development loans and grants conditional on incorporation of budgets and other measures that will ensure adequate maintenance of future infrastructure;
- Link infrastructure capital and maintenance budgets: Create direct links between the capital budget and the operating budget of each municipality, to ensure that financial provision for maintenance is specifically linked to infrastructure management plans and to decisions on investment in capital infrastructure;
- Performance management: Develop and implement performance management measures, together with incentives for individuals (e.g. elected councillors, appointed officials, and contractors' representatives) who are responsible for making decisions with respect to the infrastructure in their care;
- Monitor and evaluate: Conduct ongoing monitoring and evaluation of the state of service delivery in terms of quality, reliability and addressing of backlogs, as well as of the physical state of municipal infrastructure – including the monitoring of headline performance indicators.

Status quo of sanitation service delivery in South Africa *Suzan Oelofse*

Social upliftment through economic growth is afforded a high priority by government. South Africa's Accelerated and Shared Growth Initiative (ASGISA) provides the political drive to halve unemployment and poverty by 2014, through a 4.5 to 6% growth in the Gross Domestic Product (GDP). However, the country is faced with failing sewage treatment systems and screaming newspaper headlines such as: "Next Crisis: Collapse of sewage system" (Munnik, 2008); or "Stinking state of SA's waters" (Laganparsad and Mthethwa, 2008).

Waste and wastewater management services, together with the way in which these services are rendered and maintained, lie at the heart of the pollution of water resources in many settlements (DWAF, 2001). Although untreated or polluted drinking water are a major contributor to diarrhea-related deaths and diseases, a significant portion is also related to pollution within densely populated, poorly serviced urban settlements (DWAF, 2003). An estimated 8.3% of households in South Africa still have no toilet facility or are using the bucket system (Stats SA, 2007).

In the order of 96% of micro-, small- and medium-sized wastewater treatment plants are not adequately operated and maintained (Snyman *et al.*, 2006). Municipalities are therefore faced with a number of challenges regarding the provision of complete and effective sanitation services. Inadequate disposal and use of sludge was found at 81% of the sewage plants surveyed (Snyman *et al.*, 2006). The sampled wastewater treatment works (WWTW) are indicated with red squares on the map on the right.

Any municipality with the executive authority for the provision of water services in terms of the Municipal Structures Act is a water services authority. The Strategic Framework for Water Services (DWAF, 2003) outlines the responsibilities of water services authority as:

- Ensuring access to water services;
- Preparation of water services development plans to ensure effective, efficient, affordable, economical and sustainable access to services;
- Regulating water services provision and water services providers within the area of jurisdiction; and
- Provision of water services, either by providing the services or by selecting, procuring and contracting with other service providers.

The spatial distribution of sanitation service delivery is illustrated on the map (Figure 14). A lack of authorisation combined with a lack of capacity is reflected in poor to no sanitation services and poor operation and maintenance of sewage treatment plants (Snyman *et al.*, 2006).

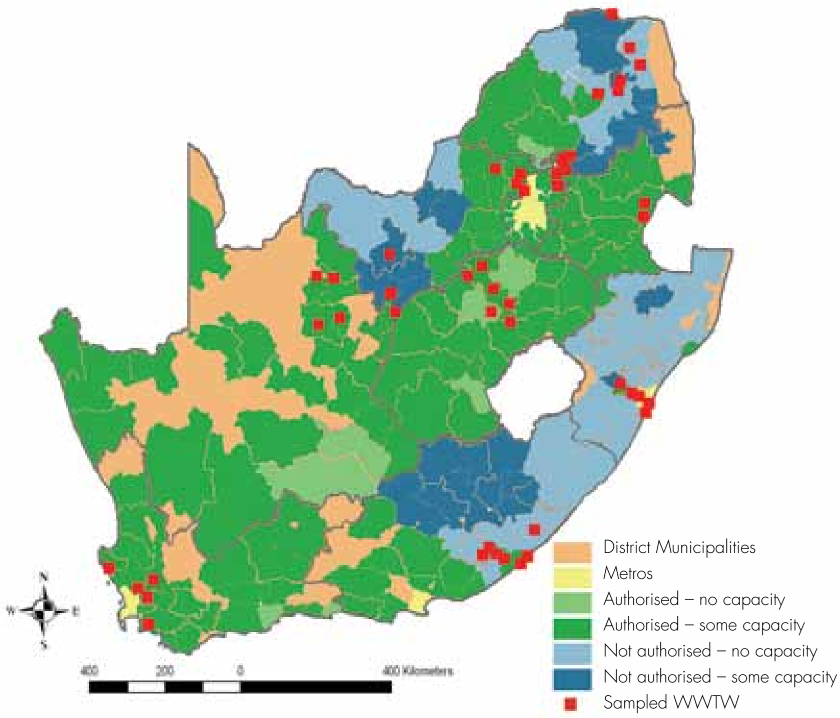
According to South African legislation (Republic of South Africa, 1996) sanitation services are the mandate of municipalities. However, there is an increasing trend of poor service delivery in this regard.

The 2007/2008 municipal capacity assessments showed that 37% of the 231 local municipalities had no capacity to perform their sanitation functions (Municipal Demarcation Board, 2008).

One of the key challenges faced by local municipalities in South Africa is therefore the need to find the most effective and efficient way of delivering adequate sanitation services to communities (Lorenz, 2003) within the local constraints. Numerous obstacles – such as budget restrictions, service backlogs and insufficient skills development – prevent local municipalities from providing services (DEAT, 2007).

Wastewater facilities that do not comply to existing licences should be prosecuted. The current high level of non-compliant municipal wastewater treatment facilities (Snyman *et al.*, 2006) is a case in point which may be viewed as leniency towards municipalities. In addition, the current situation has the potential to create dual standards in the management and operation of public and private facilities in South Africa.

FIGURE 14: Capacity of municipalities to provide waste water treatment services



WATER AND SUSTAINABLE MINING

PHIL HOBBS

Worldwide, the uncontrolled discharge of contaminated water from defunct mining operations represents the most pernicious threat to the receiving environment. It is widely accepted that acid mine drainage (AMD) is responsible for costly environmental and socio-economic impacts.

Whilst the gold mining sector in South Africa is now in decline, the current and planned exploitation of other mineral commodities, such as coal and platinum, show no sign of abatement. Witness to these circumstances is the Witwatersrand Goldfield on the one hand, and the Waterberg Coalfield (Limpopo), the Highveld Coalfield (Mpumalanga) and the Eastern Limb of the Bushveld Complex (platinum) on the other.

While the declining gold mining sector poses a severe strain on the environment in the form of AMD and attendant water quality impacts, the burgeoning coal and platinum mining sectors impose similarly severe consumptive demands on available water resources. These demands are exacerbated by those of the client or customer industries which, in the case of coal, are primarily power generation.

Worldwide, the uncontrolled discharge of contaminated water from defunct mining operations represents the most pernicious threat to the receiving environment (Banks *et al.*, 1997; Pulles *et al.*, 2005). AMD is responsible for costly environmental and socio-economic impacts. The *South Africa Environment Outlook Report* (DEAT, 2006) identifies acidification, a direct legacy of mining, as one of the water quality threats to the environment.

Despite significant progress being made in South Africa in shifting policy frameworks to address mine closure and mine water management, and the mining industry changing practices to conform to new legislation and regulations, the current situation still hosts vulnerabilities.

As early as 1987 the US Environmental Protection Agency recognised that "...problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk. The release to the environment of mining waste can result in profound, generally irreversible destruction of ecosystems" (EEB, 2000). The effect of mining on the environment includes the release of many chemical contaminants into water resources, environmental damage that can persist for a long time after mine closure, and the health and safety of nearby communities that are compromised. Apart from its impact on surface and groundwater resources, AMD is also responsible for the degradation of soil quality, aquatic habitats and for allowing heavy metals to seep into the environment (Adler and Rascher, 2007).

Persistence is an exacerbating characteristic of AMD. According to the European Environmental Bureau (EEB, 2000) this pollution is so persistent that, in the absence of available remedies, in many instances the contaminated sites may never be completely restored.

Current challenges

Acid mine water started to decant from defunct flooded underground mine workings near Krugersdorp on the West Rand (Gauteng Province) in August 2002. Subsequent media reports have focused attention on this phenomenon with headlines such as "Cradle's Heritage status in danger" (Bega, 2008), "Tide of toxic water poses health risk" (Jordan, 2009), and "Rising tides of AMD" (Naidoo, 2009). An article in the *Mail and Guardian* (Fourie 2005-04-12) has accused scientists, mining companies and government of reluctance to discuss the mine water decant and its impact publicly, stating "…and yet it is the start of a problem of such magnitude that it will affect our environment and health for decades to come". Other areas that have received media attention for similar reasons are Randfontein and the Wonderfontein Spruit (also from gold mining), and the Loskop Dam and Olifants River in Mpumalanga Province from coal mining.

The potential volume of AMD for the Witwatersrand Goldfield alone amounts to an estimated 350 Mℓ/day. This represents 10% of the potable water supplied daily by Rand Water at a cost of R3/kℓ (R3 000/Mℓ) to municipal authorities for urban distribution in Gauteng and surrounding areas. These figures place not only the volume but also the potential economic value of mine water in perspective. It is against this background that the Western Utilities Corporation (WUC) has initiated the fast-tracking of a mine water treatment plant (Naidoo, 2009) that will produce some 60 Mℓ/day of industrial grade "process" water and 15 Mℓ/day of potable water.

FIGURE 15: Mining areas and minerals particularly susceptible to the formation of AMD
Source: Hobbs and Kennedy, 2011.

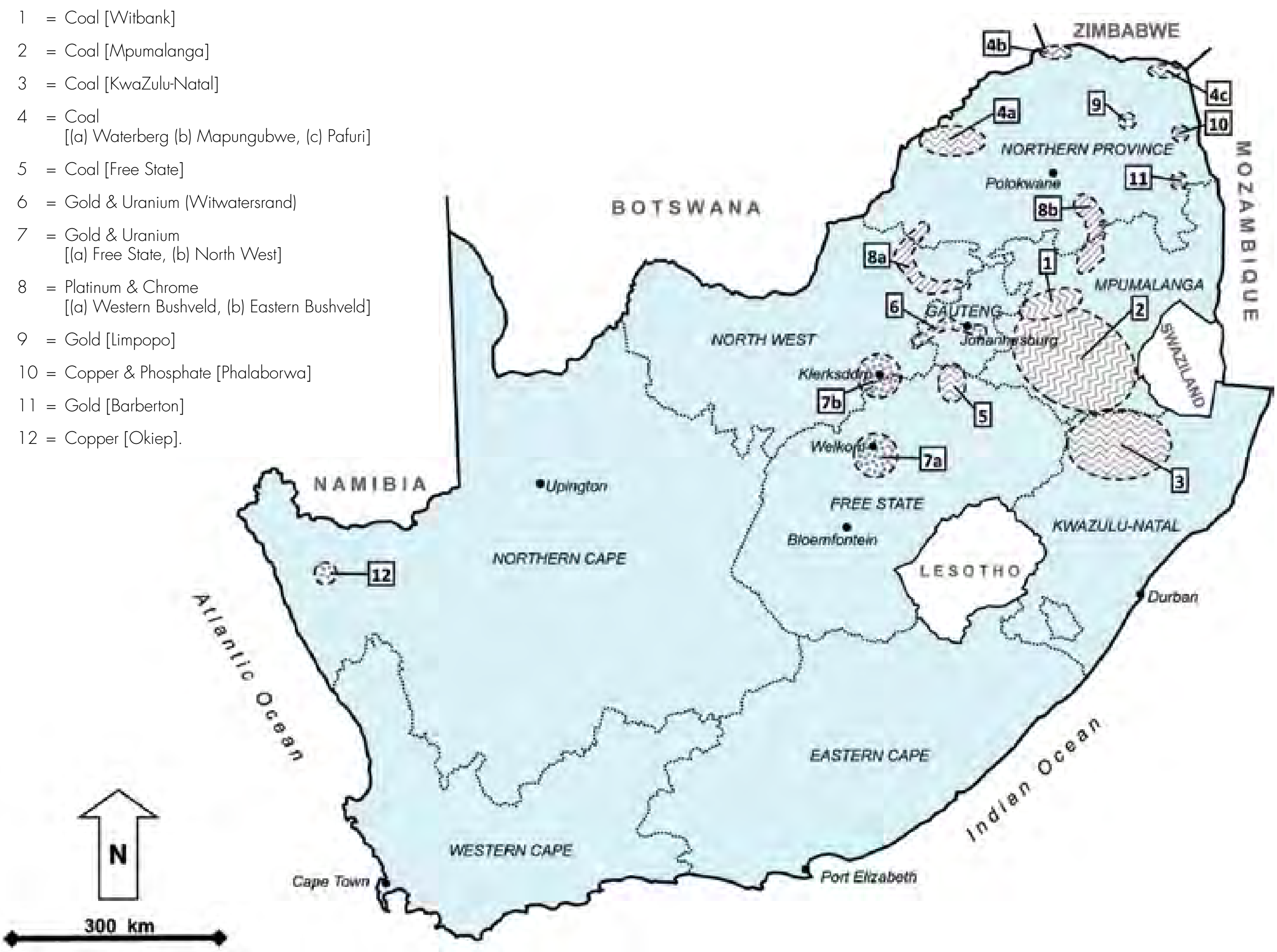


TABLE 3: Tabulated listing of characteristics and variables that describe the main mining areas susceptible to AMD (see map Figure 15) Source: Hobbs and Kennedy, 2011.

ASPECT		MINING AREA															
		Witbank	Mpumalanga	KwaZulu-Natal	Waterberg	Mapungubwe	Pafuri	Free State	Witwatersrand[(a)]	Free State	North West	Western Bushveld	Eastern Bushveld	Limpopo (Giyani)	Phalaborwa	Barberton	Okiep
BASIC CHARACTERISTICS																	
No. on Figure 15		1	2	3	4a	4b	4c	5	6	7a	7b	8a	8b	9	10	11	12
Major mineral(s) mined		Coal							Gold & Uranium			Platinum & Chrome		Gold	Copper & Phosphate	Gold	Copper
Age of mining (y)		>100	>30	>100	20	0	>20	>50	>120	>50	>50	40	<20	>20	60	>110	>100
Activity status		Active + New	Active + New	Closed	Active + New	Proposed New	Active	Active + New	Active + Closed	Active	Active	Active	Active	Active + Closed	Active	Active + Closed	Active
Remaining lifespan[(1)] (y)		25-30	40-50	10	200	>10	<10	15-20	5-50	20	20	50	50-100	20	15	<20	<50
Mine type[(2)]		OC + shallow UG	OC + shallow UG	Mainly UG	Mainly UG	OC + UG	UG	Mainly UG	Mainly UG	UG	UG	UG	UG	UG + artisinal	OC + UG	UG + artisinal	UG
DIAGNOSTIC VARIABLES																	
Conditions (wet/moist)		Very wet	Very wet	Wet	Moist	Moist	Moist	Wet	Very wet	Wet	Wet	Moist	Moist	Wet	Moist	Wet	Moist
Basic chemistry	pH	<4	<4	<5	<5	<6	<7	<6	<4	<4	<4	<7	<7	<5	<7	<5	<4
	TDS (g/L)	>4	>4	<4	<2	<2	<2	<4	>5	>4	>4	<2	<2	<2	<2	>4	<4
	Radioactivity[(3)]	1	1	1	2	1	1	1	3	2	2	1	1	1	1	1	0
	"Problem" elements	Al, Cd, Co, Cu, Fe, Hg, Mn, Pb, SO_4, Zn		Al, Cu, Fe, Mn, SO_4, Zn	Al, Fe, Mn, U, Zn	Al, Fe, Mn	Al, Fe, Mn, Ni	Al, Cu, Fe, Mn, SO_4, Zn	Al, Cu, Fe, Hg, Mn, Th, U, SO_4, Zn	Al, Cu, Fe, Hg, Mn, Th, U, Zn	Al, Cu, Fe, Hg, Mn, Th, U, Zn	Al, Cd, Cr, Fe, Ni, Mn, SO_4, V, Zn	Al, Cd, Cr, Fe, Ni, Mn, SO_4, V, Zn	Al, As, Cu, Cd, Fe, Hg, Mn, SO_4, Sb, Zn	Al, Cu, Fe, Hf, Mn, PO4, SO_4, Th, U, Zn	Al, As, Cu, Cd, Fe, Hg, Mn, SO_4, Zn	Al, Cd, Cu, Mn, Ni, Sr, Zn,
Water availability for mining		Yes	Yes	n/a In closure	Limited	Limited	Limited	Yes	Yes	Yes	Yes	Limited	Highly limited	Highly limited	Limited	Limited	Limited
Mine water treatment infrastructure required		Moderate	High	Moderate	Moderate	Low	Low	Low	High	Moderate	Moderate	Low	Low	Moderate	Low	Moderate	Low
Volume of mine water to be treated		High	High	Moderate	Low	Low	Low	Moderate	High to very high	Moderate	Moderate	Low	Low	Low	Low	Low	Low
Current aquatic environmental state[(4)]		−1 D	−1 D	0	+1	0	0	0	−1 D	−1	−1	0 D	0 D	0	0	−1	0
Environmental impact[(b)] if status quo maintained		Severe	Severe	Moderate	Potentially severe	Potentially moderate	Light	Moderate	Potentially very severe	Moderate	Moderate	Light	Light to moderate	Moderate	Light to moderate	Moderate to severe	Light
Priority for water supply/ ecosystems		Very high	High	Moderate	High	Moderate	Low	Moderate	Very high	Moderate	Moderate	Low	Low	Low	Very low	Moderate	Low

NOTES

(1) Estimated

(2) OC = opencast, UG = underground

(3) Associated with host rock/ore

(4) −1 = poor, 0 = neutral, +1 = pristine, D = declining trend

COMMENTS

(a) Comprises the Witwatersrand Basin, i.e. the Evander, East Rand, Central Rand, West Rand and Carletonville gold fields.

(b) Does not consider environmental aspects related to the atmosphere (e.g. acid rain, airborne dust), heritage, culture, etc.

Colour coding should be interpreted as follows: **Red** = Intervention certainly required in the short-term; **Orange** = Intervention probably required in the medium-term; **Yellow** = Intervention possibly required in the long-term.

This follows the example set by the Emalahleni Water Reclamation Plant at Emalahleni (Witbank) in Mpumalanga which treats 25 Mℓ/day of acid mine water generated by coal mining to a drinking water standard (Günther *et al.*, 2006). Although the principal beneficiary of the treated mine water is ostensibly the Emalahleni Local Municipality, it is arguably the receiving aquatic environment that benefits most, albeit incalculably, from the initiative (Hobbs *et al.*, 2008).

The post-closure decant from defunct coal mines in this region is estimated at ~62 Mℓ/day (DWAF, 2004c). In the order of 50 Mℓ/day of AMD discharges into the Olifants River Catchment (Maree *et al.*, 2004). Continuous management of large volumes of polluted mine water will therefore be necessary for decades to come.

Internationally, the European Commission's 5th Framework Research and Development project carried out by the ERMITE (Environmental Regulation of Mine waters In The European Union) Consortium attempt to develop guidelines (ERMITE Consortium, 2004a,b) aimed at understanding and dealing with mining impacts on the water environment within the context of catchment management strategies. This project has also to some extent dealt with the substantial gap in consistent information on how mining wastes are managed in different countries (Pulles *et al.*, 2005), at least within the European Union.

Locally, the defunct Chamber of Mines Research Organisation (COMRO) conducted studies on the impact of gold mining activities on the environment of the Witwatersrand. Most recently, the Department of Mineral and Energy Affairs commissioned the Council for Geoscience to develop a Regional Mine Closure Strategy (RMCS) for the gold mining industry. A set of RMCS documents for the various goldfields is currently under review.

How to manage the unavoidable

The threat of AMD to the environment will not be solved in the short- to medium-term. It is likely to persist for centuries to come. It is also not solved by a single intervention. It will require the integrated implementation of a range of measures such as:

- Active water treatment (as exemplified by the Emalahleni and proposed WUC plants);
- Passive water treatment systems (for example constructed wetlands);
- Prevention of water ingress into mine voids;
- Controlled placement of acid-generating mine waste;
- Prevention of AMD loss from flooded mine voids (for example with engineered barriers constructed in zones of preferential subsurface leakage); and possibly even
- Reduction of water leakage from ageing and old municipal water supply reticulation networks in urban areas located on undermined land.

Whilst AMD threatens the scarce water resources of South Africa, and as a result also human health, food security and ecosystems in and downstream of mining areas, it also presents an opportunity to generate "new" water (Wood, 2008) through appropriate technologies.

> Whilst AMD remains a threat to the scarce water resources of South Africa, it also presents an opportunity to generate "new" water through appropriate technologies.

The magnitude of the task to overcome the threat of AMD increases exponentially as the implementation of intervention measures is delayed. While the "too-much-too-soon" approach is probably less of a risk than the "too-little-too-late" approach in terms of consequence, the "Avoid the unmanageable and manage the unavoidable" dictum (United Nations Foundation, 2007) might well be taken to heart also in this regard.

How do we manage the unavoidable? Five key options are:

- Rationalise and align national legislation on mining waste to remove ambiguity arising from institutional fragmentation and overlapping or vaguely defined roles and responsibilities regarding the management and control of mining waste (Funke *et al.*, 2009);
- Develop policy and regulations based on sound scientific evidence by building the links between research providers and key line departments of Government (Funke *et al.*, 2009). In similar vein, strengthen the links between universities, research organisations and their counterparts in the international community;
- Develop a centralised and uniform data base of historical, current and potential future mine pollution events from which to determine the nature and extent of impacts, and identify priority areas and actions for the implementation of remedial measures;
- Develop a research programme to investigate the impacts of AMD on biota, ecosystems and sensitive physical environments such as dolomitic aquifers in order to implement appropriate management interventions based on a better understanding of the inter-relationships that exist; and
- Make compliance with regulations a prerequisite of each new mining permit that is issued.

The information provided in Figure 15 and Table 3 provides a broad overview of AMD in South Africa.

INDUSTRY AND WATER QUALITY SUZAN OELOFSE

Water is a strategic resource for supporting South African economic growth through industrial development.

Water that is used in a non-consumptive manner becomes available for direct recycling and reuse or is returned to the water resource after treatment, thereby becoming available for re-use.

In 2006, approximately 50% of urban and industrial drainage was returned for reuse in urban and industrial areas such as Johannesburg and Pretoria (DEAT, 2006). However, the reuse of return flows is largely dependent on the quality of the return flow combined with the quality requirements of the users.

Water quality requirements for industrial use

The water required for industrial use must be available at a relatively constant rate throughout the year (at a high assurance of supply) (DWAF, 2004a). In addition, the water needs to be of a suitable quality for the specific industrial use. Industry specific target water quality guidelines (DWAF and WRC, 1995) for use are summarised in Table 4. Because most industries in South Africa are located close to urban areas, those industries receive water through the municipal reticulation system at drinking quality standards. This may be considered as a waste of good quality water since water of a lesser quality would also suffice in many instances.

The impact of industry on water quality

Mining is the single industry sector with the largest water quality impact (by volume) in South Africa. The effects of mining include changes in pH (acidity), increased salinity, increased metal content and increased sediment load. In the mining areas around Johannesburg the polluted groundwater discharging into streams in the area contributes up to 20% of the stream flow. The effect of the contaminated water from the mines can persist for more than 10 km beyond the source (Naicker *et al.*, 2003).

Industrial contributions to pollution are varied, depending on the industrial process, but can include poisonous and hazardous chemicals, nutrients, elevated salinity and increased sediments. The main impacts of chemicals in the water relate to salinisation (increase in dissolved salts) which may render water unfit for reuse or very costly to treat. Typical pollutants associated with industrial water use include:

- Heavy metals (lead, chromium, cadmium, arsenic, vanadium)
- Dyes
- Chemicals such as chlorine, phosphate and nitrates
- High organic compounds in the form of Chemical Oxygen Demand (COD)
- Brine and sewage sludge.

TABLE 4: Summary of the Target Water Quality Guidelines for industrial use (DWAF and WRC, 1995)

	Industry					
Constituent	**Leather tanning**	**Power generation***	**Iron and steel**	**Pulp and paper**	**Petrochemical***	**Textile**
pH	6.0-8.0	7.0-9.0 7.0-9.0	7.0-9.0	6.5-8.5	7.5-8.5 7.5-8.5	7.0-8.5
Electrical conductivity mS/m	10-70	0-20 10-70	0-100	10-70	0-30 10-70	10-70
Suspended solids mg/ℓ	0-5	0-10 0-10	0-5	0.5	0-5 0-5	0-5
Total hardness mg/ℓ	0-250	0-100 0-150	0-200	0-75	0-120 0-250	0-25
Alkalinity mg/ℓ	0-150	0-50 0-50	0-100	0-100	0-100 0-150	0-100
Sulphate mg/ℓ	0-200	0-30 0-50	0-400	0-200	0-100 0-200	0-250
Chloride mg/ℓ	NS	0-20 0-20	0-20	0-20	0-20 0-20	NS
Iron mg/ℓ	0.0-0.2	0.0-0.2 0.0-0.2	0.0-0.2	0.0-0.1	0.0-0.5 0.0-0.5	0.0-0.2
Manganese mg/ℓ	0.0-0.1	0.0-0.1 0.0-0.1	NS	0.0-0.1	0.0-0.2 0.0-0.2	0.0-0.1
Chemical oxygen demand (COD) mg/ℓ	0-20	0-20 0-20	0-30	0-10	0-10 0-10	0-10

* Target values for steam generation (upper value) and cooling/other purposes (lower value) are given separately for these industries. NS = not specified

TABLE 5: Examples of pollution loads for different industries
(WRC Natsurv series) (Republic of South Africa, 1984; WRC, 1987a,b,c; WRC, 1989a,b; WRC, 1990a,b; WRC, 1993)

Industry	Specific water intake#	Target specific pollution load of untreated effluent
Poultry industry	15 - 20 ℓ / bird	29 g COD/bird 7 g SS/bird (AP-Grade abattoirs)
Red meat industry	1.1 m^3 / wrcu*	5.2 kg COD / wrcu* 1.6 kg SS / wrcu (A-grade abattoirs)
Sugar industry	30 - 100 m^3 / t of cane processed	1500 - 2000 mg / ℓ COD
Brewing industry	6 m3 / m^3	7.5 kg COD / m^3 beer
Soft drink industry	2.7m3 H2O / m^3 of softdrink	3.5 kg COD / m^3 softdrink
Wine making	700 - 3800 ℓ / t of grapes 1.8 - 6.2 ℓ / ℓ absolute alcohol - Spirit distillation	1.7 - 5.6 kg COD / ton of grapes 95 - 145 kg COD / hℓ absolute alcohol
Paper and Pulp industry	33 - 136 m^3 / t Integrated plant 1 - 49 m^3 / t paper and pulp products	9 - 80 kg COD / t & 21-183 kg TDS / t 4 - 10 kg COD / t & 2-110 kg TDS / t

* wrcu – the number of non-bovine species equivalent to one bovine cattle unit in terms of water usage during processing
# The water intake for a particular period (during brewing, distilling and production processes, or at mills and abattoirs) divided by the product volume for the same period

Chemical industries, including petro-chemical industries, produce large quantities of waste and wastewaters. Industrial wastes may contain thousands of compounds, especially organic compounds originating from raw materials, intermediates, products, reagents, solvents and catalysts. Special attention is therefore required to prevent water pollution from chemical industries.

Coal-fired power stations provide the main source of electricity in South Africa. The major use of water in coal-fired power generation is for evaporative cooling. The water that evaporates is pure water, leaving any dissolved salts (TDS) in the recirculating cooling water. The process causes a continuous increase in the levels of TDS in the cooling water. Typically blowdown water contains about 1200-1500 mg/ℓ TDS (WRC, 1993). The main potential for pollution is therefore from cooling water blowdown, regenerants from the ion exchangers and leachate and run-off from ashing systems.

Fly ash and gasses formed during combustion of coal are major sources of air pollution which may also impact on water quality due to atmospheric fall out.

Metal industries include manufacturers of steel, stainless steel and other metals, such as manganese and zinc as well as the metal plating industries. As with power generation, metal manufacturing utilises a lot of water for cooling purposes with similar consequences. However, the bulk of pollution from the metal plating industry derives from dumping of process solutions (WRC, 1987b).

Industries related to the agricultural sector contribute high levels of organic pollutants and suspended solids to pollution loads.

Management of industrial wastewater

The Department of Water Affairs is developing a Waste Discharge Charge System (WDCS) aimed at providing economic incentives and penalties to operationalise the "polluter pays principle".
It is envisaged that this system will provide the necessary incentives for industry, not only to treat their effluent to acceptable standards for reuse, but also to minimise their water use.

Pollution resulting from industrial use of water was traditionally controlled through "end-of-pipe-treatment". General and special effluent standards (determined by the water management area in question) for the discharge of industrial effluent was introduced in 1984 (Republic of South Africa, 1984). This approach focused only on the quality of the treated effluent without considering the total pollution load and therefore the impact on the receiving water body. In cases where it was difficult or impossible to treat the effluent to the required standards, the easy way out was to dilute the effluent with clean water to meet the required standards.

A more pro-active approach to industrial wastewater management was necessary. The new approach required the introduction of waste minimisation, cleaner production and water conservation measures. A receiving water quality objective approach was introduced with the promulgation of the National Water Act (Act No. 36 of 1998). Following this approach, site-specific circumstances at the point of discharge will dictate the quality requirements to be met.

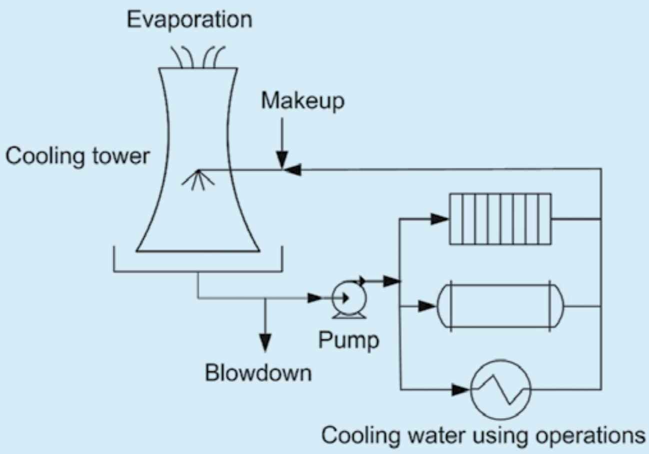
Industries located within urban areas discharge their effluent into municipal sewage systems as prescribed by the Water Services Act, 1996. As a result, many municipal waste water treatment works treat significant volumes of industrial effluent.

The development of a Waste Discharge Charge System (WDCS) by DWA will provide the necessary incentives for industry to treat their effluent to acceptable standards for reuse and minimise their water use.

Cooling water systems optimised

Water cooling systems have high consumption of fresh water and shed the same amount of waste water. This, according to research conducted by the CSIR and the University of Pretoria, is because of the heat exchangers arranged in a parallel manner. Now, researchers have managed to reduce both the amount of fresh water consumption and waste water shedding by these cooling towers by decreasing the flowrate of the circulating water.

This implies that a given set of cooling towers can manage an increased heat load. From the case studies, 22% decrease in circulating water flowrate was realised. The blowdown and makeup were also decreased by 7%. Furthermore, the cooling tower effectiveness was improved by 4%. A decrease in the overall circulation water has an added benefit of decreasing the overall power consumption of the circulating pumps.



COMPETING FOR WATER TOWARDS DEVELOPMENT: WATER AND FOOD SECURITY

CONSTANSIA MUSVOTO AND MIRIAM MURAMBADORO

Water is inextricably linked to food security because it directly and indirectly affects the availability of food, access to food and use of food, as well as stability of food supplies.

Water and food production

Growing crops to provide food for human consumption is the largest water consuming sector in South Africa (FAO, 2005).

For plants to grow and develop, they need sufficient water of adequate quality, in appropriate quantity and at the right time, within reach of their roots (FAO, 2003a). Most of the water absorbed by a plant has the function of raising dissolved nutrients from the soil to the aerial parts of the plant from where the water is mostly lost to the atmosphere through transpiration. Agricultural use of water is thus consumptive. The amount of water required for food production varies depending on the food product. Meat production generally requires more water than the production of crops, with production of one kilogram of meat requiring six to twenty times more water than for a similar quantity of cereal (FAO, 2003a).

For crops, water requirements differ depending on the crop and local climatic conditions. The amount of water involved in food production is significant and most of it is provided by rainfall (FAO, 2003a).

TABLE 6: Examples of the quantities of water required to produce one unit of selected food products (FAO, 2003a)

Product	Unit	Equivalent water in m^3 per unit
Cattle	Head	4 000
Sheep and goat	Head	500
Fresh beef	kg	15
Fresh lamb	kg	10
Fresh poultry	kg	6
Cereals	kg	1.5
Citrus fruit	kg	1
Palm oil	kg	2
Pulses, roots and tubers	kg	1

According to the Food and Agricultural Organisation (FAO, 2003a), depending on the composition of meals and allowing for losses in the production chain, the present average daily food intake of 2 800 calories per person would require approximately 1 000m^3 of water per year to produce. As populations increase and demand for food rises, agricultural water consumption will also increase. The outlook for the coming decades is that agricultural productivity needs to continue to increase and will require more water to meet the demands of growing populations (Ludi, 2009). To meet the needs of a growing population, farmers have to produce more food using less water (CGIAR, 2009).

The role of rainfall and irrigation

Most of the world's food is produced using non-irrigated agriculture (also referred to as rain fed agriculture), and this depends entirely on rain water stored in the soil profile. Rain fed agriculture is, however, only possible in areas where rainfall quantity and distribution ensure adequate soil moisture during critical periods for crop growth.

In South Africa, only 35% of the country receives enough rainfall for successful rain fed crop production. About 70% of crop production is rain fed while 30% is irrigated. South Africa has an estimated 1,3 million hectares of irrigated land (both commercial and smallholder) (Bambridge,1996; Perret, 2002). The main irrigated crops in South Africa are fodder crops, wheat, maize, sugar cane, vegetable and pulses (FAO, 2005). Irrigation, which depends on the use of surface and/or ground water, provides a critical management tool for stabilising food production as it provides protection against the unpredictability and fluctuations of rainfall.

Irrigated agriculture uses over 60% of the groundwater, surface water and recycled water (Backeberg, 1997). South Africa's existing water resource availability includes 77% surface water, 9% groundwater and 14% re-use of return flows. Although irrigation plays a strategic role in food production during dry years, water scarcity impedes irrigation on a broader scale (UNESCO, 2006). The availability of water provides communities or individuals with opportunities to both stabilise and increase food production in terms of quantity, quality and diversity.

Water and food security

As a key agricultural input, water is inextricably linked to food security as it both directly and indirectly affects food availability, access, utilisation and stability. Food security is defined as a situation when "all people at all times, have physical, social and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2003b). Food security is multi-dimensional (FAO, 2006):

- **Food availability:** The availability of sufficient and appropriate quantities and quality of food at both household and national level supplied through domestic production or imports (including food aid);
- **Food access:** Access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet. Entitlements are defined as the set of all commodity bundles over which a person can establish command given the legal, political, economic and social arrangements of the community in which they live (including traditional rights such as access to common resources);
- **Food utilisation:** Use of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met; and
- **Stability:** Food security entails stability as, to be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g., an economic or climatic crisis) or cyclical events (e.g., seasonal food insecurity).

According to FAO (2009) water is the key ingredient to food security. Lack of water can be a major cause of famine and undernourishment especially in areas where people depend on local production for food and income. Drought is the most common cause of severe food shortages in developing countries. Between 2000 and 2002, drought was responsible for 50 to 80% of all food emergencies in developing countries (FAO, 2009).

According to Ludi (2009), food security and rural livelihoods are fundamentally linked to water availability and use, with food security being determined by the options available to people for securing access to their own agricultural production and exchange opportunities. These opportunities are influenced by access to water (FAO, 2009). In developing countries, people who have better access to water have lower levels of undernourishment than those with less access to water.

At a national level, South Africa is food secure because it can produce the main staple food (maize and wheat), exports its surplus food and imports what it needs to meet its food requirements (Department of Agriculture, 2002). However, the food security situation at household and intra-household level is different. According to the South African Food Bank (Food Bank South Africa, 2009) about 19 million South Africans are food insecure. Food insecurity in South Africa is a result of a suite of political (past apartheid policies), social and economic factors at various scales and environmental stressors (droughts and floods) leading to a decrease in production levels.

Local food production could address food insecurity in some areas of South Africa, especially the remote rural areas. However, lack of water for agriculture (due to the seasonality and unreliability of rainfall and lack of irrigation) results in periods of food insecurity for many households (FAO, 2005). The challenge in South Africa has been to secure household food security when a large proportion of the population lives a subsistence lifestyle and depends on rain fed agriculture to support their livelihoods (UNESCO, 2006).

Climate change threats to water and food security

Although at national level South Africa is currently food secure, future threats to water supplies would also threaten food security. If food production in South Africa falls below domestic requirements, food insecurity is likely to increase, especially among the poor.

Climate change is one of the biggest threats to water and food security in southern Africa. Future patterns of rainfall and periods of drought are difficult to project using climate models but temperature projections are a more reliable tool (Ludi, 2009). These projections show that increased evaporation, evapo-transpiration and associated soil moisture deficits will affect rain fed agriculture especially in Sub-Saharan Africa (Ludi, 2009).

Climate change is one of the biggest threats to water and food security in southern Africa.

Estimates show that increasing temperatures will reduce agricultural production because, when soil moisture levels fall below the wilting point, plant growth slows and eventually stops, and the potential crop yield is not fulfilled (FAO, 2008). Dry spells in drought prone areas are expected to increase in severity and occurrence, which would also affect food production. In Sub-Saharan Africa cereal production is expected to decrease by about 12%, and about 40% of the countries in the region will be at risk of crop and pasture declines (and livestock losses) as a result of climate change (Fischer et al., 2005; Shah et al., 2008). Climate change is expected to increase water scarcity and increased evaporation in open water storages will also reduce the amount of water available for irrigation and other uses.

> Currently it is estimated that about 200 million people in Africa experience water stress and this number is likely to increase as a consequence of climate change.

The United Nations Development Program (UNDP) has warned that the progress in human development achieved over the last decade may be slowed or even reversed by climate change as new threats emerge to water and food security, agricultural production and access and nutrition and public health (UNDP, 2008). UNDP further points out that the various impacts of climate change – such as sea level rise, droughts, heat waves, floods and rainfall variation – could push another 600 million people into malnutrition and increase the number of people facing water scarcity with 1,8 billion by 2080.

In order to be prepared to deal with the possible consequences, scientists and managers need to better understand the impacts of climate change on agriculture and natural resources in South Africa and other developing countries and to develop the adaptive capacity needed to respond to these impacts. Ludi (2009) posits that short-term strategies to deal with food insecurity, economic growth and better access to water should be placed in the context of future climate change. This ensures that short-term activities in a specific area do not increase vulnerability to climate change in the long term.

WATER, ENERGY AND CLIMATE CHANGE

ALAN BRENT[2]

It is necessary to understand, in a holistic and comprehensive manner, the dynamic interaction between society and its energy needs, as well as the constraints of nature, and specifically water resources.

The relationship between energy and water use is beginning to get more attention as policy makers worldwide grapple with measures to transition from heavy dependence on fossil fuels and to aggressively address global climate change by capping carbon emissions.

A recent study of the World Business Council for Sustainable Development (WBCSD, 2009) highlights that water, energy and climate change cannot be addressed as separate problems: "If we truly want to find sustainable solutions, we must ensure that we address all three in a holistic way". This realisation is due to the following (WBCSD, 2009):

- Water and energy are inextricably linked:
  - Both water and energy are essential to every aspect of life: social equity, ecosystem integrity and economic sustainability;
  - Water is used to generate energy, and energy is used to provide water; and
  - Both water and energy are used to produce crops and crops can in turn be used to generate energy through biofuels.
- Global energy and water demands are increasing:
  - Energy and water demands vary proportionately to changes in income and lifestyle (socio-economic development). At low income levels, energy and water are used for basic needs such as drinking, cooking and heating, and in rural areas also for watering of vegetable gardens. But as income increases, people use more energy and water for refrigerators, swimming pools, transport, watering and cooling to meet their new lifestyle and diet needs;
  - In an increasing spiral, demand for more energy will drive demand for more water, and demand for more water will drive demand for more energy; and
  - Business, in cooperation with civil society, needs to continue to improve its water and energy efficiency to enable sustainable growth.

Water, energy and ecosystems

Industrial, agricultural and domestic water and energy uses can have adverse impacts on ecosystems, including loss of habitat, pollution and changes in biological processes (such as fish spawning). Such ecosystem impacts also affect the amounts of water or energy supplies that are available.

Maintaining environmental flows are critical for river functioning and ecological health. In turn, healthy river systems can supply water to business, energy systems, and ecosystems. Water, energy and ecological footprints cannot be addressed in isolation.

Climate change will affect availability and use of both water and energy, and acts as an amplifier of the already intense competition over water and energy resources. It is therefore necessary to understand, in a holistic and comprehensive manner, the dynamic interaction between society and its energy needs, the available energy-related technologies and their management, and the constraints of nature, and specifically water resources.

Endeavours to clarify this understanding are dominated by the emerging field of sustainability science (Kates *et al.*, 2001), and particularly social learning and adaptive management approaches (Pahl-Wostl, 2002). Technological research is viewed as one of the four branches of sustainability science, concentrating on the design of devices and systems to produce more social goods with less environmental harm.

Sustainability science is the study and integration of particular issues and aspects of radical, systemic approaches to innovation and learning for ecological and social sustainability (Struyf, 2003). The merger of these two fields has led to concepts such as Environmentally Sound Technologies (ESTs), namely technologies that have the potential for significantly improved environmental (and social) performance relative to other technologies (IETC, 2003).

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To this end, the linkage between sustainability science and technology management aims to promote joint problem solving by scientific, societal, economic and political stakeholders through a trialogue model (Turton *et al.*, 2007) (Figure 16) to:

- Systematically understand technological, sociological, ecological, economic, and institutional system complexity; and
- Develop assessment frameworks and methods to assist decision- and policy makers of energy and water technologies and innovations to enhance the sustainability of associated management practices and policies.

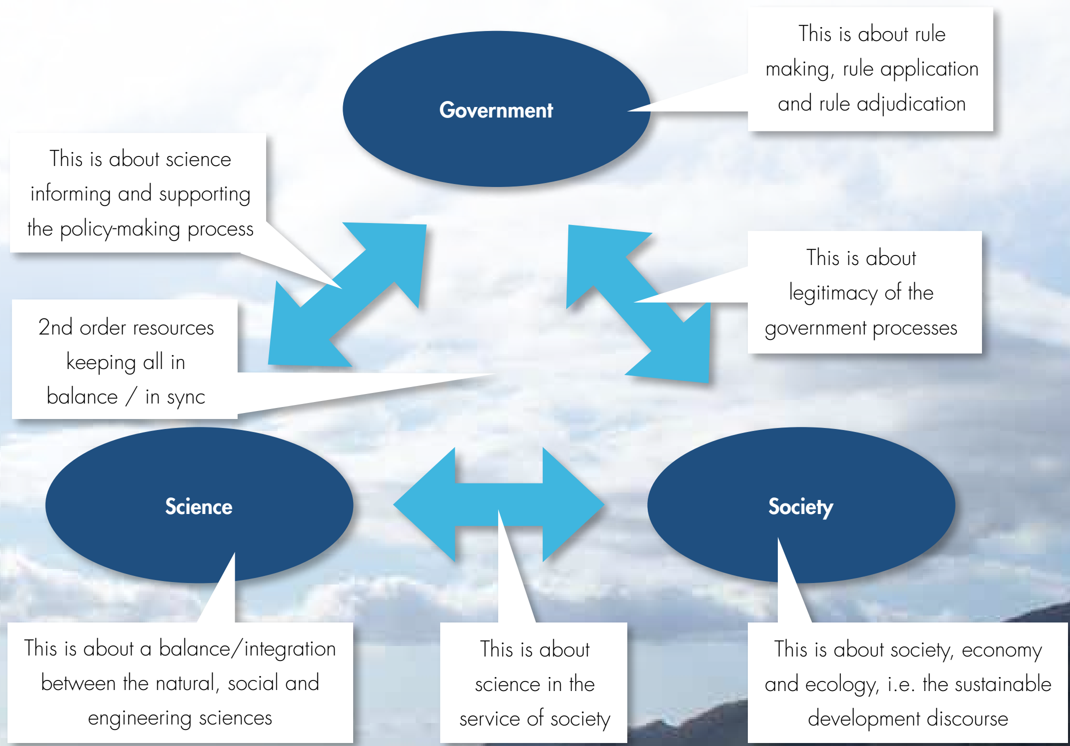
Energy use in agricultural production

An analytical structure of energy use that is equally applicable to agriculture, fisheries and livestock is one that differentiates direct and indirect inputs of energy (FAO, 1995). In agriculture, direct energy inputs can be further subdivided into mobile and stationary energy inputs.

- Mobile energy inputs in agriculture are required during the following activities: soil preparation; sowing; weeding; application of manure, fertilisers and pesticides; harvesting; threshing; and transport of harvested crops;
- Stationary inputs are mainly linked to post-harvest operations such as drying, cooling and milling.

Indirect energy inputs in agriculture are used for provision of water; manufacture and supply of fertiliser; and production and supply of pesticides.

FIGURE 16: Trialogue model (adapted from Turton *et al.* 2007)



The research indicated that policymakers need to be aware of the differences in water use – particularly for irrigated and non-irrigated biofuel feedstocks – in the planning of alternative fuel adoption. Petrou and Pappis (2009) highlight additional disadvantages of biofuels in terms of water pollution due to pesticides and fertiliser run-off, and the acidification and eutrophication potential, as well as climate change impacts, due the release of nitrous oxides and other emissions in the life cycle of biofuels.Policymakers need to carefully compare these disadvantages with those of conventional fuel life cycles.

Biofuels versus conventional fossil fuels

A recent study (King and Webber, 2008) compared the amount of water withdrawn (water taken from source, used and returned for reuse) and consumed (water that is not directly returned to source) per distance travelled by a typical car powered by conventional fossil-fuel based petrol and diesel, and biofuels. Biofuels derived from irrigated crops require up to three orders of magnitude more water per distance travelled than conventional fuels. However, non-irrigated biofuels are just as low in water consumption and usage as petrol and diesel.

THE WATER SITUATION IN SOUTH AFRICA:
SOME INCONVENIENT TRUTHS

WILLEM DE LANGE

Sustainable water resource management requires an integrated mix of supply and demand management strategies. However, the scope for supply management strategies in South Africa is decreasing rapidly as more and more water is allocated to dedicated users.

Currently most of South Africa's available water supply has already been allocated, with the only "supply options" available being linked to inter-sectoral re-allocations. The key to strategic water resource management therefore lies in effective demand-side approaches. To achieve this, we need to improve our understanding of how water is currently used to incentivise the use of the resource in smarter ways.

The adoption of sophisticated technologies to engage this challenge is often not effective within a developing country context such as South Africa. We also need to appreciate why people in South Africa use water in the way they do. We need to develop a better understanding of the incentives of water use behaviour for different use-profiles and different use-categories – how incentives influence water use. When we have an understanding of how these "behavioural levers" of water demand work, it will be possible to start manipulating them towards efficiency gains.

The effect can be quite dramatic. For example, what is the impact of human rights and government's "free water" drive on consumer profiles given an arid environment? In other words, what incentivises efficiency gains within a "free water" regime? The answer is, very little. Sometimes the physical-biological limitations of earth do cast some boundaries in stone. We need to respect these. If we start to bridge those boundaries with "technological advances", the risk of disaster increases exponentially, especially with a commodity such as water in an arid country.

Effective management of water use must be based on a clear and unambiguous appreciation of human behaviour related to water use patterns. Continued drives to increase the efficiency of water use will not necessarily lead to decreases in water use. Efficiency gains in water use either reduce the amount of the water used to realise the same output or enable more output to be realised with the same water inputs.

Either way, the improved efficiency will lower the relative cost of water, which could increase the demand for water in the medium and longer-term; this will increase the overall volume of water used. This argument is particularly relevant in situations where water management authorities turn to agriculture as a potential source of future supply (the above-mentioned inter-sectoral re-allocation).

Agriculture is under constant pressure to realise efficiency gains in terms of water use, often through the incorporation of high-tech irrigation systems. However, this will probably not realise a decrease in overall irrigation water demand because of increased pressure to produce more food and fibre in the medium and long term.

Also, the more efficient water users such as commercial irrigated agriculture become, the more vulnerable they became to risk events like droughts. Highly efficient systems are optimised in terms of water usage and very little room is left to accommodate any decrease in supply during droughts. This argument is not exclusive to the water sector of our country. Electrical energy and waste generation profiles also present little room for manoeuvre.

South Africans must be prepared to adapt to rapid changes in the environment with very little warning. The consequence of not doing so will be widespread economic hardship.

THE ROAD AHEAD

PETER J. ASHTON

This report has provided evidence that highlights the deteriorating water quality of South Africa's major river systems, water storage reservoirs and ground water resources – the core water supply systems that underpin social and economic development in our country. The available evidence is clear: we simply cannot continue to exploit our water resources by following a 'business as usual' approach. If we do so, South Africa's freshwater resources will be fully depleted and unable to meet the needs of people and industry by the year 2030 – this will happen even sooner if we experience prolonged droughts. The problems will be made worse by more frequent incidents of water pollution and increased costs of water treatment.

This report also draws attention to some of the specific causes of water quality problems in different parts of South Africa and draws attention to the social, economic and health risks that these pose for society. It is vitally important for us all to remember that water is essential for our lives and livelihoods – if we fail to ensure that everyone has reliable access to sufficient water of suitable quality, we will not be able to achieve a just, equitable and sustainable future for our people. This will have equally bleak prospects for our neighbours. We are all aware that several of the water quality problems we face today are 'legacy issues' that we have inherited from previous political systems. It is now up to us to solve them; we cannot simply walk away from these problems and expect our descendents to bear the burden of resolving them.

South Africa's future development depends on the continued use of our country's rivers and reservoirs. If we wish to sustain the integrity of our water resources and at the same time continue to draw from the same water resources to meet our needs, everyone must become more closely engaged in the social and institutional processes that will be needed to ensure successful management of our water resources.

South Africa already faces an enormous task in dealing with the problems posed by key water quality issues such as acid mine drainage, eutrophication (or nutrient enrichment) and salinisation, coupled to the apparent ineffectiveness of many institutions to treat domestic sewage and industrial effluent to levels that are safe for discharge to rivers and streams. None of these problems can be dealt with by a simple, quick-fix, one-size-fits-all solution. In each case, the prevailing conditions must be carefully evaluated and a robust set of solutions designed to suit the specific circumstances of each situation.

While the Department of Water Affairs is designated as the formal custodian of South Africa's water resources, several other government departments (e.g. Environmental Affairs, Agriculture, Health, Mineral Resources) and all sectors of government (national, provincial and local) share

responsibility for different aspects of the use and management of water resources. Importantly, every individual water user is also responsible for ensuring that water is used sparingly and wisely, avoiding wasteful or unnecessary use of water, and preventing contamination.

South Africa's landmark water legislation (the Water Services Act No. 108 of 1997 and the National Water Act No. 36 of 1998) provides an excellent legal framework for managing our country's water resources and providing sufficient water of suitable quality at an affordable price to meet human needs. However, it is clear that shortages of skills and funds, institutional ineffectiveness at many levels, and a lack of specific water treatment technologies, have made it extremely difficult to resolve all of the problems and achieve the goals to which our legislation aspires. It is equally clear that the current situation cannot continue indefinitely and that we must all embrace a fresh new 'water ethic' where we appreciate the true value of water; we act more prudently and responsibly to avoid unnecessary wasteful uses of water, and we prevent contamination of water that would ultimately require expensive treatment before it can be used by society.

In addition to adopting new ways of viewing, valuing and caring for water, we also need to develop and implement new legal instruments, while also creating new institutional structures and deriving new technological solutions. At the same time, we must dramatically increase the numbers of trained and competent individuals who are tasked with implementing legislation, treating wastes, and supplying potable water to society. In parallel, we must collectively seek ways to increase our ability to sustain the delicate balance between conserving water resources and exploiting the benefits we derive from these resources.

If we fail to radically improve our water quality management approaches and treatment technologies, we will face an inevitable outcome: a gradual decline in the volume of water available per person, progressive worsening of water quality, loss of biological integrity in our aquatic ecosystems, and continually rising costs associated with treating water for people to drink. Ultimately, this will prevent us from achieving social and economic growth and eliminating poverty.

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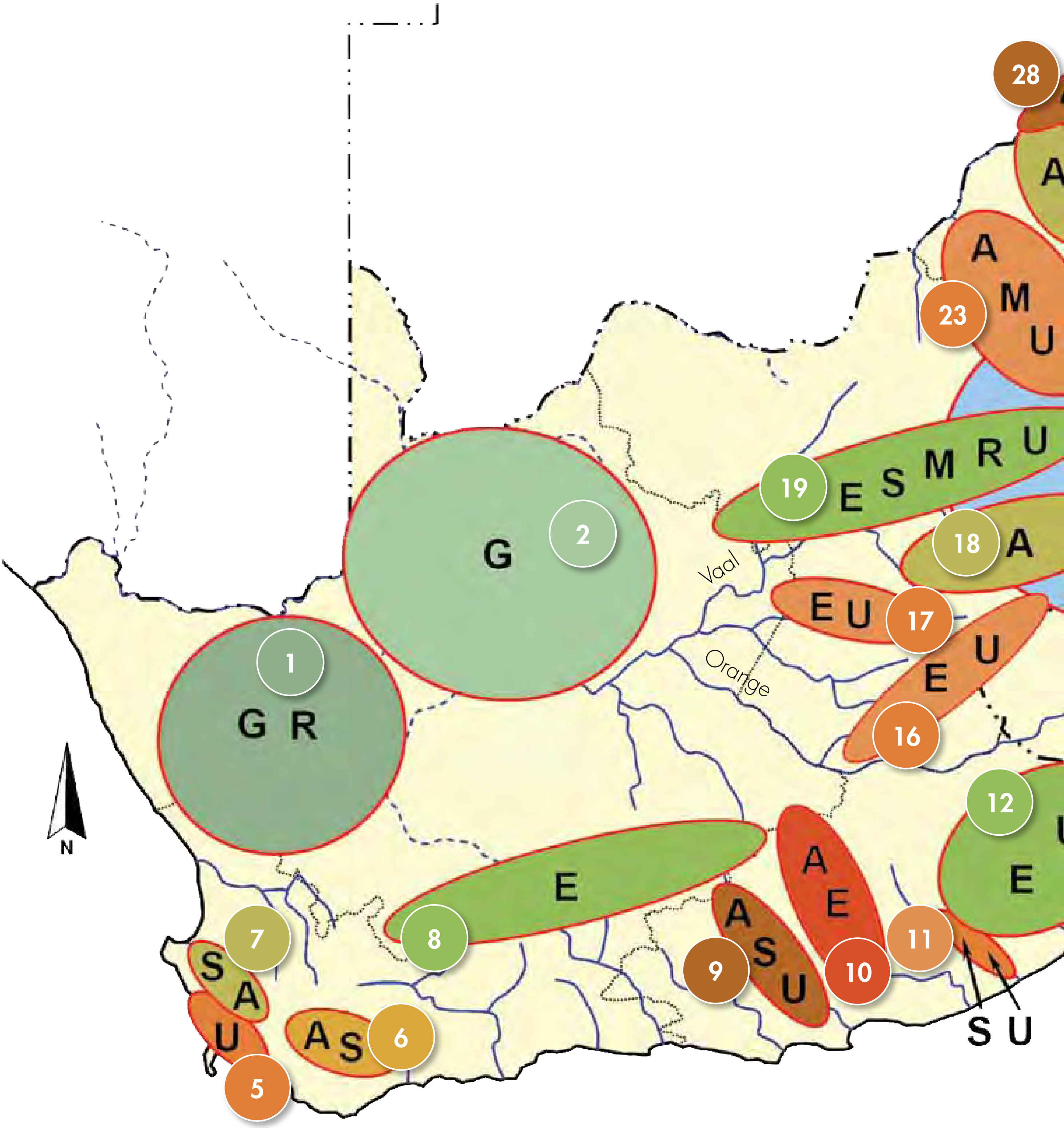
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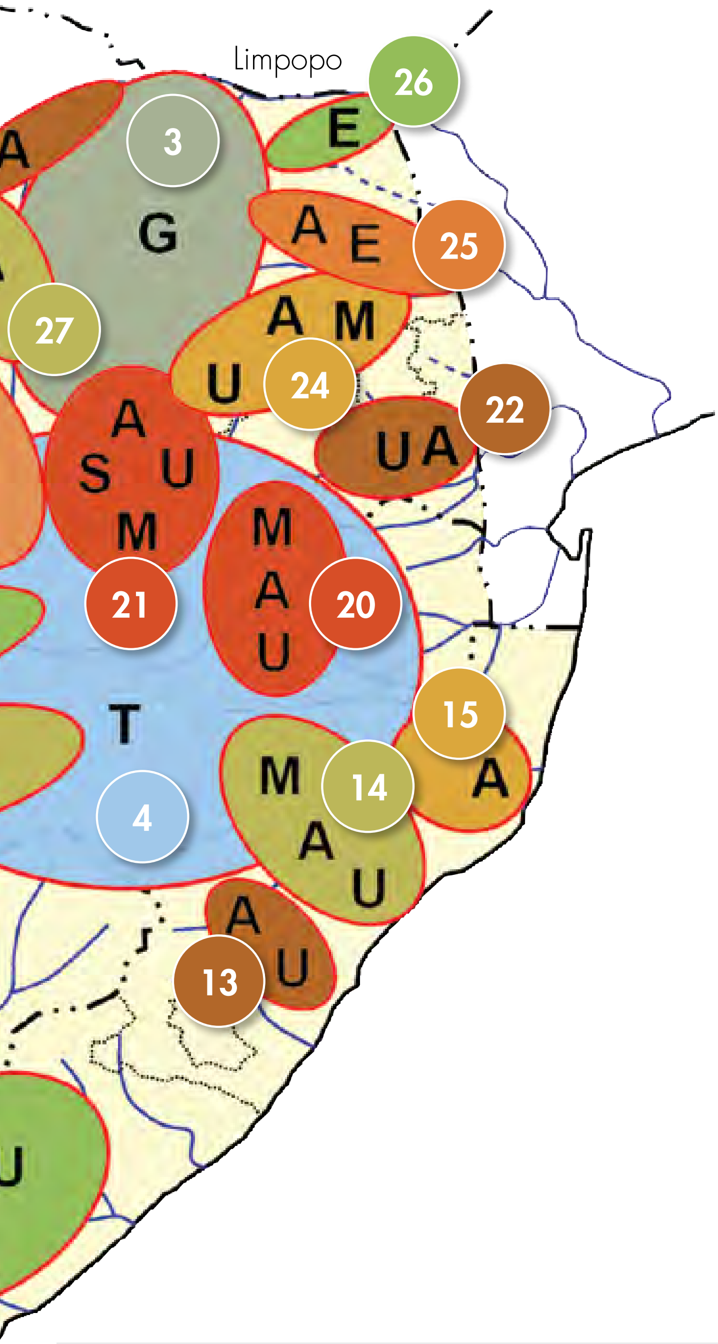


S = Salinity

R = Radioactivity

M = Metals (from mining and waste disposal)

E = Excessive sediment

A = Agricultural chemicals

T = Acidic atmospheric deposits

G = Groundwater contamination

U = Urban/industrial effluent

12 Eastern Cape: Transkei river systems

- Highly erodible rocks and soils combined with high population numbers and depleted vegetation cover due to over-grazing have led to accelerated rates of erosion, resulting in elevated concentrations of suspended silt in the rivers.
- Discharges of treated, partially treated and untreated urban and industrial effluent from Mthatha, as well as contaminated runoff from smaller urban centres and informal settlements, result in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocryne Disrupting Compunds (EDCs).

13 KwaZulu-Natal: uMngeni River system

- Return flows and seepage from agricultural lands (crops, livestock and forestry) result in elevated concentrations of pesticides and nutrients reaching the river.
- Contaminated runoff from urban centres and informal settlements, combined with discharges of treated, partially treated and untreated urban and industrial effluent, result in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocryne Disrupting Compunds (EDCs). All of these substances pose severe health risks to humans and livestock.
- Toxic blooms of cyanobacteria (*Microcystis aeruginosa*) occur frequently in the major reservoirs.
- Past discharges of mercury-rich effluents have accumulated in the river sediments and are now re-appearing in the water.

14 KwaZulu-Natal: Thukela River system

- Operating and defunct coal mines contribute large volumes of AMD to the river system, resulting in lowered pH values and elevated concentrations of total dissolved salts, especially sulphate.
- Heavy industries (e.g. iron and steel works) contribute a variety of inorganic and organic compounds to the river system.
- Return flows and seepage from agricultural lands (principally livestock ranching, dairy farming, cultivation of crops, sugar cane) and forestry result in elevated concentrations of pesticides and nutrients reaching the river.
- Discharges of treated, partially treated and untreated urban and industrial effluent, contaminated runoff from urban centres and informal settlements, and a significant percentage of the large rural population lacking access to appropriate sanitation systems, result in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocryne Disrupting Compunds (EDCs).

15 **KwaZulu-Natal: Umfolozi and Mkhuzi river systems**

- Irrigation of croplands is extensive and return flows and seepage from the agricultural lands (sugar cane dominating) and forestry areas result in elevated concentrations of pesticides and nutrients reaching the rivers.
- Many residents from the numerous small urban centres and the large rural population do not have access to appropriate sanitation systems. Discharges of treated, partially treated and untreated urban and industrial effluent, combined with contaminated runoff from urban centres and informal settlements, result in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocryne Disrupting Compunds (EDCs).

16 **17** **Free State: Caledon and Modder river systems**

- Overgrazing of vegetation on the easily erodible rocks and soils, together with heavy rain, increase the already naturally high concentrations of suspended sediments, which make their way to Gariep Dam downstream.
- Many smaller urban centres and rural communities lack access to appropriate sanitation systems and where systems are present they seldom work effectively. Small industries discharge their effluent directly into the river, resulting in increased concentrations of a variety of salts and organic compounds.
- Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the rivers.
- Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements, result in the Caledon River containing large numbers of pathogenic organisms, high concentrations of nutrients and salts, and moderately high concentrations of Endocryne Disrupting Compunds (EDCs).
- Periodic blooms of toxic cyanobacteria (*Microcystis aeruginosa*) have been recorded from the Krugersdrift Dam.

18 **Free State: northern river systems**

- Many residents of the smaller urban centres and rural communities located in the catchment lack access to appropriate sanitation systems or, where these systems are present, they seldom work effectively.
- Return flows and seepage from the agricultural lands carry elevated concentrations of pesticides and nutrients to the rivers and their tributaries, eventually flowing into the Vaal River.
- Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements, result in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of Endocryne Disrupting Compunds (EDCs).

19 **Gauteng/North West/Free State: Vaal River system**

- The numerous active and defunct gold and uranium mines in the Witwatersrand complex contribute large volumes of AMD to the river system – both passively and by active de-watering. Large volumes of 'unaccounted for water' leak from the water reticulation systems across the Witwatersrand complex, enter the active mines and mined-out areas, and aggravate the AMD problem. The AMD results in lowered pH values and elevated concentrations of metal ions and total dissolved salts, dominated by sulphate, as well as relatively high levels of radioactivity in certain tributary rivers.
- The numerous cities, towns and smaller urban centres are surrounded by informal settlements; many of these settlements lack formal sanitation systems. Many of the sanitation systems within the Witwatersrand complex do not function effectively with the result that large volumes of treated, partially treated and untreated domestic and industrial effluent enter the Vaal River system.
- Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Vaal River and its tributaries.
- Discharges of urban and industrial effluents, as well as contaminated runoff from larger cities, smaller urban centres and informal settlements, contribute large numbers of pathogenic organisms and high concentrations of nutrients and salts, as well as low to moderately high concentrations of Endocryne Disrupting Compunds (EDCs) to the Vaal River.
- Blooms of toxic cyanobacteria (*Microcystis aeruginosa*) have been recorded from impoundments located on the Vaal River.
- Heavy industries in the Vanderbijlpark area – principally iron and steel works – contribute additional quantities of inorganic and organic compounds to the Vaal River. There is also a growing concern around the presence of Dense Non-Aqueous Phase Liquids (DNAPLs) in groundwater around the iron and steel mills. The presence of DNAPLs makes the water unfit for all human uses. In addition to the DNAPLs, the groundwater in many areas contains the lighter non-aqueous phase liquids (LNAPLs) typically associated with leakage from underground fuel storage depots.

20 **21** **Mpumalanga: eastern river systems and Mpumalanga/Limpopo: upper Olifants River system**

- Due to the varying levels of iron pyrite in the coal ore-bodies, the numerous operating and defunct coal mines contribute large volumes of AMD to the river systems. Especially in the Olifants

River system, AMD results in lowered pH values (sometimes to below pH 3.0), and elevated concentrations of metal ions (especially aluminium, iron, cadmium, zinc and cobalt) and total dissolved salts, dominated by sulphate.

- Atmospheric depositions from the large coal-fired power plants deplete the buffering capacity of the soil and contribute to the acidic soil water which releases heavy metals that eventually are washed into the rivers.
- Heavy industries in the Witbank and Middelburg area (mainly iron and steel works) contribute additional quantities of inorganic and organic compounds to the Olifants River.
- Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients.
- Discharges of urban and industrial effluents, as well as contaminated runoff from larger towns, smaller urban centres and informal settlements (many lacking proper and/or functioning sanitation systems), contribute large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderate concentrations of Endocryne Disrupting Compunds (EDCs) to the rivers.
- Blooms of toxic cyanobacteria (*Microcystis aeruginosa*) have been recorded from Loskop Dam.

22 Mpumalanga: Komati-Crocodile-Sabie river systems

- Anti-malarial campaigns using DDT to control the mosquito vector have the undesirable side-effect that DDT and its breakdown components occur in these river systems.
- Return flows and seepage from the agricultural lands and orchards result in elevated concentrations of a wide variety of pesticides and nutrients reaching the rivers and their tributaries.
- Many residents of the smaller urban centres and rural communities located in the catchment lack access to appropriate sanitation systems or, where these systems are present, they seldom work effectively. Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements, result in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of Endocryne Disrupting Compunds (EDCs).

23 North-West: Crocodile (West) River system

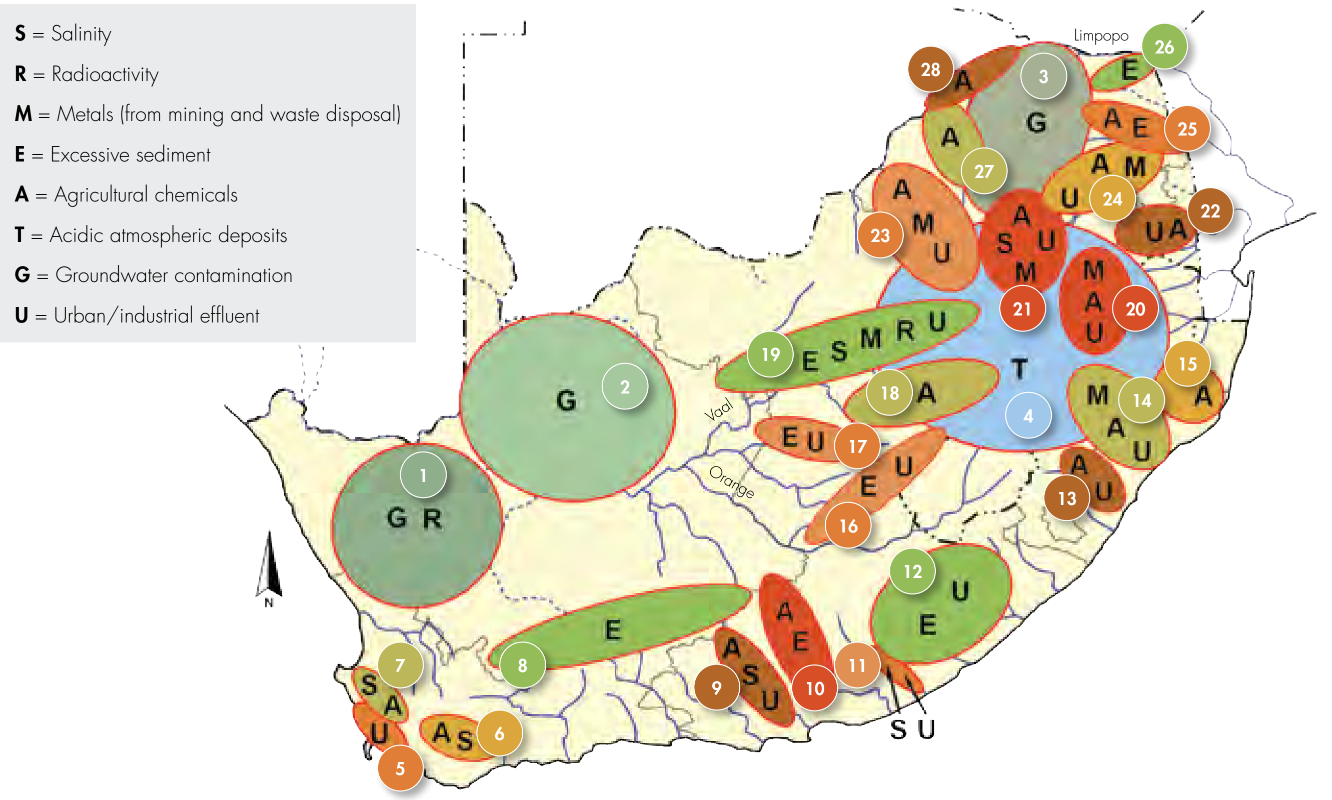
- The many chrome and platinum mines produce acidic effluent and AMD, though the quantities are far lower than those associated with Witwatersrand gold mines or the Mpumalanga coal mines.
- Return flows and seepage from the agricultural lands result in elevated concentrations of pesticides and nutrients reaching the rivers and their tributaries, eventually flowing into the Crocodile River.
- Discharges of large volumes of treated, partially treated and untreated urban effluent, especially from the northern areas of the Witwatersrand, as well as contaminated runoff from urban centres and informal settlements, result in the Crocodile River containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of Endocryne Disrupting Compunds (EDCs). All of these substances pose health risks to humans and livestock that may consume the water.
- Blooms of toxic cyanobacteria (*Microcystis aeruginosa*) occur annually in the hyper-eutrophic Hartbeespoort Dam

24 Limpopo: lower Olifants River system

- Seepage and effluent discharges from the mining-industrial complex at Phalaborwa (copper, mica, phosphate and zirconium) as well as mines that secure a variety of other minerals such as chrome, platinum, vanadium, fluorite, corundum, iron, asbestos and tin) contribute elevated concentrations of copper, aluminium, phosphate and some radioactivity to the lower Olifants River.
- Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients.
- Extensive areas of over-grazing plus areas where land management practices are not effective, contribute elevated concentrations of suspended sediments to the river systems.
- Many of the smaller towns and informal settlements lack either formal or functioning sanitation systems. As a result, large volumes of treated, partially treated and untreated domestic and industrial effluent enter the middle and lower reaches of the Olifants River system.
- Discharges of urban and industrial effluents, as well as contaminated runoff from larger towns, smaller urban centres and informal settlements, contribute large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderate concentrations of Endocryne Disrupting Compunds (EDCs) to the Olifants River.
- The necessity to control the mosquito vector of malaria by spraying with DDT has resulted in the presence of DDT and its breakdown components in the lower Olifants River system.

25 Limpopo: Letaba River system

- Return flows and seepage from orchards and agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Letaba River and its tributaries.



- Discharges of urban and industrial effluents, as well as contaminated runoff from the towns, smaller urban centres and informal settlements (many lacking access to functioning sanitation systems) pollute the Letaba River and its tributaries. Pollutants include large numbers of pathogenic organisms and high concentrations of nutrients, salts and low concentrations of Endocryne Disrupting Compunds (EDCs). All of these substances pose health risks to humans and livestock that may consume the water.
- Streams draining the Giyani Greenstone belt (where illegal artisanal gold mining occurs) contain low concentrations of mercury, which is used in the extraction of gold from ore.
- Extensive areas of over-grazing plus areas where land management practices are not effective, contribute elevated concentrations of suspended sediments to the river systems.
- The necessity to control the mosquito vector of malaria by spraying with DDT has resulted in the presence of DDT and its breakdown components in the Letaba River system.

26 Limpopo: Levhuvhu-Mutale river systems

- Many of the small towns and scattered rural communities along the middle and lower reaches of the river lack access to sanitation systems or sanitation systems that work effectively.
- The necessity to control the mosquito vector of malaria by spraying with DDT has resulted in the presence of DDT and its breakdown components in the Mutale and Levhuvhu rivers.
- The extensive areas of cultivation and poor land management techniques have resulted in elevated concentrations of suspended sediments in middle and lower reaches of the Mutale and Levhuvhu rivers.
- Discharges of low volumes of urban and industrial effluents, as well as contaminated runoff from the towns, smaller urban centres and informal settlements, contribute some pathogenic organisms, nutrients and salts to the Levhuvhu River.

27 Limpopo: Mokolo and Lephalala river systems

- Return flows and seepage from heavily irrigated agricultural lands (wheat, lucerne, maize, tobacco and cotton) result in elevated concentrations of pesticides and nutrients reaching the Mokolo and Lephalala rivers and their tributaries.
- The climate in this area is hot and dry with low rainfall, so little urban effluent enters the river systems. Discharges of urban effluent, as well as contaminated runoff from towns, smaller urban centres and informal settlements, contribute moderate numbers of pathogenic organisms and modest concentrations of nutrients, salts and low concentrations of EDCs to the river systems.

28 Limpopo: middle Limpopo River system

- Return flows and seepage from irrigated cotton and tobacco fields in the South African part of the catchment carry pesticides and nutrients to the Limpopo River. The presence of these substances poses a health risk to humans and livestock.
- Because of the low rainfall received in the area and the predominantly hot and dry climate, very little urban effluent from the few small towns and rural settlements enters the Limpopo River system.

Source: Ashton, P.J. 2009. An Overview of the Current Status of Water Quality in South Africa and Possible Future Trends of Change. CSIR, DMS report no. 192725.

THE OVERALL WATER QUALITY SITUATION IN SOUTH AFRICA

PETER J ASHTON

Taken together, human activities have had a series of profound effects on the water quality in South Africa's rivers, dams, wetlands and reservoirs, as well as adverse effects on several groundwater systems.

In many areas, several different sets of activities have combined to exert complex changes in water quality, with the result that the water quality in many areas of the country has been compromised to the extent that it poses serious risks to human health and to the natural environment.

This map illustrates the distribution of the different types of natural and human-induced effects on water quality across the country.

1 2 North-western & Northern Cape

- High concentrations of fluoride and nitrate in groundwater, as well as higher than expected concentrations of radionuclides, all of natural origin and derived from the area's geology. Concentrations are variable, and in most areas well above the recommended maximum concentrations for human consumption.

3 North-western Limpopo

- High concentrations of nitrate and fluoride in groundwater. Almost all the nitrate is of natural origin with a few small areas showing minor elevations in nitrate concentrations caused by agricultural activities.

4 Central Highveld

- Atmospheric depositions derived from coal-fired power plants and heavy industries contain low concentrations of sulphur and nitrogen oxides and have a moderately acidic pH. When the natural buffering capacity from the carbonate salts in the soil is exhausted, the excess acid interacts with clay particles. Silica and aluminium are released into the soil water and washed into streams and rivers, causing a gradual build-up of aluminium in the surface waters. The mild acidity from the atmospheric deposition is accentuated by the highly acidic seepage (AMD) from operating and abandoned mines.

5 Western Cape: Cape Town urban rivers

- Large volumes of contaminated runoff from urban areas and informal settlements; discharges of treated, partially treated and untreated domestic and industrial effluent. The receiving urban rivers contain large numbers of pathogenic organisms and high concentrations of metal ions, nutrients, salts and Endocryne Disrupting Compunds (EDCs).

6 Western Cape: Breede River system

- The elevated concentrations of dissolved salts from the naturally saline soils and groundwater are aggravated by intensive agricultural land-use.
- Irrigation return flows contain a wide variety of agro-chemicals (fertilisers and pesticides).

7 Western Cape: Berg River system

- Intensive agriculture and naturally saline soils, particularly along its lower reaches, and mildly saline groundwater.
- Elevated concentrations of dissolved salts are aggravated by return flows from irrigated agriculture, which also contain a wide variety of agro-chemicals (fertilisers and pesticides).

8 Karoo river systems

- Easily erodible and vulnerable soils and rock formations.
- Strong flowing rivers after rainfall events carry high concentrations of suspended silt and clay, posing difficulties to stock farmers in the area and leading to rapid accumulation of sediment in water storage structures.

9 Eastern Cape: Sundays River system

- Progressive increase in river salinity due to naturally elevated concentrations of dissolved salts, high evaporation rates and high rates of water abstraction for irrigation.
- Return flows from irrigated agriculture contain elevated concentrations of a variety of pesticides and fertilisers.
- The water transferred from the Gariep Dam on the Orange River often contains high concentrations of suspended solids.
- The lower reaches receive urban runoff, as well as inflows of treated, partially treated and untreated domestic and industrial effluent from towns, cities and informal settlements. These effluents contain large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocryne Disrupting Compunds (EDCs).

10 Eastern Cape: Great Fish River system

- Progressive increase in river salinity due to naturally elevated concentrations of dissolved salts and high evaporation rates combined with high rates of water abstraction for irrigation.
- The rocks and soils forming the catchment are easily erodible and over-grazing by livestock results in high concentrations of suspended sediments.

11 Eastern Cape: Buffalo River system

- Saline effluents discharged from tanneries cause elevated concentrations of dissolved salts and metal ions in the lower reaches of the river.
- Discharges of treated, partially treated and untreated urban and industrial effluent, as well as contaminated runoff from urban centres and informal settlements, result in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocryne Disrupting Compunds (EDCs).
- Toxic blooms of cyanobacteria (*Microcystis aeruginosa*) occur frequently in the major reservoirs located close to East London.

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