WATER QUALITY MANAGEMENT POLICIES AND STRATEGIES FOR SOUTH AFRICA

WATER QUALITY AND WATER QUALITY MANAGEMENT CHALLENGES IN SOUTH AFRICA

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Water Quality Planning

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EXECUTIVE SUMMARY

Introduction

The focus of this project is to develop a Water Quality Management Policy, Strategy and implementation actions that are relevant to addressing water quality deterioration and that are pragmatic, implementable and appropriate to the future institutional and governance landscape in South Africa.

The objective of this situation assessment report is to identify water quality issues and water quality management challenges for South Africa by providing a high-level overview of the water quality situation. The report provides a review of a wide range of water quality issues for both surface water and groundwater, the root causes of water quality deterioration and geographical differences in water quality issues across South Africa. Based on the findings of this review a prioritisation exercise identified five issues that require high prioritisation in terms of water quality management. A SWOT analysis is included that identifies the strengths, weaknesses, opportunities and threats for water quality management in South Africa at a high level.

This situation assessment (Report 1.3 in the series), along with a comprehensive review of water quality management policies and practice in the South African context as well as international best practices (Report 1.2 in this series), will be used to inform both the policy and strategy development process.

The findings described in this report was workshopped with relevant stakeholders on 17 February 2016 to ensure that a comprehensive document is drafted as ‘’Edition 1’’ for the approval process.

Water quality issues

A wide range of water quality issues and their primary characteristics is reviewed in this section. The review distinguishes between surface water and groundwater issues and is pitched at a high level, i.e. it is based on existing published documents and does not include the outcomes of new data analyses customised for this project.

Out of the wide range of water quality issues reviewed, five are shown to require high prioritisation in terms of water quality management. These five priority issues are: *eutrophication, salinisation, acid mine drainage and acidification, sedimentation and urban runoff pollution*. Some of the remaining water quality issues, such as microbial (pathogen) pollution, agrochemical pollution and metals pollution, are known to be potentially harmful, but because of inadequate monitoring, their geographical prevalence is not known and for that reason they are not classed (yet) as priority issues.

Figure E.1 presents the conceptual mapping of the range of water quality issues against a continuum of “knowledge and understanding” and “severity of impacts” in a South African context and shows the clustering of the above five issues in the “high impacts/high level of knowledge/understanding” area of the diagram. The implication of information in this diagram for the policy and strategy development process is that the focus for the five priority issues will need to be on reduction of their prevalence and impacts, while many of the other issues require much-extended monitoring.

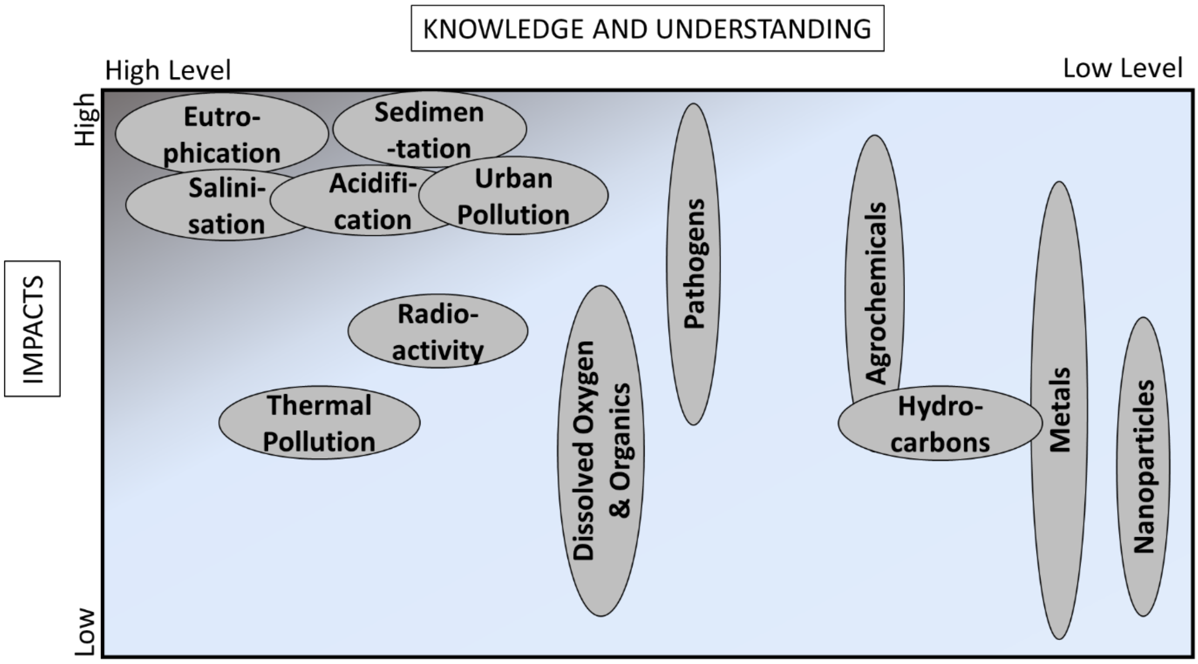

Figure E.1: Prioritisation of water quality issues

The prevalence and/or severity of impact of particular water quality issues varies markedly from river system to river system and from WMA to WMA, as illustrated by **Figure E.2**.

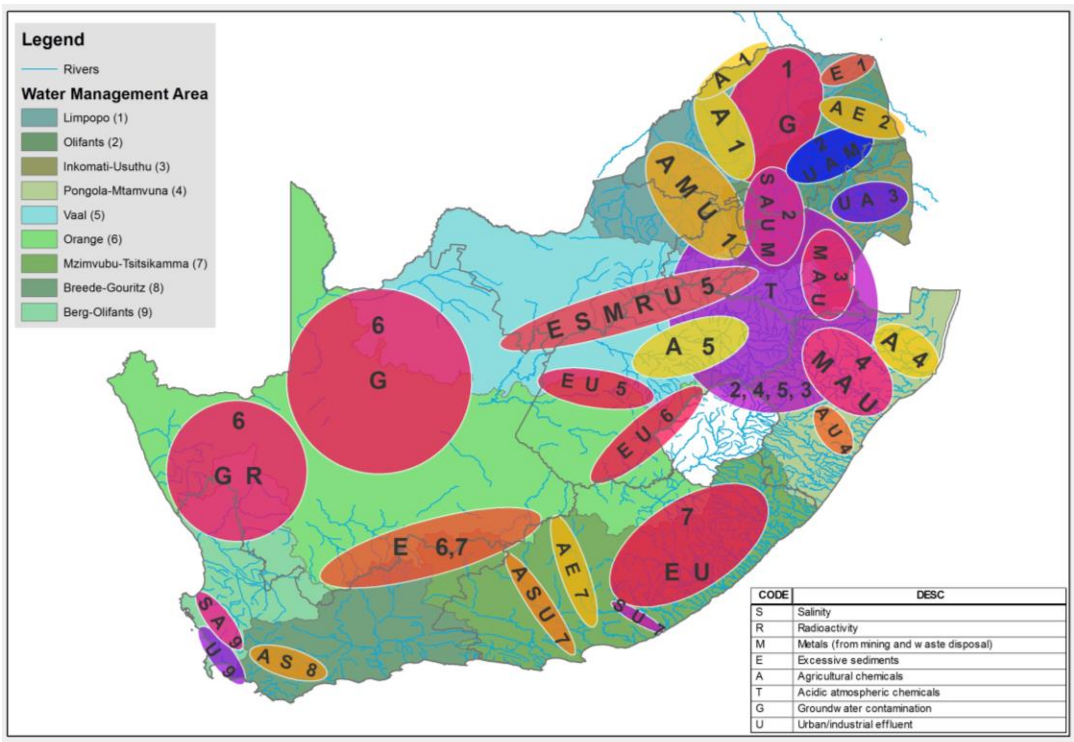

Figure E.2: Map showing the different types of water quality problems that have been recorded in South Africa (adapted from CSIR, 2010)

Future trends and water quality impacts

Through a review of future-scanning literature across various sectors, we identified five "mega-trends" which can be expected to unfold in South Africa during the next few decades, relating to climate, energy production, sustainability and rural-urban migration, which would lead to new or accelerated water quality challenges in many locations across the country. These are as follows: *climate change; hydraulic fracturing; renewable energy, water-energy-food security nexus; growth of inadequately serviced densely populated settlements; water re-use*. The potential primary water quality impacts related to these trends are outlined in **Table E.1**.

Table E.1: "Mega-trends" and their primary potential water quality impacts

"Mega-trends"	Primary Potential WQ Impacts
Climate change	Increased water temperature and evaporation. Changes in rainfall, affecting runoff and mobilisation of nutrients and other pollutants. Changed circulation patterns in deep water bodies. Increased rate of biogeochemical and ecological processes that determine water quality. Less dilution of water quality constituents in areas of decreased river flow and groundwater recharge. Increased suspended sediment, organic matter, nutrient, and hazardous substance loads washed from soils and sewer overflows due to more frequent extreme precipitation and flood events.
Hydraulic fracturing	Contamination of surface water and groundwater through spillages and/or leaks of chemical additives in hydraulic fracturing liquid. Penetration of hydraulic fracturing fluid into nearby natural groundwater. Contamination of surface water because of inadequate treatment and storage of backflow mix of fracturing liquid and natural water. By-products forming at backflow water treatment plants through reactions between hydraulic fracturing contaminants and disinfectants.
Renewable energy	CPV: No direct WQ concerns. CSP: No direct WQ concerns. Indirect concern - wet cooling

"Mega-trends"	Primary Potential WQ Impacts
	increases pressure on freshwater resources. Wind power: No direct WQ concerns. Hydropower: Impact on the downstream aquatic environment, including water quality constituents such as temperature and dissolved oxygen.
Water-energy-food nexus	Water quality management challenges covered elsewhere in this report that relate to the energy and food production sectors, as well as sectors that support the latter, such as mining and manufacturing, are relevant.
Growth of inadequately serviced densely populated settlements	Increased loadings of the following problematic constituents, in order of importance: • Pathogens, particularly E. coli – due to raw sewage inflows, faecal matter washoff during rainstorms and sullage that finds its way to a stream. • Phosphorous and nitrogen – due to raw sewage inflows, faecal matter washoff during rainstorms and sullage that finds its way to a stream. • Litter and solid waste – due to washoff during rainstorms and intentional dumping into river courses.
Water re-use	• For direct re-use: the assurance that all risks to human health or industrial process integrity (whichever is applicable) are adequately minimised. • For indirect re-use: the assurance that all risks to downstream domestic users, irrigators and eco-systems are adequately minimised. • Sludge disposal needs to be undertaken with minimal risks to surface water and groundwater near the disposal operation. • Brine disposal needs to be undertaken with minimal risks to surface water and groundwater near the disposal operation.

Root cause analysis of priority water quality issues

Against the background of the above review of water quality issues and their characteristics, an analysis of the primary drivers and the root causes of the five priority water quality issues was performed. The findings are outlined in **Table E.2.**

Table E.2: Primary drivers and root causes of the priority water quality issues

Primary Drivers	Root Causes
Eutrophication	
Municipal sewage discharges and overflows	A notable degree of dysfunction in many municipalities due to a range of institutional, technical/management incapacity, financial and political reasons. Poor cooperative governance and inadequate cross-regulatory interfaces with DWS
Diffuse nutrient loadings from cultivated land	Inappropriate fertiliser, tillage and land management practices Poor cooperative governance and inadequate cross-regulatory interfaces with DWS
Acidification and Acid Mine Drainage	
Discharge of acidified groundwater from mines	Historical and recent lack of precautionary planning, regulation and enforcement Poor cooperative governance and inadequate cross-regulatory interfaces with DWS
Contaminated seepage, runoff and spills - mines and coal-fired power stations	Lack of compliance with licence conditions; inappropriate licence conditions; inadequate enforcement capacity Poor cooperative governance and inadequate cross-regulatory interfaces with DWS
Washoff and leaching of acidic atmospheric deposits stemming from smoke-stack emissions	Inappropriate licence conditions; lack of monitoring and reporting of own pollution loads; lack of enforcement Poor cooperative governance and inadequate cross-regulatory interfaces with DWS
Salinisation	
Diffuse drainage and washoff of rainfall-mobilised natural salts in dryland-cultivated soils, as well as diffuse sub-surface irrigation return flows	Inappropriate dry-land tillage and crops, over-irrigation, inappropriate irrigation technology, lack of intercepting drains leading to evaporation ponds Poor cooperative governance and inadequate cross-regulatory interfaces with DWS

Primary Drivers	Root Causes
Mine water drainage and acidic atmospheric deposits	See previous water quality issue
Urban Runoff Pollution	
Stormwater runoff from formalised pervious and impervious urban areas or sewer overflows into stormwater conduits	Inadequate implementation of best management land-use practices and a notable degree of dysfunction in relevant municipalities
Stormwater runoff from less-formalised dense human settlements, including direct disposal of domestic refuse, grey water, seepage from latrines and human and animal excrement, as well as sewer overflows	Notable degree of dysfunction in relevant municipalities and inadequate implementation of best management land-use practices Poor cooperative governance and inadequate cross-regulatory interfaces with DWS
Sedimentation	
Anthropogenically-driven erosion of surface soils of catchments and of stream/river banks through poor land management activities where soils are erodible or by in-stream and riparian disturbance	Inappropriate crop cultivation and silviculture practices; over-grazing; destruction of riparian vegetation buffer zones; destruction of wetlands; physical modification of river channels and banks; less-formalised dense human settlements; careless construction activities Poor cooperative governance and inadequate cross-regulatory interfaces with DWS

SWOT analysis

A SWOT (strengths/ weaknesses/ opportunities/ threats) analysis of the water quality management environment in South Africa was conducted during the Stakeholder Workshop No. 1 in the form of five parallel breakaway teams. The outcomes of that exercise as well as inputs from other stakeholders are presented in matrix form below. The Strengths/Weaknesses component focused on the water quality management environment internal to DWS and CMAs, while the Opportunity/Threats component focused on the water quality management environment external to DWS and CMAs. The outcomes of the SWOT analysis provide a range of highly relevant internal and external focal points for the formulation of a Policy framework and the eventual development of the IWQMS and its Implementation Plan.

Conclusions

1. A wide range of water quality issues has been identified for both surface water and groundwater and, of these, five are shown to require high prioritisation in terms of water quality management. These five priority issues are: *eutrophication, salinisation, acid mine drainage and acidification, sedimentation and urban runoff pollution*.
2. Some of the remaining water quality issues, such as microbial (pathogen) pollution, agrochemical pollution and metals pollution, are known to be potentially harmful, but because of inadequate monitoring, their geographical prevalence is not known and for that reason they are not classed (yet) as priority issues.
3. The prevalence and/or severity of impact of particular water quality issues varies markedly from river system to river system and from WMA to WMA.
4. A root cause analysis of the five priority water quality issues indicates that, in each case, lack of prioritisation of cooperative governance and related cross-regulatory interfaces by various combinations of government institutions are obstacles in dealing effectively with the "drivers" of such water quality issues.
5. A root cause of eutrophication is the notable degree of dysfunction in many municipalities, implied by the 2013 Green Drop Analysis results, which found that almost 50% of 824 municipal wastewater treatment facilities had to be rated as "critical" or "poor".
6. Inappropriate land-use and poor land management by various land-use and water-use sectors are root causes of both sedimentation and salinisation.
7. The root cause analysis also indicates that acid mine drainage and acidification is the result of past and current neglect of a range of best management practices in mine rehabilitation, waste control and contaminated runoff management in the mining and energy sectors.
8. A root cause of urban runoff pollution is the notable degree of dysfunction in many municipalities, referred to above, as well as inadequate implementation of best management land-use practices.
9. Six "mega-trends" are identified which can be expected to unfold in South Africa during the next few decades, relating to climate, energy production, sustainability and rural-urban migration, which would lead to new or accelerated water quality challenges in many locations across the country. These are as follows: climate change; hydraulic fracturing; renewable energy; water-energy-food security nexus; growth of inadequately serviced densely populated settlements; water re-use.
10. A SWOT analysis of the water quality management environment identifies a range of internal strengths and weaknesses of DWS (including CMAs) that should inform the formulation of a Policy framework: 61 "weaknesses", which should be among the to-

be identified focal areas for the implementation of the future IWQMS, and 28 “strengths”, which should be recognised as foundational to the formulation of the future IWQMS.

11. In the water management environment external to DWS (including CMAs) 43 “threats” and 32 “opportunities” are identified through the SWOT analysis. These considerations should play a critical role in guiding formulation of a Policy framework and development of components of the IWQMS and its Implementation Plan.

12. On the basis of the Root Cause and SWOT analyses a number of “must do” pointers are outlined for the Policy and Strategy development process.

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LIST OF ACRONYMS

Abbreviation	Meaning
AMD	Acid Mine Drainage
BOD	Biological Oxygen Demand
CARA	Conservation of Agricultural Resources Act
CEO	Chief Executive Officer
CFC	Chlorofluorocarbons
CFC	Chlorofluorocarbons
CFRI	Commercial Forestry Research Institute
CM&E	Comprehensive Monitoring and Evaluation
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
COD	Chemical Oxygen Demand
COGTA	Department of Cooperative Governance and Traditional Affairs
CPV	Concentrated photovoltaic
CSIR	Council for Scientific and Industrial Research
CSR	Concentrated solar power
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DHS	Department of Human Settlement
DMR	Department of Mineral Resources
DNAPLs	Dense Non-aqueous Phase Liquids
DO	Dissolved oxygen
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
DWS	Department of Water and Sanitation
EDC	Endocrine Disrupting Chemicals
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organisation
GA	General Authorisation
GCM	Global Circulation Models
GDG's	Global Development Goals
HCB	Hexachlrorobenzene
HFD	Hybrid frequency distribution

HP	Hydropower
IMC	Interim Ministerial Committee
IRP	Integrated Resource Plan
IT	Information Technology
IWQM	Integrated Water Quality Management
IWRM	Integrated Water Resources Management
LNAPLs	Light Non-aqueous Phase Liquids
LTAS	Long Term Adaptation Scenarios
MDGs	Millennium Development Goals
MPRDA	Mineral and Petroleum Resources Development Act
MW	Megawatt
MWh	Megawatt hour
NBBN	National Biodiversity and Business Network
NCMP	National Chemical Monitoring Programme
NDP	National Development Plan
NEMA	National Environmental Management Act
NEMP	National Eutrophication Monitoring Programme
NGA	National Groundwater Archive
NMMP	National Microbial Monitoring Programme
NPS	Non-point Source
NTMP	National Toxicant Monitoring Programme
NWA	National Water Act
NWRS	National Water Resource Strategy
NWRS2	National Water Resource Strategy-2
OPs	Organic Pollutants
PAC	Project Administration Committee
PAH	Polycyclic Aromatic Hydrocarbons
PASA	Petroleum Agency of South Africa
PCB	Polychlorinated biphenyls
PCB	Polychlorinated biphenyls
PCBs	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PCPs	Personal Care Products
PhACs	Pharmaceutically Active Compounds
PMC	Project Management Committee

POPs	Persistent Organic Pollutants
PSC	Project Steering Committee
PV	Photovoltaic
RDM	Resource Directed Management
REIPPP	Renewable Energy Independent Power Procurement Programme
RQIS	Resource Quality Information Services
RQS	Resource Quality Services
RSA	Republic of South Africa
SABS	South African Bureau of Standards
SABS	South African Bureau of Standards
SAIAE	South African Institution of Agricultural Engineers
SAICE	South African Institution of Civil Engineers
SALGA	South African Local Government Association
SCPOPs	Stockholm Convention on Persistent Organic Pollutants
SDG	Sustainable Development Goals
SDGs	Spatial Development Goals
SWOT	Strength Weaknesses Opportunities Threats
TCE	Trichloroethylene
TCE	Trichloroethylene
TDS	Total Dissolved Solids
UNEP	United Nations Environmental Programme
USA	United States of America
USEPA	United States Environmental Protection Agency
UST	Underground Storage Tanks
WARMS	Water Authorisation and Registration Management System.
WDCS	Waste Discharge Charge System
WHO	World Health Organisation
WMA	Water Management Area
WMS	Water Management System
WQ	Water quality
WQM	Water Quality Management
WRC	Water Research Commission
WWTW	Waste Water Treatment Works

1. INTRODUCTION

In South Africa, Water Quality Management (WQM) has evolved over time from a pollution control approach that focussed on the enforcement of uniform effluent standards. The current approach of resource planning and management is complemented with appropriate source management controls and remedial efforts, within the context of Integrated Water Resource Management (IWRM). The water law review in 1998, for the first time, introduced the legal means to implement modern-day Integrated Water Quality Management (IWQM) imperatives. However, implementation is in many respects hampered by the lack of suitable supporting strategic and operational direction. The focus of this project is to develop Water Quality Management Policies, Strategies, and implementation actions that are relevant to addressing water quality deterioration and that are pragmatic, implementable and appropriate to the future institutional and governance landscape in South Africa.

The objective of this situation assessment report is to identify water quality issues and water quality management challenges for South Africa by providing a high-level overview of the water quality situation. The report provides a review of a wide range of water quality issues, the root causes of water quality deterioration and geographical differences in water quality issues across South Africa. Based on the findings of this review a prioritisation exercise identified five issues that require high prioritisation in terms of water quality management. A SWOT analysis is included that identifies the strengths, weaknesses, opportunities and threats for water quality management in South Africa at a high level.

This situation assessment (Report 1.3 in the series), along with a comprehensive review of water quality management policies and practice in the South African context and international best practices (Report 1.2 in the series), **constitute part of the assessment phase of the project** and will be used to inform the policy, strategy and implementation plan (converting policy into practice) development process (**Figure 1**).

Figure 1: Phases of the project

2. BACKGROUND TO WATER QUALITY ISSUES

Water quality is the term used to describe the physical, chemical, biological and aesthetic properties of water that determines its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems (DWAF, 1996).

Physical water quality concerns refer to changes in the physical properties of the water such as the water temperature, water clarity, odour, taste, pH, etc. Concerns related to the physical properties of water bodies include:

- Artificial changes to the **temperature** of the water because of cold or heated discharges;
- Changes in water clarity due to increased **suspended sediment** loads;
- Changes in the **dissolved oxygen** content of the water due to warmer water temperatures or the discharge of oxygen-consuming compounds in the water;
- Unnatural **odours** due to chemical discharges or the decomposition of organic material in the water;
- The presence of **urban litter** (e.g. building rubble, plastic containers, and food wrappers) in urban streams;
- Unnatural **tastes** due to chemical discharges or the breakdown of blue-green algae in the water.

Chemical water quality concerns refer to changes in the chemical properties of the water such as the amount of dissolved salts, the pH, dissolved nutrients, etc. These concerns include:

- An increase in **salinity** of the water due to irrigation return flows or the discharge of industrial effluents into water bodies;
- An increase in the **nutrient** content of the water due to the discharge of nutrient-rich treated and untreated domestic effluents to rivers;
- **Acidification** of streams and rivers due to the inflow of acid mine drainage into these water bodies and/or atmospheric deposition;
- The presence of **agro-chemicals** in water bodies from pesticides and herbicides used to control agricultural pests; or
- The presence of **radioactive material** in the water from upstream mining activities.

Biological water quality concerns refer to changes in the biological properties of the water such as the amount of algae in the water, harmful bacteria and pathogens, health of biota such as fish, invertebrates, or aquatic reptiles and animals, etc. These concerns include:

- Blooms of harmful **algae** as a result of enrichment of the water with plant nutrients;
- Increase in water borne **pathogens** as a result of raw or partially treated domestic wastewater discharges or leaking sewers;
- **Fish** kills as a result of low oxygen, high suspended sediment or spills of toxic agro-chemicals into the water;
- Impairment of the endocrine systems of aquatic organisms due to the presence of **endocrine disrupting chemicals** (EDCs) in the water; or
- Death of **crocodiles** as a result of poor water quality and other wildlife due to high concentrations of toxic cyanobacteria.

These concerns and the water quality status of South African water bodies are unpacked in more detail in the next section of the report.

It is rare that only a single water quality concern would be present. Most often, a water quality concern would become problematic due to a combination of factors. This concept is illustrated in **Figure 2** for waterborne pathogens pollution and in **Figure 3** for nutrient enrichment and resultant proliferation of nuisance algae. As an example, heavy rainfall creates runoff that often carries with it suspended particles that make the water turbid. For example, in an urban area with blocked sewers, the runoff will be contaminated with faecal coliforms. The joint presence of nutrients and suspended solids can be problematic because nutrients adsorb onto particle surfaces. This can in turn increase faecal coliform growth rates. Higher water temperatures also increase growth rates while, on the other hand, extreme pH conditions increase the rate at which they decay. Thus, although the concern is the presence of pathogens in the water, their fate (growth or decay rate) is affected by other constituents present in the water.

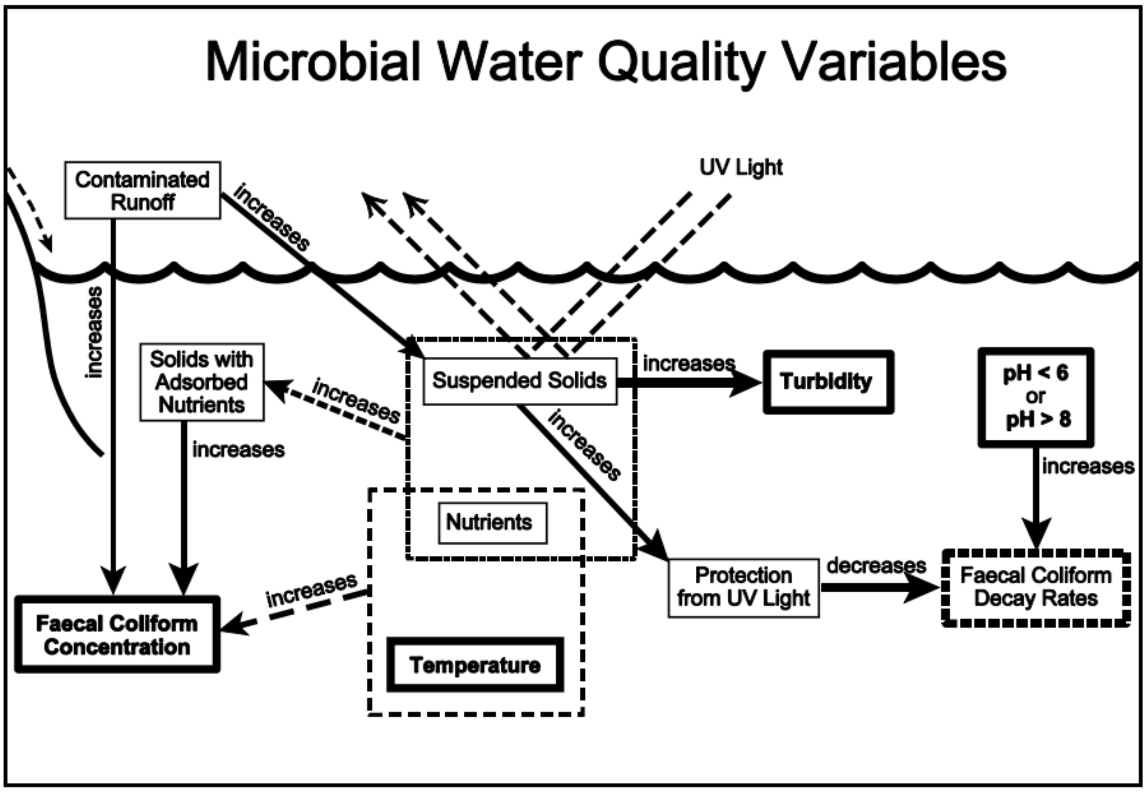

Figure 2: An overview of microbial pollution and the interactions with other constituents and physical characteristics (DWAF, 2002a)

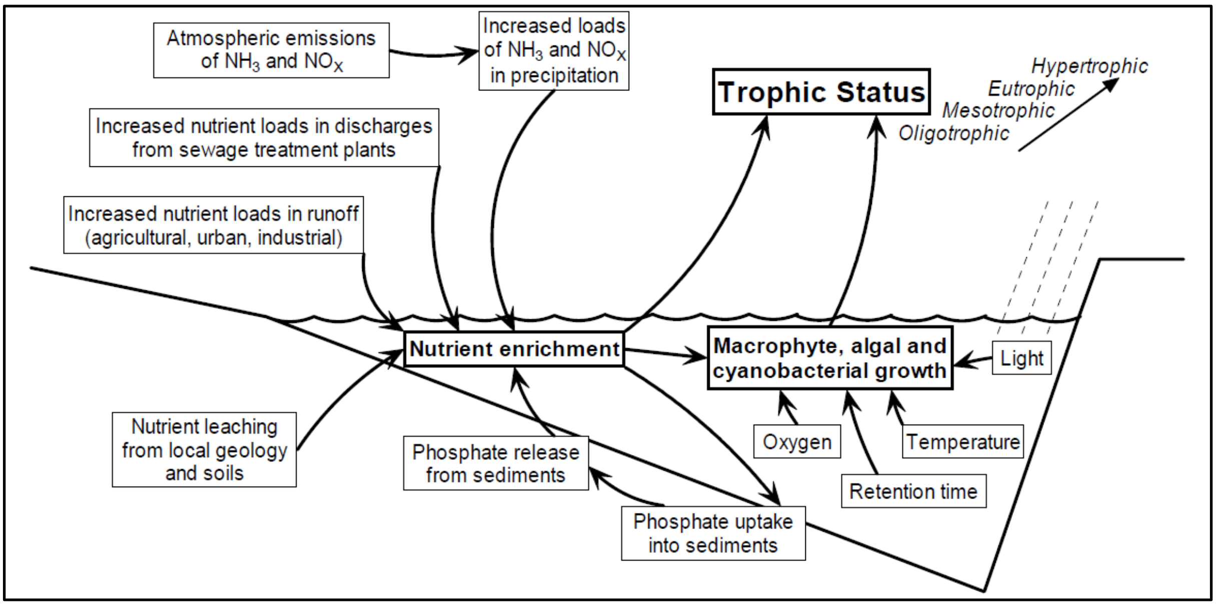

Figure 3: An overview of nutrient enrichment and algal growth and the interactions with other constituents and physical characteristics (DWAF, 2002b)

3. WATER QUALITY ISSUES

3.1 Salinisation

Salinity refers to the total dissolved inorganic compounds in the water and is generally measured as the total dissolved solids (TDS) (DEAT, 2000), the electrical conductivity of the water, or as the individual constituents that make up the TDS. Salinisation refers to the increase in the amount of salts or dissolved solids in the water, as well as the accumulation of salts in soils, to the detriment of cultivated crops. It also refers to the build-up of salts in a river system to such a level that it poses a threat to the ecological integrity of the river and interferes with the desirable uses of the water.

3.1.1 Surface water situation

Human activities that contribute to salinity in surface waters include the discharge of municipal and industrial effluent; irrigation return water; urban storm-water runoff; surface mobilisation of pollutants from mining and industrial operations and seepage from waste disposal sites, mining and industrial operations (Van Niekerk *et al*., 2009). Effects of increased salinity include salinisation of irrigation soils and a reduction in crop yields; 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 aquatic biota.

In South Africa, there are three main sources of salts. The first is naturally saline soil which, if disturbed, leaches salts into surface water streams, the second source is irrigation return flows, and the third source is mine water drainage and the discharge of industrial effluents, either directly into a water resource or via a domestic WWTW (**Figure 4**). In general, the salt concentrations of domestic wastewater fall within the general effluents standards, not adding much to the salt load. However, industrial wastewater treated at a domestic WWTW can add substantially to the salt loads from that works. River systems such as the Breede, Olifants (both Mpumalanga and Western Cape), Orange and middle and lower Vaal system all show significant increasing longitudinal salinity gradients as a result of industrial and irrigation return flows (DWA, 2010, Van Niekerk *et al*., 2009).

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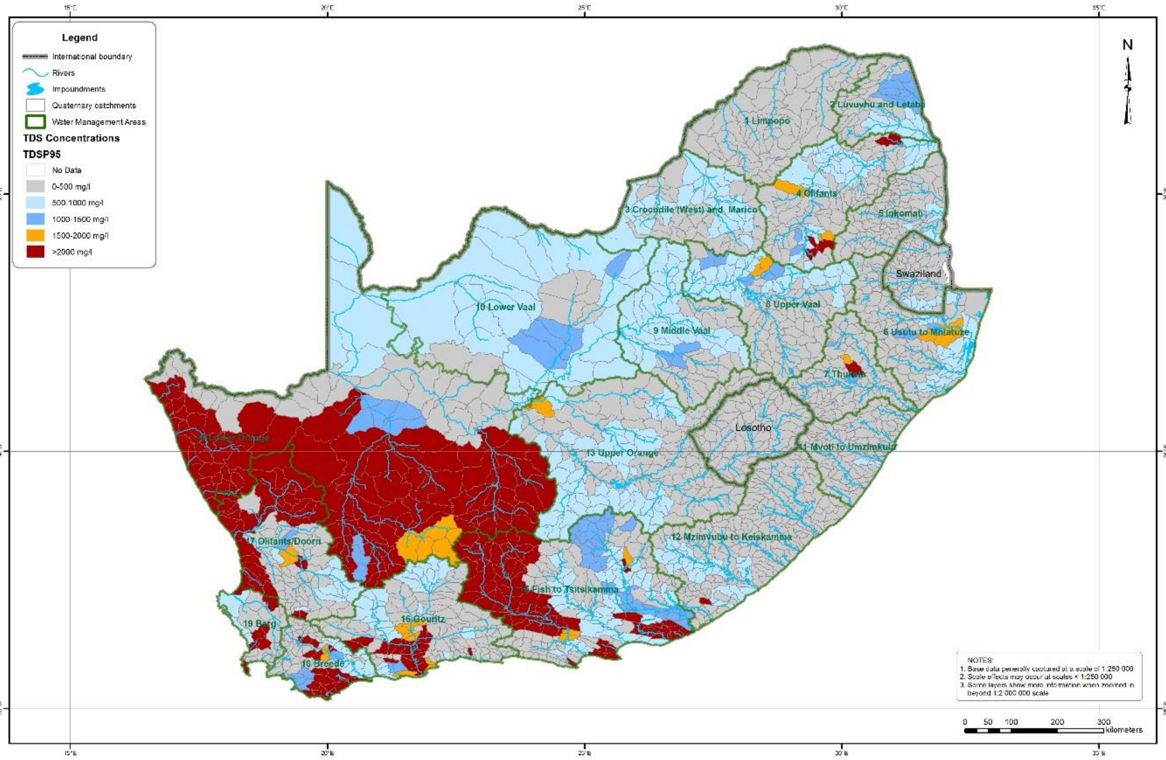

Figure 4: Total dissolved solids (TDS) concentrations in surface waters in South Africa (Bailey and Pitman, 2015).

Anthropogenic salinisation of inland waters emanate from a number of sources, e.g. saline industrial effluents, irrigation, clear-felling and return flows from sewage effluents. 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 (CSIR, 2010).

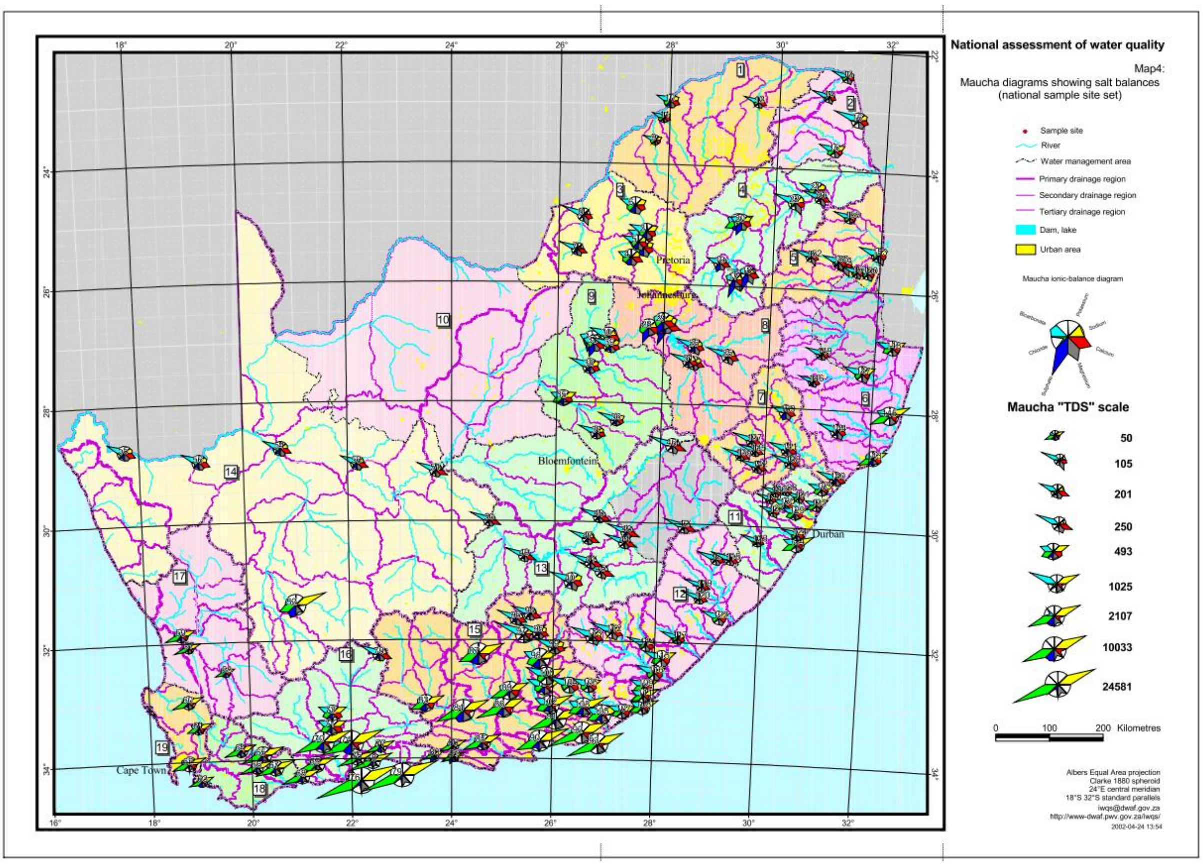

Figure 5: Overview of TDS concentrations and its composition at selected monitoring points in South Africa (DWS, 2008).

Problems associated with salinisation include (CSIR 2010, Griffen *et al*. 2014):

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

The Department's RQIS investigated the long-term changes in salinity and the value of long-term data sets (Van Niekerk *et al*., 2009). They identified 25 monitoring points with continuous data over a 25-year period and analysed these for long-term trends (**Figure 6**). They found that most sites were too far apart for detailed analysis of whole river systems, though an upward trend was apparent in the Lower Orange River and a downward trend in the Great Fish River. Salinity in the Tugela River remained stable, well below the 70 mS/m guideline for drinking water. Their findings underlined the importance of long-term data sets for assessing and managing aquatic systems and for providing the impetus to continue building and maintaining long-term sampling programmes.

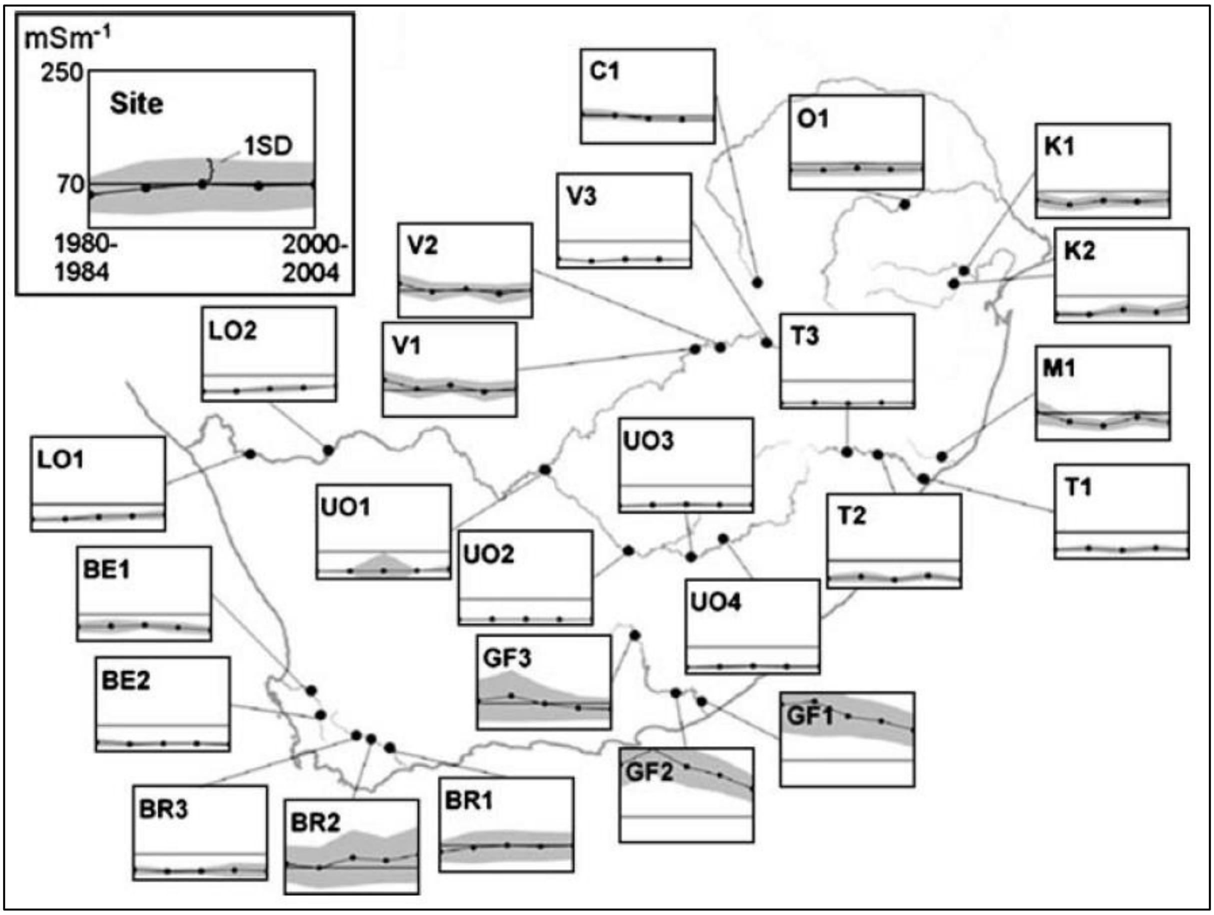

Figure 6: Map showing changes in EC from 1980 to 2004 in selected rivers. The graphs depict the mean EC for the periods 1980 to 1984, 1985 to 1989, 1990 to 1994, 1995 to 1999 and 2000 to 2004. The area between −1 and + 1 standard deviations is shaded on each graph. The horizontal lines on the graphs show the 70 mS/m guideline for drinking water (Van Niekerk *et al*, 2009).

Dallas and Day (2004) summarised the impacts of increasing salinity levels on aquatic organisms (Griffen *et al*, 2014):

- The rate of change rather than the final salinity levels is often most critical. Many organisms can physiologically adapt to slow changes or acclimate to higher salinity levels.
- Juveniles are generally more sensitive to changing salinity levels.
- In general, there appears to be an upper salinity level of around 5000-8000 mg/L above which acclimation is no longer possible.
- Salinity may act antagonistically or synergistically with other toxicants due to its impact on speciation.

- The response of freshwater organisms is also related to their evolutionary origin.
- Toxicity of various salts is related to the toxicity of individual ions.

The National Chemical Monitoring Programme (NCMP) monitors the chemical water quality of South Africa’s surface water resources. The NCMP is the longest running of the national monitoring programmes, with some sample sites having data extending back to the 1970s and earlier. More than 700 sites are monitored of which about 330 are sampled at an average frequency of about two weeks. The raw data are stored on DWA’s Water Management System (WMS) database. DWA’s Resource Quality Information Services (RQIS) section has a very good record of water quality going back some forty years and covering hundreds of sites, mostly rivers, throughout the country. There is very good knowledge of some aspects of the water chemistry of rivers, particularly levels of Electrical Conductivity or salts (i.e. Total Dissolved Solids, TDS), major ions and dissolved nutrients.

Gaps in NCMP include routine monitoring of metals, organic pollutants in rivers and reservoirs, turbidity and suspended sediments, river and reservoir temperature and oxygen – all which are important for determining the water quality status of rivers.

3.1.2 Groundwater situation

Natural salinisation of groundwater occurs in arid areas where the evaporation rate exceeds the recharge rate of groundwater. These areas generally occur to the west of the country where low rainfall and high temperatures prevail. In areas such as the Kalahari and certain parts of the Karoo, naturally saline or brackish groundwater is found and is locally referred to as “brakwater”.

In coastal regions, solutes of chloride and sulphate may be blown inland by sea breezes and deposited on the surface where dilution and transport occurs during recharge events. Intrusion of seawater may occur in coastal regions where the over-abstraction of groundwater takes place. Seawater intrusion generally occurs in coastal towns dependent on primary sandy aquifers located close to the coast (<5km).

Other sources of salinity are the results of anthropogenic activities such as mining and industrial processes. In mining, the process of neutralising acidic mine water results in large amounts of saline or brine water. Leaks in infrastructure may result in saline water leaking into the groundwater, thereby increasing salinity.

Airborne solutes of chloride and sulphate may also be found in airborne dust generated by industrial processes. When this dust is deposited on the surface, recharge events may transport these solutes to the groundwater table, thereby increasing salinity.

Groundwater is also monitored by DWS as part of long-term monitoring. Groundwater monitoring stations around the country are shown in **Figure 7**7 (DWA 2010). Data is stored in a web-based database called the National Groundwater Archive (NGA) that was released internally to users in the Department in October 2008.

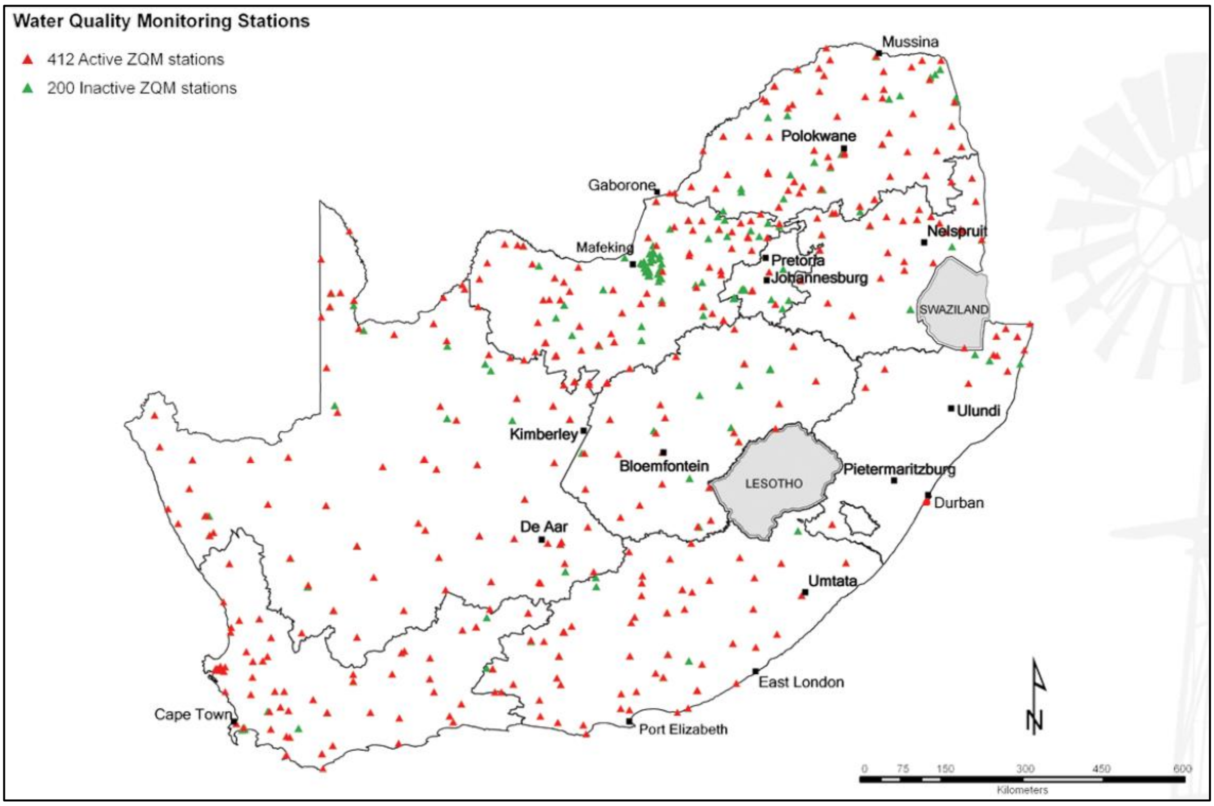

Figure 7: Groundwater quality monitoring network (DWA, 2010)

The NGA contains data for more than 249 000 geosites, of which 242 000 are boreholes. However, a number of issues exist (DWA, 2010):

- There is evidence that groundwater data holdings are declining in parts of the country (e.g. the Tshwane dolomites near Pretoria);
- Inaccessibility of data and fragmentation of databases are also serious problems;
- Earlier records contain estimated locations based on the cadastral farm name on which the borehole is found – this can lead to inaccuracies in position of several kilometres;
- Records date from the early part of the last century to the present day; some records are many decades long, others consist of only a single point and date;
- Much groundwater data is held by the private sector, where it is difficult to access, and private sector drillers do not submit borehole data to the Department;
- A lack of standard data capturing formats also hampers the integration of databases;
- Improved institutional arrangements for data collection are required;
- Existing data needs to be verified, and existing databases need to be integrated; and
- The backlog of sample processing / analysis at laboratories is a concern.

3.2 Nutrient enrichment and eutrophication

Nutrient enrichment refers to the accumulation of plant nutrients in rivers and dams in excess of natural requirements, resulting in eutrophication that may affect the composition and functioning of the natural aquatic biota (DEAT, 2000, Rossouw *et al*., 2008). The most essential nutrients required by plants are nitrogen and phosphorus in various forms (NO_2, NO_3, NH_4, and PO4). Eutrophication is of concern because it can have numerous negative impacts, which include ecological impacts (such as the deterioration of water quality and loss of biodiversity), as well as aesthetic, recreational and human health impacts. These negative impacts also have a significant economic impact. The direct impact is the excessive growth of microscopic algae and macrophytes (rooted and free-floating water plants), leading to impacts on recreation and sporting activities; the presence of toxic metabolites in blue-green algae (cyanobacteria); the presence of taste- and odour-causing compounds in treated drinking water; and difficulty in treating the affected water for potable and/or industrial use.

3.2.1 Surface water situation

In South Africa, nutrient enrichment is generally associated with water bodies that receive large volumes of treated and untreated wastewater, and agricultural runoff rich in fertiliser.

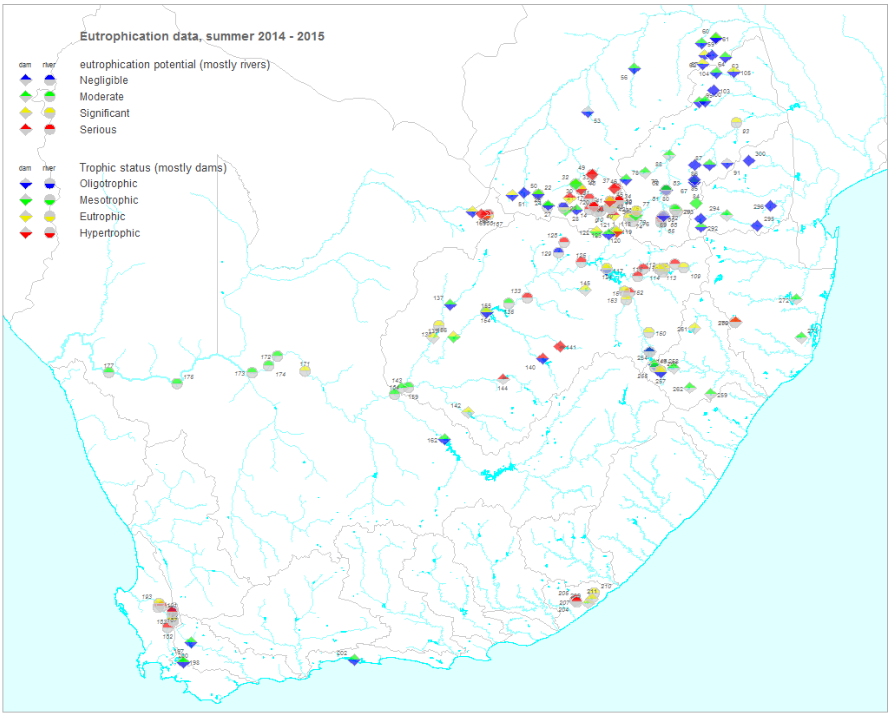

Figure 8: Eutrophication potential and trophic status of South African water bodies for the summer of 2014/15 (NEMP report by DWS)

In thermally stratified reservoirs, internal loading of nutrients from the anoxic hypolimnion can also add substantial amounts of nutrients to the water column during autumn turnover. Many South African reservoirs show symptoms of eutrophic and even hypertrophic

(**Figure 8 and 9**) (highly enriched) conditions (DWA, 2010; CSIR, 2010; Thornton *et al*., 2013; Matthews and Bernard, 2015).

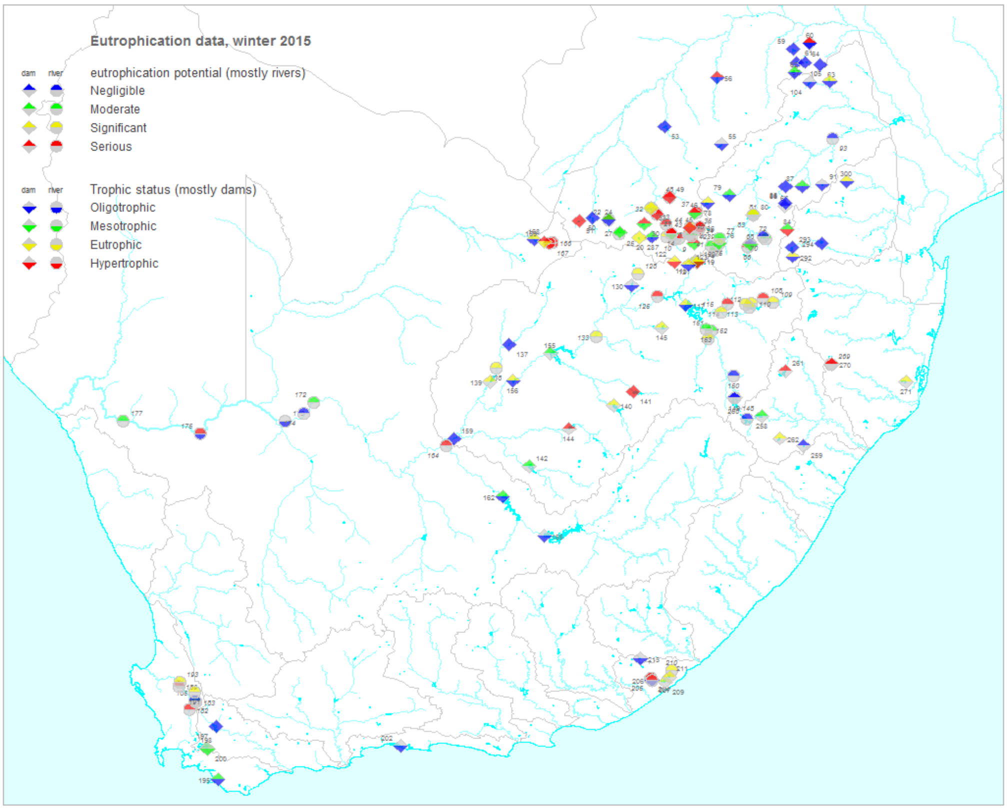

Figure 9: Eutrophication potential and trophic status of South African water bodies for the <u>winter</u> of 2014/15 (NEMP report by DWS)

The causes of nutrient enrichment include:

- Accelerated population growth and associated settlement patterns.
- Catchment development changes, such as dams that are built for water storage to supply increasing population needs.
- Increased wastewater treatment works discharges.
- Increased fertiliser applications to increase food production.
- Intensive farming practices that cause increased nutrient-polluted return flows.
- Poor agricultural practices, for example when farmers plough and cultivate the riparian zones of water resources.

Downing and van Ginkel (2004) found that that cyanobacterial blooms (blue-green algae) are widespread and typically seasonal, with water resources subject to eutrophication commonly experiencing water quality problems. These bloom events vary in frequency, duration and severity primarily due to the condition of the catchment, but also the nature of the water source, abstraction points, and regional climatic conditions.

Microcystis is the dominant problem cyanobacterial genus, with Anabaena also being common. Both Microcystis and Anabaena produce hepato- and neurotoxic secondary metabolites, resulting in acute or sub-acute liver toxicity. However, the most common problem associated with cyanobacterial blooms is taste and odour in treated drinking water. Data on toxin and geosmin / 2-methyl isoborneol levels are extremely limited due to the limited resources for analysis and the cost of such analyses.

The presence of high concentrations of nutrients also supports the rapid growth of macrophytes (Griffen *et al*., 2010). Excessive macrophyte biomass blocks waterways, impedes access to dams and rivers, clogs drainage systems and contributes to flooding and the destruction of canals. Control of water hyacinth (Eichhornia crassipes) alone costs South Africa in the order of R12 million per annum. Many aquatic macrophytes are exotic, problem-causing species, including water hyacinth, red water fern (Azolla spp.), water lettuce (Pistia stratiotes), Kariba weed (Salvinia molesta), Hydrilla (Hydrilla verticillata) and parrot's feather (Myriophyllum aquaticum). Hydrilla is the latest addition to the list of problematic species, although its presence was already recorded in South Africa as early as 1963 (Coetzee *et al*. 2011, cited in van Ginkel 2011).

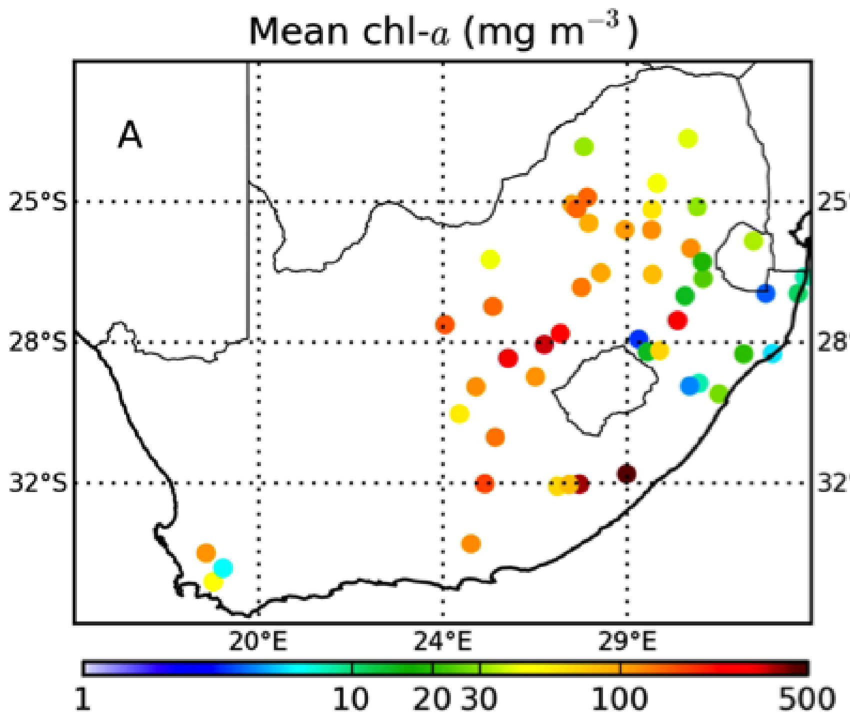

Figure 10: Trophic status in 50 South African water bodies (expressed as mean chlorophyl-a) (Matthews, 2014)

The National Eutrophication Monitoring Programme (NEMP) monitors variables such as chlorophyll, dissolved oxygen, total nitrogen and total phosphorus, and algal species composition in addition to the variables measured by the NCMP and is mostly targeting reservoirs. Monitoring data exists for about 80 reservoirs.

3.2.2 Groundwater situation

High nitrate levels occur in groundwater in a variety of geological settings and a diversity of environmental conditions. In most cases, the occurrence of high nitrate in groundwater is due to contamination related to anthropogenic activities. Naturally occurring high nitrate levels are found in geological formations such as the Stormberg Basalt in the Springbok Flats and can be attributed to the secondary characteristics of the geological formation and associated factors allowing the enrichment with nitrogen derived from other sources (Tredoux and Talma, 2006, cited in Israel *et al.* 2011).

Feedlots, dairy farming, sewage disposal & irrigation, fertiliser application, inappropriate on-site sanitation at rural villages and towns are some of the major sources of nitrate. Such activities should be restricted to areas of aquifers that have impermeable layers to protect the groundwater resource. Low soil organic contents in the interior of South Africa limits the occurrence of natural denitrification, hence the persistence of nitrate in semi-arid and arid environments in South Africa.

Nitrate concentrations in South Africa have been studied for decades (Tredoux and Talma, 2006, cited in Israel *et al*. 2011). A nitrate distribution map was produced and published during 2001 (Tredoux *et al*., 2001). Israel *et al*. (2011) developed a nitrate distribution map for the country, using all available data to get an overview of the distribution and concentrations that are present in South Africa's groundwater resources (**Figure 11**). The resultant map is very similar to that produced by Tredoux *et al*. (2001), however, areas of the Northern Cape are now lacking data and areas in the Western Cape are now showing concentrations that are more elevated.

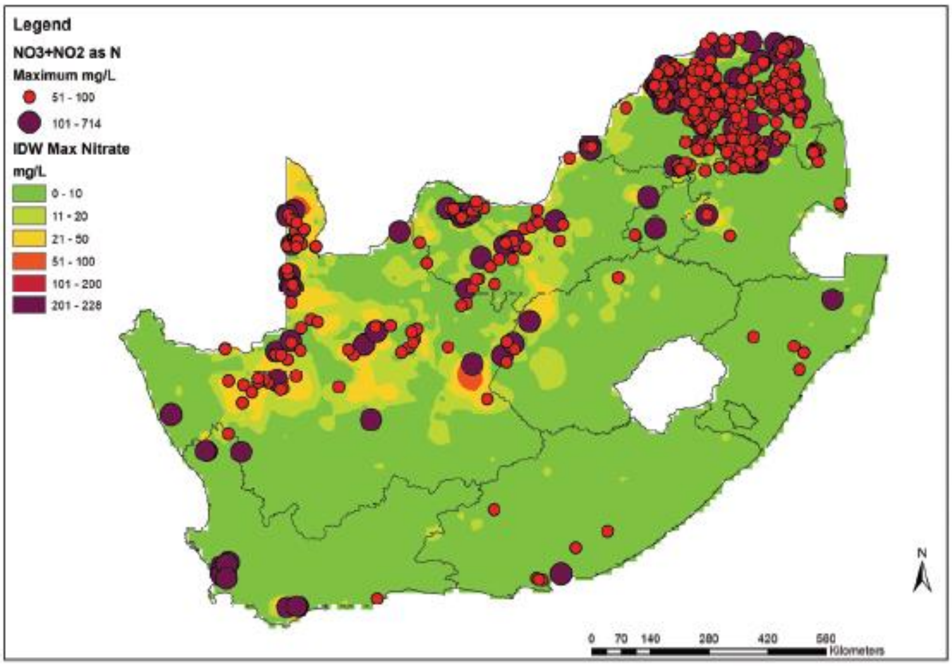

Figure 11: Sampling points with a Maximum NO_3+NO_2 as N greater than 50 mg/L overlain on the Interpolated N map from Tredoux *et al*., 2001 (Israel *et al*. 2011)

Israel *et al*. (2011) concluded that:

- The Western Cape Province would seem to be more negatively affected by elevated nitrate concentrations over the last decade than before;
- According to available data the Limpopo Province and Kalahari are still strongly affected by elevated nitrate concentrations;
- There is a scarcity of data points in certain urban centres as well as in the central part of the country; and
- A part of the Northern Cape Province now lacks data which was used in the previous 2001 map. This may indicate abandonment of well fields, a halt to sampling or an error in the database. This area previously had elevated nitrate levels.

Elevated nitrate levels are associated with mining areas, urban areas (in particular the rural cluster), and formal and informal human settlements. Elevated levels of nitrate within the agricultural sector, namely, permanent and temporary commercial dryland, and temporary subsistence dryland farming were confirmed by the data. In areas where monitoring is ongoing and data is available, nitrate pollution and elevated nitrate concentrations still persists. The extent and distribution would seem to be increasing with new areas being affected. The lack of data in certain parts of the country may be obscuring the actual extent of nitrate pollution in South Africa's groundwater resources.

3.3 Acidification, acid mine drainage, and alkalinity

Acid mine drainage refers to water that is polluted by contact with mining activities. The pH of natural waters is determined largely by geological and atmospheric influences. Freshwater resources in South Africa are relatively well-buffered. However, human-induced acidification, from industrial effluents, mine drainage and acid precipitation, can cause a lowering of the pH, leading to mobilisation of elements such as iron, sulphate, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc. This may affect the aquatic biota, as well as mining, domestic, industrial and agricultural users (corrosion of metal equipment and appliances). It can also cause unnatural colours in streams and rivers receiving acid mine drainage water.

3.3.1 Surface water situation

In South Africa, acid mine drainage and acidification are generally associated with coal and gold mining activities (CSIR, 2010, DWA, 2011) and acidic atmospheric deposition (Josipovic *et al.*, 2011) in the Highveld and eastern interior. A recent assessment by DWS indicated that, in general, pH appears to be increasing and our rivers are becoming more alkaline (DWS, 2015). It was recommended that this phenomenon be investigated in more detail.

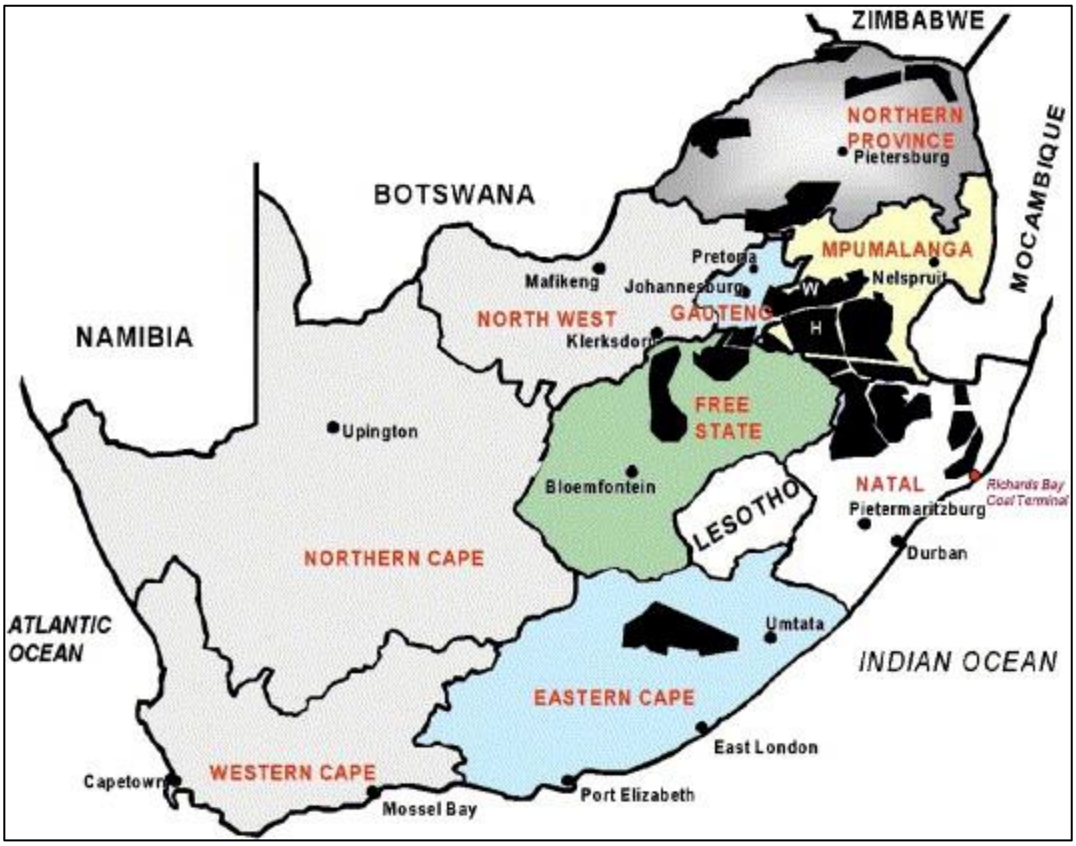

Figure 12: The distribution of the South African coalfields (Pinetown *et al.*, 2007).

Acid mine drainage (AMD) occurs when water flows over exposed sulphide minerals, which oxidise in the presence of water and oxygen, causing the water to become acidic, which then dissolves other toxic metals. Exposure and oxidation of pyrite and other sulphide minerals occur in mine wall rocks, backfill, waste rock piles, low-grade ore stockpiles and tailings deposits. In and around South African gold mines, pyrite (FeS_2) present in gold ore dissolves on oxidation and releases iron and sulphuric acids. Apart from iron, the associated decreasing pH is also conducive to the mobilisation of various other metals, such as copper, lead, aluminium, manganese and uranium. Although the AMD generating reactions also occur in abiotic environments, colonies of microorganisms such as certain acidophiles (bacteria thriving under acidic conditions), greatly accelerate the decomposition of metal ions. AMD, generated through the ingress of water into mine voids, is generally characterised by one or more of the following: low pH, high salt content (mostly made up of sulphates), and high levels of metals – particularly iron (giving it the red-orange colour). In cases where uranium is present, radiological risks may also be present (Refer to Section 3.13).

Pyrites are also common in coal deposits and AMD is found in association with coal mining areas in South Africa (**Figure 12**).

AMD has been described as the largest single environmental problem facing the mining industry, particularly because it is persistent and costly, and tends to be a liability for mines long after they cease to operate. The importance of finding a solution to the rising AMD issue in South Africa and the need for inter-departmental cooperation led to the establishment in 2010 of an Inter-Ministerial Committee (IMC) on AMD, comprising the Ministers of Mineral Resources, Water and Environmental Affairs, and Science and Technology, and the Minister in the Presidency: National Planning Commission.

Due to the potentially high impact of AMD discharge into the Vaal River system specifically, a Feasibility Study for a long-term solution to address Acid Mine Drainage (AMD) associated with the East, Central and West Rand underground mining basins in the Gauteng Province was launched in 2011 by the Department of Water Affairs and was completed in 2013 (www.dwa.gov.za/projects/AMDFSLTS).

If AMD is discharged without any mitigation into the Vaal River System, the high salt load will require large dilution releases to be made from the Vaal Dam to maintain the fitness-for-use objectives set for the Vaal Barrage and for further downstream users. This would result in unusable water surpluses developing in the Lower Vaal River. Moreover, if dilution releases were still required after 2015, the acceptable levels of assurance of water supply from the Vaal Dam would be threatened. This will mean that there would be an increasing risk of water restrictions in the Vaal River water supply area, which will have negative economic and social implications. These negative impacts will be much greater if the catchments of the Vaal River System enters a period of lower-than-average rainfall with drought conditions. Since decant started in the Western Basin in 2002, the continuous flow of untreated AMD, and now the salt load from the continuous flow of the neutralised AMD from the Western Basin, are impacting on the Crocodile (West) River System (DWA 2013b).

The main contributors to acidification in South Africa are therefore the gold mining area of the Witwatersrand and the coal mining industry. The groundwater within the gold mining areas is heavily contaminated and is discharging into streams in the area and contributing up to 20% of total stream discharge, lowering the 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 coalfields, the Witbank coalfield represents the largest conterminous area of active coal mining in South Africa. These coalfields produce coal for power generation and support 48% of the country's total power generating capacity (CSIR 2010). The impacts of coal mining on the upper Olifants River catchment because of coal mining activities have been investigated (Heath *et al*. 2010, Aston and Dabrowski 2011, Dabrowski and De Klerk 2013).

Industrial contributions to pollution depend on the industrial process adopted but can include poisonous and hazardous chemicals, nutrients, elevated salinity and increased sediments (CSIR 2010). The main impacts of industrial chemicals relate to salinisation, which may render water unfit for reuse or very costly to treat. Typical pollutants associated with industrial water use include, heavy metals (e.g. 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; and organic compounds originating from raw materials, intermediates, products, reagents, solvents and catalysts.

3.3.2 Groundwater situation

Certain host rocks, particularly those containing large amounts of calcite or dolomite, are able to neutralise the acid. However, this is not the case for coal and gold deposits and in these the natural neutralising processes are overwhelmed and large quantities of acidic water are released into the environment by mining activities, initially into the groundwater and ultimately into streams and rivers. The acidic water increases the solubility of aluminium and heavy metals, which may be present in the affected region. The overall effect is to render the water toxic to varying degrees. Ultimately, the water becomes neutralised by a combination of dilution and reaction with river sediment or various minerals in soils, but certain constituents have relatively high solubilities and remain in the water, particularly sulphate. Not all of South Africa's mineral deposits are afflicted by acid production: diamond, iron, manganese, chrome and vanadium mines do not generate acid-producing wastes and the majority of our platinum mines seem to be free of this problem.

Hodgson & Krantz (1998) conducted an investigation into the groundwater deterioration in the Olifants River Catchment above Loskop Dam. A deterioration in water quality, mainly due to coal mining and power generating activities, was noted above and a further deterioration in groundwater quality caused by AMD is widely documented.

3.3.3 Alkalinity

A recent review of the water quality situation in South Africa (DWS, 2015) found that alkalinity appears to be increasing in many river systems. Alkalinity is a measure of the acid-neutralising capacity of water and is an indication of the base content of the water. Ions that contribute to the alkalinity of water are bicarbonate (HCO_3) and carbonate (CO_3), and at high pH values, hydroxide (OH). Total alkalinity is the sum of these three ions. High alkalinity can shorten the lifespan of heating or heat exchange equipment through scaling, it can interfere with industrial processes, affect ammonia toxicity for aquatic organisms, is related to algal blooms, harden drinking water, and make it more difficult to dispose of wastewater, and increase salinization.

The increase in alkalinity appears to be related to acidification. A recent study investigating similar trend in Europe's rivers has suggested that acid rain, AMD and agricultural fertilizers, are to blame as the acid eats away at limestone and other carbonate rocks, causing their alkaline particles to then be picked up by the water. However, an investigation into similar increases in alkalinity in USA rivers (Stets *et al*., 2014) concluded that the increase was as a result of receding acidification and increased use of agricultural lime. Stets *et al*. (2014) also concluded that a diversity of catchment processes could contribute to the increasing alkalinity trend. Kaushal *et al*. (2013) investigated increased river alkalinisation in the Eastern US and found that alkalinisation rates were significantly related to watershed carbonate lithology, acid deposition, and topography. They concluded that the rise of alkalinity in many rivers throughout the Eastern U.S. suggested human-accelerated chemical weathering, in addition to documented impacts of mining and land use. The increasing alkalinity situation in South African rivers clearly requires scientific scrutiny.

3.4 Erosion and sedimentation

Sedimentation refers to the erosion; wash-off and silt load carried by streams and rivers and typically reflects the natural geophysical and hydrological characteristics of the upstream catchment. Many South African rivers carry a naturally high suspended solids load (DEAT, 2000; Gibson, *et al*., 2010; CSIR, 2010; DWA, 2011). This has been further increased through construction activities; poor agriculture and silviculture practices; over-grazing; destruction of the riparian vegetation, and the physical disturbance of land by industry and urban development.

South Africa has been actively involved in research and practical aspects of erosion and sedimentation for a long period of time (Gibson *et al*., 2010). Since the 1960’s, a rich knowledge base of erosion and sedimentation has been accumulated through experience and research. It is from this knowledge base that the problem of reservoir sedimentation has been continuously analysed. An analysis of the reservoir sediment deposit data for South

African dams showed that almost 25% of the total number of reservoirs have lost between 10 to 30% of their original storage to sedimentation (**Table 1**).

Table 1: State of reservoir sedimentation in South Africa (storage lost as a percentage of the original capacity) (DWAF, 2006 cited in Gibson *et al*., 2010)

Storage lost (%)	Percentage of dams	Cumulative percentage of dams
0-5	28	28
5-10	18	46
10-20	20	66
20-30	6	72
30-40	5	77
40-50	7	84
50-60	8	92
>60	8	100

High suspended-solids loads decrease light penetration of water; change natural productivity; affect the natural balance of predators and prey in biotic communities; smother habitats and organisms and change the viability of riverine vegetation. Additionally, high sediment loads are deposited in impoundments, reducing their storage capacity over time.

Suspended sediment or turbidity is not routinely monitored as part of the National Chemical Monitoring Programme (NCMP), although some suspended sediment data are collected from time to time at some river sampling points. However, the Department conducts hydrographic surveys of reservoirs regularly. This is referred to as the Reservoir Survey Programme and its aim is, inter alia, to calculate the reservoir volume, and after a re-survey, the volume of sediment that has accumulated in the reservoir (Gibson *et al*., 2010) after a number of years. This information is used to calculate the sediment yields of catchments in South Africa (Gibson *et al*., 2010).

To date sediment is only measured as an average load through the reservoir survey programme. As catchment management starts to take off, a much greater focus on erosion and runoff control can be expected with an emphasis on more detailed sediment concentration monitoring. Interpretation and management of many water quality constituents also require knowledge of the concurrent sediment concentrations (DWAF, 2004).

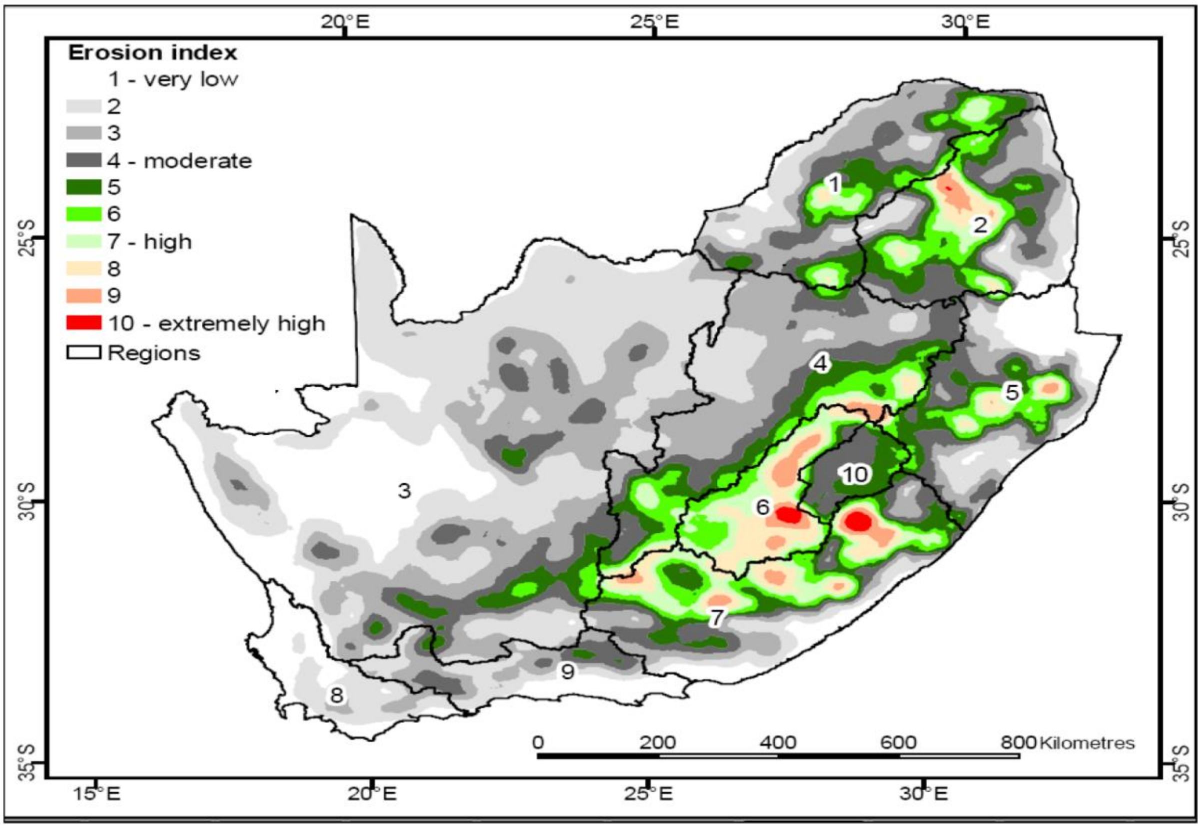

Figure 13: New sediment yield regions showing erosion indices (Gibson *et al.*, 2010)

3.5 Urban runoff pollution, litter and solid waste

Urban stormwater runoff can be polluted by, inter alia, nutrients, low pH (acidity), micro-organisms, toxic organics, heavy metals, litter/debris, oils, surfactants and increased water temperature. While the impact of litter may appear to be mainly visual and of aesthetic importance, litter can have serious impacts on the aquatic ecosystem of urban streams and rivers (Marais and Armitage, 2003).

This section is focused on concerns associated with solid waste or litter in urban streams and rivers. Solid waste refers to litter (other terms used include trash / rubbish / garbage / refuse / floating matter) that enter the stormwater drainage system and that are deposited into urban streams and rivers. This includes solid waste that has deposited directly into the river or tributaries. One definition of litter is “all improperly discarded waste material, including, but not limited to, convenience food, beverage, and other product packages or containers constructed of steel, aluminium, glass, paper, plastic, and other natural and synthetic materials, thrown or deposited on the lands and waters”. Marais and Armitage (2003) developed a hierarchical classification system for solid waste items (**Table 2**).

Table 2: Hierarchical classification system for solid waste items (Marais and Armitage, 2003)

Main categories	Sub-categories	Examples of items
Plastic	Packaging Polystyrene Containers	Shopping bags, wrapping Polystyrene blocks and pellets, cooler boxes Containers, bottles, crates. Straws, straps, ropes, nets, music cassettes, syringes, eating utensils
Paper	Packaging. News / stationery. Cardboard	Wrappers, serviettes Newspapers, advertising flyers, ATM dockets Food and drink containers, bus tickets.
Metal	Cans	Foil, bottle tops, number plates.
Glass	Bottles	Beer and wine bottles
Vegetation	Leaves & branches Food	Garden refuse Rotten fruit and vegetables.
Sediment	Sand	Building sand, building rubble
Miscellaneous	Animal Construction material Cloth Fibre-glass	Dead dogs and cats, sundry skeletons. Shutters, planks, timber props, broken bricks, lumps of concrete. Old clothing, rags, blankets. Fibre-glass Shoes, sponges, balls, pens and pencils, balloons, oil filters, cigarette butts, tyres.

Solid waste has a number of impacts on water quality:

- **Aesthetic impacts** – Activities such as picnicking and hiking alongside urban rivers are concerned with the scenic and aesthetic appreciation of the river. The economic value of recreational water bodies is often closely related to scenic appreciation since this is a major factor in determining the value of waterfront properties. The presence of large amounts solid waste detracts from the aesthetic appeal of the river and affects the economic value of waterfront properties.
- **Impacts on dissolved oxygen** – The decomposition of biodegradable solid waste (garden refuse, food wastes, dead animals, faecal matter, etc.) can have a significant localised impact on oxygen depletion in the river. This affects the dissolved oxygen content of the water and in turn, aquatic organisms that are sensitive to low dissolved oxygen concentrations. Dissolved oxygen also affects the solubility of trace metals and nutrients and low concentrations promote the release of metals and nutrients from the sediments.

- **Bacteriological impacts** – Solid waste can threaten the health of contact (e.g. swimmers and kids playing in the river) and limited contact recreational users (e.g. canoeists). Of particular concern are bacteria and viruses associated with disposable nappies, medical wastes, animal carcasses, and human and domestic pet wastes. Ingestion of river water during recreation can expose users to water borne diseases such as diarrhoea, gastroenteritis, cholera, salmonellosis, dysentery, and eye, ear, nose and skin infections.
- **Safety of recreational users –** Lacerations caused by broken glass or sharp metal fragments can expose the bloodstream of recreational users to microbes that can cause waterborne diseases such as hepatitis, and typhoid fever.
- **Impeding flow and bank destabilisation** – The accumulation of floating solid waste, dumping of building rubble, or dumping of large objects such as car bodies, broken furniture, tyres, and shopping trollies can redirect stream-flow and destabilise the river channel.
- **Entanglement of wildlife and aquatic organisms –** Entanglement can occur if animals or aquatic organisms are ensnared by debris in the river. It can occur accidentally and lead to wounds and infections, or loss of limbs in wildlife and farm animals. It can also cause strangulation or suffocation, or impair the ability of to swim resulting in drowning or difficulty in movement which may affect the ability to find food or escape from predators.
- **Ingestion by organisms –** Ingestion of floating or deposited rubbish can lead to starvation or malnutrition if the intestinal tract is blocked or digestion of food is impaired. Ingestion of sharp objects can also cause damage of the mouth, digestive tract or stomach lining causing infection and pain in the animal. Rubbish that settle at the bottom of the river such as glass, cigarettes, rubber, and construction debris, are a problem for bottom-feeders and -dwellers.
- **Hydrocarbon pollution** – Hydrocarbon pollution from dumped oil cans or automotive parts can kill microscopic organisms in the river.
- **Trace metals –** Trace metals from rusting batteries or electronic equipment can be toxic to aquatic organisms.
- **Nutrient enrichment –** the decomposition of organic solid waste and release of nutrients in this process would contribute to nutrient load in the river. However, when compared to other nutrient loads from sources such as treated and untreated wastewater and agricultural runoff or seepage, decomposing organic solid waste would probably represent a minor source.

Solid waste in urban streams and rivers is not routinely monitored. The City of Cape Town has included the presence of garden refuse and building litter on the forms their officials complete when undertaking their sampling rounds. The Western Cape Regional Office of

DWS has developed a more comprehensive Visual River Assessment Form for monitoring solid waste in the Berg River (Rossouw, 2013).

3.6 Microbial pollution, water-borne pathogens and human health

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 (CSIR, 2010).

The spread of diseases such as cryptosporidiosis, dysentery, cholera and typhoid is caused by the use of water that is contaminated by faecal matter. Pathogens derived from faecal matter can also affect fruit and vegetable crops through contaminated irrigation water. 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, 2007). Despite big improvements in the provision of domestic water in rural areas, 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, CSIR, 2010).

In South Africa, almost 2 000 children die annually before they reach an age of one month, and an additional 51 300 die between the ages of 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 cholera outbreak in Limpopo in 2008 is just one 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).

High population densities, a shortage of proper sanitation infrastructure and a shortage of purified water for domestic use (NMMP, 2000) cause the health risk in these areas.

3.6.1 Surface water situation

Urban runoff from dense settlements and overloaded sewage systems is the major source of deteriorating microbiological water quality (CSIR, 2010; DWA, 2011). Most waterborne pathogens occur in human or animal faeces and enter waterways via various pathways. Micro-organisms include protozoa (e.g. Giardia & Cryptosporidium), bacteria (e.g. E. coli), bacterial infections (e.g. shigella), viruses (e.g. hepatitis) and helminthes. Urban stormwater runoff is also a major source of suspended sediment as well as heavy metals such as cadmium, chromium, manganese and iron, some of which are often particle-bound. Urban runoff is also a major source of litter and solid waste in river and stream courses which has both aesthetic and habitat implications.

The National Microbial Monitoring Programme (NMMP) monitors the extent of faecal contamination in surface waters (www.dwa.gov.za/iwqs/microbio/nmmp.aspx). The specific objectives of the NMMP are to:

- Locate, assess and prioritise those areas in the country where potential health risks related to faecal pollution of water resources are highest,
- Provide information on the status and trends in faecal pollution in the potential high risk areas,
- Provide information to help assess the potential health risk to humans associated with the possible use of faecal polluted water resources, and
- To help assess the effectiveness of measures to protect water resources against faecal pollution.

Regular bi-monthly reports are produced by RQIS (**Figure 14**) and the Department is currently developing dashboards for showing water resources data from multiple sources (**Figure 15**).

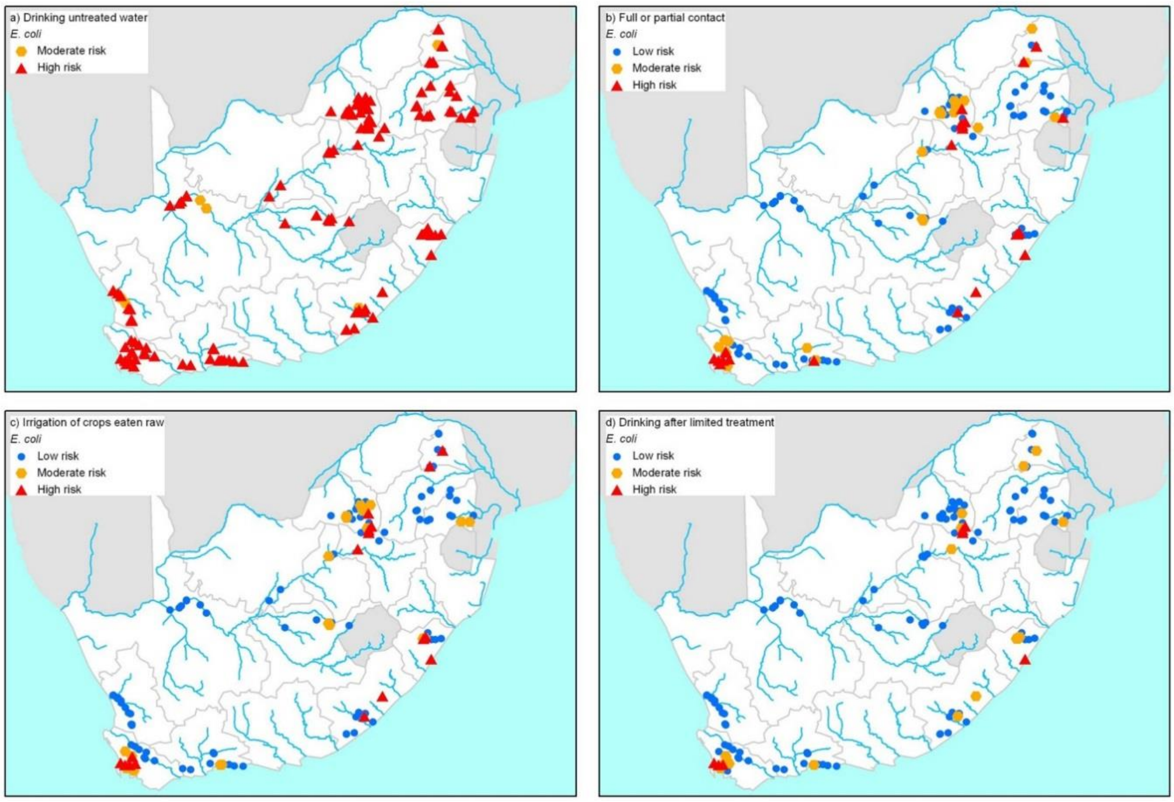

Figure 14: Microbial status of selected water bodies in South Africa (DWA, 2008)

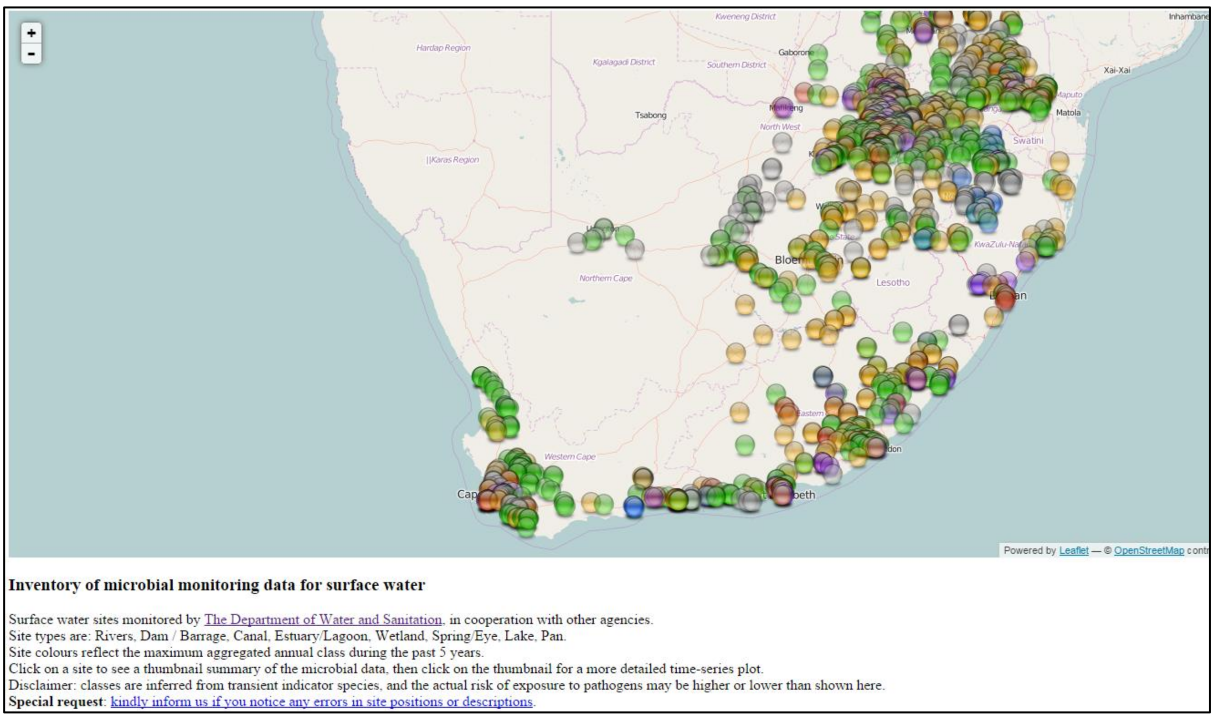

Figure 15: More recently, the Department has experimented with the JavaScript leaflet library for mapping microbial water quality, and dashboards for showing data from multiple sources (Online, accessed 19 Jan 2016).

3.6.2 Groundwater situation

In rural areas of South Africa, a significant portion of water used for domestic consumption originates from groundwater sources. Groundwater extracted from deep aquifers that are well protected is usually free of pathogenic microorganisms (WHO, 1993, cited in Murray *et al*. 2004). However, the quality of groundwater as a drinking-water source can easily be compromised by microbiological contamination, which can have severe public health implications (Pedley and Howard, 1997, cited in Murray *et al*. 2004).

It is often assumed that groundwater is free of harmful microorganisms (Sinton, 2001 cited in Murray *et al*. 2004), and farmers in South Africa are usually informed that groundwater is safe for human consumption and that chlorine or filter treatment is generally not required. In the USA, however, a groundwater disinfection rule is in place to prevent waterborne diseases. Cryptosporidium parvum oocysts and viruses are thought to hold the greatest risk in groundwater sources, and the disinfection rule is aimed at specifically controlling these two factors (Kramer *et al*, 1996 cited in Murray *et al*. 2004).

Pathogens occurring in groundwater consist of viruses, bacteria and protozoa. The viruses that typically contaminate groundwater sources cause a variety of diseases, varying from asymptomatic infections to severe disease, leading to hospitalisation or death. Viruses are considered the greatest risk for contamination of groundwater sources because of their high infectivity, small size and persistence in the environment (Schijven, 2001, cited in Murray *et al*. 2004).]

Bacteria occur naturally in groundwater sources, often leading to biofouling when biofilm growth continues unchecked. Most of these autochthonous bacteria do not pose any health risk to humans or animals, but sometimes pathogens enter aquifers through a variety of routes, leading to disease outbreaks (Dzeda *et al*, 1997 cited in Murray *et al*. 2004). Conditions favourable to bacterial survival and growth continue as deep as 2000m underground, enabling pathogenic organisms to persist for long periods in groundwater ecosystems (Fry *et al*, 1997 cited in Murray *et al*. 2004).

Protozoa have been found in both pristine and contaminated aquifers (Novarino *et al*, 1997; Kinner *et al*, 1998 cited in Murray *et al*. 2004). The occurrence of these relatively large organisms in groundwater supplies is cause for great concern, because if they are present in large enough numbers to cause disease, the presence of smaller microbes like viruses could be common. Another factor increasing the potential health risk associated with protozoa is the high level of persistence of their dormant stages, such as spores and oocysts. Very little is known of the movement and motility of these organisms in soil. It is thought that the processes involved in the removal of viruses in soil also apply to protozoa, but to a different extent (Schijven, 2001 cited in Murray *et al*. 2004).

Murray *et al*. (2004) listed a number of possible sources of microbial contamination of groundwater: flooding of boreholes by rivers during floods and normal surface runoff; sewage discharges and spills; seepage from septic tanks and pit-latrines; faecal contamination from wild and domestic animals (especially feedlots and manure deposits); graveyards (both from the microbes involved in decomposing and the pathogens present in the body at the time of burial); artificial groundwater recharge using contaminated water; landfill leachate; natural recharge from a polluted dam or river; and induced recharge from contaminated dams or rivers by pumping boreholes.

Murray *et al*. (2004) developed a groundwater-monitoring manual with the specific aim to develop a prototype manual that formally describes a detailed groundwater monitoring system design and all aspects of subsequent implementation. The eventual overall aim of this project was to extend the existing National Microbial Water Quality Monitoring Programme for surface waters to include groundwater. To what extent groundwater monitoring was incorporated, is unknown.

3.7 Agrochemicals and toxic substances

Toxic substances or toxicants encompass a wide range of compounds (DWA, 2011). These include inorganic and organic compounds (**Figure 16**). Inorganic toxicants (like heavy metals) and organic toxicants (like many pesticides, petroleum products, pharmaceuticals, etc.) can enter water resources and have devastating impacts on aquatic ecosystems and other water users. Some of the issues associated with toxicants in water include:

- Besides occasional immediate and highly visible impacts of accidental spills (like fish kills), many toxicants have more subtle, though no less serious, long-term impacts on aquatic biota.
- Some impacts, like endocrine disruption, manifest at extremely low concentrations of toxicants.
- The nature of many long-term impacts makes them difficult to detect and quantify.
- Some toxicants are highly resistant to degradation in the environment and may persist for decades.
- Some organic toxicants degrade rapidly in the environment, or are metabolised, to other chemicals that may also be toxic.
- Many organic toxicants and some heavy metals (like mercury) have an affinity for animal tissue (e.g. in fish) and sediments in water resources. They can gradually accumulate in these media to levels many thousands of times the original background levels.
- Contaminated animals can be eaten by other animals up the food chain (including humans).
- Contaminated sediments can be scoured during floods, mobilising trapped toxicants and increasing the risks of exposure downstream.
- Some toxicants, like the persistent organic pollutants (POPs) addressed in the Stockholm Convention (2001), are highly volatile. They can be transported vast distances through

the atmosphere away from their original sources. POPs have even been found in the Arctic, Antarctic and remote Pacific islands (UNEP, 2002 cited in DWA, 2011).

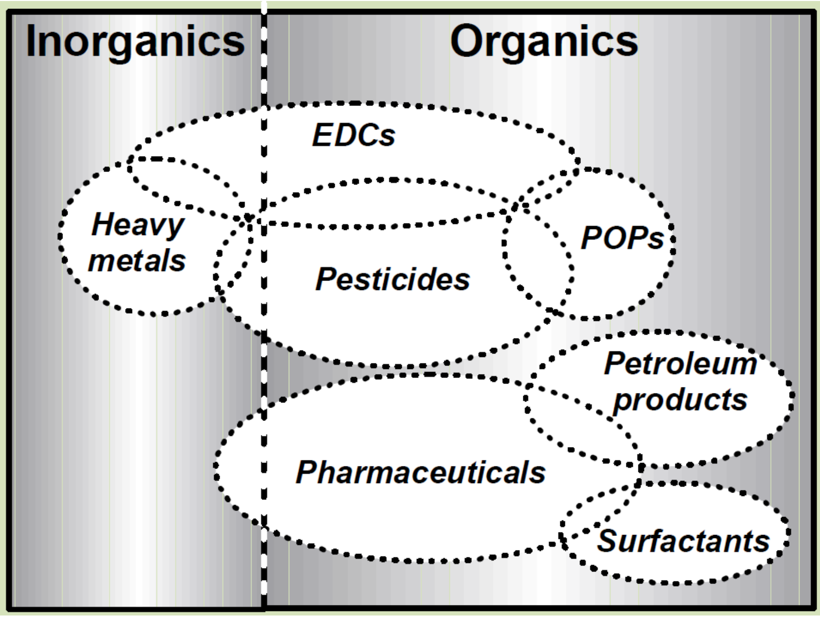

Figure 16: Illustration of some of the overlaps between some classes of toxicants (EDCs = Endocrine Disrupting Compounds, POPs = Persistent Organic Pollutants) (DWA, 2011).

3.7.1 Surface water situation

Heavy or trace metals are discussed in Section 3.9 and petroleum products are discussed in the section on hydrocarbon pollution (Section 3.10).

Agrochemicals and biocides, also known as pesticides, are chemicals that kill living organisms and are used in the control of pests (Griffen *et al*, 2011). The most commonly used biocides are herbicides, fungicides and insecticides (Dallas and Day, 2004). South Africa is a significant user of pesticides in agriculture, suggesting that the potential for non-point source environmental contamination is high. The type of pesticide and usage pattern is variable across South Africa, depending on climatic conditions and crop types, e.g. fungicides are used widely in the wetter grape-, fruit- and wheat-producing areas of the Western Cape, but herbicides are more prevalent in the maize-growing areas. Pesticide use also occurs as vector control in public health, commercial pest control, domestic use, and in selected industrial or food-processing technologies (e.g. dried fruit and timber-related production activities). However, the infrastructure to monitor and control pesticide use is also poorly developed. Data on pesticides in water sources are sparse, with previous results constrained by high detection limits masking significant levels of pesticides. This is of particular significance as endocrine disrupting effects occur at concentrations far lower than other toxic effects (London *et al*. 2000).

The factors determining runoff and leaching of biocides include the physiochemical properties (e.g. water solubility, soil mobility and pesticide persistence) of the pesticide and soil properties (e.g. texture, organic matter content, depth of the soil horizon, erosion potential, pH and microbial content) (London *et al*. 2000). Of primary concern, however, is the persistence and accumulation of pesticides in food chains, and the role of certain pesticides in causing reproductive failure and endocrine system abnormalities in species not intended as their target. Control of pesticide use is therefore paramount.

Endocrine disrupting chemicals (EDCs)

There has been a great deal of interest and, in some cases, concern, regarding human health effects associated with pharmaceuticals, hormones, and other organic waste water contaminants. Chemicals that interfere with the endocrine systems of humans and wildlife are termed endocrine disrupting chemicals (EDCs). Chemicals that elicit a pharmaceutical response in humans are termed pharmaceutically active compounds (PhACs). EDCs and PhACs are not mutually exclusive classifications, as some, but not all, PhACs are also EDCs.

An EDC has been defined as "an exogenous substance or mixture that alters the function(s) of the endocrine systems and consequently causes adverse health effects in an intact organism, or its progeny or (sub) populations". From reports in literature, a wide range of chemicals has been found or suspected to be capable of disrupting the endocrine systems. The list of EDCs includes:

- pesticides (e.g. DDT, vinclozolin, TBT, atrazine),
- persistent organochlorines and organohalogens (e.g. PCBs, dioxins, furans, brominated fire retardants),
- alkyl phenols (e.g. nonylphenol and octylphenol),
- heavy metals (e.g. cadmium, lead, mercury),
- phytoestrogens (e.g. isoflavoids, lignans, β-sitosterol), and
- synthetic and natural hormones (e.g. β-estradiol, ethynylestradiol).

Pharmaceuticals and personal care products (PhAC and PCPs) include a large number of chemical contaminants that can originate from human usage and excretion, veterinary applications of a variety of products, such as prescription/non-prescription medications, and fungicides and disinfectants used for industrial, domestic, agricultural and livestock practices. PhACs, PCPs and their metabolites are continually introduced into the aquatic environment and are prevalent at detectable concentrations that can affect water quality and potentially impact drinking water supplies, and consequently ecosystems and human health respectively.

An investigation by De Jager *et al*. (2013) was undertaken to examine the estrogenic activity and endocrine disrupting chemical (EDC) status in water obtained from selected distribution points in Pretoria and Cape Town. Some estrogenic activity was found in samples from the water distribution points in Pretoria and Cape Town. Although the results were below the recommended trigger value, the fact that Bisphenol-A and 17ß-Estradiol were present was still of concern due to the possible effects of chronic low dose exposure. The development of a monitoring strategy was therefore recommended.

Testing for individual compounds can be very expensive and for this reason (Genthe *et al*., 2010) recommend a tiered monitoring approach in order to assess the risk for EDCs. The WRC has developed a research programme for the detection, assessment and future management of EDCs especially given the emphasis on wastewater re-use in South Africa.

Persistent organic pollutants (POPs)

Persistent Organic Pollutants (POPs) are highly stable, toxic, hydrophobic and lipophilic compounds, with the ability to accumulate in biological tissues. Many POPs can be lethal in high concentrations but their greatest detrimental effects lie in their chronic toxicity, leading to dermal effects, liver and kidney disease, defects of the immune-, reproductive-, nervous-, and endocrine systems and even cancer. Because of their lipophilic nature, these pollutants tend to accumulate in matrices rich in organic matter, such as soil, sediment and biota, and can bio-accumulate in food chains. Global concerns about POPs lead to the United Nations Environment Programme (UNEP) initiating the Stockholm Convention on Persistent Organic Pollutants (SCPOPs) in May 1995. The convention is an international, legally binding treaty initially focussing on the reduction and elimination of the twelve most harmful POPs. These POPs included certain chlorinated pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex and toxaphene), two groups of industrial chemicals – hexachlorobenzene (HCB) and polychlorinated biphenyls (PCB), and unintentional combustion by-products known as polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF). Later more chemicals were added to the list. South Africa played a major role in the negotiations and implementation of the SCPOPs.

A WRC-funded investigation by North-West University and the CSIR into the scale and significance of certain organic pollutants (OP) and POPs pollution in South African waters (Roos *et al*., 2011). The objectives of the study were:

- To assess the scale and significance of the occurrence of POPs in the water environment in South Africa, the potential short-term and long-term impacts on water resources and water-linked ecosystems and the associated threats to sustainability of these resources;
- To better identify and quantify the fate and effect of selected POPs in the water environment; and
- To guide the development of appropriate policy and regulatory measures that will support implementation of the requirements of the Stockholm Convention, and substantially contribute to the protection of water resources and water-linked ecosystems with regard to POPs.

Research in South Africa has shown that very little is known about levels of POPs and PAHs or distribution patterns, whereas more is known about heavy metals. For example, South

Africa has been listed as the country with the second highest mercury emissions in the world (Pacyna *et al*. 2006, cited in ORASECOM 2013), based on estimates of total mercury emissions from gold mining and coal combustion.

3.7.2 Groundwater situation

Over 3000 pesticides are registered for use in South Africa and many studies have highlighted the movement of pesticides to agricultural crops from the point of application into non-target environments, particularly surface and groundwater resources (Dabrowski 2015). Exposure to pesticides can lead to serious human health and environmental effects.

A 3-year investigation into the presence of pesticides in rural water sources in the Western Cape was undertaken with the financial support of the Water Research Commission from 1997 to 1999. The study arose out of a concern for the lack of data in South Africa on the presence of pesticides in rural water sources, and the important policy implications that pesticide pollution of water would have for rural development. South Africa is a significant user of pesticides in agriculture and public health and available evidence suggest the potential for environmental contamination is high. Moreover, the infrastructure to monitor and control pesticides reaching water is poorly developed (London *et al*. 2000).

Results from this investigation indicated that only a limited number of pesticides were being detected in rural water sources in the region. The two most commonly detected were the insecticides endosulfan and chlorpyrifos. Although this investigation was limited to water resources within the Western Cape, it important to identify critical areas within South Africa where specific pesticides may result in a high risk of exposure to humans or the environment.

(Dabrowski 2015) developed “Pesticide Use Maps” for South Africa. Crop-specific pesticide use data were obtained from a market research company and integrated into a geographical information system detailing the distribution of agricultural crops in South Africa as determined by an agricultural census performed in 2002. By estimating the total application of a specific pesticide to all crops produced in a magisterial district, it was possible to generate maps that provide an estimate of the application rate of over 200 pesticides per magisterial district. These maps were intersected with an agricultural land-cover map to provide a refined map giving details of the spatial distribution of pesticide use across the country.

While a number of geographical and physico-chemical factors influence the movement of pesticides into surface and groundwater, the quantity and rate of application of pesticides used (and by implication the relative application rate) in an area is the most important indicator of the potential for contamination of non-target environments. In this respect, the maps provide important information, not only in terms of estimated application rates, but also in terms of identifying where in the country specific pesticides are most likely being applied. Integrating these data together with geographical data of slope, soil and climate in a GIS platform can significantly improve our ability to identify ground- and surface water resources at risk of pesticide exposure through leaching and runoff. Considering the large number of active ingredients used in South Africa, as well as the expense of monitoring these chemicals, the use of these maps in combination with existing information on the relative risks of pesticides to human health and the aquatic ecosystem provide guidance on which pesticides should be monitored and where they should be monitored. By combining the maps with information on community access to water, we can identify those communities that may be at risk of pesticide exposure through use of river or groundwater for drinking purposes.

3.7.3 Monitoring

The National Toxicant Monitoring Programme (NTMP) was designed to measure, assess and regularly report on the status and trends of the nature and extent of the following in a manner that will support strategic management decisions in the context of fitness for use of those water resources, and will be mindful of financial and capacity constraints, yet, be soundly scientific:

- Potentially toxic substances in South African water resources (watercourses, groundwater and estuaries).
- The potential for toxic effects to selected organisms.

The NTMP was designed in response to increasing local and international concerns about the detrimental effects of toxicants that are being released into the environment and to address the current lack of a coherent source of information on the occurrence of toxic substances in South African water resources. The project was initiated in 2002, the same year that South Africa signed the Stockholm Convention on Persistent Organic Pollutants (POPs), which came into force on 17 May 2004.

3.8 Dissolved oxygen and organic pollution

Most aquatic organisms are dependent on the maintenance of adequate dissolved oxygen concentrations in the water for its survival and functioning (Dallas and Day, 2004). Dissolved oxygen fluctuates diurnally, depending on the relative rates of respiration and photosynthesis of aquatic plants. Factors causing an increase in DO include atmospheric re-aeration, increasing atmospheric pressure, decreasing temperature and salinity, and photosynthesis by plants. Factors causing a decrease in DO include increasing temperature and salinity, respiration of aquatic organisms, decomposition of organic material by microorganisms, chemical breakdown of pollutants, re-suspension of anoxic sediments and release of anoxic bottom water.

The focus of this section is on oxygen demand that reduces the DO in water, specifically the decomposition of organic material and the chemical breakdown of pollutants.

3.8.1 Surface water situation

The presence of oxidisable organic matter, either of natural origin (detritus) or originating in waste discharges, can lead to reduction in the concentration of dissolved oxygen in surface waters (Dallas and Day, 2004). Oxygen depletion may be due the aerobic decomposition of organic waste by microorganisms or the breakdown of chemicals. The potential for organic wastes to deplete oxygen is commonly measured as biochemical oxygen demand (BOD) and chemical oxygen demand (COD). BOD is a common measure of organic pollution. COD is a measure of the oxidation of reduced chemical species in water, i.e. the "reducing capacity" of an effluent.

The impact of dissolved oxygen depletion on aquatic organisms depends on the frequency, timing and duration of such depletion (DWAF 1996, Dallas an Day, 2004). Continuous exposure to concentrations of less than 80 % of saturation is most harmful, and is likely to have acute effects, whilst repeated exposure to reduced concentrations may lead to physiological and behavioural stress effects. Occasional short-lived depletion of oxygen is less important. In all cases, if the rate of change in dissolved oxygen concentration is rapid, adverse effects on biota will be increased significantly. The extent to which any organism is affected by a decrease in dissolved oxygen is determined by its dependence on water as a medium. Most fish are 100% aquatic and are thus very dependent on dissolved oxygen for respiration and are very sensitive to low concentrations. The oxygen requirements of fish and other aquatic organisms vary with type of species (particularly warm- or cold-water species), with life stages (eggs, larvae, nymphs, adults) and with different life processes (feeding, growth, reproduction) and size. Cold water-adapted species are especially sensitive to depletion of dissolved oxygen. If possible, many species will avoid anoxic or oxygen-depleted zones. A few species, such as lungfish and some catfish, can, however, survive out of water for some time.

Certain aquatic invertebrates respire with gills or by direct cuticular exchange, and are thus subject to the same stresses as fish. Other insects are able to utilize atmospheric oxygen (e.g. many hemipterans and coleopterans carry air bubbles under their wings or under special mats of hairs) and are thus less affected by reduced dissolved oxygen concentrations.

The main sources of organic enrichment of rivers include domestic sewage, food-processing plants, breweries and vegetable canning, animal feedlots, abattoirs and cattle grazing (Dallas and Day, 2004). Of these, enrichment by organic matter from sewage and sewage effluents is probably the most common and extensively documented type of pollution in rivers (**Figure 17**). Most organic material in sewage is not directly toxic to aquatic organisms but it leads to a decrease in dissolved oxygen concentrations. Other impacts include an increase in turbidity and the concentration of suspended solids, an increase in nutrient concentrations, and possibly bacterial contamination of the receiving water body.

The Green Drop certification provides an indication of compliance to microbiological, physical, and chemical requirements (www.dwa.gov.za/dir_ws/GDS). In 2015 (Jan-Dec

2015), 347 out of 896 WWTWs submitted information. Of these, 29.62% complied with microbiological requirements, 38.84% complied with the physical requirements, and 34.54% complied with the chemical requirements. The low chemical compliance is a concern as it reflects, inter alia, the high COD loads entering receiving water bodies.

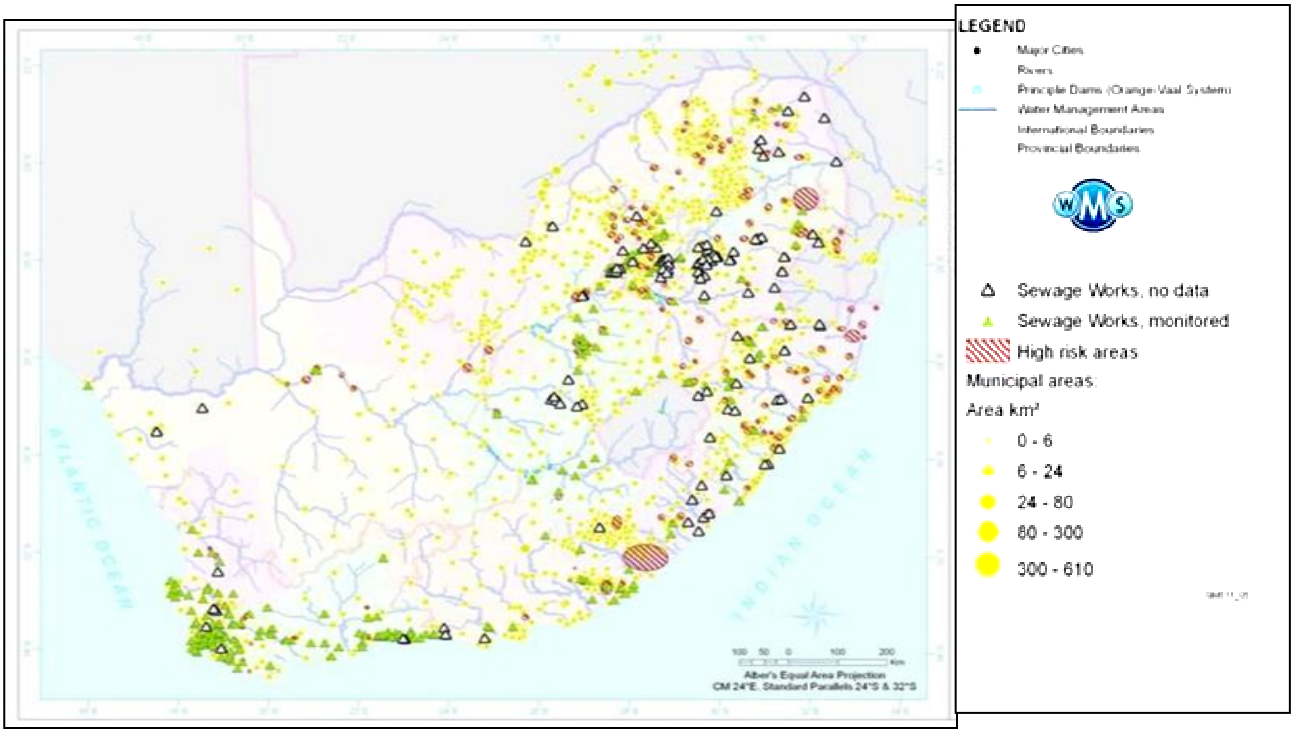

Figure 17: Location of sewage treatment works and National Microbial Monitoring Programme high risk areas (DWAF, 2008)

Dissolved oxygen in rivers is not routinely measured by any of the national monitoring programmes. Dissolved oxygen and temperature profiles are measured from time to time in selected reservoirs as part of the NEMP (National Eutrophication Monitoring Programme).

3.8.2 Groundwater situation

Dissolved oxygen (DO) naturally occurs in all groundwater to varying degrees of concentration. The presence of DO is not limited to certain geographical locations, although the concentration normally decreases with depth.

DO in groundwater is spatially heterogeneous at macro- (km), meso- (m) and micro- (cm) scales. This heterogeneity, an essential feature of the groundwater environment, reflects changes in sediment composition and structure, groundwater flow velocity, organic matter content, and the abundance and activity of microorganisms. Dissolved oxygen also exhibits strong temporal changes in the hyporheic zone of streams as well as in the recharge area of aquifers, but these fluctuations should be strongly attenuated with increasing distance from the stream and the recharge zone.

Dissolved oxygen gradients along flow paths in groundwater systems and hyporheic zones vary over several orders of magnitude (e.g. declines of 9×10^{-5} to 1.5×10^{-2} mg/l O_2 /m in confined aquifers and 2×10^{-2} to 1 mg/l O_2 /m in parafluvial water). Several factors explain this strong variation. Where the water table is close to the surface, oxygen is likely to be consumed rapidly in the first few metres below the water table because of incomplete degradation of soil-generated labile dissolved organic carbon (DOC) in the vadose zone. Where the water table is far from the surface, strong oxygen depletion near the water table does not occur, DO being then gradually consumed as groundwater flows down the hydraulic gradient. In unconfined groundwater systems, oxygen consumption along flow paths may be compensated by down-gradient replenishment of DO, resulting either from the ingress of atmospheric oxygen or water recharge through the vadose zone. In confined groundwater systems, where replenishment of oxygen is impossible, the removal time of DO varies from a few years to more than 10 000 years, depending mainly on the organic carbon content of the sediment. Comparison of the hyporheic zones between systems also reveals strong differences in the removal time and length of underground pathways for DO. This strong variability among systems seems related to differences in contact time of water with sediment (Malard *et al*. 1999).

Dissolved oxygen content in groundwater decreases with depth and residence time to a point where the groundwater system changes from aerobic to anaerobic conditions due to the consumption of oxygen by microorganisms. When groundwater becomes anaerobic and a sudden source of oxygen is introduced (e.g. drawdown of the static water level due to excessive pumping), a sudden increase of aerobic organisms may occur in the vicinity. Dissolved minerals such as Fe and Mn may then precipitate from solution.

In cases where organic contamination occurs (e.g. sewage irrigation at wastewater treatment works), the dissolved oxygen content in the groundwater decreases due to the presence of bacteria. Microorganisms, present in groundwater, metabolizing the organic compounds, consume the dissolved oxygen. It is therefore possible to use the DO concentration as a tracer in order to measure or indicate organic contamination present within an aquifer.

3.9 Trace Metals

Metals include sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), titanium (Ti), iron (Fe) and aluminium (Al). Trace metals are defined, in geological terms, as those occurring at 1000ppm or less in the earth's crust. Trace metals can be divided into two groups: (i) those like cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn)] that occur naturally in trace amounts in most waters (and most of which are plant nutrients) and (ii) those like cadmium (Cd), lead (Pb) and mercury (Hg) that do not usually occur in measurable amounts in natural waters, are potentially toxic in low concentrations, and have become widely distributed as a result of human activities (Dallas and Day, 2004).

The main sources of trace metals in water bodies are geological weathering, the atmosphere, industrial effluents, agricultural runoff and acid mine drainage (from both direct discharge and leaching from the spoils of operational and abandoned mines). Many trace metals are employed in, and result from, industrial activities.

The overall ecological consequence of trace metal contamination of aquatic ecosystems is a reduction in species richness and diversity and a change in species composition (Dallas and Day, 2004). The selective elimination of less tolerant species, with the resultant reduction in competition and predation, may result in an increase in the abundance of more tolerant species. The degree of change is related to the concentration of the metal(s) and the type (chronic, acute, constant, intermittent) and timing (in relation to season and thus flow rate) of exposure.

3.9.1 Surface water situation

Concerns have been expressed about trace metals in rivers and a number of studies have been undertaken to describe the status and their impacts. These include studies on the Olifants River in Mpumalanga, the Ethekwini area in Kwazulu-Natal, the Vaal Basin, Letaba River, Thohoyando, the Mooi River system, the Swartkops River, and the Crocodile River. In many cases these metals are associated with acid mine drainage and industrial discharges in the affected catchment.

Trace metal monitoring is undertaken infrequently as part of the National Chemical Monitoring Programme.

3.9.2 Groundwater situation

The type and concentration of metals present within groundwater is dependent on factors such as residence time in the aquifer, geology, water chemistry, natural and anthropogenic contamination etc. Naturally occurring metals include but are not limited to Fe, Mn, Na, K, Ca, Mg, Cu, Ni, Al, and Zn. The metals are present in the majority of rock types that form the aquifers in which groundwater occurs. The concentration of these metals in groundwater is related to amongst other, the residence time, chemistry of the rock types, groundwater chemistry, temperature, rainfall in the area, evaporation rate and vegetation.

Although the occurrence of heavy metals in groundwater is rare, the majority of naturally occurring heavy metals are found within mineralized zones such as orebodies. Areas such as the Springbok Flats is known for its naturally occurring uranium present within the coal seams of the Karoo geology of the area. Uranium is also present within the gold reefs of the Witwatersrand basin. Other metals such as chromium, hexavalent chrome and other trace metals are found within the mineralized zones of the Merensky reef of the Bushveld Complex. Mineralized water containing heavy metals occur in hot springs where geothermal activity carries the water from deep within the earth's crust where mineralization of the water takes place.

Due to anthropogenic activities such as formal and informal solid waste disposal sites, mining waste rock dumps and slimes dams, metals such as cadmium, cobalt and nickel are introduced into the groundwater environment. Metal content in groundwater is also increased in areas where AMD/ARD occurs as a result of the oxidizing environment created by the mine water. In solid waste landfill sites, heavy and trace metals are leached into the groundwater due to the presence of metallic waste as well as waste such as rechargeable batteries, electronic waste, plastics containing metals etc.

Metals can also be leached into groundwater due to poor management practices when applying fertilisers to agriculture land. In a recent project funded by the Water Research Commission, cadmium contamination of South African aquifer groundwater systems via phosphate fertiliser was investigated. The study looked into fertiliser contribution to trace metal mobilisation and bioavailability in soils and groundwater (Umvoto Africa, 2014).

From this study it emerged that cadmium is a highly mobile, bioavailable and potentially toxic trace metal, especially in environments such as acidic, sandy, non-calcareous soils (with low clay and organic matter contents) and acidic groundwater (with low salinity and hardness, and a low organic matter, suspended matter, clay and iron/manganese oxide/hydroxide content). Although at relatively low concentrations within the product itself, continuous application of phosphate fertiliser and treated sludge/wastewater with cadmium impurities can cause long term cadmium contamination of soil and ultimately (through leaching) groundwater systems. The observed cadmium (among other trace metals such as arsenic, lead, nickel and selenium) contamination within the unconfined Nardouw and Quaternary Aquifers in the greater Hermanus region (and specifically the eastern Fernkloof residential area), could possibly be a result of the application of phosphate fertiliser and treated wastewater/sludge in local recreational, residential and agricultural areas in association with acidic Table Mountain and Bredasdorp Group soil/sediment and groundwater.

3.10 Hydrocarbon pollution

Petroleum and petroleum-derived products are complex mixtures, mainly of hydrocarbons (compounds of only carbon and hydrogen) plus some other compounds of sulphur, nitrogen and oxygen, and a few additives. The hydrocarbons range from the very volatile C_4 up to the heavy end $C_{45+.}$ The more common petroleum products include petrol, napthas and solvents, aviation gasoline, jet fuels, paraffin, diesel fuel, fuel oils and lubricating oils.

3.10.1 Surface water situation

Surface water concerns about hydrocarbon pollution are about washoff from road surfaces and parking lots, especially during the early season rains, and dumping of used oil into stormwater drains. According to Nekhavhambe *et al*. (2014) few studies have been conducted South Africa to determine the presence and levels of polycyclic aromatic hydrocarbons (PAHs) in the environment. For example, Das *et al*. (2008) (cited in Nekhavhambe *et al.*, 2014) followed the sources of, and historic changes in, PAH inputs into Zeekoevlei since the early 1990s. They found very low levels of low molecular weight (MW) PAHs, attributable to low traffic volumes in the catchment, with higher concentrations of high-MW PAHs during the rainy winter season, suggesting stormwater input and atmospheric deposition from non-point sources. The discharge of used motor oil into stormwater drains has been raised as a concern related to hydrocarbon pollution and urban runoff. Hydrocarbons are not routine monitored by any of the national water quality monitoring programmes.

3.10.2 Groundwater situation

Petroleum and petroleum-derived products are divided into Light Non-Aqueous Phase Liquids (LNAPLs) and Dense Non-Aqueous Phase Liquids (DNAPLs). LNAPLs are those organic compounds which do not dissolve in water and which will float on groundwater, most commonly petrol-derived products and degreasers. DNAPLs are those organic compounds which do not dissolve in water and sink to lower levels, such as chloroform, liquid chlorofluorocarbons (CFC), trichloroethylene (TCE), creosote and polychlorinated biphenyls (PCB) (Weaver *et al*. 2007).

These products are ubiquitous in our lives, and can be spilled into the environment in a variety of ways: overturned fuel tankers, automobile and truck crashes, spillage at the fuel pump, leakage from storage tanks, discarding sump oil; to mention only a few. Leakage from underground storage tanks (USTs) is probably the source that has the greatest impact on groundwater. In South Africa we have several filling stations constructed in the 1980’s and even before, with little to no maintenance on tank and pipework. These leakages often go undetected for years and thousands of litres of fuel can be discharged.

In South Africa filling stations and bulk fuel storage facilities must comply with the relevant SABS standards, for example SABS 089, 1535, 0131, 0108 and 0400. These standards make provision for observation wells, leak detectors, overfill protectors, etc.

The serious health risk posed by contaminated land or water systems to human health and the environment is widely recognised. The carcinogenic properties of the halogenated hydrocarbons are well documented. Awareness of this reality has led to international efforts to remediate many of these contaminated sites, either as a response to the health risks or to control the detrimental effects on the environment. For decades, efforts have been directed toward the evaluation of cost effective methods to rehabilitate hydrocarbon contaminated soil and groundwater. Over the years, many clean up methods have been developed and applied. However, the remediation of hydrocarbon-contaminated land is extremely difficult and costly due to their varying physical properties and complex mixture of chemical compounds. Hydrocarbon degradation in the natural environment depends on several factors such as pH, chemical composition, and physical properties of the contaminated soil and/or water, among others.

3.11 Thermal pollution

Thermal pollution refers to the discharge of heated or cold water into rivers and receiving water bodies and the impacts it has on aquatic biota. Heated effluent from industrial heat exchangers is an example of discharges with a temperature greater than the ambient water temperature. The temperature of heated effluents is controlled with a general authorisation in terms of the National Water Act. It specifies that an effluent may not increase the natural ambient water temperature by more than 2-3 °C depending on the volume discharged. However, the concerns about cold-water bottom discharges from stratified reservoirs are probably more widespread than concerns about heated discharges.

Many reservoirs in South Africa are only equipped with bottom outlets for releasing water for environmental requirements and the needs of downstream users. When these reservoirs stratify during the summer months, cold water is trapped in the bottom layers of the reservoir. The thermocline in a thermally stratified dam is an effective barrier to mixing of water in the warm surface layers and the cold bottom layers of a reservoir. The bottom water can be several degrees colder than the ambient river water temperatures. Inversely, during summer months the surface layers can be a few degrees warmer than what would normally be expected in natural rivers systems. A surface layer discharge may therefore release warmer water into the downstream river.

The water temperature recovers as the water flows in a downstream direction. The recovery distance is the length of river downstream of a reservoir that is required for the return to temperatures that would normally be found in an unregulated river. The recovery distance below an impoundment is dependent on a number of factors (EPA Victoria, 2004). These include the discharge volume, temperature of the release waters, size of the impoundment, location of the dam in the river continuum, river size, influence of downstream tributaries and their characteristics (flow and temperature), atmospheric conditions, air temperature, degree of shading by riparian (stream bank) vegetation, bed substrate, stream morphology, and ground water influences.

Temperature exerts a strong impact on many physical and chemical characteristics of water including the solubility of oxygen, chemical reaction rates and toxicity, and microbial activity (Dallas and Day, 2004). Higher temperatures reduce the solubility of dissolved oxygen in water, decreasing its availability to aquatic organisms. Chemical reaction rates and the toxicity of many substances (e.g. cyanide, zinc, phenol, xylene), and the vulnerability of organisms to these toxins, is intensified as temperature increases (Dallas, 2008). In systems with high organic loadings, oxygen depletion are increased by greater microbial activity at the higher water temperatures.

Temperature plays an important role in determining aquatic invertebrate abundance and distribution. Changes to natural thermal characteristics induced by cold-water reservoir releases can have dramatic effects on aquatic macroinvertebrate communities (EPA Victoria, 2004, Dallas, 2008).

Thermal signals to downstream biota associated with a particular flow can be delayed, or eliminated. Delays in the thermal maxima or minima may cause changes in the life cycles of both alien and indigenous river biota, which may lead to complete changes in community structures. Modifications to the thermal regime can cause drastic alterations to macro- and microbiological processes downstream of the reservoir with concomitant ramifications throughout the food web.

Changes in thermal regimes may create conditions that become favourable for existing parasites and other disease vectors.

Flow modification, a decrease in natural flows, inter-basin transfers, and climate change can also contribute to a change in the thermal characteristics of rivers.

Many of the newer reservoirs are now equipped with multi-level drawoff structures which allows water to be abstracted at a level in the dam that best resembles the temperature of the inflowing river. Berg River Dam is a good example of this (Van Wyk *et al*., 2012).

The DWS national monitoring programmes do not routinely monitor river water temperature, but spot measurements may be available for some rivers. Institutions such as Rand Water and KOBWA have installed continuous loggers in their areas of operations to monitor, inter alia, rivers water temperature and electrical conductivity, and in some cases variables such as pH and dissolved oxygen.

3.12 Nanoparticles

Nanomaterials or nanoparticles are defined as objects with one, two, or three external dimensions in the size range of 1-100 nanometres (nm). Examples of nanotechnology applications include the development of highly accurate and sensitive medical diagnostic devices, new ways of disease therapy, and the monitoring and remediation of basic water supplies. South Africa, through the National Nanotechnology Strategy (NSS) (DST, 2007), has initiated a national coordinated effort to guide the country’s nanoscience and nanotechnology to ensure that the country remain competitive within the international research community in this fast-developing field (Wepener *et al*., 2013).

Nanoparticles are commonly used in personal care products, food storage containers, cleaning supplies, bandages, clothing, and washing machines (Chalew and Schwab, 2012). Nanoparticles are likely to enter surface waters during the production, usage, and disposal of nanoparticle containing products. Estimates of nanoparticle concentrations in some natural surface waters are in the ng/L - µg/L range (parts per trillion to parts per billion), but the concentrations may increase with greater production and use of nanoparticle-containing products (Chalew and Schwab, 2012).

Musee *et al*. (2010) indicated that in South Africa it was important that the environmental, and health and safety-related (EHS) risks associated with nanotechnology be investigated carefully. They felt that against the background of increasing levels of pollution arising from industrial and commercial activities, the ability to profile nanotechnology risks at an early stage would avoid adding yet another source of unknown risks, which in turn could exacerbate existing pollution problems. In their paper they highlighted some of the specific challenges associated with monitoring and assessing the environmental risks posed by nanoparticles. These include:

- The scarcity of environment, health, and safety information on nanomaterials;
- The absence of a single index to measure the toxicity of nanomaterials;
- Nanotechnology nomenclature is still under development and, there appears to be little shared understanding of the most salient physicochemical characteristics that define a particular nanomaterial;
- The ready environmental transportation of nanomaterials increases chances of exposure. Nanomaterials can easily be distributed throughout an ecosystem due to their small size and solubility and, hence, they can present an increased risk of exposure;
- Nanomaterials are not easily monitored in real time and therefore cheap and easy-to-use monitoring technology is not yet in place; and
- Nanomaterials may pose system-level human health and environmental risks, where attention to one set or system overlooks the greater impacts.

The authors concluded that concerns were being expressed both nationally and globally, advocating caution and forethought about EHS issues related to nanotechnology, because these issues have yet to receive the attention they deserve. They propose a practical strategy that can help to establish a nationally coordinated research programme to investigate the potential adverse effects of nanotechnology. The strategy centres on:

- Developing a new generation of scientists and researchers that are suitably qualified to ensure safe and responsible development of a nanotechnology-based industry in South Africa;
- The development of state-of-the-art R&D infrastructure that fosters advanced research in EHS fields relating to nanotechnology; and
- The development of a focused research strategy for the EHS aspects of nanotechnology would provide a ‘road map’ for the generation of data, information and knowledge to support informed risk-management decisions.

This paper and other concerns lead to the development funded by the WRC of a framework for a WRC Research Programme on Engineered Nanomaterials (Wepener *et al*., 2013).

The adoption of a proactive and adaptive approach to the management of nanoparticles in water would help to safeguard South African society from being locked into systems that are difficult to reverse (Musee *et al*., 2010).

3.13 Radioactivity

Concerns have been expressed about radioactivity and radioactive substances associated with active gold mines and discarded mine dumps on the Witwatersrand (DWA, 2011) as well as the impacts of uraniferous waste on surface and groundwater (Liefferink, personal communication 2016, March 20).

Screening surveys of radioactivity in the Mooi River catchment conducted by the Resource Quality Information Services (RQIS) (then IWQS) of the Department of Water and Sanitation (DWAF, 1999) found that elevated levels of the radionuclides of uranium and radium were detected in streams close to gold mining activities. It found that the majority of sampling sites in the catchment showed low levels of water-borne radionuclides. The sites that showed significant concentrations of water-borne radionuclides were associated with discharge of mine water into the river system. Levels of radioactivity in the water column decreased with distance from the mining operations. This monitoring tracked water-borne radionuclides and was followed by a WRC-funded study by the CSIR (Wade *et al*., 2002) that hypothesised that some of the radionuclides were preferentially accumulating in the sediments of the Mooi River system. The CSIR study found that radionuclides accumulated in the sediments of the Mooi River, the main radionuclide of interest, being uranium, seemed to be adsorbed to the environmental phases: carbonate, iron and manganese oxy-hydroxides, and organics, and that uranium may be remobilised into the water column by perturbation of TDS, pH or oxidation potential.

Investigations by North West University into uranium pollution of the Wonderfonteinspruit (WFS), a tributary of the Mooi River, found that goldmine tailings deposits in the WFS catchment are estimated to contain well over 100 000 tons of U constituting a large reservoir for ongoing future U pollution. Apart from tailings, underground water in contact with uraniferous reefs constitutes another major source of waterborne U pollution. This applies to water pumped from underground mine workings as part of the active de-watering of overlying karst aquifers as well as decanting water from flooded mine voids. The discharge of U-polluted water together with largely uncontrolled outflow of uraniferous seepage from tailings deposits are major sources of water pollution in the WFS catchment (Winde, 2010 a,b).

In 2005 RQIS also undertook a survey of the radiological and chemical quality of water resources in selected sites of the Northern Cape Province (DWAF, 2005). This was in response to concerns expressed by Toens *et al.* (1998) that there are possible problems with the quality of the water in the Northern Cape and that people may be at risk of drinking water contaminated with radioactivity. The survey found that from a chemical point of view the results show that most of the boreholes sampled could indeed pose a health risk to people using the water for drinking purposes. In addition, out of sixteen boreholes sampled, only one borehole at Kotzesrus showed a possible health risk due to radiation and the borehole should not be used for domestic purposes.

At present monitoring of radioactivity and radionuclides is only undertaken when a specific concern is raised with the Department.

3.14 Description of water quality issues per WMA

Water quality problems are manifested at various scales (**Figure 18**). Salinisation, sedimentation, nutrients enrichment, and microbial pollution probably occur at a national scale while acid mine drainage and agrochemicals occur at regional or site specific scales. Two very good overview reports on the water quality situation in South Africa were produced by CSIR (2010) and DWA (2011). In the following section the key findings of the two reports were combined to summarise the key concerns at a Water Management Area scale.

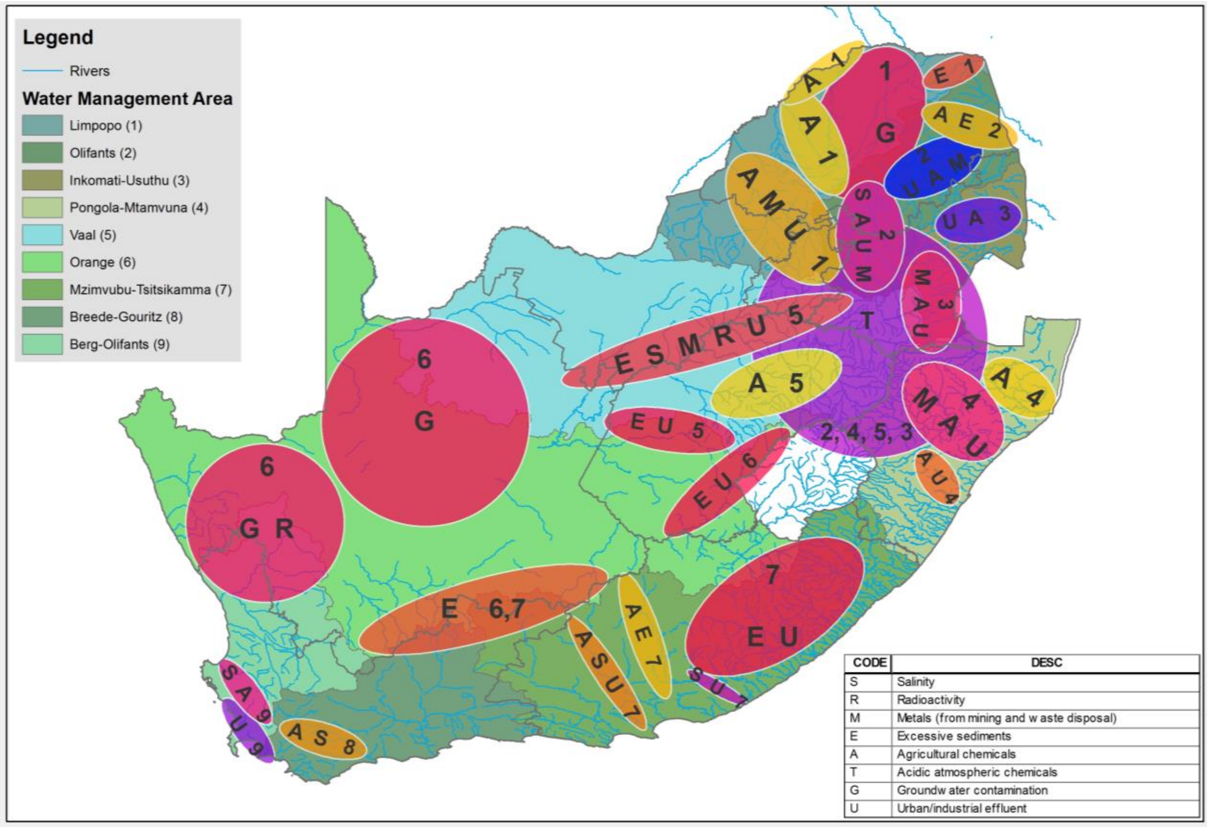

Figure 18: Map showing the different types of water quality problems that have been recorded in South Africa (Adapted from CSIR, 2010)

3.14.1 Limpopo WMA

The catchments of the Mokolo and Lephalala rivers are characterized by extensive areas of game ranching and irrigated agriculture, with one large opencast coalmine (Grootgeluk Mine) located close to the dry-cooled Matimba power plant located near the town of Lephalale. A few smaller settlements are also present in these catchments. Large volumes of water are abstracted from these rivers for irrigation of wheat, lucerne, maize, tobacco and cotton. Return flows and seepage from irrigated agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Mokolo and Lephalala rivers and their tributaries. Discharges of contaminated runoff from towns, smaller urban centres and informal settlements, contribute moderate numbers of waterborne pathogens and modest concentrations of nutrients, salts and low concentrations of endocrine disrupting chemicals (EDCs) to the river systems. Due to the low rainfall received in the area and the predominantly hot and dry climate, very little urban effluent enters the river systems.

The South African segment of the middle reaches of the Limpopo River system supports extensive areas of irrigated agriculture – principally cotton and tobacco. The area also has a few small towns and rural settlements. Return flows and seepage from irrigated agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Limpopo River.

Concerns have been expressed about the impacts of expanding coal-mining activities in the Mokolo River catchment and the ancillary industries, urban developments and dense settlements associated with the coal mining activities. In many areas, sand mining activities are increasing the turbidity in rivers. The catchment of the Crocodile River and its tributaries drains the northern portion of the Witwatersrand complex and contains several cities, large towns, urban centres and numerous informal settlements. The catchment supports extensive areas of arable agriculture and livestock ranching, as well as several chrome and platinum mines plus their ancillary industries. Many of these mines produce acidic effluent and acid mine drainage (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 – plus contaminated runoff from urban centres and informal settlements – result in the Crocodile River containing large numbers of waterborne pathogens and high concentrations of nutrients, salts and low to moderately high concentrations of endocrine disrupting chemicals (EDCs). Blooms of toxic cyanobacteria have been recorded annually from the hyper-eutrophic Hartbeespoort Dam, Klipvoor Dam, and Roodeplaat Dam.

3.14.2 Olifants WMA

The upper reaches of the Olifants River system in Mpumalanga and Limpopo provinces drains the northern edge of the Highveld and flow into the lower Olifants River down to Loskop Dam. This river is regarded as “one of the hardest working rivers” in South Africa because of its poor water quality. The catchment is characterized by numerous operating and defunct coalmines, as well as one diamond mine and a few iron and steel mills and large coal-fired power plants, plus several large towns, smaller urban centres and scattered rural communities. Most of the large towns and urban centres are surrounded by large informal settlements. Extensive areas of arable agriculture and livestock ranching are also present. The coal ore-bodies of all of the coalmines contain varying levels of iron pyrite and all of the mines contribute large volumes of acid mine drainage (AMD) to the Olifants River system. This AMD results in lowered pH values as well as elevated concentrations of metal ions (especially aluminium, cadmium, zinc and cobalt) and total dissolved salts, dominated by sulphate.

Many of the smaller towns and informal settlements either lack formal sanitation systems or, where these are present, seldom work effectively, with the result that large volumes of treated, partially treated and untreated domestic and industrial effluent enter the Olifants River system. Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Olifants River and its tributaries. Discharges of urban and industrial effluents, and contaminated runoff from larger towns, smaller urban centres and informal settlements, contribute large numbers of waterborne pathogens and high concentrations of nutrients, salts and low to moderate concentrations of endocrine disrupting chemicals (EDCs) to the Olifants River. Blooms of toxic cyanobacteria have been recorded from Loskop Dam on the Olifants River and several fish kills as well as dead crocodiles have been reported for this impoundment. Heavy industries in the Witbank and Middelburg area, principally iron and steel works, contribute additional quantities of inorganic and organic compounds to the Olifants River. The concentrations of trace metals (notably aluminium) in the Olifants River pose health risks to humans when the water is used to irrigate crops.

The lower Olifants River system receives inflows from Loskop Dam and several important tributary rivers along its route to the Kruger National park and into Mozambique. The catchment contains numerous chrome, platinum and vanadium mines, as well as mines that secure a variety of other minerals such as fluorite, corundum, iron, asbestos and tin. The large mining- industrial complex around the town of Phalaborwa produces copper, mica, phosphate and zirconium. The catchment also contains a large number of small urban centres and an extremely large rural population. All of the towns are surrounded by informal settlements of various sizes, and extensive areas of arable agriculture, livestock and game ranching are present in the catchment. Many of the smaller towns and informal settlements either lack formal sanitation systems or, where these are present, seldom work effectively. 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. Seepage and effluent discharges from the mining-industrial complex at Phalaborwa contribute elevated concentrations of copper, aluminium, fluoride, phosphate and some radioactivity to the lower Olifants River. Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Olifants River and its tributaries. Discharges of urban and industrial effluents, contaminated runoff from larger towns, smaller urban centres and informal settlements, contribute large numbers of pathogenic organisms and high concentrations of nutrients, salts. 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. The Letaba River catchment drains a section of the Limpopo Province and joins the lower Olifants River immediately before it enters Mozambique. Landuse in the upper portion of the catchment is extensive commercial forestry while the middle reaches contain extensive areas of citrus and sub-tropical fruit orchards as well as large areas of game ranching and subsistence agriculture. The Levhuvhu and Mutale rivers flow in a northeasterly direction, through the northernmost portion of the Kruger National park, to join the Limpopo River at the point where it enters Mozambique. Landuse includes large areas of commercial forestry in the upper reaches, while the middle and lower reaches of the river contain extensive areas of commercial and subsistence agriculture and numerous small towns and settlements.

The WMA contains several small towns and a very large rural population, most of whom are concentrated in scattered settlements that lack access to functioning sanitation systems. Return flows and seepage from orchards and agricultural lands result in elevated concentrations of pesticides and nutrients reaching the main rivers and its tributaries. Discharges of urban and industrial effluents, stormwater runoff from the towns, smaller urban centres and informal settlements, contribute large numbers of pathogens, and high concentrations of nutrients, salts and low concentrations of endocrine disrupting chemicals (EDCs). Where artisanal gold mining occurs, low concentrations of mercury, used in the extraction of gold from ore, have been detected. 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 surface waters.

3.14.3 Inkomati-Usuthu WMA

The Komati, Crocodile (East) and Sabie rivers drain the eastern portion of the Highveld and flow through the Lowveld into Swaziland and Mozambique. The catchments are characterized by extensive areas of commercial forestry as well as large areas of arable agriculture, cultivation of citrus and sub-tropical fruits, and livestock plus game ranching. The lower reaches of the Crocodile River support extensive areas of irrigated sugar cane. Numerous towns, smaller urban centres and densely populated rural areas are present in these catchments. Many of the residents living in 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 result in elevated concentrations of pesticides and nutrients reaching the rivers and their tributaries, which eventually flow into Mozambique. 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 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. Discharges of treated, partially treated and untreated urban effluent result in the rivers containing large numbers of waterborne pathogens and high concentrations of nutrients, salts and low to moderately high concentrations of endocrine disrupting chemicals (EDCs). Concerns have also been expressed about increased sulphate concentrations in the Kaap and Queens Rivers because of gold mining activities in the Baberton area.

The catchments of the rivers draining eastwards from the Highveld into Swaziland are characterized by the presence of extensive agriculture and forestry activities, as well as numerous underground and surface (strip-mining) coalmines. In addition, the area supports several small urban centres and informal settlements, as well as a few large coal-fired power plants. Several large inter-basin water transfer schemes ensure that sufficient water is available for power generation. Many of the smaller urban centres and informal settlements lack access to functional sanitation systems. All of the coal ore-bodies contain high levels of iron pyrite and all the coalmines are characterized by acid mine drainage (AMD). This AMD results in lower (acidic) pH values and elevated concentrations of total dissolved salts, as well as increased concentrations of metal ions (principally iron, manganese, aluminium, cadmium and zinc). Return flows and seepage from the agricultural lands result in elevated concentrations of pesticides and nutrients reaching the river systems, which eventually flow into Swaziland. Discharges of treated, partially treated and untreated urban effluent results in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of endocrine disrupting chemicals (EDCs).

3.14.4 Pongola-Mzimkulu WMA

Water quality in the upper Pongola was good but there was a concern about localised impacts of acid mine drainage from existing coal mining activities and closed or abandoned coal mines in the Paulpietersburg area. Studies have found evidence of localised acid mine drainage impacts but did not find evidence of widespread impacts. Water quality data collected downstream of the Pongola Irrigation Scheme found that the quality was moderate to poor for sugarcane irrigation. During the winter months, farmers stopped pumping irrigation water from the river due to the poor water quality. The mean nitrate concentrations were high and have caused algal blooms in the upper reaches of the Pongolapoort Dam. These effects were ascribed to irrigation return flows from the Pongola Irrigation Scheme.

The catchments of the Umfolozi and Mkhuzi rivers support extensive areas of forestry and agriculture; sugar cane is the dominant crop grown along the lower reaches of these rivers. Large volumes of water are abstracted from these rivers for irrigation of croplands. These catchments also contain numerous small urban centres and a large rural population; many of the residents in these catchments do not have access to appropriate sanitation systems. Return flows and seepage from the agricultural lands result in elevated concentrations of pesticides and nutrients reaching the rivers. Discharges of treated, partially treated and untreated urban and industrial effluent results in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and endocrine disrupting compounds (EDCs).

The upper reaches of the Thukela catchment contain a large number of operating and defunct coalmines that contribute relatively large volumes of acid mine drainage (AMD) to the river system. This AMD results in lowered pH values and elevated concentrations of total dissolved salts, especially sulphate. The presence of heavy industries (iron and steel works, chrome chemicals) contributes a variety of inorganic and organic compounds to the river system. The upper catchment contains a large rural population, many of whom lack access to appropriate sanitation systems. Discharges of treated, partially treated and untreated urban and industrial effluent results in the river containing large numbers of waterborne pathogens and high concentrations of nutrients, salts and endocrine disrupting chemicals (EDCs).

Large areas of the upper catchment also support extensive forestry and agricultural activities (principally livestock ranching, dairy farming and cultivation of crops), while extensive areas support the cultivation of sugar cane along the lower reaches of the river. Return flows and seepage from the agricultural lands result in elevated concentrations of salts, pesticides and nutrients reaching the rivers. Concerns have also been expressed about the impacts of overgrazing and poor land management on erosion and the sediment loads in the Thukela River.

The Mgeni River system drains the cities of Pietermaritzburg and Durban, plus several smaller urban centres. Large portions of the upper catchment support extensive areas of forestry and agriculture, including crops grown on arable land and a variety of livestock. Return flows and seepage from the agricultural lands result in elevated concentrations of pesticides and nutrients reaching the river. Discharges of treated, partially treated and untreated urban and industrial effluent results in the river containing large numbers of waterborne pathogens, organic matter and high concentrations of nutrients, salts and endocrine disrupting chemicals (EDCs). Toxic blooms of cyanobacteria occur frequently in the major reservoirs located along the Mgeni River posing additional health risks to humans and livestock. Concerns have also been expressed about the impacts of sugar and paper mills on water quality in estuaries. Erosion, overgrazing, settlement patterns, poor agricultural practices and sand mining operations have resulted in high sediment loads and a reservoir like Hazelmere Dam has lost over 20% of its storage capacity.

3.14.5 Vaal WMA

This area is recognized as the central zone where atmospheric depositions derived from coal- fired power plant and a variety of heavy industries are highest. Most of the atmospheric deposits contain low concentrations of sulphur and nitrogen oxides and have a moderately acidic pH. On contact with soil, these mildly acidic deposits can be neutralized by the natural buffering capacity present as carbonate salts in the soils. However, when this buffering capacity is exhausted, the acidic deposits interact with clay particles, separating the aluminium silicate matrix and releasing both silica and aluminium into the soil water. The flow of water from soils into streams and rivers results in a gradual build-up of aluminium in the region's surface waters. In turn, this aluminium poses health risks to humans, livestock and wildlife, as well as increased risks via the accumulation of aluminium in crops that are irrigated with this water. Elevated concentrations of aluminium inhibit fertilization in maize and result in reduced crop yields, increasing the threat to national food security. The situation can become severely aggravated where existing mild acidity from atmospheric deposition is accentuated by highly acidic acid seepage from operating and abandoned mines that release acid mine drainage (AMD).

The catchment of the middle and lower reaches of the Vaal River system drains the urban and industrial centres that form the Witwatersrand complex, and contain extensive areas of croplands (mainly maize and sunflower farming) and livestock ranching. There are numerous active and defunct gold and uranium mines in the Witwatersrand complex and these mines contribute large volumes of acid mine drainage (AMD) to the 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. This 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 uranium and radioactivity in certain tributary rivers (such as the Wonderfonteinspruit and the Mooi River). 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 contribute large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of endocrine disrupting chemicals (EDCs) to the Vaal River. Blooms of toxic cyanobacteria 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.

As its name implies, the Modder River contains high concentrations of suspended sediments. These are derived from the easily erodible rocks and soils of its catchment, and the situation is aggravated by the extensive areas of cropland and livestock ranching within the catchment. The city of Bloemfontein is the major urban centre in the catchment, while several smaller urban centres and informal settlements are also present. Many of the residents living in 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 result in elevated concentrations of pesticides and nutrients reaching the Modder River and its tributaries, which eventually flow into the Bloemhof Dam on the Vaal River. Discharges of treated, partially treated and untreated urban effluent results in the Modder River containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and moderately high concentrations of endocrine disrupting chemicals (EDCs). Periodic blooms of toxic cyanobacteria have been recorded in Krugersdrift Dam.

3.14.6 Orange WMA

The Caledon River forms the northern border between Lesotho and the Free State Province of South Africa. The catchment drained by the river and its tributaries consists predominantly of easily erodible mudstones, siltstones and shales; as a result, the river always contains high concentrations of suspended solids. The catchment supports extensive areas of croplands and livestock ranching and extensive over-grazing occurs within Lesotho. The naturally high concentrations of suspended sediments in the Caledon River become aggravated after heavy rainfalls and is particularly severe in areas of northern Lesotho that are over-grazed. Many of the residents living in the smaller urban centres and rural communities located along the length of the river lack access to appropriate sanitation systems. Small industries in the city of Maseru in Lesotho discharge their effluent directly into the river, resulting in increased concentrations of a variety of salts, organic compounds, and dyes used in textile industries. Return flows and seepage from the agricultural lands result in elevated concentrations of pesticides and nutrients reaching the rivers. Discharges of treated, partially treated and untreated urban effluent results in the Caledon River containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and moderately high concentrations of endocrine disrupting chemicals (EDCs). The increased sediment loads carried by the Caledon River lead to accelerated sedimentation in the downstream Gariep Dam.

The lower Orange WMA refers to the stretch of Orange River between the Orange-Vaal confluence and Alexander Bay where the river enters the Atlantic Ocean. The Orange River forms a green strip in an otherwise arid but beautiful landscape. Minerals and water from the Orange River is the key elements for economic development in the region and irrigation is by far the dominant water use sector. The availability of water and the climate makes the strip around the river particularly suitable for the growing of high value crops such as table grapes, dates, raisins, wine, flowers, vegetables, grain and fodder crops. High volumes of irrigation return flows enter the Orange River bringing with it salts, nutrients, and agrochemicals. The river regularly exceeds of 500 mg/ℓ TDS between Boegoeberg Dam and Kakamas which is a concern. Algal blooms in the lower Orange River and outbreaks of pest blackflies are further concerns in this WMA.

Concerns have been raised about the impacts of mining on groundwater in the northern Cape area, specifically AMD where old goldmines are located, brines associated with diamond mining, and the closure of iron ore mines and the impacts that might have dolomitic freshwater systems. During droughts groundwater become an important source for smaller towns and rural communities, raising the profile of groundwater protection in those areas. Groundwater can become brackish as the water table drops. Concerns have also raised about the potential impacts of hydraulic fracking on groundwater quality.

3.14.7 Mzimvubu - Tsitsikamma WMA

The Buffalo River system traverses the urban-industrial axis formed by the cities of King Williams Town and East London, plus several smaller urban centres. Saline effluents discharged from tanneries in King Williams Town 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 – plus contaminated runoff from urban centres and informal settlements – results in the river containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and endocrine disrupting chemicals (EDCs). All of these substances pose severe health risks to humans and livestock that may consume the water. Toxic blooms of cyanobacteria occur frequently in the major reservoirs located close to the city of East London and pose additional health risks to humans and livestock.

The rocks and soils forming the upper catchments of rivers flowing through the Transkei region are easily erodible. High population numbers combined with over-grazing by livestock have depleted the vegetation cover in many areas and have led to accelerated rates of erosion. All of the rivers contain elevated concentrations of suspended silt. Discharges of treated, partially treated and untreated urban and industrial effluent from the city of Mthatha results in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and endocrine disrupting chemicals (EDCs).

The main rivers of the Fish to Tsitsikamma WMA are the Great Fish, Sundays, Bushmans, Kowie and Kariega Rivers. All these rivers drain to the Indian Ocean.

With the exception of a few coastal catchments, the water quality concerns in the Fish to Tsitsikamma WMA is dominated by elevated salinities mostly from natural sources. The Sundays River and many of its tributaries contain naturally elevated concentrations of dissolved salts that are derived from ancient marine sediments in its catchment. High rates of water abstraction for irrigation, mainly of citrus crops, plus high rates of evaporation results in a progressive increase in the salinity of this river system from its headwaters to its mouth close to the city of Port Elizabeth. Return flows from irrigated agriculture contain elevated concentrations of a variety of pesticides and fertilisers, leading to a further deterioration in water quality. The river receives water transferred from the Gariep Dam on the Orange River, which often contains high concentrations of suspended solids. Along its lower reaches, the Sundays River receives inflows of treated, partially treated and untreated domestic and industrial effluent from towns, cities and informal settlements. These effluent inflows – plus contaminated runoff from urban areas – cause a further deterioration in water quality along the lower reaches. The water in the lower reaches of this river contains large numbers of pathogenic organisms and high concentrations of nutrients, salts and endocrine disrupting chemicals (EDCs).

The Great Fish River and its tributaries contain naturally elevated concentrations of dissolved salts that are derived from ancient marine sediments in its catchment. High rates of evaporation result in a progressive increase in the salinity of this river system from its headwaters to its mouth. The rocks and soils forming the catchment are easily erodible and over-grazing by livestock results in high concentrations of suspended sediments along the length of the river.

Dense settlements informal housing areas around Grahamstown, Port Elizabeth and Uitenhage have raised concerns about microbial pollution in those areas. The current level of services is often inadequate and problems are experienced with the disposal of nightsoil, grey water, litter and solid waste. These problems contribute to poor microbiological water quality in stormwater runoff and dry weather flows from informal settlements and poorly services high density settlements. These raise the risk of water-borne diseases and its impacts on human health, and aquatic ecosystem impacts such as low dissolved oxygen concentrations.

Concerns have also been raised about the impacts of intensive industrial developments in the Port Elizabeth/Uitenhage area on heavy metal concentrations in the Swartkops River.

Concerns have been raised about agrochemicals downstream of the Fish and Sundays River irrigation schemes. Similarly, concerns were associated with intensive irrigation agriculture alongside the Kouga River (Langkloof Valley) and Gamtoos Rivers where vegetables, fruit and tobacco is produced.

3.14.8 Breede - Gouritz WMA

The headwaters of the many seasonal and ephemeral rivers that drain northwards towards the Orange River from the southern portion of the Karoo are located on easily erodible and vulnerable soils and rock formations. These rivers tend to flow strongly after rainfall events and carry high concentrations of suspended silt and clay. This suspended sediment poses difficulties to stock farmers in the area and leads to rapid accumulation of sediment in water storage reservoirs and farm dam.

The Gouritz WMA is situated in the southwest region of South Africa and falls predominately within the Western Cape Province, with small portions in the Eastern - and the Northern Cape Province. The other rivers, which drain the inland area include the Buffels, Touws, Groot, Gamka, Olifants and Kammanassie Rivers. Several smaller rivers drain the coastal belt. Water quality concerns in the Gouritz WMA (DWA, 2011) included the elevated salinity found in the Gouritz River and its major tributaries that occurs naturally in the inland catchments of the Great and Little Karoo. Farmers have adapted to this by selecting crop types that allowed them to continue financially viable farming operations, and making best use of the available water for irrigation.

In the developed urban areas, particularly the more densely populated coastal towns, man-made activities result in problems commonly associated with urban water use. These include discharge of water containing waste, WWTWs not meeting their required effluent water quality standards, and diffuse pollution from informal settlements.

Concerns have been expressed about sewage and wastewater treatment systems in the WMA. In the larger urban centres such as Oudtshoorn, vandalism of the sewage reticulation and pump station infrastructure occasionally leads to sewage spills into the Olifants River. The industrial expansion taking place in the Oudtshoorn area would introduce additional loads on the WWTW and upgrading of the works will be necessary to avoid spills.

The disposal of wood processing waste is a potential problem throughout the coastal catchments (K catchment). Many saw mills operate without the necessary permits for discarding their waste. Leachate consisting of organic acids and of high COD concentration from sawdust and woodchips is a concern. The extent of unlawful disposal of this waste is not well known and the extent of impact on water quality has not been determined.

The Breede Water Management Area (WMA) is situated in the south-west corner of South Africa, falling entirely within the Western Cape Province and is comprised of the tertiary drainage regions G40 (excluding G40A), G50 which makes up the Overberg Area and H10 to H70 which makes up the Breede River basin. The Breede River is the main river in the catchment and its largest tributary is the Riviersonderend River. Other key rivers in the WMA include the Sonderend, Sout, Bot and Palmiet rivers.

The Breede River valley is an area of intensive agriculture and has naturally saline soils and groundwater. Salinisation of the middle and lower Breede River and its tributaries are the result of the irrigation return flows discharged to the rivers, the geology of the area, and agricultural practices. Of particular concern is the intentional leaching of natural salts where new lands are cleared and soils purposefully leached to prepare those lands for irrigation. Acceptable salinity levels in the Breede River are maintained by freshening releases out of the Greater Brandvlei Dam.

Concerns have also been expressed about nutrient enrichment and the occurrence of algal blooms under low flow conditions at certain locations within the middle Breede River as well as the clogging of canals with filamentous algae and aquatic weeds. This concern is related to WWTW not meeting their effluent standards fertiliser runoff from diffuse sources.

Microbial pollution related to the discharge of inadequately treated wastewater effluent from WWTWs, and irrigation with untreated winery and other industrial effluent is a further concerns. Most municipal WWTWs and larger industries are attempting to meet licence conditions but the cumulative effect of many smaller operators irrigating with effluent that does not meet the GA requirements, remains a concern. Diffuse pollution from poorly serviced informal settlements and the use of soak-aways on the banks of the Lower Breede River are also of concern to the microbiological quality of the Breede River and other rivers in the WMA.

Studies in the Hex River valley have detected pesticide residues in irrigation return flows (London, 1999, London *et al*, 2000). It is probably reasonable to assume that the same patterns of pesticide contamination would occur in the rest of the basin where intensive irrigation agriculture is practised. The water quality poses risks to aquatic life and to any humans that may drink directly from the river.

3.14.9 Berg – Olifants WMA

The Berg Water Management Area (WMA) is situated in the extreme southwest corner of South Africa and consists of secondary drainage region G1 and G2, as well as the quaternary G30A in the north and G40A in the south. The entire Berg WMA is a winter rainfall region. The major rivers include the Berg, Steenbras and Diep Rivers. Water is exported from the Breede WMA via the Riviersonderend-Berg River Tunnel System into the Berg WMA.

The urban rivers flowing through or near to the city of Cape Town receive large volumes of contaminated runoff from urban areas. The water in these rivers contains large numbers of pathogenic organisms and high concentrations of metal ions, nutrients, salts and endocrine disrupting chemicals (EDCs).

The most significant water quality problem in the Berg River catchment is salinisation in the middle and lower reaches. The Berg River valley is an area of intensive agriculture and has naturally saline soils, particularly along its lower reaches, and mildly saline groundwater. The combination of elevated concentrations of dissolved salts is aggravated by return flows from irrigated agriculture, which also contain a wide variety of agro-chemicals (fertilisers and pesticides).

A further concern in the Berg River is nutrient enrichment as a result of the discharge of treated sewage effluent from WWTWs, irrigation with winery effluent, and the direct discharge of winery effluent.

Concerns have also been expressed about the microbiological quality of rivers affected by treated wastewater effluent discharges and runoff from informal settlements. Rivers such as the Plankenberg and Eerste River near Stellenbosch, Stiebeul River near Franschhoek, and the Kuils River in Bellville are affected by poor quality effluents and runoff from informal settlements and high-density settlements with poor sanitation services.

Many of the urban river systems in the Berg WMA serve as conduits for treated effluent discharged to the sea. These rivers no longer display seasonal flow patterns, and some, notably the Black/Salt and Kuils Rivers have become severely modified.

There are concerns about the accumulation of pesticide and herbicide residues in the surface waters, biota and sediments downstream of intensive irrigation areas. Concerns have also been expressed about the presence of endocrine disrupting chemicals (EDCs) in surface waters near intensive irrigation systems.

The major river in the Olifants Doorn WMA is the Olifants River, of which the Doring River (draining the Koue Bokkeveld and Doring areas) and the Sout River (draining the Knersvlakte) are the main tributaries (DWAF, 2005). It comprises the E primary drainage region.

The upper reaches of the Olifants and Doring Rivers have good water quality. Water is stored in Clanwilliam Dam and used intensively in the Olifants River Irrigation Scheme via a series of irrigation canals. Irrigation return flows to middle and lower Olifants River lead a significant increase in salinity, nutrients and to a lesser degree, agrochemicals, in these river reaches. Concerns have been expressed about microbial water quality in the upper reaches of the Olifants River and the impacts it may have on the fruit export industries. The Citrusdal valley of the Olifants River experiences nutrient enrichment problems which are largely attributed to agricultural return-flows, especially in the summer months when the flow is relatively low in the river. Treated domestic wastewater, municipal solid waste management and informal settlements contribute towards this problem. Concerns have been raised about the impacts of residues from agricultural chemicals such as pesticides and herbicides on surface and sub-surface waters in intensive irrigation areas and upper Doorn River. Concerns have also been expressed about sand mining activities and its impacts on turbidity and sediment loads in rivers.

The quality of water in the upper Doring River, when flowing, is suitable for agriculture and domestic water supplies. However, TDS concentrations in the Kruis River are very high and variable and the water quality has been classified as “tolerable” to “unacceptable” (DWAF, 1998). Water quality in middle Doring River becomes marginal and TDS concentrations increase in a downstream direction. In the lower reaches, the water quality varies between “acceptable” at the end of winter and “tolerable” at the end of summer, probably as a result of the predominantly winter rainfall in the catchment. It has been reported that farmers stop irrigating when the water begins tasting salty. Highly saline flows from the Tankwa Karoo tributaries have a sporadic influence on the Doring River.

The water quality status of non-perennial rivers like the Wolf, Koebee and Oorlogskloof, Sout, Krom, and Hantams Rivers are unknown while the Knersvlakte is arid and naturally high in salinity.

3.15 Prioritisation of water quality issues

A wide range of water quality issues is outlined in the preceding sub-sections to this part of the report. Individually, these issues differ in terms of the following characteristics:

- the geographical extent of their impacts,
- the cumulative severity of their impacts on the fitness-for-use of the resource, on water users’ health, on the local and regional economy, and on local and downstream ecosystems,
- the extent to which they have been / are being monitored,

- levels of technical/scientific knowledge and understanding of the above impacts, their temporal patterns and geographic prevalence.

We reviewed these characteristics for each of the water quality issues against the information in the above sub-sections in order to identify those issues that should receive high-priority management attention. **Table 3** provides an outline of the above characteristics for all the water quality issues.

Table 3: Summary characteristics of water quality issues per Water Management Area

Water Quality Issue	Geographical Prevalence	Severity of Impacts	Extent of Monitoring	Knowledge & Understanding
Salinisation	Five WMAs	High severity locally and downstream	High – all DWS and other monitoring stations include TDS, EC and SO_4.	High – both temporal and technical
Eutrophication	Six WMAa	High severity locally and downstream	High - most DWS and some other monitoring stations include P, N and Chlorophyll	High – both temporal and technical
Acidification	Four WMA	High severity locally and less downstream	High - all DWS and other monitoring stations include TDS, EC and SO_4	High –both temporal and technical
Sedimentation	All WMAs	High severity locally and downstream	Medium to low – Sediment accumulations in most RSA dams are surveyed by DWS on a roughly 5-yearly basis, but suspended river sediment concentrations are only intermittently sampled.	High – technical Low - temporal
Urban runoff pollution	All WMAs	High severity locally, but less severity downstream	Medium to low – monitored by some DWS and other stations downstream of urban areas	High – technical Medium - temporal
Pathogens	All WMAs	High severity locally, but less severity downstream	Low	High – technical Low - temporal

Water Quality Issue	Geographical Prevalence	Severity of Impacts	Extent of Monitoring	Knowledge & Understanding
Agrochemicals	Some WMAs	High severity locally, but less severity downstream	Low - National Toxicant Monitoring Programme still being rolled out	Medium – technical Low - temporal
Dissolved oxygen	All WMAs	High severity only locally	Low	High – technical Low - temporal
Metals	Most WMAs	Medium severity locally and less downstream	Very low	Low - technical Low temporal
Hydrocarbons	Unknown	Unknown	Very low	Medium – technical Low - temporal
Thermal pollution	Most WMAs	High severity locally but low severity downstream	Medium – downstream monitoring picks up Hypolimnion cold-water releases from dams.	High – technical Medium - temporal
Radioactivity	Three WMAs	Medium severity only locally	On demand monitoring and surveys	High – technical Low - temporal
Nanoparticles	Unknown	Unknown	None	Low – both technical and temporal

Figure 19 graphically depicts the "mapping" of the water quality issues on a continuum of Impacts against Knowledge and Understanding. It can be seen that five water quality issues occupy the High Impacts/High Knowledge area on the diagram, namely Eutrophication, Salinisation, Sedimentation, Acidification and Urban Pollution. This signifies that they should receive high priority management attention.

The water quality issues that plot in the right-hand half of the diagram are issues of which there is less Knowledge and Understanding – mainly because they are not adequately or widely monitored. The wide range of Impacts indicated for them signifies the extent of our uncertainty about these water quality issues.

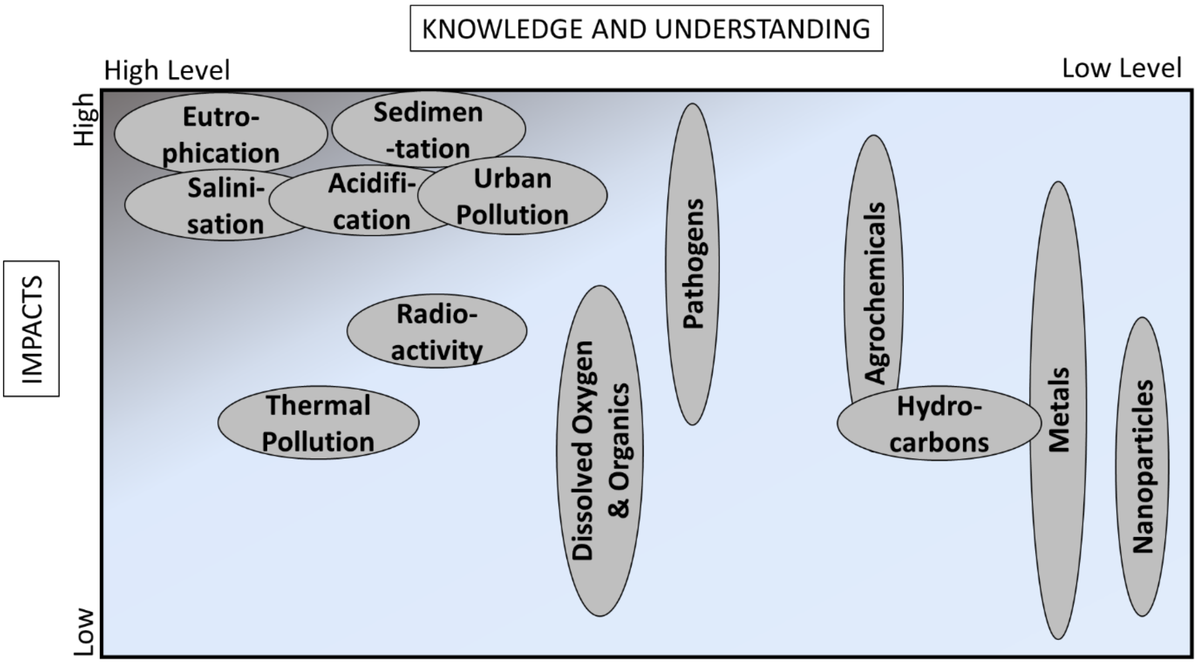

Figure 19: Mapping of water quality issues against Impacts and Knowledge/Understanding

The implication of the information contained in this diagram for the policy and strategy development process is that the focus for the five priority issues will need to be on reduction of their spatial prevalence and the intensity and threat-level of their impacts, while many of the other issues require much-extended monitoring, spatially and temporally.

4. FUTURE TRENDS AND WATER QUALITY IMPACTS

4.1 Introduction

A number of “mega-trends” can be expected to unfold in South Africa during the next few decades relating to climate, energy, sustainability and rural-urban migration (National Planning Commission, 2012a&b; Institute for Futures Research, 2013) which can be expected to lead to new or accelerated water quality impacts in many locations across the country. In specific terms, these mega-trends are as follows:

- Climate change (DEA, 2013 a&b)
- Unconventional oil and gas extraction through hydraulic fracturing (Steyl and Van Tonder, 2013; Esterhuyse, 2014)
- Renewable energy (Sparks *et al*., 2014)
- Water-energy-food security nexus (FAO, 2014)
- Growth of inadequately serviced densely populated settlements (National Planning Commission, 2012 a&b)
- Water re-use (DWA, 2011).

4.2 Climate change

4.2.1 Climate change scenarios for South Africa

A recent review of existing climate models identified four possible future scenarios as part of the Long Term Adaptation Scenarios (LTAS) flagship research programme of the Department of Environmental Affairs (DEA, 2013a):

- Warmer (<3˚C above 1961-2000) and wetter with greater frequency of extreme rainfall
- Warmer (<3˚C above 1961-2000) and drier with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events;
- Hotter (>3˚C above 1961-2000) and wetter with substantially greater frequency of extreme rainfall events, and
- Hotter (>3˚C above 1961-2000) and drier with a substantial increase in the frequency of drought events and somewhat greater frequency of extreme rainfall.

These impacts would also vary quite significantly for different regions as summarised in **Figure 20**.

Scenario	Limpopo/ Olifants/ Inkomati	Pongola-Umzimkulu	Vaal	Orange	Mzimvubu-Tsitsikamma	Breede-Gouritz/ Berg
1: warmer/ wetter	↑ spring and summer	↑ spring	↑ spring and summer	↑ in all seasons	↑ in all seasons	↓ autumn, ↑ winter and spring
2: warmer/drier	↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ in all seasons, strongly ↓ summer and autumn	↓ in all seasons, strongly ↓ in the west
3: hotter/wetter	Strongly ↑ spring and summer	Strongly ↑ spring	↑ spring and summer	↑ in all seasons	Strongly ↑ in all seasons	↓ autumn, ↑ winter and spring
4: hotter/ drier	Strongly ↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ all seasons, strongly ↓ in summer and autumn	↓ all seasons, strongly ↓ in the west

Figure 20: Summary of possible climate change impacts on precipitation (up-arrows=increase; down-arrows=decrease) for six hydro-climate zones in South Africa determined from the LTAS analysis of available climate models (DEA, 2013a).

The LTAS study concluded that while there was a consensus that temperatures would continue to increase into the future, the level of increase would be dependent on the outcomes from global mitigation efforts. Under a "business as usual" scenario, South Africa would likely experience a much "hotter" future with an average increase in temperature greater than 3˚C by the end of the century. If however there were improved global co-operation on climate change and a significant reduction in greenhouse gas emissions then South Africa would like face only a "warmer" future. For both scenarios, the potential impacts would apply for all regions of the country, but with inland areas likely to experience greater increases than coastal zones and the mountains. Under both the "hotter" and "warmer" futures there was still much uncertainty about the possible impact on precipitation, but it was generally agreed that *the variability in extreme rainfall would increase under both scenarios, and more so under the "hotter" scenario.*

A study undertaken by National Treasury, which also contributed to the LTAS Study, applied a risk-based approach to assessing climate change futures in South Africa (National Treasury, 2013; DEA, 2014). This study considered a hybrid frequency distribution (HFD) analysis of over 350 possible climate futures derived from MIT's Integrated Global Systems Model using outputs from 17 global circulation models (GCM) under both an Unconstrained Emissions Scenario (UCE) and a Level 1 Stabilization (L1S) scenario. The potential biophysical impacts of a range of possible climate futures was analysed using a rainfall-runoff model at quaternary catchment scale, as well as a water resources yield model configured at secondary catchment scale for the whole of South Africa that includes all the major water supply infrastructure, dams and inter-basin transfer systems.

The ratio of potential climate change impacts on the average annual precipitation by 2050 from multiple models under the UCE mitigation scenario relative to the base scenario in each secondary catchment is shown in **Figure** 21 **21** (National Treasury, 2013; DEA, 2014). The solid line indicates the median impact of all the climate futures and the shaded and dotted lines show the range of potential impacts.

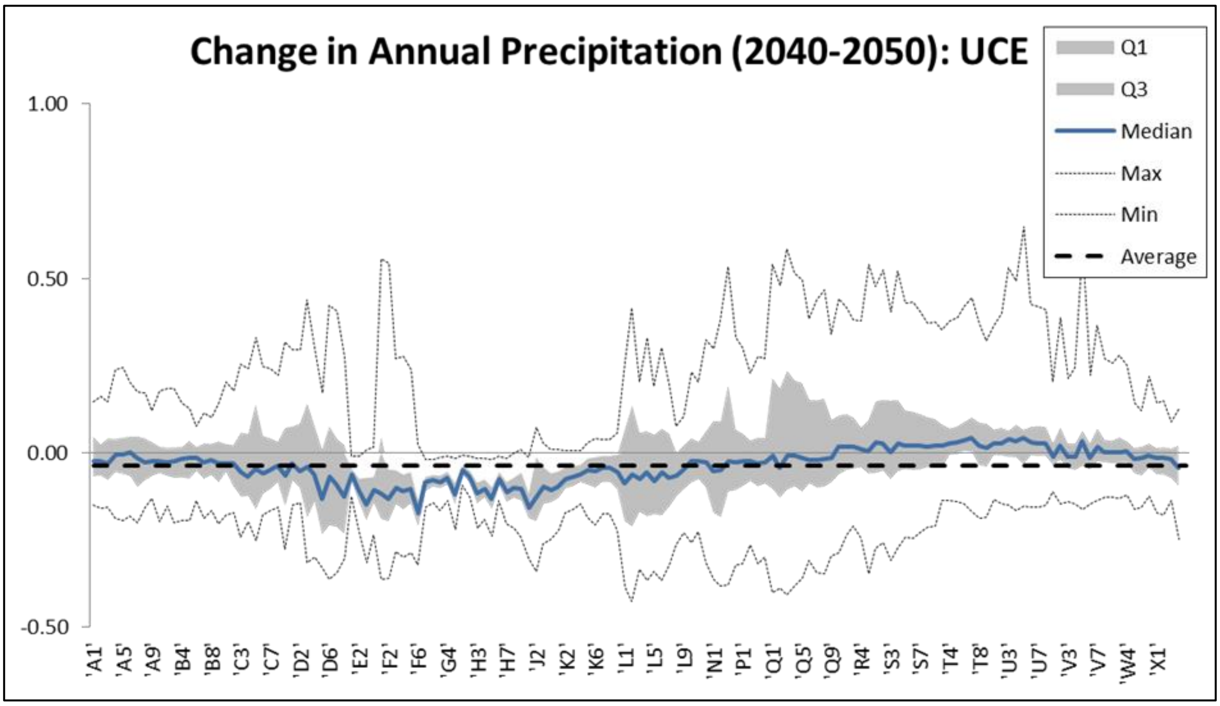

Figure 21: Range of potential change in mean annual precipitation (as a ratio relative to that for 1961 to 2000) for the period 2040 to 2050 in each secondary catchment of South Africa under the UCE climate scenario (DEA, 2014).

Despite a wide range of uncertainty across much of the country, there is a predominant indication that for most simulated climate futures the mean annual precipitation in the E, F, G, H, J, K and L secondary catchments (i.e. winter-rainfall and all-year-rainfall regions) is decreased relative to 1961 – 2000 values. In contrast, the results for the R, S, T and U secondary catchments (summer-rainfall region) in the east of the country predominantly indicate increases in the mean annual precipitation.

NB: It should be noted that despite the indication of decreased mean annual precipitation for certain regions, increased frequency of extreme rainfall events is nevertheless indicated.

The discussion of the potential impacts of climate change on water quality presented below is primarily based on the following two sources: (i) a generic overview provided in a report by the then Department of Water Affairs (DWA, 2013) on a climate change adaptation strategy for water for South Africa, and (ii) a wide-ranging literature review regarding this topic by the European Environment Agency (ETC Water, 2010).

4.2.2 Generic overview of water quality impacts

Climate change will potentially affect water quality through increased temperature and through changes in rainfall affecting runoff and mobilisation of nutrients and other pollutants. The increased water temperature will affect circulation patterns in deep water bodies as well as increase the rate of biogeochemical and ecological processes that determine water quality. In areas with decreased river flow and groundwater recharge, water quality may also deteriorate due to less dilution of constituents. More frequent extreme precipitation events and higher intensity and frequency of floods are expected to increase the load of pollutants (suspended sediment, organic matter, nutrients, and hazardous substances) washed from soils and overflows of sewage systems to water bodies.

Increased temperatures and knock-on effects:

Since water temperature is mainly determined by heat exchange with the atmosphere, higher air temperatures caused by climate change would lead to higher surface water temperatures. Increased surface water temperature could affect, inter alia, the dissolved oxygen content of water, the rates of chemical and biological reactions in both water and soil, as well as have wide-ranging repercussions in the health sector through the creation of favourable conditions for the incubation and transmission of water-borne diseases.

In deep water bodies, temperature would increase more in the upper regions of the water column than in the lower regions, resulting in generally steeper vertical temperature gradients and enhanced thermal stability (stratification). This would significantly affect the mixing of water in dams and lakes, which in turn would affect deep-water oxygen conditions, nutrient cycling and phytoplankton biomass in those water bodies.

Higher air and water temperatures would cause additional evaporation, over and above that under present climatic conditions, from open water bodies such as dams and wetlands as well as from the soil and plant systems. Increased evaporation would cause increased concentration of dissolved and suspended constituents in an open water body when the water volume is reduced. On the other hand, CO_2 solubility would increase and that may precipitate some of the problematic constituents out of solution and thus make them less bio-available.

It would also increase the concentration of salts and other water constituents in the soil when soil moisture is reduced because of increased evaporation at the soil surface and water losses through increased evapotranspiration from plants.

Altered dilution of surface water constituents:

Increased frequencies and/or sustained durations of low-streamflow periods due to climate change would generally reduce dilution of all dissolved/suspended surface water constituent concentrations, such as inorganic salts, suspended sediments, dissolved organic carbon, nutrients, pathogens and hazardous substances, and, thereby, increase the concentrations of all the above surface water constituents.

Conversely, increased frequencies and/or sustained durations of high-streamflow periods due to climate change would increase dilution of all dissolved/suspended surface water constituent concentrations indicated above.

Nutrient concentrations and loading:

More frequent extreme precipitation events due to climate change would cause increased surface runoff and erosion in catchments, leading to increased nutrient loading to surface waters – particularly from agricultural land and from more frequently surcharged sewers. More frequent high flow episodes in streams would also increase the nutrient loads to surface waters, because the transported nutrients would possibly end up bypassing biological “sinks” which would otherwise have captured them under present-day climate conditions. On the other hand, increased temperatures might possibly result in increased biotic activity, which would lead (all else being equal) to increased nutrient entrapment. The higher temperatures would also increase mineralisation of soil organic matter, which, in turn, would lead to increased nitrate leaching – particularly from agricultural lands. Eutrophication of dams and rivers can be expected to increase under the above scenarios. However, in areas projected to be drier under climate change (e.g. all of the Western Cape Province), long-term nutrient loadings can be expected to decrease (all else staying the same) due to less runoff in the long-term.

The internal phosphorus loading in stratified dams and lakes are projected to increase with climate change due to stronger water column stability in summer, longer summer stratification periods and decreased bottom water oxygen concentrations. Rising temperatures in the water column would lead to enhanced mineralisation of organic matter and increased release of phosphorus attached to bottom sediments.

Water transparency:

Underwater light conditions in rivers, dams and lakes are mainly affected by suspended sediment concentration (mineral turbidity), dissolved organic carbon (DOC) concentration and phytoplankton density. Climate change might cause alteration of the underwater light conditions of surface waters through increased sediment loads due to increased erosion from catchments, affecting both mineral turbidity, DOC concentrations and background input of nutrients, and through changes in the carbon cycling processes in catchment affecting the input of humic substances. Moreover, if the stratification patterns of dams and lakes are altered by climate change, the depth of the circulating water column would be affected and thereby also the underwater light needed for phytoplankton photosynthesis.

Dissolved oxygen:

Dissolved oxygen concentrations in river/dam water columns would decrease as a direct result of temperature increase, but also as an effect of increased respiration, either as a direct response to increased temperature or due to increased nutrient levels brought about by climate change as described above. In deep water bodies the resulting increase in thermal stability (strengthened stratification) would reduce the frequency of vertical mixing of oxygen. This could be expected to lead to hypolimnetic oxygen depletion and to increased risk of deep-water anoxia.

This climate change-related impact could be particularly evident in relatively mixed water bodies of intermediate depth in which oxygen depletion is currently less common than in deep water bodies which stratify only once or twice per year. However, with increased surface water temperatures, stratification may occur more frequently and more pronounced in these water bodies and also last longer, thereby increasing the severity of oxygen depletion.

Hazardous substances:

Research on the effect of climate change on concentration of hazardous substances is still limited. The effects seem to depend on the type of hazardous substance in question. Most hazardous substances bind strongly to particles and are thus likely to be affected by impactful changes in ambient hydrological processes. Direct temperature effects, on the other hand, would largely be limited to compounds that are volatile, such as mercury, and/or subject to degradation processes, such as organic pollutants.

Climate change might affect future use of pesticides. Increased prevalence of existing pests, weeds and diseases and increased pest resistance could lead to wider and more frequent application of pesticides, and introduction of new products. On the other hand, in areas severely affected by drought due to climate change, the decline in agriculture would reduce the use of pesticides. Increased temperature might increase the rate of dispersal and lead to wider distribution of pesticides.

Climate change could also affect remobilisation of previously released hazardous substances persisting in soil and sediment. Increased frequency of intense rainfall events and floods would cause increased soil erosion, increasing the pollutant concentration in aquatic systems. More intense rainfall would also give more by-pass flow and more rapid movement of pesticides from agricultural soils to surface water. This would be enhanced by warmer, drier summers causing increased cracking of soils.

Pathogens:

Pathogens derive both from point sources and diffuse sources. Increased precipitation and higher frequency of intensive rainfall events might lead to increased occurrence of sewage overflows. This could lead to a higher load of pathogenic microbes to surface waters. High intensity rainfall might also lead to increased input of pathogens from pastures. Loading of livestock wastes on grasslands could generate a potential surface store of pathogens, which might be released through significant precipitation events. Increased discharge may also lead to resuspension of microbes historically adsorbed in stream sediments.

4.3 Unconventional Oil and Gas extraction by means of hydraulic fracturing

During the past decade, the requirement for new energy sources has gained strong momentum and part of this new focus is on shale gas in Karoo-type formations, with exploration areas covering six of the nine provinces in South Africa, as shown in **Figure 22** (Steyl and Van Tonder, 2013).

There currently are five pending applications related to exploration in the Karoo, three belong to Shell and one each to Falcon Oil & Gas and Bundu Gas & Oil Exploration. To the north is the exploration area allocated to the petrochemical group Sasol. An exploration area has also been allocated to Anglo American adjacent to the Sasol area. The primary extraction method to be used for these unconventional shale gas resources is hydraulic fracturing.

The most prominent types of unconventional hydrocarbon that occur in South Africa are shale oil and gas and coalbed methane. A map showing the extent of the areas for which permits have been applied for from the Petroleum Agency of South Africa (PASA) (as of August 2014) is shown in **Figure 23** (Esterhuyse *et al*., 2014). Information about more recent permits can be requested from PASA (http://www.petroleumagencysa.com/).

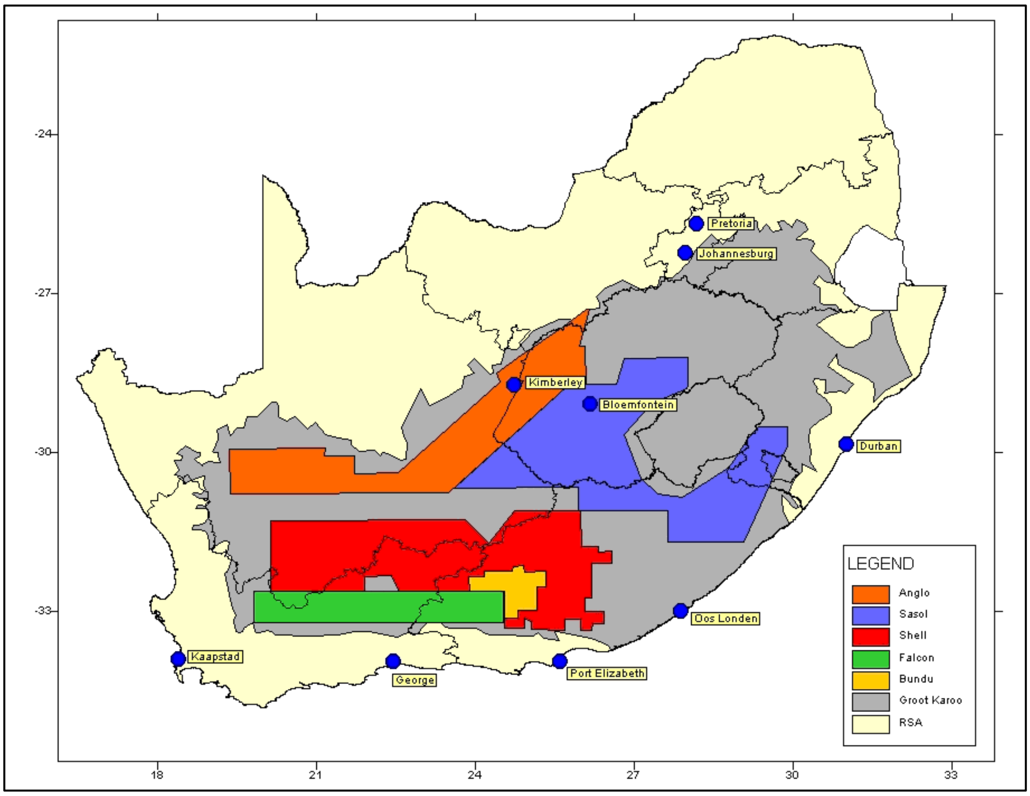

Figure 22: Regional map of South Africa, showing the exploration rights and companies associated with these permits (Steyl and Van Tonder, 2013).

Hydraulic fracturing (also known as "fracking") comprises the extraction of natural gas or oil from hydrocarbon-bearing low-permeability strata by horizontal drilling and hydraulic fracturing of the relevant strata to increase permeability and release the gas or oil through the induced fissures. The fracturing is caused by the high-pressure injection of thousands of m^3 of water, chemicals and sand into the well. Hydraulic fracturing poses a number of water quality risks and challenges during the following activities that constitute the hydraulic fracturing water cycle (US EPA, 2015; Steyl and Van Tonder, 2013):

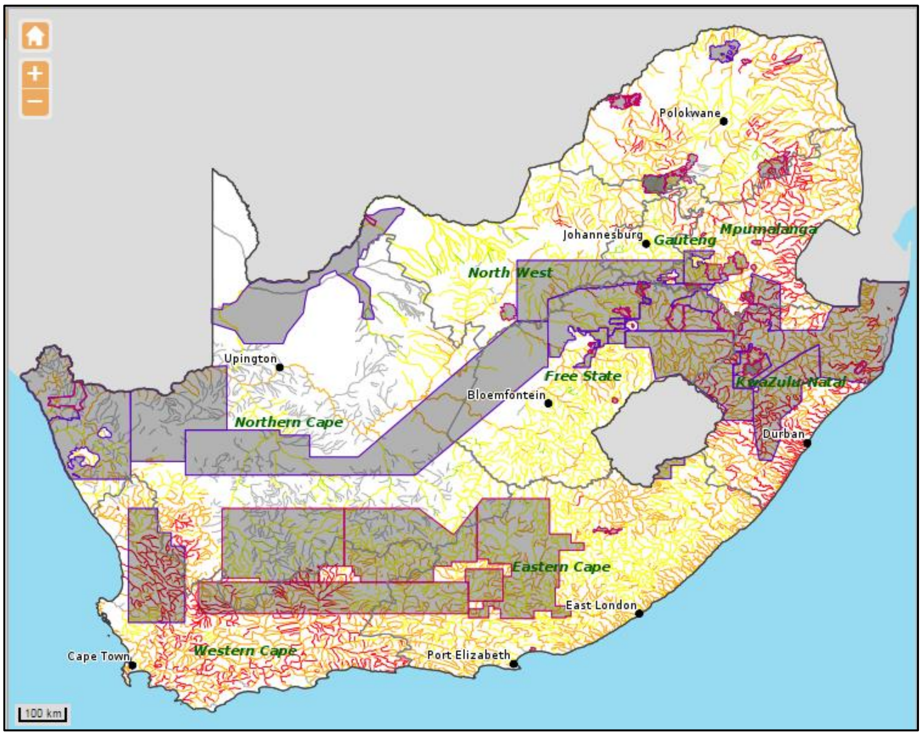

Figure 23: Permit application areas compiled from data provided by the Petroleum Agency of South Africa in 2014 (Esterhuyse *et al*., 2014, http://fracking.webmaps.co.za/)

Stage 1: Water acquisition

- Large volumes of water needed for the high-pressure injection are abstracted from existing surface water and groundwater resources. Gallegos *et al*. (2015) compiled water volumes injected to hydraulically fracture over 263 000 gas and oil wells drilled between 2000 and 2014 across the USA. They found that the *median* annual water use per well across all the horizontally drilled wells (about 60% of the total) was 19 425 m^3/a for gas wells and 15 275 m^3/a for oil wells. The maximum *average* value was 36 620 m^3/a (for a horizontal gas well).
- *Potential impacts on water resource quality*
  - In the case of surface water, this means less water available for natural dilution and ecosystem health requirements.

- In the case of groundwater, this means less water available for the groundwater ecological reserve and for surface water quality optimisation through conjunctive surface water-groundwater use.

Stage 2: Chemical mixing

- Once delivered to the well site, the acquired water is combined with chemical additives and proppant to constitute the hydraulic fracturing fluid. The proppant is usually sand and serves to "prop" open the induced fractures. The additives have a range of functions, e.g. to dissolve minerals, minimise friction, increase viscosity, prevent scale deposits, prevent corrosion and so forth (Steyl and Van Tonder, 2013). The US EPA (2015) assembled water use and chemical data on over 38 000 wells hydraulically fractured between January 1, 2011, and February 28, 2013 across the United States. Hydraulic fracturing fluids were on average found to contain 89% (by mass) water, 10% quarzitic sand used as proppant and 1% additive ingredients. A total of 698 unique chemical ingredients were reported and the median number of additive ingredients per well was 14. Hydrochloric acid, methanol and light petroleum distillates were reported in more than 65% of cases analysed in this US EPA Study.
- *Potential impacts on water resource quality*
  - Contamination of surface water and groundwater through spillages and/or leaks.

Stage 3: Well injection

- The hydraulic fracturing fluid is injected into the well under high pressure, inducing cracks in the geological formation that allow gas or oil to escape through the well to be collected at the surface.
- *Potential impacts on water resource quality*
  - Penetration of hydraulic fracturing fluid into the nearby groundwater through inadequate well construction or operation.
  - Movement of hydraulic fracturing fluid from the target formation to drinking water aquifers through local man-made or natural features, e.g. abandoned wells and existing faults.
  - Movement into drinking water aquifers of unwelcome natural substances found underground, such as metals and radioactive materials, which are mobilised by the drilling and hydraulic fracturing activities.

Stage 4: Hydraulic fracturing wastewaters

- When pressure on the well is released, hydraulic fracturing fluid, water resident in the formation and gas/oil begin to flow up the well to the surface. This mix of fluids, containing chemical additives and natural substances, is stored on site until it can be treated, recycled or disposed of.
- *Potential impacts on water resource quality*
  - Contamination of surface water and groundwater through spillages and/or leaks.

Stage 5: Wastewater treatment and waste disposal

- Wastewater is dealt with in a number of ways, including treatment followed by disposal to surface water resources, disposal by underground injection, recycling (with or without treatment) for use in further hydraulic fracturing operations.
- *Potential impacts on water resource quality*
  - Contamination of surface water resources because of inadequate treatment.
  - By-products forming at drinking water treatment plants through reactions between hydraulic fracturing contaminants and disinfectants.

In preparation for the water quality challenges that South Africa might expect from hydraulic fracturing operations, Steyl and Van Tonder (2013) examined the water quality loadings of some of the USA hydraulic fracturing operations. They concluded the following:

- South African operations would most likely not be allowed to dispose of brine by re-injection into deep wells unless an exception in relation to the Water Act is obtained. This will introduce another issue, namely disposal of solids and brines that are produced from water purification processes.
- The volume of material produced over the lifetime of a well field might require some engineering adaptation and/or disposal in dedicated waste storage facilities constructed just for this purpose. It is an open question as to how this will be managed.
- Desalination plant efficiencies will need to be increased as the systems are currently sensitive to inflow water quality. It will most likely be associated with a multi-stage facility to remove organics as well as total dissolved salts from the produced water. The composition of the salts may be assumed to be mostly NaCl, but it is expected that Ca, Fe and Mg salts will also be present. The presence of Fe salts would pose processing challenges for these plants.
- The presence of dolerite formations and thermal springs indicate that there might be a possible upward migration pathway for contamination migration. The possibility of this occurring in the vicinity of the well field cannot be ruled out; especially if control measures and well field integrity are not adequately monitored over the lifetime of the well.

Esterhuyse *et al*. (2014) investigated unconventional oil and gas extraction and hydraulic fracturing in order to understand the exploration and extraction process and its possible related impacts. This WRC project also developed an interactive vulnerability map to aid in decision-making, and developed a monitoring framework for the monitoring of specific entities, including surface water, groundwater, vegetation, seismicity and socio-economics.

4.4 Renewable energy

To meet the foreseen electricity needs of South Africa in the context of a changing climate, the Department of Energy developed an Integrated Resource Plan (IRP) (DoE, 2010). The national strategy of the Plan is to meet growing electricity demand and at the same time to meet South Africa's international commitment to reduce greenhouse gas emissions by 34% below business as usual by 2030. The IRP strategy is to diversify our energy supply from South Africa's current primary reliance on coal-fired electricity, to an energy mix in which a third is generated by renewable sources (DoE, 2010). To meet this goal, the government has been offering the opportunity for investment in renewable energy technologies through the Renewable Energy Independent Power Procurement Programme (REIPPP).

Water quality concerns regarding the steadily increasing installation of renewable energy power plants in South Africa vary across the range of renewable technologies. **Table 4** summarises the relationship between the primary renewable energy options and their respective water requirements/water quality impacts, based on a recent review by the Energy Research Centre, University of Cape Town (Sparks *et al*. 2014), that encompassed many relevant, prominent studies, both locally and internationally.

The abovementioned review covered the following primary renewable energy technology options for South Africa:

- Concentrated photovoltaic technology
- Concentrated solar power
- Wind power
- Hydropower
- Biomass energy
- Carbon capture/storage

The above review indicated that the renewable energy options of biomass energy and carbon capture/storage did not appear to be favourable for South African conditions; therefore, these two options are not included in **Table 4** below. However, it should be noted that, if implemented, both biomass energy production and carbon capture/storage technologies might be accompanied by water resource quality management challenges.

It should be noted that the above review did not cover landfill gas power, a renewable power source that might be minor on a regional scale, but more important on a local scale.

Table 4: Renewable technologies relevant to South Africa: Consumptive water requirements and water quality concerns

Renewable Technology	Description	Total Capacity: Combined Historical Build and Planned as per the Renewable Energy IPP Programme[1]	Consumptive Water Requirements[2,3]	Water Quality Concerns
Concentrated photovoltaic technology (CPV)	Photovoltaic (PV) cells convert sunlight directly into electricity by absorbing protons and releasing electrons. These free electrons are captured on an electrode and result in an electric current. CPV plants use optics such as Fresnel lenses or curved mirrors to focus large amounts of sunlight (radiation) onto PV cells to generate electricity more efficiently than conventional PV panels.	Planned capacity of 2279 MW, of which 919 MW is already operational. An ultimate total of 46 CPV plants is foreseen.	Operational water consumption is typically less than 0.1 m^3/MWh and comprises mainly dust suppression, plant hygiene and washing of PV panels.	No emerging water quality concerns during CPV plant operations.
Concentrated solar power (CSP)	CSP plants use mirrors to redirect sunlight on to a specific point to heat a fluid. The heat in the fluid is then used to drive generators and produce power. CSP plants using steam cycles require cooling to condense the steam exiting the turbines, which can be achieved by either wet (water) cooling or dry (air) cooling. Dry cooling typically reduces electricity	Planned capacity of 500 MW, of which 150 MW is already operational. An ultimate total of 7 CSP plants is foreseen, of which one (100 MW) will	Wet cooling water consumption is typically 2-3 m^3/MWh, i.e. 10 000 - 20 000 m^3/MW per annum, or 1 – 2 million m^3 per annum for a 100MW plant.	Wet cooling means less surface water available for natural dilution and ecosystem health requirements. In the case of groundwater, this means less water

[1] According to https://en.wikipedia.org/wiki/List_of_power_stations_in_South_Africa; accessed on 7/1/2016.

[2] These consumptive water requirements can be compared with typical cooling water use for coal-fired power plants of 1.4 m^3/MWh.

[3] It should be noted that in all the renewable technologies water is consumed during the extraction of raw materials used in the manufacturing of plant components, during the manufacturing process itself and during the construction of the plants. This pre-operational water consumption is relatively minor compared with operational consumption. The corresponding pre-operational water quality concerns are covered by conventional water quality management measures for the mining, manufacturing and construction sectors.

Renewable Technology	Description	Total Capacity: Combined Historical Build and Planned as per the Renewable Energy IPP Programme[1]	Consumptive Water Requirements[2,3]	Water Quality Concerns
	production by 7% and increases capital cost by 10% relative to wet cooling.	be dry-cooled.	A dry-cooled CSP plant has minimal water requirements – similar to those of CPV plants.	available for the groundwater ecological reserve.
Wind power	The generation of electricity by wind is through the use of the kinetic energy of the moving air molecules. The wind drives the blades of large electro-magnetic turbines, which in turn creates electric currents. The magnets used in wind turbines contain important rare earth components. A large wind turbine (approximately 3.5 MW) typically contains 600 kg of rare earth metals.	Planned capacity of 3326 MW, of which 1034 MW is already operational. An ultimate total of 38 wind power farms is foreseen.	Operational water consumption is minimal and comprises only plant hygiene and washing of turbine blades.	No emerging water quality concerns during wind farm operations.
Hydropower (HP)	HP comprises the conversion of the potential energy of a supplied water stream to kinetic energy by flowing through an elevation (hydraulic head) difference. This kinetic energy then drives the blades of large electro-magnetic turbines, which in turn creates electric currents. HP installations larger than 2 MW can comprise any one of the following technologies: large in-stream storage; minimal in-stream storage; pumped-storage.	Planned capacity of 3529 MW, of which 2192 MW is already operational. An ultimate total of 13 HP plants larger than 2 MW is foreseen. Five of these plants (2500+ MW) are of the pumped-storage variety.	HP water consumption is due to increased nett evaporation from storage. This impact is negligible for RSA, given that large in-stream storage HP plants are adjuncts to large water supply schemes and pumped-storage schemes are in high-rainfall locations.	HP operations generally modify the streamflow regime. This could be expected to impact the downstream aquatic environment, including water quality constituents such as temperature and dissolved oxygen.

4.5 Water-energy-food security nexus

4.5.1 Nexus overview

Water, energy and food are inextricably linked. Water is an input for producing agricultural goods on the land and along the entire agro-food supply chain. Energy is required to produce and distribute water and food: to pump water from groundwater or surface water sources, to power farm machinery and irrigation systems, and to process and transport agricultural goods.

There are many synergies and trade-offs between water and energy use and food production. Using water to irrigate crops might promote food production but it can also reduce river flows and hydropower potential. Converting surface irrigation into high efficiency pressurized irrigation may save water but may also result in higher energy use. Growing bioenergy crops in an irrigated agriculture scheme may help improve energy supply, but it may also result in increased competition for land and water resources, with impacts on local food security (UNESCO, 2014).

In this context, the Water-Energy-Food Security Nexus has emerged as a useful concept to describe and address the complex and interrelated nature of resource systems, on which humans depend to achieve different social, economic and environmental goals. (FAO, 2014; Aurecon, 2014). This is also in line with the National Framework for Sustainable Development in South Africa (DEAT, 2008). In practical terms, it presents a conceptual approach to better understand and systematically analyse the interactions between the natural environment and human activities, and to work towards a more coordinated management and use of natural resources across sectors and scales. This can help to identify and manage trade-offs and to build synergies, allowing for more integrated and cost-effective planning, decision-making, implementation, monitoring and evaluation (Hoff, 2011).

Nexus interactions are complex and dynamic, and sectoral issues cannot be looked at in isolation from one another. Importantly, they exist within a wider context of transformational processes – or drivers of change – that need to be taken into account, as depicted in **Figure 24.**

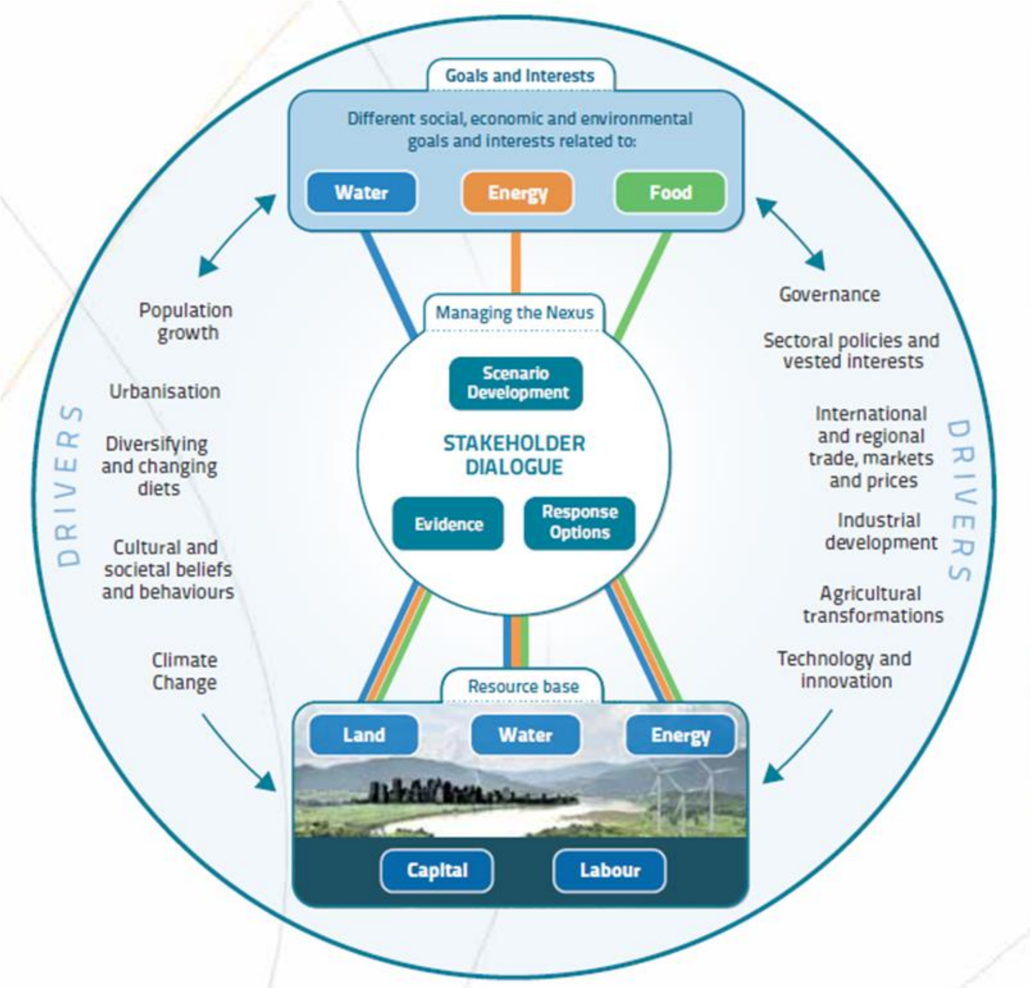

Figure 24: FAO approach to the Water-Energy-Food Nexus (FAO, 2014).

4.5.2 Water quality management challenges

When considering water quality management in a Nexus context, the numerous water quality management challenges covered elsewhere in this report that relate to the energy and food production sectors (as well as sectors that support the latter, such as mining and manufacturing), are quite relevant, as follows:

Cooperative governance

- Inadequate cooperative governance, overlapping mandates and discontinuous regulatory interfaces between the national departments (including their provincial counterparts) responsible for managing the requirements of the Nexus, i.e. Department of Water and Sanitation, Department of Agriculture, Fisheries and Forestry, Department of Energy, Department of Environmental Affairs and Department of Mineral Resources.

Coal mining for thermal power generation

- Discharge into surface waters of groundwater acidified by long-term continuous contact with acidifying geological strata, such as coal exposed by mining.

- Contaminated seepage, leaching, washoff and spills in relation to waste-rock dumps, open cast excavations, stockpiles, and pollution control dams.

Thermal power generation

- Washoff and leaching of widespread acidic atmospheric deposits from Highveld and neighbouring catchment surfaces stemming from smokestack emissions.
- Contaminated seepage, leaching and washoff in relation to stockpiles and combustion fly-ash dumps.

Hydropower generation

- Modification of natural flow regimes downstream, potentially leading to changes in degree of dilution, temperature and dissolved oxygen.

Hydraulic fracturing (under consideration for South Africa)

- Contamination of surface water and groundwater through spillages and/or leaks of the hydraulic fracturing fluid or the eventual wastewater.
- Penetration of hydraulic fracturing fluid into the nearby groundwater through inadequate well construction or operation.
- Movement of hydraulic fracturing fluid from the target formation to drinking water aquifers through local human-made or natural features, e.g. abandoned wells and existing geological faults.
- Movement into drinking water aquifers of unwelcome natural substances found underground, such as metals, saline water and radioactive materials, which are mobilised by the drilling and hydraulic fracturing activities.

Crop cultivation and animal husbandry

- Diffuse drainage and washoff of rainfall-mobilised natural in-situ salts in soils and in the underlying geological strata that have been disturbed by dry-land cultivation.
- Diffuse sub-surface irrigation return flows rendered saline by the concentrating effect of the consumptive use of irrigation water by crops, as well as mobilisation of natural in-situ salts along the return flow drainage paths.
- Washoff or spillage of waste effluent from confined animal facilities, rich in phosphorus, nitrogen and pathogens and with high chemical oxygen demand.
- Erosion of surface soils of catchments and of stream/river banks due to inappropriate crop cultivation practices, over-grazing, destruction or encroachment of riparian vegetation buffer zones, destruction or encroachment of wetlands and physical modification of river channels and banks.

Food processing, canning and wine-making

- Washoff from waste stockpiles or spillage of waste effluent from holding facilities, often rich in phosphorus, nitrogen and organic salts and with high chemical oxygen demand.

4.6 Growth of inadequately serviced densely populated settlements

4.6.1 Context

After the lifting, in 1986, of South Africa's infamous influx control measures, migration of rural Black people to cities and towns in search of economic opportunities and better living conditions accelerated steadily. Most of these new urban arrivals have been ending up in densely populated and inadequately serviced informal or semi-formal settlements on the fringes of cities and towns (DWAF, 2001a; DWAF 2001b). The 2011 Census determined that about 2.4 million households (about 8 million people) were located in so-called informal residential areas linked to cities and towns (Housing Development Agency, 2013). This dense settlement migration trend may be expected to continue for decades into the future, as explained below.

The National Development Plan states in its Executive Summary (National Planning Commission, 2012a) that "The proportion of South Africans living in rural areas has fallen by about 10 percentage points since 1994. Currently, about 60 percent of the population lives in urban areas. In line with global trends, the movement of people from the countryside to the cities is expected to continue, and by 2030 about 70 percent of the population will live in urban areas. Gauteng and the cities of eThekwini and Cape Town are the fastest-growing city-regions, with implications for planning and delivery of basic services."

Chapter 8 of the National Development Plan (National Planning Commission, 2012b) states that "Since 1994, more than 3 million subsidised housing units have been built for poor families. Access to basic services has expanded – 97 percent of households have access to water and almost 75 percent have access to sanitation and electricity. *Despite these achievements, access to adequate housing, reliable electricity, safe water supplies and hygienic and dignified sanitation facilities remains a daily challenge for many South Africans, particularly in poor rural and peri-urban communities* (our italics.)"

Looking to the future, Chapter 8 of the National Development Plan (National Planning Commission, 2012b) states that "Despite slower urbanisation than in other parts of Africa, another 7.8 million people will be living in South African cities in 2030 and a further 6 million by 2050, putting pressure on municipalities to deliver services. *A large proportion of new urban residents will be poor, reflecting a phenomenon referred to as the 'urbanisation of poverty'* (our italics.)"

In a later section, Chapter 8 of the National Development Plan (National Planning Commission, 2012b) states that…."Despite the new focus on informal settlement regularization and upgrading, at national level, *there is still a high level of ambivalence towards informal settlements across spheres of government, and the capacity and* *implementation mechanisms to achieve the national objectives are still poorly developed locally* (our italics)."

4.6.2 Causes and effects of water pollution from settlements

The causes of water pollution from inadequately serviced densely populated settlements are outlined in the National Strategy for Managing the Water Quality Effects of Settlements (DWAF, 2001a), which we paraphrase below:

Settlements have an impact on water quality when the waste that is generated as part of the day-to-day activities in the settlement reaches the water resource. This may be sewage waste from failing or non-existent sanitation systems, household refuse and litter (solid waste), or dirty wash water (grey water or sullage). Stormwater drainage is often non-existent and runoff from rainfall washes sediment, faecal matter and litter into nearby rivers, which also impacts the quality of the water resource.

Pollution from settlements occurs when there is a *physical failure* of the services in any of these waste streams or an absence of such services. However, *physical* problems tend to be caused by underlying *social problems*, i.e. when the services are not used properly through apathy or lack of understanding and awareness, or are vandalised. Similarly, *physical problems* may be underlain by *institutional* problems, i.e. when the municipality does not maintain the services properly, or where the services are inappropriate or inadequate for the community's needs. These municipality shortcomings are partially due to inadequate capacity, which in turn is exacerbated by non-payment for services because of wide-spread poverty in these communities. In most cases, pollution in and downstream of a settlement is caused by the complex interaction of all these factors. The water quality impacts of settlements are therefore caused by a combination of the way in which the community uses the waste services, and the way in which they are supplied and maintained by the municipalities. Sustainable management of this problem must recognise and address these underlying social and institutional causes.

Pollution from dense settlements impacts the health of the communities living in them. Failing (or absent) sanitation systems increase the risks of direct contact with faecally contaminated effluent in the settlement, or from transmission of faecal material by insects which breed in solid waste left in the settlement. The risks associated with poor hygiene practices are also much greater in polluted settlements, as members of the community are more likely to come into contact with faecally polluted material.

Figure 25 depicts the cyclical dynamic of the factors at play in this matter.

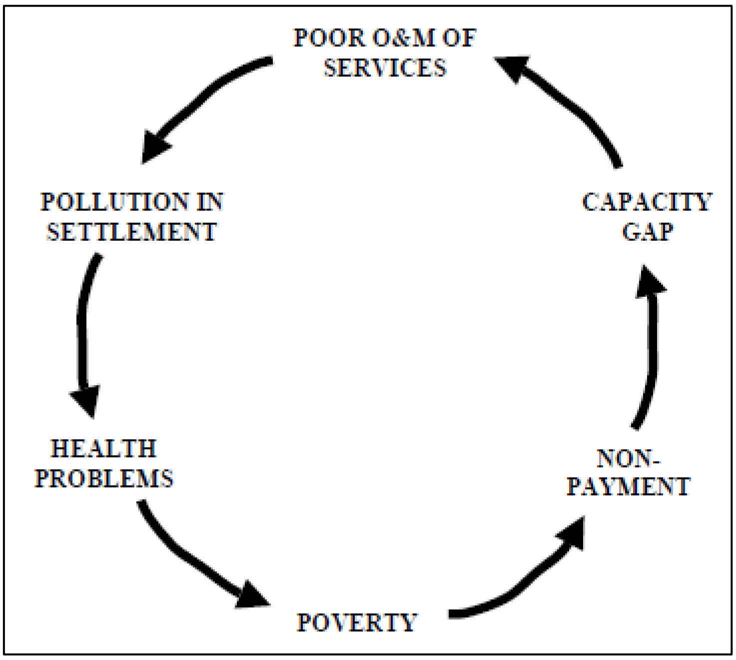

Figure 25: The "Cycle of Poverty and Pollution" showing how poverty, local authority capacity gaps, pollution and community health are interlinked (DWAF, 2001a).

4.6.3 Water quality impacts

Water resources downstream of inadequately serviced densely populated settlements experience unwelcome increases in loadings of the following problematic constituents, in order of importance:

- Pathogens, particularly E. coli – due to raw sewage inflows, faecal matter washoff during rainstorms and sullage that finds its way to a stream.
- Phosphorous and nitrogen – due to raw sewage inflows, faecal matter washoff during rainstorms and sullage that finds its way to a stream.
- Litter and solid waste – due to washoff during rainstorms and intentional dumping into river courses.

4.7 Water re-use

4.7.1 Context

The re-use of wastewater effluents and other return flows, both treated and untreated, currently accounts for approximately 14% of total water use in South Africa and form a significant part of water available for use in some of our important river systems (DWA, 2011). As future water demands continue to increase in response to population growth and economic development, availability of natural surface water and groundwater will be under increasing pressure. It follows that re-use of wastewater, after treatment, would need to be increasingly utilised as an indispensable additional water resource, given the inevitable future shortfalls in water availability from other sources. In preparation for this trend a national strategy for water re-use was developed in 2011 by the DWS's predecessor department (DWA, 2011).

4.7.2 Terminology

The following terms are commonly used in the re-use domain (DWA, 2011; City of Cape Town, 2015):

- Direct re-use: Re-use of treated or untreated wastewater by directly transferring it from the site where it is produced to a different/separate facility for further use.
- Indirect re-use: Re-use of treated or untreated wastewater after it has been discharged into a natural surface water or groundwater body, from which water is taken for further use.
- Direct potable re-use: Treating the used water to a level which is fit for direct use by a second water user. The treated water is then supplied directly to the second user without going through a natural or manmade water body such as a stream, dam or aquifer. Irrespective of the way in which water re-use is implemented, desalination technology such as Reverse Osmosis is typically required.
- Indirect potable re-use: Treating the used water and discharging the treated water to a natural or man-made stream, dam, aquifer, etc. before abstraction and use by a second downstream water user. Indirect re-use of water to potable levels therefore introduces a natural or man-made environmental barrier between the first water user and the second water user.
- Recycling: Utilisation of treated or untreated wastewater for the same process that generated it, i.e. it does not involve a change of user. For instance, recycling the effluents in a pulp and paper mill.
- Reclaimed water: Wastewater that has been treated to a level that is suitable for sustainable and safe re-use.
- Return flows: Treated and/or untreated wastewater that is discharged to a natural surface water or groundwater body after use.

4.7.3 Current re-use schemes in South Africa

About 20 re-use schemes, both direct and indirect, are in existence, or are being planned, at a number of locations across the country (DWA, 2011; City of Cape Town, 2015). The wastewater treatment and water reclamation plants serving these schemes are, or will be, operated by a range of metros, municipalities, coal mines and Sasol. The reclaimed water user institutions include power stations, refineries, mines, municipalities, feedlots, irrigators and Sasol. The related water use categories include industrial process water, aquifer recharge with urban stormwater, cooling water, metallurgical/mining process water, domestic and municipal water, agro-industry process water and irrigation water.

4.7.4 Wastewater treatment and water reclamation processes

When considering the treatment needed to reclaim water from wastewater there are ultimately three main goals (City of Cape Town, 2015):

- ensuring that the reclaimed water is safe
- ensuring that the reclaimed water is aesthetically pleasing
- that the technology applied does not create further problems.

The best practice in water re-use projects applies the “multiple barrier” approach to the control and removal of pollutants. This implies that in the sourcing, treatment and distribution of reclaimed water several control, technological and management barriers are set up to achieve a high level of assurance with respect to pollutant removal and producing a reclaimed water fit-for-use and safe for human consumption (DWA, 2011).

All water reclamation plants receive secondary wastewater treatment effluent as influent, but the process pathways to potable standards through tertiary and advanced treatments might differ, as depicted in **Figure 26**. Notable is the use of either of two advanced and expensive technologies, namely advanced carbon adsorption and reverse osmosis.

4.7.5 Water quality management considerations

Figure 27 depicts typical treatment products and disposal requirements, covering the full progression from raw wastewater influents to delivery of potable water effluents through three progressive stages of conventional treatment followed by an advanced water treatment (AWT) stage.

Figure 27 also shows that the required advanced water treatment includes removal of nutrients, dissolved organics and excess TDS. These advanced treatment processes raise the following water quality management concerns:

- For direct re-use: the assurance that all risks to human health or industrial process integrity (whichever is applicable) are adequately minimised.
- For indirect re-use: the assurance that all risks to downstream domestic users, irrigators and eco-systems are adequately minimised.
- Sludge disposal needs to be undertaken with minimal risks to surface water and groundwater in the vicinity of the disposal operation.

- Brine disposal needs to be undertaken with minimal risks to surface water and groundwater in the vicinity of the disposal operation. At or near the coast a marine outfall for brine would be a favourable option, while at an inland location, lined evaporation ponds would be essential.

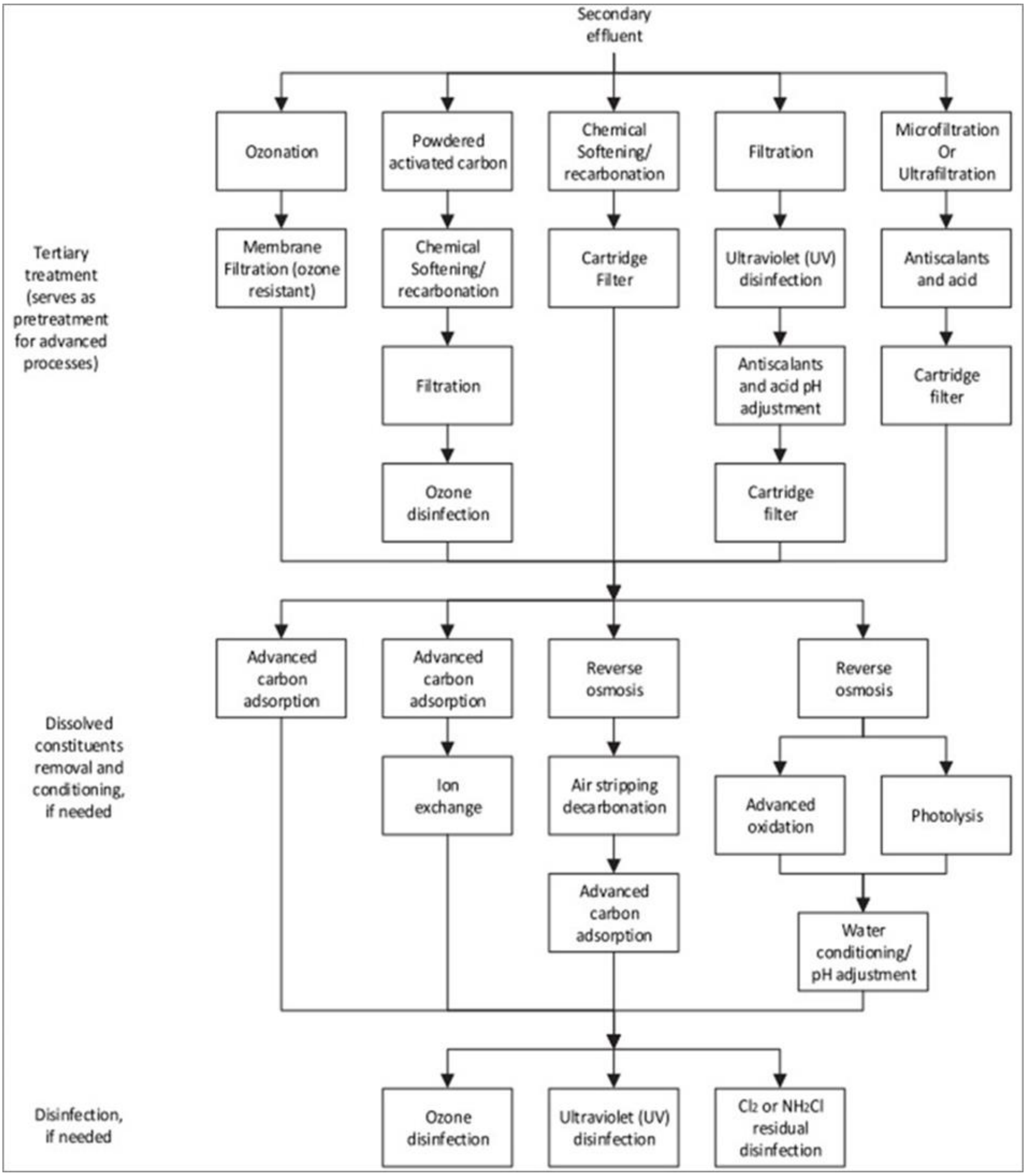

Figure 26: Alternative water reclamation process configurations (City of Cape Town, 2015)

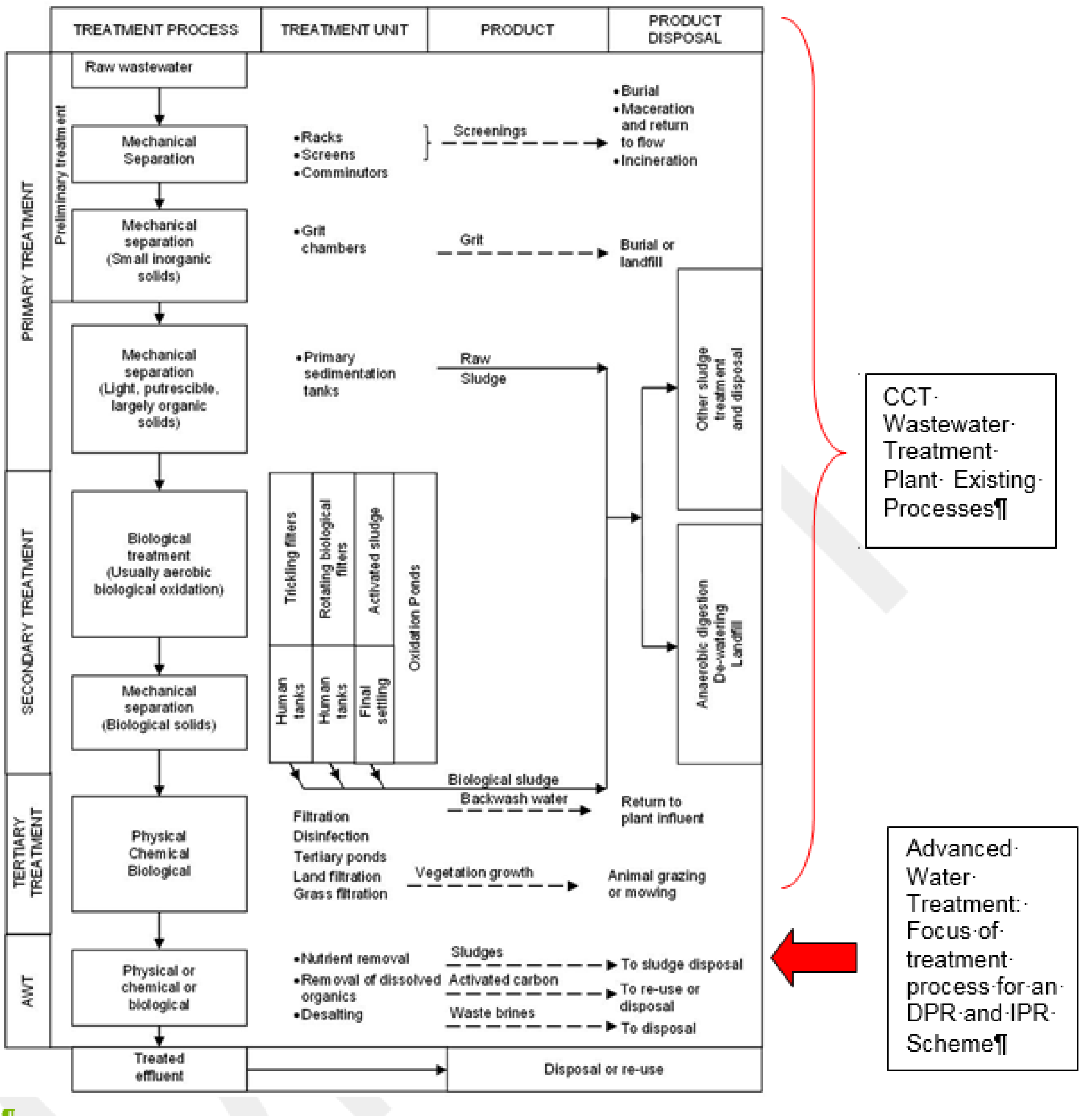

Figure 27: Wastewater treatment stages, progressing from primary treatment via secondary, tertiary and advanced treatment to the delivery of potable water – also highlighting the crucial final stage (City of Cape Town, 2015).

5. ROOT CAUSE ANALYSIS OF PRIORITY WATER QUALITY ISSUES

The five primary water quality challenges outlined above all have multi-sectoral characteristics and speak to the overlapping or adjacent mandates of a range of government institutions. For that reason, we believe that the requisite future management responses to these challenges will need to go well beyond the statutory and regulatory mandate, measures, controls, instruments and processes of DWS alone. The future management of these water quality challenges will need strategic regulatory collaboration and partnerships between DWS and various other state institutions across all three tiers of government, the CMAs, water boards, the private sector and organised civil society. Therefore, in order to understand these primary water quality challenges, it is useful to explore the drivers, the root causes and the cooperative governance and civic partnership considerations relevant to these challenges. This understanding starts to provide insight as to how we should formulate the solutions required to improve water quality management.

5.1 Eutrophication

5.1.1 Primary Drivers

- Wide-spread discharge of raw or inadequately treated municipal sewage into the tributaries of the rivers that feed the dams. The 2013 Green Drop Analysis rated 49.7% of 824 municipal wastewater treatment facilities as “critical” or “poor”, as compared with 16.3% with ratings of “good” or “excellent” – the rest were rated as “average”.
- Raw sewage overflows into municipal stormwater systems due to blocked sewers. This is a common occurrence in the more disadvantaged residential areas in many municipalities (DWAF, 2001a&b).
- Diffuse runoff and drainage from fertilized cultivated land under both irrigated and dry-land conditions. This phenomenon has been demonstrated and quantified in numerous scientific studies, both local and international (e.g. Alberts and Spomer, 1985; Cullis, Görgens and Rossouw (2005); Rossouw and Görgens (2005); Van der Laan *et al*. 2012; Lorentz (2012).

5.1.2 Root Causes

- The root cause of municipal sewage discharges and overflows into surface water resources is a notable degree of dysfunction in many municipalities, implied by the 2013 Green Drop Analysis results. The dysfunction could manifest as any or all of the following shortcomings in the affected municipalities’ operations: inadequate financial and operational planning, inappropriate financial prioritisation, lack of pro-active infrastructure maintenance, inadequate problem reporting/response systems, lack of appropriate technical personnel and financial shortfalls. Overarching this situation are inadequate cooperative governance and cross-regulatory interfaces between DWS and the affected municipalities, the Department of Cooperative

Governance and Traditional Affairs (COGTA) and various other government institutions indicated in the table below.

- The root causes of diffuse nutrient loadings from cultivated land are inappropriate farming practices, such as over-fertilisation, inappropriate tillage, over-irrigation and encroachment on or destruction of riparian buffer zones and wetlands. Inadequate cooperative governance and cross-regulatory interfaces between DWS and the National Department of Agriculture, Forestry and Fisheries (DAFF) and its provincial counterparts and various other government institutions indicated in **Table 5** hinders the management of these phenomena.

5.1.3 Cooperative Governance/Partnership Considerations

The table below gives the partnership considerations required for eutrophication.

Table 5: Partnership Considerations for eutrophication

DRIVER	REQUIRED COOPERATIVE GOVERNANCE & OTHER COLLABORATION PARTNERS FOR DWS
Municipal sewage discharges and overflows	Department of Cooperative Governance and Traditional Affairs (COGTA); Department of Human Settlements; Department of Health; National Treasury; Water Boards; CMAs; SALGA; the South African Institution of Civil Engineers (SAICE), Water Stewardships, Adopt-a-River Programme, etc.
Diffuse nutrient loadings from cultivated land	National Department of Agriculture, Forestry and Fisheries (DAFF); Provincial Departments of Agriculture; CMAs; Organised Agriculture; National Department of Environment Affairs (DEA); Provincial Departments of Environment Affairs; Land care organisations.

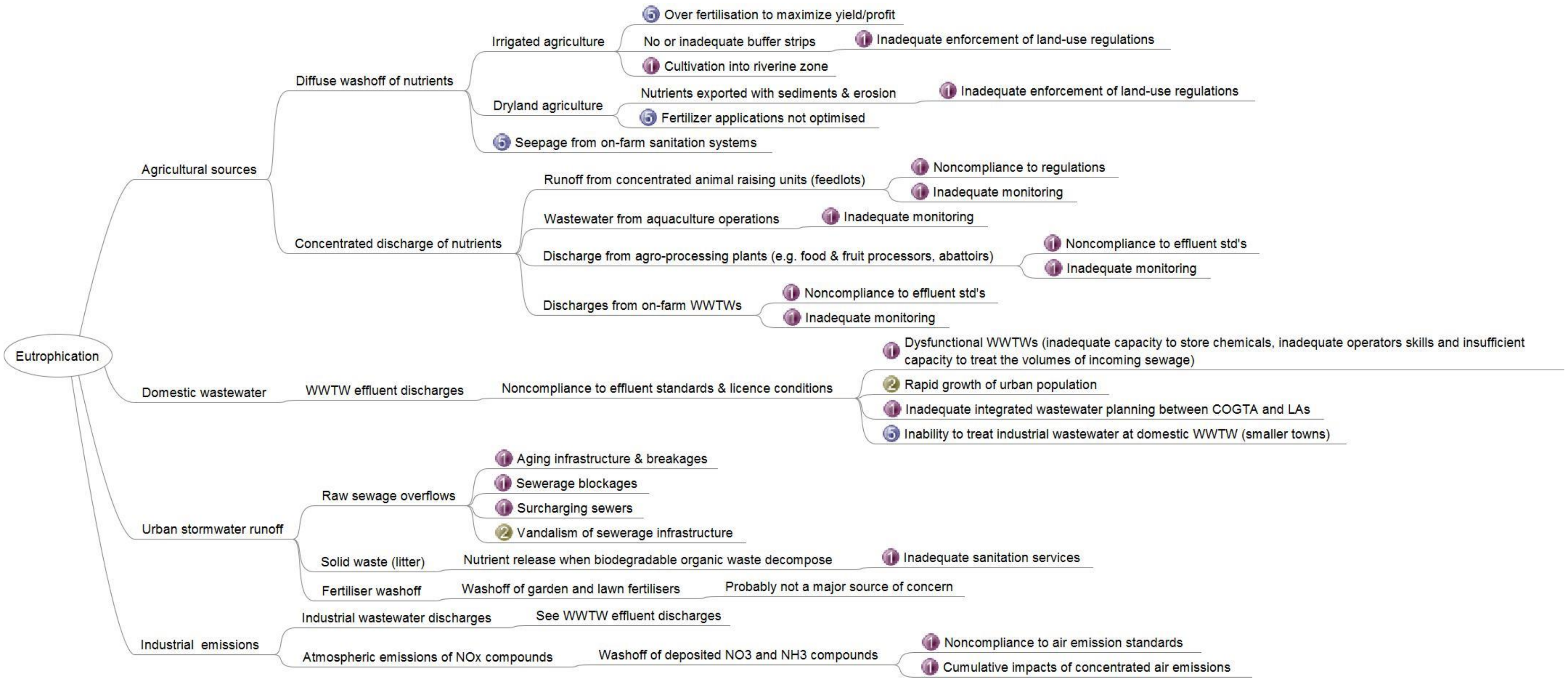

Figure 28: Causal chain for eutrophication concerns (1 = Institutional, 2 = Social, 3 = Legal, 4 = Political, 5 = Technical)

5.2 Acidification and Acid Mine Drainage

5.2.1 Primary Drivers

- Discharge into surface waters from abandoned mine shafts of groundwater acidified by long-term continuous contact with acidifying geological strata, such as coal exposed by mining.
- Contaminated seepage, leaching, runoff and spills in relation to waste-rock dumps, open cast excavations, stock piles, combustion fly-ash dumps, landfill, effluent irrigation, pollution control dams, pipelines, evaporation ponds and slimes dams.
- Washoff and leaching of widespread acidic atmospheric deposits from Highveld and neighbouring catchment surfaces, stemming from smoke-stack emissions.

5.2.2 Root Causes

- The root causes of water resource acidification due to acid mine drainage is a historical and recent lack of precautionary planning, regulation and enforcement by the relevant authorities, and of ring-fenced rehabilitation financing for the necessary rehabilitation by the relevant mining companies.
- The root causes of contamination of water resources by heavy metals and related acidification are any of the following: lack of compliance by mines and thermal power stations of their licence conditions; lack of or inappropriate licence conditions; lack of monitoring and reporting of their own pollution loads; inadequate enforcement capacity in the national and provincial Environment Affairs departments and DWS; and inadequate cooperative governance and cross-regulatory interfaces between the Department of Mineral Resources (DMR), the National Energy Regulator, DEA and DWS (see **Table 6**).
- The root causes of acidic atmospheric deposits is inappropriate licence conditions for Eskom and Sasol; lack of monitoring and reporting of their own pollution loads; lack of enforcement; and inadequate cooperative governance and cross regulatory interfaces between Eskom, Sasol, the National Energy Regulator, DEA and DWS (see Table 6).

5.2.3 Cooperative Governance/Partnership Considerations

The table below gives the partnership considerations for acid mine drainage

Table 6: Partnership Considerations for acidification and acid mine drainage

DRIVER	REQUIRED COOPERATIVE GOVERNANCE & OTHER COLLABORATION PARTNERS FOR DWS
Acid mine drainage	DMR, DEA, National Treasury, CMAs; Chamber of Mines, etc.
Contamination by heavy metals and related acidification	DMR, National Energy Regulator, DEA; Provincial Departments of Environment Affairs; CMAs; Chamber of Mines, etc.
Acidic atmospheric deposits	Eskom; Sasol, National Energy Regulator; DEA; Provincial Departments of Environment Affairs, CMAs, etc.

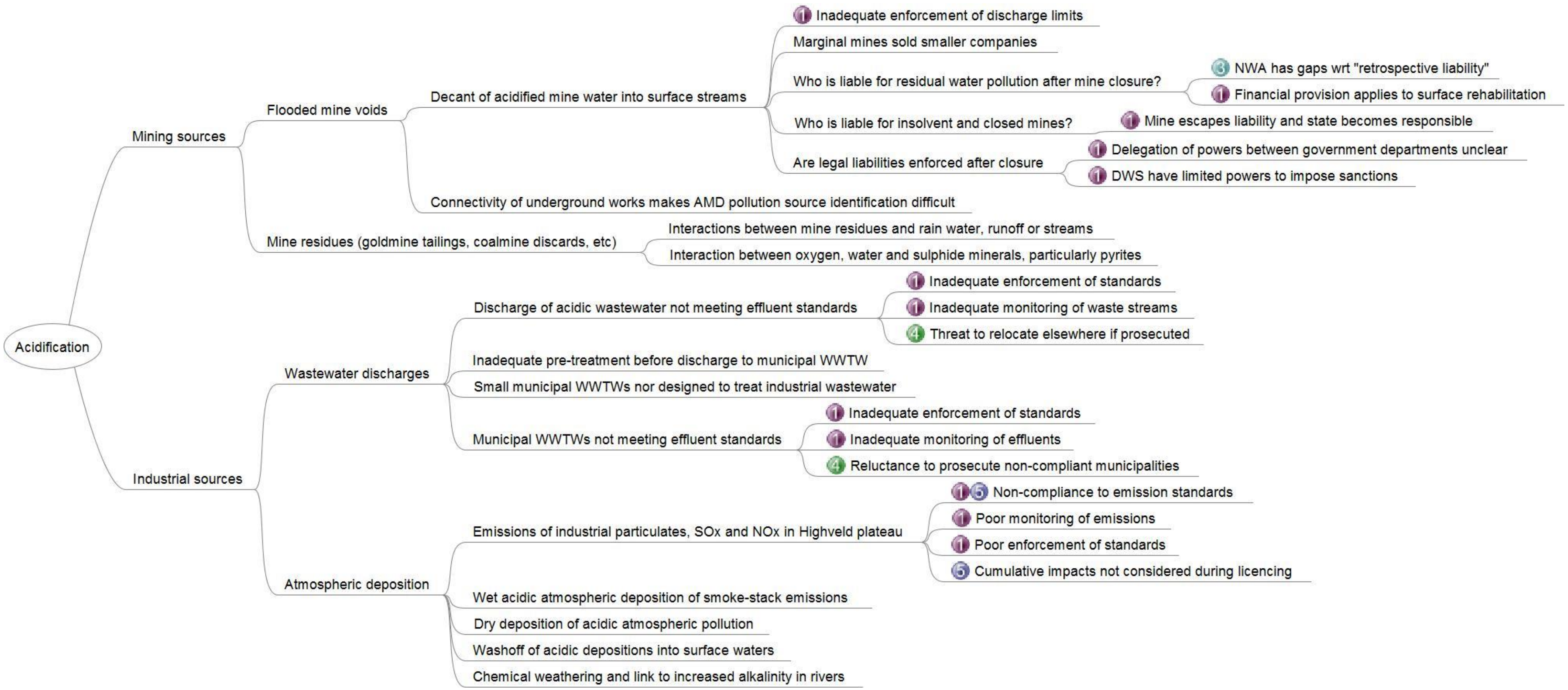

Figure 29: Causal chain for eutrophication concerns (1 = Institutional, 2 = Social, 3 = Legal, 4 = Political, 5 = Technical)

5.3 Salinisation

5.3.1 Primary Drivers

- Diffuse drainage and washoff of rainfall-mobilised natural in-situ salts in soils and in the underlying geological strata that have been disturbed by dry-land cultivation.
- Diffuse sub-surface irrigation return flows rendered saline by the concentrating effect of the consumptive use of irrigation water by crops, as well as mobilisation of natural in-situ salts along the return flow drainage paths.
- Mine water drainage and atmospheric deposits.

5.3.2 Root Causes

- The root causes of salinisation due to crop cultivation activities are inappropriate farming practices, such as inappropriate dry-land tillage, inappropriate dry-land crops, over-irrigation, inappropriate irrigation technology, lack of intercepting drainage and related evaporation pond infrastructure, and inappropriate irrigation water conveyance practices.
- Overarching this situation are inadequate cooperative governance and cross-regulatory interfaces between DWS and DAFF and its provincial counterparts, and various other government institutions indicated in **Table 7**.
- The root causes of acid mine drainage and acidic atmospheric deposits are outlined in Section 0 above.

5.3.3 Cooperative Governance/Partnership Considerations

The table below gives the partnership considerations for salinisation

Table 7: Partnership Considerations for salinisation

DRIVER	REQUIRED COOPERATIVE GOVERNANCE & OTHER COLLABORATION PARTNERS FOR DWS
Diffuse salinisation related to crop cultivation	DAFF; Provincial Departments of Agriculture; CMAs; Organised Agriculture; the South African Institution of Agricultural Engineers (SAIAE), etc.
Salinisation due to acid mine water drainage and atmospheric deposits	Outlined in Section 0 above.

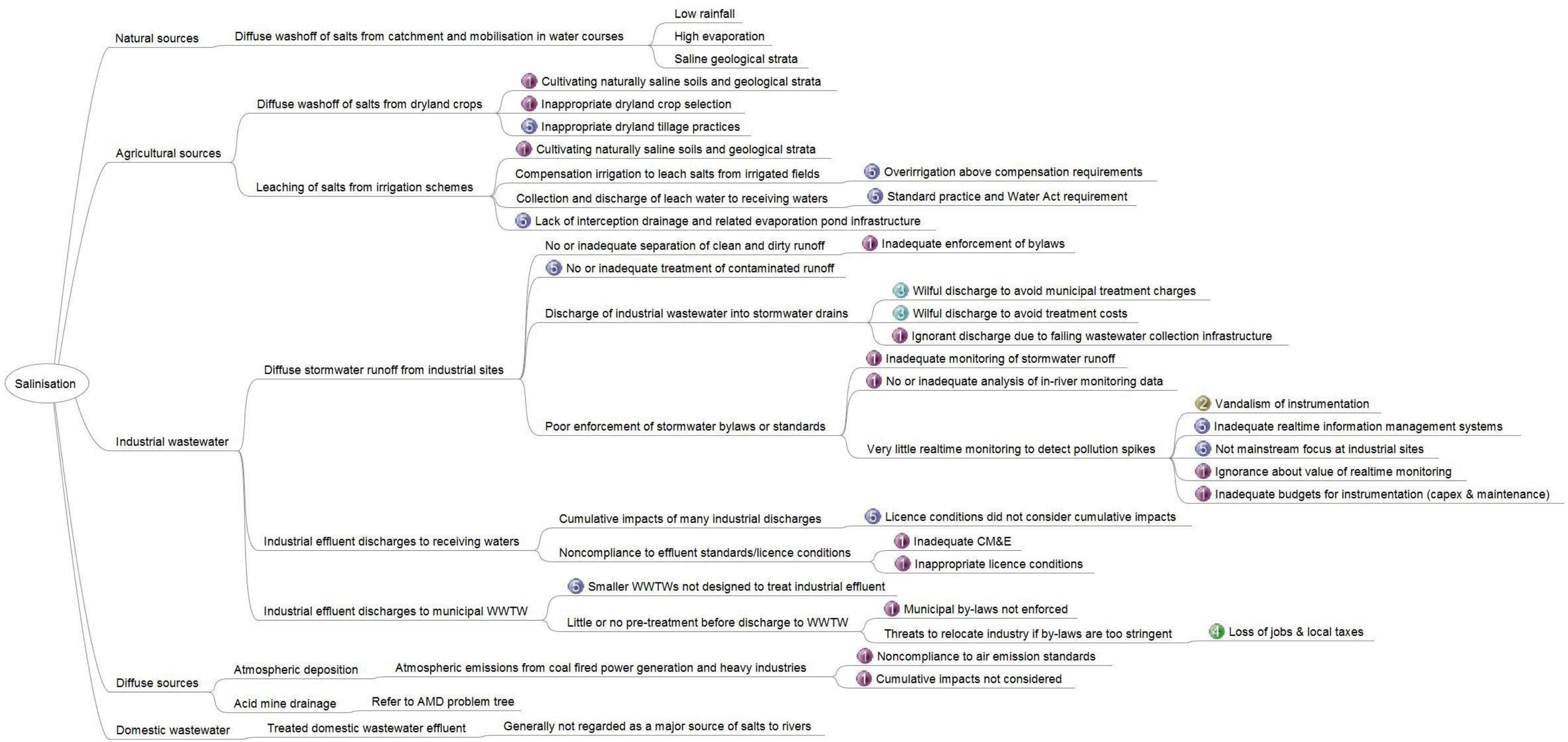

Figure 30: Causal chain for salinisation concerns (1 = Institutional, 2 = Social, 3 = Legal, 4 = Political, 5 = Technical)

5.4 Urban Runoff Pollution

5.4.1 Primary Drivers

- Stormwater runoff from formalised pervious and impervious urban areas or sewer overflows into stormwater conduits: contaminants include nutrients; metals; organics; inorganic salts; pathogens and litter.
- Stormwater runoff from less-formalised dense peri-urban or rural human settlements, including direct disposal of effluent or waste into the resource: contaminants include nutrients; organics; pathogens and litter. Common effluents and wastes include domestic refuse, grey water, seepage from latrines and human and animal excrement.

5.4.2 Root Causes

- The root causes of excessive water pollution from both formalised urban areas and other less-formalised dense human settlements vary from context to context, but it is often related to a notable degree of dysfunction in many municipalities. The causes are often the lack of or inappropriate infrastructure, inadequate financial and operational planning, inappropriate financial prioritisation, inadequate problem reporting/response systems, lack of pro-active infrastructure maintenance, lack of appropriate technical personnel and financial shortfalls.
- As with other issues, inadequate cooperative governance and cross-regulatory interfaces between the affected municipalities, DWS, Department of Cooperative Governance and Traditional Affairs (COGTA) and various other government institutions further exacerbate the above-mentioned causes. These institutions are indicated in **Table 8.**

5.4.3 Cooperative Governance/Partnership Considerations

The table below gives the partnership considerations for urban run-off.

Table 8: Partnership Considerations for urban runoff

DRIVER	REQUIRED COOPERATIVE GOVERNANCE & OTHER COLLABORATION PARTNERS FOR DWS
Stormwater runoff from formalised urban areas	Department of Cooperative Governance and Traditional Affairs (COGTA); and National Treasury; SALGA; the South African Institution of Civil Engineers (SAICE), etc.
Stormwater runoff from less-formalised human settlements	Department of Cooperative Governance and Traditional Affairs (COGTA); Department of Human Settlements; Department of Health; National Treasury; SALGA; the South African Institution of Civil Engineers (SAICE), etc.

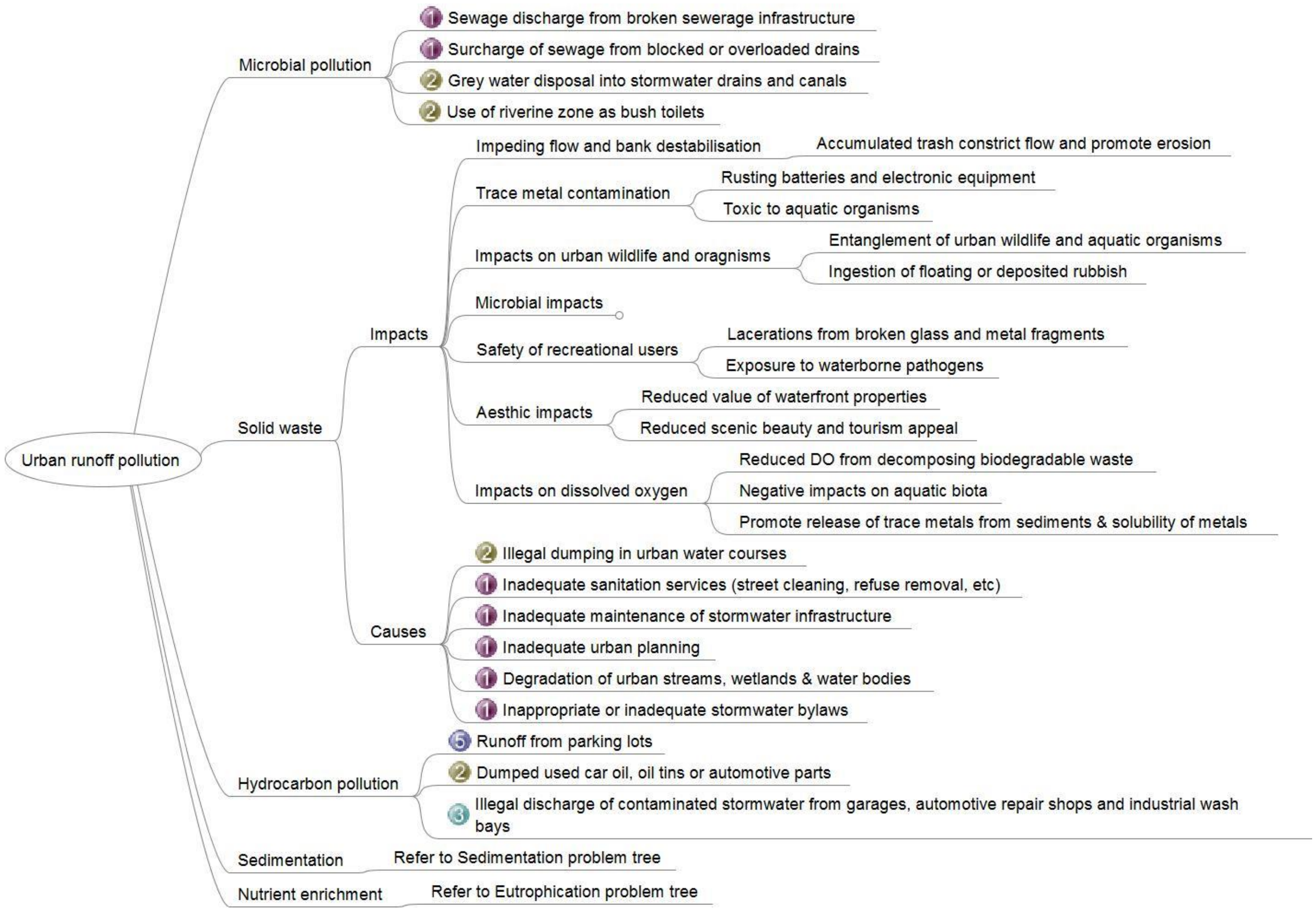

Figure 31: Causal chain for urban runoff pollution concerns (1 = Institutional, 2 = Social, 3 = Legal, 4 = Political, 5 = Technical)

5.5 Sedimentation

5.5.1 Primary Drivers

- Anthropogenically-driven erosion of surface soils of catchments and of stream/river banks. This is exacerbated by poor land management activities where soils are erodible or by in-stream activities.

5.5.2 Root Causes

- The root anthropogenic causes of sedimentation due to erosion are the following: inappropriate crop cultivation and silviculture practices; over-grazing; destruction or encroachment of riparian vegetation buffer zones; destruction or encroachment of wetlands; physical modification of river channels and banks; excessively dense less-formalised human settlements; careless construction activities; amongst others.
- A more fundamental root cause is the lack of suitable qualification criteria for farmers entering the field, combined with inadequate support from Government and the sector.
- Overarching this situation are inadequate cooperative governance and cross-regulatory interfaces between DWS and DAFF and its provincial counterparts, DEA and its provincial counterparts, and various other government institutions indicated in **Table 9**.

5.5.3 Cooperative Governance/Partnership Considerations

The table below gives the partnership considerations for sedimentation

Table 9: Partnership Considerations for sedimentation

DRIVER	REQUIRED COOPERATIVE GOVERNANCE & OTHER COLLABORATION PARTNERS FOR DWS
Sedimentation due to anthropogenic causes of erosion	DAFF; Provincial Departments of Agriculture; DEA; Provincial Departments of Environmental Affairs; CMAs; Organised Agriculture; the South African Institution of Agricultural Engineers (SAIAE); the South African Institution of Civil Engineers (SAICE); Commercial Forestry Research Institute (CFRI); SALGA; Land care organisations, etc.

Figure 32: Causal chain for sedimentation concerns (1 = Institutional, 2 = Social, 3 = Legal, 4 = Political, 5 = Technical)

5.6 Implications of these Strategic Management Considerations

- Strategic management of the primary water quality challenges will require a ***drastic intensification of cooperative governance and regulatory interfaces*** among the various affected government entities.
- In order ***to fully understand the above intra-government institutional challenges*** and to be able to derive ways to address such institutional challenges, e***ngagement with appropriate decision-making representatives*** of the affected government entities will be crucially important.
- Such intra-government engagements will require the ***approval of the Directors-General of DWS and the affected departments***, as well as of the Accounting Officers of other government entities.
- This ***intra-government engagement will need to include National Treasury*** because some of the potential strategies to deal with dysfunctional municipalities' inadequate wastewater plant operations and maintenance, as well as with historically-caused acid mine drainage, might require special public financing arrangements.
- Additional to the above intra-government engagements, a strategic management approach to the primary water quality challenges will require that ***DWS will also need to forge highly-focused, fit-for-purpose, civil society and corporate business partnerships*** that are respectively relevant to each primary water quality challenge.
- One of the weaknesses at a national level is the **fragmentation of water quality planning and management** i.e. there are different directorates in head office that deal with elements of Water Quality. Water Quality Management needs to be elevated as a priority within the Department as much of the focus is on water supply and quantity related issues. Furthermore, attention needs to be given to succession planning within the water quality management functions.

6. SWOT ANALYSIS

A SWOT (strengths/ weaknesses/ opportunities/ threats) analysis of the water quality management environment in South Africa was conducted during the Stakeholder Workshop No. 1 in the form of five parallel breakaway teams. The outcomes of that exercise as well as inputs from other stakeholders are presented in matrix form below. The Strengths/Weaknesses component focused on the water quality management environment internal to DWS and CMAs, while the Opportunity/Threats component focused on the water quality management environment external to DWS and CMAs. The outcomes of the SWOT analysis provide a range of highly relevant internal and external focal points for the formulation of a Policy framework and the eventual development of the IWQMS and its Implementation Plan.

NB: It should be noted that the individual points in the SWOT matrix are opinions or perspectives of stakeholders and may not necessarily be wholly correct or reflect the full context in each case.

<table>
<tr><th colspan="2">INTERNAL TO DWS AND CMAs</th></tr>
<tr><th>STRENGTHS</th><th>WEAKNESSES</th></tr>
<tr><td>Legal/Regulatory:
1. Sound statutes, policies, strategies and regulations: Constitution, NWA, NWRS, CMSs, etc.
2. Fully developed Waste Discharge Charge System (WDCS) - ready for implementation.
3. “New” Water Act – strengthen focus on WQM.
4. e-WULAAS (Electronic Water Use Licence Application and Authorisation System) is active – Client can upload data directly and is aimed at enabling DWS to keeping better records of water use authorisations.
5. Incentive based regulation at municipal level, e.g. Blue- , Green- and No-Drop accreditation, is now well-established.
6. Sound mine water regulations.</td><td>Legal/Regulatory:
1. Inappropriate water use licence conditions.
2. Inaccurate or out-of-date water use licence database
3. “New” Water Act – non-transparent process hitherto

Institutional - Structural:
4. The WQM structure of the Department too fragmented – needed: a single “centre of excellence”.
5. WQM roles and responsibilities not clear, no clearly stated goals, no dedicated WQ programme with reporting.
6. Inadequate or insufficient enforcement, conviction and punitive measures for non-compliance due to inadequate integration in DWS - enforcement relies heavily on functions of / information gathered by other DWS sections.</td></tr>
</table>

INTERNAL TO DWS AND CMAs	
STRENGTHS	**WEAKNESSES**
Institutional – Structural: 7. CMA establishment process recently prioritised. 8. Strong water institutions – e.g. TCTA, Water Boards, Regional Water Utilities. **Institutional – Processes:** 9. Sound water quality management instruments - guidelines, protocols, manuals, strong licensing process. 10. IWRM is a central competency in DWS and CMAs. 11. Classification and RQOs development in progress and RQO implementation will be facilitated by the DWS project on operationalising RDM. 12. IWQMS project has been initiated. 13. New integrated NWIS system being developed. 14. Ability of DWS to mobilise in times of water crisis. **Institutional – Capacity:** 15. Pockets of scientific and management excellence in DWS and CMAs. 16. Increasing capacity in CM&E at national level. 17. Internal WQM training course has been partially re-instated. 18. Investment in relevant graduate training programmes. 19. Alignment of DWS bursaries with scientific	**Institutional – Management:** 7. Slow implementation of the NWRS, although this improved with NWRS2. 8. Failure to implement the WDCS. 9. Inadequate implementation of policies and strategies. 10. Slow CMA establishment processes, although this has started to improve. 11. Inadequate understanding of WQM at management level. 12. Insufficient succession planning and gaps created by loss of both experienced and recently trained staff. 13. Lack of a customer service orientation in some regional offices. 14. DWS currently does not have active contracts with a number of private laboratories. 15. Inadequate delegations within DWS with regard to Water Quality - supresses innovation. 16. Poor staff morale, leading to decreasing productivity. 17. Long delays in decision-making in DWS. 18. Lack of management understanding of integration necessities for WQM and their costs. 19. Reduced resourcing of WQ monitoring – leading to backlogs at DWS's RQIS laboratory. 20. Lack of alignment of functions between National and regional/provincial DWS and/or CMAs. 21. Poor alignment of Business Plans and NWRS2. 22. Inadequate communication by senior DWS leadership to officials. 23. Repeated restructuring – hampers functionality and demoralises staff. 24. Lack of leadership by DWS in the Water Sector and poor promotion of /understanding of the importance of sectoral partnerships with DWS.

INTERNAL TO DWS AND CMAs	
STRENGTHS	**WEAKNESSES**
implementation needs of the Department. 20. Learning Academy for graduate trainees. 21. Continuity of research funding by WRC relevant to WQM. **Technical:** 22. Strategic spatial coverage of RSA by DWS monitoring network. 23. Project underway to identify localised monitoring gaps and to prioritise their resolution. 24. DWS and CMAs mostly have reasonable WQ data to support decision-making. 25. Growing appreciation among WR planners and managers that water quality and quantity should be managed as an integrated whole. 26. Sound chemical analysis laboratory facilities, accredited by SANAS, at national & regional levels. **Cooperative Governance:** 27. Willingness by DWS officials to collaborate with other Government and private sector institutions in support of WQM. **Social:** 28. Positive public perception of DWS.	**Institutional – Processes:** 25. Historical lack of alignment/interfaces of current IT infrastructure (WARMS/SAP/WMS/NWIS) – inadequate regional implementation. 26. Verification and validation projects do not include water quality information. 27. Lack of clarity regarding respective WQM roles and responsibilities at catchment level of DWS National, DWS Provincial/Regional, CMAs and Catchment Forums. 28. DWS functionality affected by a blurred mandate of having to be both referee and player in WQM, leading to conflicting strategic or tactical approaches. 29. Deficient implementation of RQOs - currently no guidelines for the implementation of RQOs. 30. Inadequate knowledge input regarding WQM, as well as inadequate project/ programme management. 31. Inadequate stakeholder databases for Classification and RQO determination processes. 32. Uneven and silo-like engagement of stakeholders. 33. Lack of formal policies and guidelines on how DWS should deal with innovative technologies, e.g. what criteria should be met in terms of acceptable risk, or what stance DWS should take towards new technologies. 34. Water quality guidelines and procedures are becoming outdated and have not been reviewed. 35. Lengthy procurement processes to appoint accredited private labs to support regional office sampling. 36. Inadequate network / system for learning-sharing of experience. 37. Problematic procurement processes prevent initiation of crucially needed studies.

INTERNAL TO DWS AND CMAs	
STRENGTHS	**WEAKNESSES**
	Institutional – Capacity: 38. Absence of DWS's internal WQM training course during recent years. 39. Insufficient or unsuitable technical and scientific capacity in DWS (national and regional) and CMAs. 40. CM&E function at provincial/regional level not sufficiently staffed. **Technical:** 41. Localised gaps in DWS strategic monitoring network. 42. Water Quality dimensions of planning often poorly considered in water resource planning. 43. Inadequate alignment between WRC research and DWS priorities. 44. Monitoring and data increasingly insufficient to undertake effective management of the resource. 45. Groundwater quality not adequately monitored and managed. 46. Water Quality data not available on WMS- therefore difficult to access. 47. Inaccurate entering of Water Quality-related data into DWS's systems. 48. Insufficient accredited laboratories in certain strategic regions. 49. Unfriendly data entering in current systems - officials could be using cell-phones to load data instead of having to come into the office to download / upload data. 50. Long-term streamflow gauging stations and sampling sites being de-commissioned. 51. Only one laboratory available for analysis of certain key constituents. 52. Inadequate monitoring of emerging problematic Water Quality constituents.

INTERNAL TO DWS AND CMAs	
STRENGTHS	**WEAKNESSES**
	Cooperative Governance: 53. DWS's dependency on other departments to jointly regulate and on regulatory mechanisms and tools developed by those departments. 54. DWS's current mandate precludes direct intervention in instances of dysfunctional municipalities or failing water services. 55. Insufficient communication by DWS to the public regarding pollution issues; lack of integration of communication initiatives relevant to WQM with those of other Government Departments. **Political:** 56. Inadequate political support for WQM caused by multiple changes in DGs and Ministers during recent years. 57. Lack of political will to fundamentally change approaches or tactics that have not yielded Water Quality improvements. 58. Perception in DWS management that consultants should not be needed and that all work should be done in-house. **Social:** 59. Lack of trust in recent and current WQ monitoring data and DWS monitoring. 60. Forums lack sufficient engagement support from DWS. 61. Confused public perception of WQ-related mandates – contributed to local government's neglect of WWT functions.

EXTERNAL TO DWS AND CMAs	
OPPORTUNITIES	**THREATS**
Legal/Policy/Regulatory: 1. Alignment of measures under NEMA, CARA, MPRDA and NWA to support WQM. 2. “New” Water Act – opportunity to strengthen focus on WQM. 3. DWS to promote institutional/legal framework to intervene in failing water and sanitation functions at municipalities with a lead by COGTA and National Treasury. 4. Water policy - currently under review. 5. Establishment of integrated regulatory water monitoring committees. 6. Influence SADC processes/agreements re WQM. **Cooperative Governance / Partnerships:** 7. Renewed government focus on cooperative governance. 8. Integration of monitoring and sharing of resources relevant to WQM through collaboration among government institutions. 9. Water stewardships/ CEO Water Mandate – Alliance for water stewardship has developed standards. 10. Involvement of private sector to solve water quality problems through a dynamic sector-based programme.	**Legal/Policy/Regulatory/Mandates:** 1. Lack of law enforcement by municipalities in cases of WQ pollution. 2. Municipalities ignore effluent licence conditions – lack of enforcement by DWS. 3. Overlaps/confusion of statutory/regulatory/oversight mandates that affect WQM. 4. Water policy - currently under review. 5. “New” Water Act – non-transparent process hitherto. 6. Impacts of international trade agreements on WQM. **Institutional:** 7. Dysfunction in many municipalities. 8. Political uncertainty / instability at local government level - affects human and financial resources. 9. Decision-making paralysis at senior levels in non-DWS government institutions relevant to WQM. 10. CMAs not adequately prepared to deal with competing interests, e.g. mining and water are both strategically important for development in a region. 11. Susceptibility to seek quick fixes among senior managers in government institutions relevant to WQM. 12. Sustainability of water institutions, such as CMAs and Regional Water Utilities. 13. Lack of a dedicated facility external to DWS that can take the lead in Water Quality monitoring and reporting. **Cooperative Governance / Partnerships:** 14. Fragmented or absent cooperative governance regarding WQM between DAFF, DMR, DEA, DTI, COGTA, DHS, provincial and local governments and

EXTERNAL TO DWS AND CMAs	
OPPORTUNITIES	**THREATS**
11. Incentivise water users, industries and businesses to reduce water pollution. 12. Ongoing DWS / CMA engagement of sectoral and social stakeholders and partners and promoting the concept of joint custodianship of WQM. **Planning Processes:** 13. National Development Plan (NDP). 14. WSDPs and IDPs – need to give WQM priorities prominent consideration. 15. Sustainable Development Goal (SDGs) actions given RSA's signed commitment; e.g. use of SDGs to influence IDPs. 16. Climate Change – raises the profile of WRM, including WQM. **Funding:** 17. Green Fund/Climate Funds - DBSA initiative to investigate issuing of water bonds. 18. NBBN and other investments in ecological infrastructure; SANBI's ecological infrastructure directorate funds eco-infrastructure critical for WQM. 19. Financial incentives for water re-use. 20. Financial incentives (including donor funds) for municipalities to maintain declared targets for	DWS. 15. Inadequate resourcing (human and financial) of cooperative governance mechanisms. 16. Inadequate cooperative governance between Government Departments (e.g. DMR, DEA and DWS) regarding licence conditions. 17. Inadequate buy-in to the new IWQMS by relevant senior officials in DAFF, DMR, DEA, DTI, COGTA, DHS, provincial and local governments, organised agriculture, Chamber of Mines. 18. Lack of macro-strategy by DWS to foster understanding among water user sectors of importance of joint custodianship of the resource and partnerships with DWS and CMAs. 19. Confusion about water governance set-up and lack of understanding of the WQM function among relevant government institutions - leading to poor coordination and/or conflicting strategic approaches – impacts WQM negatively. **Planning Processes:** 20. Increased resource pressure from economic and social development drivers (linked to NDP) – focus on economic growth (short-term) versus sustainable growth (long-term). 21. Inadequate coordination between government development planning functions and National Treasury. 22. Unclear impacts on WQ by climate change (pathogens, flooding, disaster management). 23. Fragmented approach to planning – national, regional and municipal planning lacks integration.

EXTERNAL TO DWS AND CMAs	
OPPORTUNITIES	**THREATS**
WQM. 21. Economic down-turn - WQM institutions to be more effective with spending, finding innovative ways of treating water and seek alternative sources of funding. **Social:** 22. Organised civil society activism - engaged public can contribute to monitoring and management of WQM. 23. Improved and integrated multi-institutional WQM awareness campaigns - lead by DWS. 24. Improved and supported Civilian Science, e.g. Adopt-a-River – typically used to spot major problems that need urgent attention, e.g. spills, illegal activities. 25. Drought and other water-related crises, such as pollution events – mobilise political attention, raise profile of water management and engender innovative approaches to support WQM. 26. Use of social media by DWS and CMAs to mobilise public knowledge banks and public sense of custodianship.	**Funding:** 24. Lack of sustainable financial models for local government, leading to inadequate funds to maintain WWTWs. Alternatively, the financial models may be sufficient but there is a lack of political will to use them / address the financial provisioning requirements. 25. Current economic downturn - impacts finances available for WQM - impacts of poorer WQ on economic productivity. 26. Mining industry has been in serious decline in recent years – not amenable to investing in WQM, regardless of the Green Credits that might accompany such investments. **Social:** 27. Lack of public awareness regarding importance of WQM. 28. Failures by municipalities to execute their water/sanitation-related functions adequately, are increasingly undermining public confidence in DWS. **Technical / Management:** 29. Inadequate monitoring and management of monitoring data of effluent quality and quantity by water users & regulators. 30. Current drought conditions – loss of dilution. 31. Green/Natural Infrastructure - not adequately maintained. 32. Threats from new technologies, e.g. unconventional gas and oil production – lack of ability to test and monitor threats; lack of applicable legislation re WQM impacts. 33. Insufficient information on emerging WQM threats.

EXTERNAL TO DWS AND CMAs	
OPPORTUNITIES	**THREATS**
Technical: 27. Re-mining slimes dams and centralising slimes disposal frees up land for further development. 28. Re-use of and extraction of beneficial products from polluted water. 29. Introduce enforced metering of all water abstractors. 30. Independent water producers – "smart" solutions. **Capacity:** 31. Further research on IWRM implementation in South Africa. 32. DWS to take the lead to develop and support a compendium of external WQM-related training courses conducted by various universities, CSIR, WISA, HSRC, ARC, SAICE, etc.	34. Radioactivity, brackish water, hydrocarbons – not in baseline monitoring – lack of addressing previously unknown risks. 35. Lack of understanding or accommodation of cumulative impacts of different pollutant drivers and different WQM activities. 36. Spatial and temporal variations make it difficult to manage the resource and interconnectivity of basins makes WQM complex - can have perverse outcomes across basins. **Capacity:** 37. Technical and scientific capacity challenges in local government. 38. Continuing loss of senior technical / scientific capacity in relevant government institutions. 39. Lack of understanding or inconsistent application of the "WQM hierarchy" by water user sector managers. **Other:** 40. Deteriorating Water Quality poses a risk for competitiveness of business, particularly, fruit and vegetable exporters, and a general risk to the economy of South Africa. 41. Economic and financial losses in crop production and manufacturing caused by deteriorating WQ. 42. Political interference in WQM-related decisions - resulting in perverse outcomes. 43. Unsure political climate - results in limited investment, including in WQM.

7. "MUST DO" POINTERS FOR POLICY AND STRATEGY DEVELOPMENT

The Root Cause and SWOT analyses presented in previous sections provide the following "must do" pointers for the policy and strategy development process:

1. Promote integration of water quality & quantity in water quality management.
2. Formalise cooperative governance structures, processes and resources for water quality regulatory actions across all government institutions relevant to water quality management.
3. Formally address overlaps of or gaps between statutory/regulatory/oversight mandates of all government institutions relevant to water quality management.
4. Formalise an institutional/legal framework for DWS intervention in municipalities with failing Water and Sanitation functions.
5. Develop a Strategy and Plan for Sectoral Partnerships and PPPs (including NGOs and civil society) in the water quality domain.
6. The Implementation Plan must include a mechanism to ensure ongoing engagement with DWS senior management on water quality management.
7. The Implementation Plan must include a mechanism for continuous public and school-level engagement to promote joint custodianship of the resource.
8. Intensify water quality management capacity development across all technical and administrative levels and across all relevant sectors.
9. Overhaul all aspects of water quality monitoring and data management.
10. Intensify all aspects of compliance, monitoring and enforcement in DWS and other government institutions relevant to water quality management.
11. Mobilise funding of water quality management initiatives external to the DWS Budget.
12. In highly sensitive areas with high environmental or social importance, no developments should be considered and these areas should be protected. These include, for example, water source areas or wetland conservation areas.
13. Current planning is largely sectoral (e.g. mining sector, agricultural sector). An integrated planning approach should be followed which spans across sectors and considers all development.

8. CONCLUSIONS

1. A wide range of water quality issues has been identified for both surface water and groundwater and, of these, five are shown to require high prioritisation in terms of water quality management. These five priority issues are: *eutrophication, salinisation, acid mine drainage and acidification, sedimentation and urban runoff pollution*.
2. Some of the remaining water quality issues, such as microbial (pathogen) pollution, agrochemical pollution and metals pollution, are known to be potentially harmful, but because of inadequate monitoring, their geographical prevalence is not clear and for that reason they are not classed (yet) as priority issues.
3. The prevalence and/or severity of impact of particular water quality issues varies markedly from river system to river system and from WMA to WMA.
4. A root cause analysis of the five priority water quality issues indicates that, in each case, lack of prioritisation of cooperative governance and related cross-regulatory interfaces by various combinations of government institutions are obstacles in dealing effectively with the “drivers” of such water quality issues.
5. A root cause of eutrophication is the notable degree of dysfunction in many municipalities, implied by the 2013 Green Drop Analysis results, which found that almost 50% of 824 municipal wastewater treatment facilities had to be rated as “critical” or “poor”.
6. Inappropriate land-use and poor land management by various land-use and water-use sectors are root causes of both sedimentation and salinisation.
7. The root cause analysis also indicates that acid mine drainage and acidification is the result of past and current neglect of a range of best management practices in waste control and contaminated runoff management in the mining and energy sectors.
8. A root cause of urban runoff pollution is the notable degree of dysfunction in many municipalities, referred to above, as well as inadequate implementation of best management land-use practices.
9. Six “mega-trends” are identified which can be expected to unfold in South Africa during the next few decades, relating to climate, energy production, sustainability and rural-urban migration, would lead to new or accelerated water quality impacts in many locations across the country. These are as follows: climate change; hydraulic fracturing; renewable energy; water-energy-food security nexus; growth of inadequately serviced densely populated settlements; water re-use.
10. A SWOT analysis of the water quality management environment identifies a range of internal strengths and weaknesses of DWS (including CMAs) which should guide the formulation of a Policy framework: 61 “weaknesses”, which should be among the to-

be identified focal areas for the implementation of the future IWQMS, and 28 "strengths", which should be recognised as foundational to the formulation of the future IWQMS.

11. In the water management environment external to DWS (including CMAs) 43 "threats" and 32 "opportunities" are identified through the SWOT analysis. These considerations should play a critical role in guiding formulation of a Policy framework and development of components of the IWQMS and its Implementation Plan.

12. On the basis of the Root Cause and SWOT analyses a number of "must do" pointers are outlined for the Policy and Strategy development process.

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