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STAKEHOLDER ACCORD ON WATER CONSERVATION

Development of Quantitative Measures of Performance for a Proposed Stakeholder Accord on Water Conservation and Implementation of Recommendations from Studies of Water Quality

Consolidated Recommendations on South African Water Quality

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EXECUTIVE SUMMARY

Rapid urbanisation, a rise in the number of informal settlements, inadequate municipal and regional service infrastructure and growth in industrial and mining development have all placed increasing pressure on the availability of water resources as well as on their quality. Government, Business and Labour recognise that South Africa's water quality challenges are complex, diverse and dynamic. These stakeholders therefore commissioned a review of selected studies on water quality challenges in South Africa, with the objective of preparing a consolidated, prioritised list of recommendations and options for implementation.

The sources material used for this review comprised a list of reports submitted by the Department of Water Affairs (DWA) and approved by the Counter Part Group (CPG), Catchment Management Plans and Water Management Situation Assessments downloaded from the DWA website and a DWA-commissioned review of water quality in the Vaal River System. A small number of additional reports were selected to augment the information derived from these sources.

An initial categorisation of the various reports, based purely on the primary topics covered in each, was carried out to aid in the analysis. The individual reports within each category were reviewed and summarised, and the key water quality issues dealt with were highlighted.

The major water quality risks facing South Africa were identified through a process of inspection, and potential gaps in the areas covered were highlighted. A methodology analogous to risk assessment was then used to prioritise these challenges, using information derived from the source material. The human health, economic and environmental consequences of each risk or challenge were quantified using a notional ranking scale, and combined with an estimate of the national prevalence of each risk, were used to arrive at an index indicating priority. This process identified the following key water quality risks, in the priority order indicated below:

1. Eutrophication of surface waters;
2. Heavy metal contamination;
3. Acid mine drainage;
4. Salinity increases;
5. Increased suspended solids levels;

6. Bacterial and viral pathogens;
7. Pesticide/insecticide contamination and;
8. Contamination with estrogen and estrogen-mimicking substances.

In addition, the following water quality problems were identified as being inadequately covered by the study material reviewed:

1. Solid litter;
2. Oxygen depletion and;
3. Radionuclide contamination.

It is felt that all three of these additional problems are in some way addressed by recommendations addressing the primary water quality risks identified. However, radionuclide contamination, due to the serious health risks associated with it, and the fact that sediment can act as a reservoir of pollutants from past incidents, requires further investigation to quantify its extent and the attendant health risks to the population.

A final issue requiring mention is that of treated drinking water quality. While surface water resources in South Africa are in some instances seriously impacted by water quality problems, it is technically possible to treat incoming water to achieve defined drinking water standards. A review of drinking water quality in the Western Cape, the Free State and the Eastern Cape highlighted numerous health-related drinking water quality failures and a number of operational challenges. In particular, microbiological quality and heavy metal contamination were of concern, but a further issue requiring attention is the lack of compliance of Water Services Authorities to statutory water quality testing and reporting standards.

A detailed review of the individual water quality challenges identified from the source material is contained in the body of this report and is summarised below:

Eutrophication, the process through which aquatic systems are enriched with nutrients (primarily phosphorous and nitrogen) over time, resulting in excessive growth of algae and aquatic macrophytes, was found to be a widespread, persistent national problem. The primary causes of eutrophication are leaching and runoff from agricultural lands, specifically due to fertiliser use and livestock wastes, non-compliant wastewater treatment plants and sewerage infrastructure, inadequate or lacking sanitation services and the contribution of household products such as detergents. Discharge and receiving water phosphorous standards have been developed for the seven “sensitive” catchments identified in South Africa, but application of these standards has been reported as being poor (Walmsley, 2000). The consequences of eutrophication were shown to be severe, affecting domestic, industrial, recreational and agricultural users. Algae and plants block water transfer and irrigation systems, result in changes to the aquatic ecology and are unsightly. Of most concern are the impacts on human and animal health arising from the toxins produced by the algae associated with eutrophication. This is driven in part by the type of algae prevalent. There is in addition the risk of trihalomethane formation during water purification. When caused by problems related to sanitation service provision and malfunctioning wastewater treatment facilities, eutrophication may be accompanied by pathogenic bacterial and viral contaminants. The root causes of eutrophication could also cause oxygen depletion, arising both from the nutrient loads themselves as well as from the death of algae, and the impact that algae have on nocturnal dissolved oxygen levels. It is acknowledged that the best long-term approach in dealing with eutrophication is to address nutrients at source, but that in the short term, a suite of solutions is necessary.

Heavy metal contamination was shown, from WMA situation assessment reports, to be a widespread problem, generally related to mining activity. In some studies, for example the Umtata River study, sources of heavy metal pollution (cadmium and lead) were not identified, but in general, heavy metals are introduced through non-point sources of pollution. The pH and redox potential of receiving waters were shown to play a large role in the transport of heavy metals, determining whether they are solubilised or deposited in sediments. Heavy metals can therefore accumulate in the environment, with sediments forming a potential reservoir for these materials. Of concern in this review was the prevalence of heavy metal contamination in drinking water, some of which (e.g. aluminium) related to the operation of the purification facilities. Contamination of drinking water with other heavy metals is most probably a result of contamination of South Africa’s surface water resources. Heavy metal contamination has consequences mainly for human and animal health, where they are transmitted up the food chain and tend to accumulate in the tissues of receiving organisms, resulting in increased concentrations over time and ultimately, toxicity. The effects are primarily neurological and metabolic, and include diseases of the circulatory system. Heavy metals also cause tissue damage through the promotion of free-radical production.

Acid mine drainage was found to be primarily related to coal and gold mining in South Africa, when pyrite (iron sulphide) is oxidised in the presence of water, resulting in acid production and a drop in pH. The process results in increasing salinity as well as the dissolution of a range of metals, the specifics of which depend on the geology involved. Acid mine drainage is therefore a multidimensional problem (comprising acidification, salinity increase and heavy metal contamination) with a range of consequences, and impacts on all users of affected water resources economically as well as in terms of the health of humans, animals and plants.

Salinity was found to be a problem in most WMA's, and is caused by natural processes e.g. groundwater discharges and leaching from certain geological formations during rainy periods, as well as economic activities such as mining, irrigated agriculture and industry. The impacts of salinity depend on ionic composition and the concentration of contaminants. Domestic users are affected through the payment of increased costs for products such as skin creams and other toiletries, as well as costs incurred through impacts on appliances such as geysers, kettles irons and the like. At very high levels of salinity, human and animal health may be compromised. The World Health Organisation (WHO) reports that at a Total Dissolved Solids (TDS) level of > 1,200 mg/l, drinking water may become objectionable to consumers. Farmers are affected through a reduction in crop yield, and depending on ionic composition, an impact on soil quality. Industries that treat incoming water for salinity are most affected by salinity increases from an economic perspective.

High levels of ***suspended solids*** was found to be a problem prevalent in most WMA's in South Africa, and is a challenge largely attributed to land use practices regarding activities such as mining, agriculture and development of human settlements. Sediments and other suspended solids impair the transmission of light and hence the development of aquatic flora (including algae) and the ability of some predatory aquatic species to find prey. Filter feeders are also affected, and hence there are potentially significant ecological impacts. Suspended solids can also serve as carriers for other pollutants such as heavy metals, leading to secondary impacts on human and animal health. None of the reports reviewed dealt specifically with the suspended solids issue as a central topic, but it did feature strongly in the review of small-scale mining and is reflected in the sediment yields of the various WMA's, indicated in the situation assessment reports obtained from the DWA website.

Bacterial and viral pathogens were found to be responsible for a large proportion of total mortality in South Africa, particularly among children. Almost all of the reports reviewed stressed the vulnerability of the immuno-compromised, the elderly and children to exposure, with the main effects being in the form of diarrhoea and dysentery, and in severe cases circulatory shock and death. The causes of contamination are primarily related to service delivery challenges in sanitation, the growth of un-serviced informal settlements and problems with municipal treatment and reticulation infrastructure. Runoff from livestock agriculture also plays a role in the contamination of water resources.

Estrogen and estrogen-mimicking substances include some pesticides, but comprise a wide range of organic pollutants, many of which are used by industry and agriculture, and others that are present in many household products. They affect the sexual development and reproductive systems of animals and there are concerns that these substances have similar implications for humans. Many of these substances are toxic, and some, like dioxins and polychlorinated biphenyls, have been characterised by the United States Environmental Protection Agency (US EPA) as likely human carcinogens, even at background levels of contamination. The US EPA asserts that these substances cause developmental defects in animals at body burden levels only a tenth of that induced by background exposure. The national prevalence of these substances is extensive, comprising the crop-growing areas of South Africa, areas where malaria control is practised and the Pretoria, Johannesburg and Vereeniging areas. Some substances, notably dioxins and aldicarb, were excluded from the review on the basis that local capacity to conduct analyses of these substances is lacking. This situation is of some concern since South Africa became a signatory to the Stockholm Convention on Persistent Organic Pollutants in 2001 and should therefore have this capability. Certain sites within well-established South African industries, such as the pulp and paper industry, are known to produce dioxins, polychlorinated biphenyls and furans as by-products of their processes.

Pesticide pollution was found to be a problem in rural areas of the Western Cape and areas of Kwa-Zulu Natal and is indicated as a problem in the Breede River and Fish to Tsitsikamma WMA in situation assessment reports. The true extent of this problem nationally is not well indicated by the reports reviewed, but it is most likely prevalent in most agricultural areas due to the modes of contamination identified, which include runoff and spray drift. The consequences are largely in the form of damage to aquatic ecosystems and human health impacts, which include endocrine and toxic effects. Some of these substances are persistent bio-accumulators, and there appears to be limited capacity in local environments to analyse for these substances in water supplies.

The identification and review of water quality risks were followed by the extraction of the recommendations relevant to those risks. These are presented in their original form in Appendix 1. These recommendations were then clustered into groups based on their relationship to a common issue and used to synthesise policy-level recommendations. In all, 48 recommendations were compiled. As regards the original recommendations that were consolidated for discussion by stakeholders, many of these were not directed at the policy level, which is the level of engagement envisaged for the final recommendations presented. The final recommendations are therefore to an extent a view as to what is required, based on the recommendations proposed by the authors of the source material. In instances where no recommendations were made, recommendations were synthesised, and this was in all cases done only on the basis of evidence contained in the source material. It is therefore important to appreciate that the recommendations presented are a function of the source material, and that they are not necessarily comprehensive.

The recommendations are too numerous to repeat here, but it may be concluded that they seek to address the following general problems associated with water quality management in South Africa, arranged in no particular order of importance:

- A need for more specific strategic, policy and local responses to water quality challenges, beginning with modifications to the National Water Resource Strategy, and cascading to Catchment Management Strategies for Water management Areas and Catchment Management Plans for individual catchments. Hence a National Non-point Source Strategy and a National Eutrophication Strategy are proposed, and this approach could be extended to some of the other major water quality challenges such as salinity, heavy metal contamination and toxic organics.

- The need for a multi-stakeholder, and possibly sector-based approach is apparent. While this study is in itself evidence of such an approach being pursued, the complexity of the water quality problems faced requires that the policy debate that will be facilitated by this study be followed by more detailed approaches involving specific user groups and the agencies (in both the public and private sectors) that deal with those sectors.

This is a complementary approach to that of strategies aimed at specific challenges, mentioned above. As an example, the proliferation of informal settlements with attendant water quality challenges is an issue requiring input from a range of national Government Departments as well as Local Government, along with other stakeholders. By the same token, as issue such as salinity affects all water use groups, and is in part, caused by diverse business sectors such as mining, irrigated agriculture and manufacturing. It is only in engaging with these sectors to assess and address the underlying drivers of these problems that they can be solved.

- A need to improve national water quality monitoring systems. Many of the studies contained comments on a lack of sufficient water quality data, both in terms of the measurement of parameters as well as the recording of pollution sources. There are also some problems associated with national capabilities, two examples being the inability to measure dioxins and aldicarb by South African laboratories. Accurate information on the condition of South African water quality is a prerequisite for the establishment of a workable strategy to address these issues, since it informs stakeholders as to the extent of individual problems. The sense given by the review is that there is a significant element of unquantified risk to which water users are exposed, largely because the status of the quality of the water being used may not always be known. There are also clearly challenges for enforcement that arise from this situation, since enforcement cannot be executed in the absence of information on non-compliance.

- A need to improve capacity and knowledge as regards water quality management among all stakeholders was a recurring theme of many of the studies. While recommendations were made by individual researchers in this regard, often with respect to specific problems, a more integrated capacity building strategy is most likely required. Such a strategy should begin with a detailed needs analysis, followed by the design of the appropriate solutions, which could include training, community awareness programmes, coaching and mentoring. Capacity gaps appear to exist among all stakeholders and at all levels, and while capacity building is already an element of the NWRS, a more detailed and holistic strategy is required.

- The impacts on water quality of service delivery challenges in water and sanitation are shown to be very serious, widespread and multi-dimensional. The problems are both in the area of service delivery roll-out as well as in the operation of existing services. It is clear that even in developed metros, compliance to measurement and reporting standards is poor, exposing consumers of treated drinking water to unnecessary risk. Compliance to nutrient standards, even in sensitive catchments, appears poor, leading to eutrophication and potential oxygen depletion problems. An unacceptably high prevalence of mortality from water-related intestinal diseases indicates that poorly serviced informal settlements and problems associated with existing infrastructure are exacting a heavy toll in terms of the spread of bacterial and viral pathogens. It should be noted that these are not however the only source of pathogens, as there are contributions from other sources such as agricultural runoff.

This study has some limitations in that the selection of data sources, while carried out through a process that attempted to be as comprehensive as possible, was necessarily subjective since choices were made as to the nature and scope of the source material used. Hence, not every aspect of water quality could be covered by this review. A few examples of notable omissions include the following:

i. The issue of aerial deposition of heavy metals was not covered in any detail in this review. The US EPA has found that approximately two thirds of the mercury contained in the coal delivered to coal-fired power stations is emitted to air, and given that South Africa’s power stations are not currently equipped with flue gas treatment technologies, this is potentially a serious matter for South African water quality. It is noted that the CSIR is currently investigating mercury pollution in surface water resources and that the outcomes of this research will be of interest to Government, Business Labour and affected communities.

ii. The study did not cover the impact of industrial effluents on eutrophication in any great depth, and it should be noted that industries such as the agro-processing industry have the potential to contribute significantly to eutrophication;

iii. The impact of large-scale mining on suspended solids was not assessed, and should be investigated further in future reviews.

The review is nevertheless considered to be of sufficient scope to enable meaningful debate between Government, Business and Labour as to the key water quality challenges faced by South Africa, and options through which these may be resolved. It is therefore proposed that the presented recommendations be debated by the stakeholders and that those deemed feasible for implementation be developed further with the requisite implementing agents.

ABBREVIATIONS

ADI	Acceptable daily intake
ANPS	Agricultural Non-point Source
AMD	Acid mine drainage
ARC	Agricultural Research Council
CFU	Colony forming units
CFU/ml	Colony forming units per millilitre
CMS	Catchment Management Strategy
COD	Chemical Oxygen Demand
CPG	Counter Part Group
DDD	1,1 dichloro-2,2-bis(p-chlorophenyl)ethane
DDT	Dichlorodiphenyl trichloroethane
DDE	Dichlorodiphenyl dichloroethylene
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorous
DNA	Deoxyribonucleic acid
DWA	The Department of Water Affairs
EC	Electrical conductivity
EIA	Environmental impact assessment

ABBREVIATIONS

ELISA	Enzyme-linked immunosorbent assay
EPA	Environmental Protection Agency (unless otherwise stated, all references to the EPA refer to the United States EPA)
ESP	Exchangeable sodium percentage
EU	European Union
GC	Gas chromatograph
NWRS	National Water Resource Strategy
Mg/l	Milligrams per litre
ml	Millilitre
mS/m	Millisiemens per meter, the units in which electrical conductivity is measured
OA	Oxygen absorption
PENTECH	Peninsula Technikon
PCR	Polymerase chain reaction
POP	Persistent organic pollutant
RDP	Reconstruction and Development Programme
RFLP	Restriction fragment length polymorphism
RWQO	Receiving Water Quality Objectives
SABS	South African Bureau of Standards

ABBREVIATIONS

SANS	South African National Standard
SAR	Sodium adsorption ratio
SF	State Forensic
SOD	Sediment oxygen demand
spp.	Species
subsp.	Sub-species
TDS	Total dissolved solids
TSS	Total suspended solids
ULC	Underwater light climate
WHO	World Health Organisation
WRC	Water Research Commission
WRQO's	Water Resource Quality Objectives
WSDP	Water Services Development Plan

GLOSSARY

Aide memoire	A memorandum summarising the items of an agreement.
Algae	A heterogeneous group of unicellular or multicellular plant organisms that tend to live in colonies in water, usually photosynthetic and microscopic in size.
Algal bloom	Dense growth of algae, imparting a distinct colour to the water body.
Alkalinity	The ability of a solution (or more correctly the bases dissolved in water) to neutralise acids. Total alkalinity is expressed as mg/l of calcium carbonate. The bases are usually carbonate and bicarbonate.
Alluvial soil	Fine-grained, fertile soil that is deposited by water flowing over flood plains or on river beds.
Anopheles	A genus of mosquito.
Alum	The term is used to describe a group of compounds characterised as being hydrated double sulphates. In water treatment, ammonia alum, chemical formula $NH_4Al(SO_4)_2 \cdot 12H_2O$, is used as a flocculant.
Aquifer	A geological formation, group of formations, or part of a formation that contains sufficient saturated, permeable material to yield significant quantities of water to wells and springs.
Arthropod	An animal characterised by having a rigid external skeleton, paired and jointed legs and a cavity containing most of its major organs e.g. a mosquito.

GLOSSARY

Assay	To determine how much of a substance is in a sample.
Assimilative capacity	The ability of a water body to absorb pollutants without detriment to recognised users.
Asymptomatic infection	Infection that occurs without the display of detectable symptoms.
Cyclopeptides	Ring-shaped molecules comprising amino acids.
Bacteria	Microscopic, single-celled organisms that do not have a nucleus. Their DNA is found throughout the cytoplasm, which is the part of the cell enclosed by the cell membrane. They are rod-shaped, spherical or spiral.
Benthic zone	The ecological region at the lowest level of a body of water, including the sediment and parts of the subsurface.
Blow down volume	The volume of water containing pollutants that is periodically discharged from a closed system. Make-up water with a lower concentration of pollutants is required to compensate for the volume lost (as well as losses due to evaporation and leaks). An example would be a cooling tower circuit.
Boiler	A closed device or vessel used to convert water into steam in industrial facilities.
Calcrete	A carbonate cement that forms in soil.
Carbamates	A group of insecticides comprising esters of carbamic acid. Aldicarb is an example of a carbamate.

GLOSSARY

Carbon elution	The process of removing materials adsorbed onto carbon from the carbon, typically through washing with a solvent.
Carcinogenic	Causing cancer in humans or animals.
Chemical Oxygen Demand (COD)	The amount of oxygen utilised during the oxidation of a compound with hot acid dichromate, indicating the quantity of oxidisable matter present.
Chlorophyll-***a***	The green pigment responsible for transforming sunlight into the chemical energy needed to fix carbon dioxide into carbohydrates in plants. Measuring its concentration in water provides an indication of algal biomass.
Chromosome	Thread-like structures into which DNA is packaged in the nucleus of the cell.
Ciprofloxacin	An antibiotic used to treat various bacterial infections. In the same class of antibiotics (the fluoroquinolones) as ofloxacin.
Circulatory shock	A medical condition in which insufficient blood flow reaches the tissues. If allowed to continue for long enough, it can lead to death.
Colony	A group of individuals or cells of one species living together.
Colony forming unit	A measure of viable cells, based on the premise that each colony cultured has arisen from one precursor cell.

GLOSSARY

Cooling tower	Structure used to cool water through directly contacting water with air. The air absorbs moisture, and this evaporative process removes energy from the water, cooling it in the process.
Cooling tower packing	Material arranged inside the cooling tower body which increases the surface area of contact between the water and air streams inside the cooling tower.
Crop yield	The mass of the crop (at the required quality level) that can be harvested per unit area of land under cultivation.
Crop water balance	A calculation which reconciles the quantity of water applied to a crop through irrigation and rainfall and the quantities of this water ultimately taken up by the plant and/or released to the environment through evapotranspiration, seepage to groundwater, return flows to surface waters etc.
Cultural eutrophication	Nutrient enrichment of surface waters from anthropogenic sources
Cyanobacteria	Also called “blue-green algae”, these are photosynthetic prokaryotic organisms that are typically unicellular.
Deep percolation	When water moves through the soil beyond the root zone and cannot be used by plants.
Deltamethrin	A widely used insecticide belonging to the class of synthetic compounds called pyrethroids (see below). Highly toxic to aquatic organisms.

GLOSSARY

Demineralisation	The process of removing dissolved solids from water (typically achieved through reverse osmosis or ion exchange processes).
Diatoms	Unicellular algae that occur mostly as single cells, but can also form colonies. Distinguished from other algae by the presence of a siliceous cell wall and the possession of unique photosynthetic pigments and storage products. Can be used to monitor water quality (bio-monitoring).
Disease vector	An organism that does not cause disease itself but which transmits pathogens from one host to another.
Drift	The movement of a pesticide through the air during or after application to a site other than the intended site of application.
Electrical conductivity (EC)	A measure of a material's ability to conduct an electrical current. In the case of water, it may generally be assumed that the higher the level of dissolved ionic (charged) species present, the greater will be the electrical conductivity.
Electrolysis	Process whereby an external electrical current is applied to an ionic solution to induce otherwise non-spontaneous chemical reactions (oxidation and reduction).
Endocrine disruption	Interference with development, reproduction and other hormonally-mediated processes governed by the endocrine system through the action of an exogenous chemical.
Enteropathogen	An agent capable of causing disease in the intestine.

GLOSSARY

Enterotoxin	Protein toxin released by bacteria (e.g. enterotoxigenic E. coli) in the small intestine.
Enteroviruses	Viruses that replicate in the gastrointestinal tract are excreted in faeces and are typically transmitted by the ingestion of food, water and materials contaminated with faeces. Part of the large group of enteric viruses, which includes viruses such as Hepatitis A and E, astro, rota, reo and enteric adenoviruses.
Epidemiology	The study of factors affecting the health and illness of populations.
Estrogen	The female steroid sex hormones secreted by the ovaries and responsible for typical female sexual characteristics.
Euphotic zone	Well-illuminated zone of surface waters in which photosynthesis is allowed to take place.
Eutrophication	The process of nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes amongst which increased production of algae and aquatic macrophytes (plants), deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses (OECD, 1982).
Evaporative cooling	Cooling that is effected through the evaporation of water, where the latent heat required to evaporate the water is removed from the material being cooled, thereby reducing its temperature.

GLOSSARY

Evapotranspiration	The sum of evaporation (both from the land and the surfaces of plants) and plant transpiration.
Exchangeable sodium percentage	The proportion of the cation exchange capacity of a soil that is occupied by sodium ions. The higher the ESP, the more sodic a soil is said to be, the greater the risks of interference with plant growth.
Extraction efficiency	The amount of material recovered from a sample as a proportion of the amount of material in the sample.
Faecal-oral transmission	Disease transmission from faeces to the human digestive system via the mouth.
Feeder systems	The piping systems used to distribute treated water.
Flocculants	Materials added in water treatment to facilitate the agglomeration or aggregation of coagulated particles, thereby improving the efficiency of gravitational separation.
Flotation	Process whereby milled ore is mixed with water and flotation agents (added to increase the hydrophobicity of the valuable minerals), after which air is blown through the mixture. Valuable minerals cling to rising air bubbles for recovery in downstream processes, while wastes settle and are discarded.
Foliar injury	Damage to the leaves of plants.
Gene	A hereditary unit consisting of a sequence of DNA that occupies a specific location on a chromosome and determines a particular characteristic in an organism.

GLOSSARY

Genome	The complete set of genetic information possessed by an organism.
Gram stain	A method of differentiating between different types of bacteria using a chemical (Gentian violet-iodine complex) staining technique. Gram-positive bacteria retain the stain, while gram-negative bacteria do not. Note that the technique does not work for all bacteria, with some being Gram-indeterminate and others being Gram-variable).
Gross margin	The amount by which the revenue received exceeds the costs involved in producing that revenue. In this report gross margin is expressed in R/ha.
Gypsum	Hydrated calcium sulphate, used in agriculture for its neutralising, soil improvement and nutritive properties.
^{2}H	A hydrogen isotope with an atomic mass of 2 instead of one, due to the fact that it has a neutron and a proton in its nucleus. Common hydrogen atoms do not have neutrons. Also called "heavy hydrogen" or deuterium.
Heat exchanger	A device used to transfer heat from one medium to another. Typically, the media are not in direct contact with each other, but are separated by a wall through which the heat is transferred from the medium at higher temperature to the medium at lower temperature.
Heavy metals	In terms of water resource quality, this term generally refers to arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium, vanadium and zinc.

GLOSSARY

Herbicides	Group of chemicals designed to control weeds.
Hydraulic conductivity	The ease with which water can move through a porous medium.
Hydrosalinity	Salinity as applied to water (as opposed to soil for example).
Hypertrophic system	A water body with high nutrient levels leading to algal blooms, coloured water and the loss of higher plants. This is the highest state of eutrophication.
Insecticides	Group of chemicals designed to control insects.
Integrated Pest Management	The use of a range of approaches to deal with pests rather than only the use of insecticides or poisons. The latter is viewed as a last resort with IPM. If insecticides were used as part of IPM, their use would typically be reduced as compared to non-IPM approaches.
Interflow	The water (derived from precipitation) that infiltrates the soil surface and then moves laterally through the upper layers of soil above the water table as opposed to into the water table. Interflow exits the soil when it reaches a stream channel or returns to the surface at some point lower than its point of infiltration.
In-stream habitat	The habitat within freshwater bodies, comprising such factors as soils, hydraulics, vegetation and chemical characteristics.
In vivo	In a living organism.
In vitro	In an artificial environment outside the living organism.

GLOSSARY

Ions	Atoms or molecules that have lost or gained one or more electrons, and are therefore either positively or negatively charged.
Isotope	Isotopes of a chemical element have the same number of protons, but different numbers of neutrons in their nuclei.
Lateral seepage	Seepage that does not occur in a vertical direction.
Leaching fraction	The amount of additional water required, expressed as a fraction or a percentage, in order to maintain soil salinity in the root zone at an acceptable level.
Lotic ecosystems	The ecosystems of rivers, streams and springs.
Macroinvertebrates	Animals that have no backbone and are visible without magnification e.g. aquatic snails.
Macrophyte	A large plant that is visible with the naked eye. Aquatic macrophytes grow in water bodies.
Macropore	A conduit in the soil, for example resulting from cracks, earthworm holes or decayed roots.
Methemoglobinemia	A disease in which haemoglobin levels and hence the body's capacity to carry oxygen in the blood are reduced. It is caused by the presence of high levels of nitrates in drinking water (> 50 mg/l in the case of bottle-fed infants, WHO) and infants are more readily affected (the so-called "blue baby syndrome").

GLOSSARY

Microcystins	Low molecular weight cyclopeptide hepatoxins produced by cyanobacteria. They comprise a ring of 7 amino acids, 5 of which are non-protein acids and 2 of which are protein acids. It is the 2 protein amino acids that distinguish individual microcystins from each other.
Microcystin-LR	A common toxic microcystin containing the two protein amino acids Leucine (L) and Arginine (R).
Microsporidia	Spore-forming, unicellular parasitic organisms that are restricted to animal hosts.
Molecular method	Laboratory technique based on identification and characterization of certain molecules and gene sequences of a pathogen's genetic makeup.
Motility	The ability to move spontaneously and actively, with reference to single-celled or multi-celled organisms.
Mutagenic	Able to increase the extent and/or frequency of mutation or to induce mutation in an organism.
^{18}O	An oxygen isotope with an atomic mass of 18 instead of 16, due to the presence of two additional neutrons in its nucleus.
Ofloxacin	An antibiotic prescribed for the treatment of specific bacterial infections, including those caused by E.coli.
Oocyst	A protective shell that allows parasitic organisms (e.g. Cryptosporidium parvum) to survive outside of the host. Ingestion by the host can lead to infection.

GLOSSARY

Organochlorines	Any organic chlorine-containing compound, some of which are persistent and harmful to human and animal health e.g. dioxins and DDT.
Organophosphate	Any organic phosphorous-containing compound, many of which are used as pesticides.
Parasite	An organism that lives in or on, and takes its nourishment from, another organism.
Pathogen	An agent or producer of disease, commonly used in reference to infectious organisms such as bacteria, viruses and fungi.
Perched water table	A water table or aquifer that occurs above the regional water table, usually due to the presence of an impermeable layer above the regional water table but below the surface of the land.
Persistent organic pollutants	Organic chemicals that persist in the environment i.e. that are resistant to degradation.
Phages	Viruses that infect bacteria.
Phytotoxicity	The toxic effect of a compound on plant growth.
Point-source pollution	A single, identifiable, localised source of pollution e.g. a sewer outfall.
Polymerase chain reaction (PCR)	A chemical reaction in which the polymerase enzyme is used to catalyse the replication of a “target sequence” of genetic material.

GLOSSARY

Primary production	The production of organic compounds from carbon dioxide, principally through photosynthesis. Organisms that are primary producers form the base of the food chain.
Process water	In mining or manufacturing, the water used directly in the value-adding process and which is brought into direct contact with product at various stages of processing.
Prokaryotic cells	Cells that lack a nucleus (as opposed to eukaryotic cells, which do contain a nucleus).
Protozoa	Single-celled organisms containing DNA bound in a nucleus, most of which are motile and heterotrophic i.e. they utilise organic compounds as a source of carbon. Protozoa feed on bacteria and other organic matter.
Pyrethroid	Any of a number of synthetic insecticides, similar in structure to the natural chemical pyrethrin, which is produced by flowers belonging to the genus Chrysanthemum.
Regenerants	In ion exchange. Materials used to regenerate cationic and anionic resins, thereby restoring their capacity to remove ionic species. Acidic and basic effluents are produced during regeneration.
Riparian habitat	The vegetated area along the banks of freshwater bodies, streams and rivers.

GLOSSARY

Salinisation	An increase in salinity i.e. an increase in dissolved salt levels.
Salinity	The quantity of salts present in water, where salts may comprise a range of ionic species such as sodium, potassium, sulphates etc.).
Serum (plural sera)	The part of the blood that remains after clotting i.e. after solids have been removed.
Shale	A sedimentary rock formed by the deposition of successive layers of clay, often interspersed with fragments of other minerals such as quartz and calcite.
Slimes	In mining, very fine waste materials suspended in water.
Sodium Adsorption Ratio	The ratio of sodium concentration to the square root of half of the sum of the calcium and magnesium concentrations. Concentrations are measured in mmol/l. The test is performed on soil extracts. Values above 12 – 15 indicate serious soil problems, which would make it difficult for plants to absorb water.
Stockholm Convention on Persistent Organic Pollutants	A United Nations Treaty signed in 2001 in which participants agree to eliminate or restrict the production and use of persistent organic pollutants.
Teratogenic	Able to disturb the growth or development of an embryo or foetus.
Threshold salinity	The soil salinity level above which crop yield will begin to decline.

GLOSSARY

Total dissolved solids (TDS)	The concentration of dissolved salts in water, commonly used as a measure of salinity.
Total hardness	Hard water is water of high mineral content. Total hardness is a measure of the calcium and magnesium ions in water, typically expressed as a concentration of calcium carbonate.
Total suspended solids (TSS)	The amount of filterable solids in a water sample.
Trihalomethanes (THM's)	A methane molecule that has had 3 hydrogen atoms substituted with three halogen atoms. Halogens are the elements F, Cl, Br, I and At). THM's are known carcinogens.
Unsaturated zone	The layer of soil that contains, at least some of the time, both air and water in its pores. Also called the vadose zone.
Utility water	In manufacturing and mining, the water used to supply utilities such as cooling and steam to core production processes. This water is generally not brought into direct contact with product and is typically recycled in a closed loop.
Virulence factors	Molecules produced by a pathogen that specifically cause disease (e.g. enterotoxins) or that influence the host's function, thereby allowing the pathogen to thrive.

GLOSSARY

Virus	Ultramicroscopic infectious agent that replicates itself only within the cells of a living host.
Water Resource Quality Objectives	Water quality goals, expressed as the maximum tolerable concentrations of various individual polluting species, and which seek to strike a balance between the need to protect the water resource and the need to develop and use it.
Zoonotic disease	Diseases that can be transmitted between (or shared by) animals and humans.

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1. INTRODUCTION

The quality of South Africa's water resources is of vital importance for the following primary reasons:

i. Water resources are limited, and the quality characteristics of water impact on its availability;

ii. South African water resources are shared with neighbouring countries who have defined quality requirements;

iii. Many vulnerable communities rely on un-purified water for domestic use, increasing the risks of health impacts as a result of the consumption of water of poor quality;

iv. Water use efficiency depends in part on water quality, examples being the increased cooling tower blow down rates that accompany elevated salinity levels in the industrial sector and the negative impacts of salinity on crop yield, and hence water intensity, in irrigated agriculture.

Government, Business and Labour therefore commissioned a review of past water quality reports and studies with the following aims:

i. To produce a consolidated set of recommendations from previous studies on water quality challenges in South Africa, including the domestic sector and;

ii. To develop options for implementation of these recommendations in order of priority.

The report will provide a basis for discussion between stakeholders in Government, Business and Labour as to how these stakeholders could work together to address these challenges.

2. METHODOLOGY

A list of water quality studies conducted through the Water Research Commission (WRC) by independent researchers and consultants was compiled by the Department of Water Affairs (DWA) and submitted to the Counter Part Group (CPG) for review. The report list was screened by the CPG to identify the ones deemed most relevant for the purposes of the study, and a revised list was compiled. In addition, the review of Catchment Management Plans (CMP's), available on the DWA website, was requested, with the aim of consolidating recommendations made in the CMP's with those made in the WRC reports.

The methodology followed in arriving at a consolidated list of recommendations was as follows:

1. Each report on the revised CPG list was reviewed to surface the key water quality issues contained in each report. The reports provided varied significantly in scope and the reports were therefore initially grouped together based on easily-recognisable themes in order to add structure to the review;
2. All CMP's available on the DWA website were downloaded and reviewed. Since only two CMP's were available, it was decided to include other available water quality studies. The only other information available on the DWA website was that contained in Water Resource Situation Assessments. These were available for 18 of the 19 WMA's and hence provided useful input for appreciation of the geographic spread of certain water quality issues, specifically:
    i. Mineralogical surface and groundwater quality;
    ii. Potential for faecal contamination of surface and groundwater and;
    iii. Sediment yields, which are an indicator of suspended solids levels.

In addition, the assessments covered some of the water quality challenges unique to each WMA. In all, 20 reports were downloaded from the DWA website for inclusion in the study. No other water quality reports were identified from the DWA website i.e. this review covers all water quality reports available from this source.

3. Since DWA had recently conducted a water quality study of the Vaal River System, the key findings and recommendations of this study were included in the review;

4. Finally, it was noted that even with this comprehensive source of water quality information, not all of the key known water quality issues were covered. A limited number of selected reports were therefore included for the sake of completeness, specifically to deal with issues concerning solid litter, acid mine drainage (AMD), radionuclide contamination and oxygen depletion.
5. Based on the review of the reports, Catchment Management Plans and Situation Assessments, the primary water quality risks were identified. This was carried out through a process of inspection. Additional risk categories were also identified, comprising those water problems that did not fit easily into the primary list, an example being drinking water quality. This was done so as to avoid the loss of the recommendations made concerning these issues;
6. An assessment was then conducted to prioritise these risks, based on the human health, economic and environmental consequences of each risk and the prevalence of each risk, informed by the information reviewed in the course of the study;
7. The recommendations relevant to the identified risks were then extracted from the various reports and consolidated, unaltered, into groups, based on the risks they were designed to address. These are available for inspection in Appendix 1.
8. Where recommendations were not made, which was the case for a small number of the reports reviewed, recommendations were synthesised. Where this was done, this is clearly indicated in Appendix 1.
9. The complete list of recommendations was then reviewed and decisions were made as to which recommendations would be included and which recommendations would be excluded from the consolidated list required by the terms of reference. All recommendations regarding research were automatically excluded, as were recommendations that were applicable to local environments that were not necessarily representative of the national situation.
10. Within each risk category identified, the recommendations made by the researchers and authors of the reports reviewed were clustered into groups based on the subject matter they addressed. The aim of this process was to provide the basis for the formulation of appropriate policy-level recommendations for discussion by the stakeholders.
11. These summarised, policy level recommendations were then arranged in an order of priority corresponding to that derived through the risk assessment process and presented for discussion by stakeholders.

3. REVIEW OF THE WATER QUALITY REPORTS SUPPLIED BY DWA AND THE CPG

As mentioned earlier, in order to provide structure to the review, the source reports were grouped based on broad themes. Note that at this stage of the review, these themes do not represent a holistic assessment of key water quality risks, but are based only on a preliminary assessment of the broad topics addressed by the reports provided.

3.1 THEME 1: SALINISATION OF WATER RESOURCES

Salinity in the context of this report refers to the quantity of dissolved inorganic salts present in freshwater resources. It is typically expressed through quantification of the electrical conductivity (EC) of the water (measured in mS/m), or through determination of the Total Dissolved Solids (TDS) present in the water (measured in mg/l).

3.1.1 The Economic Cost Effects of Salinity

Led by Urban Econ Development Economists, a study was conducted in the Middle Vaal to examine the economic cost effects of salinity in the household, agricultural, industrial, mining and services sectors, as well as on feeder systems (i.e. water transfer and distribution infrastructure) and the natural environment. Individual reports were compiled for each sector, and these were consolidated into an integrated report that summarised findings. The specified salinity range of the study was 200 mg/l to 1200 mg/l TDS and each sector was reviewed and modelled in order to quantify the cost impacts of different levels of salinity within this range. The aim of the study was to investigate if the costs of salinity reduction in the Middle Vaal River Area could be justified based on the costs of salinity to water users. What follows is a review of the individual studies comprising the overall Middle Vaal salinity study.

The University of Cape Town, Africon and Afridev (2000) investigated ***the economic cost effects of salinity on feeder systems and the natural environment*** in the Middle Vaal area. This report also derived analytical relationships that were used by other researchers in assessing other sectors covered by the study, specifically:

i. The development of correlations between Electrical Conductivity (EC) and Total Dissolved Solids (TDS) and;

ii. How the concentration of individual ionic species and Total Alkalinity relate to the TDS.

In essence, samples were taken at various locations in the study area and chemically analysed, with the data then processed using linear regression analysis. Mathematical relationships were derived that were used to infer ionic concentrations and alkalinity from TDS levels. TDS was determined using EC measurements.

In their review of the impact of increases in salinity on water feeder systems, the authors noted that increased TDS could increase the corrosivity of water or result in scale formation. They noted further that corrosion in pipes could be due to purely chemical reactions, but also due to the action of sulphur reducing bacteria (among other bacterial species). High sulphate concentrations were mentioned as a factor that leads to dominance of corrosion through the action of sulphur reducing bacteria. The authors asserted however, that TDS concentration alone is not a valid parameter for the determination of the corrosivity of water.

The authors reviewed several pipe systems with specific reference to their performance under the salinity levels in the study area (500 mg/l TDS) and how they would perform should TDS levels increase to 1,200 mg/l. In terms of steel lined pipes, they noted that the water was already corrosive to bare steel piping at the TDS levels observed at the time of the study, and that these pipes should be lined regardless of whether the TDS increased or not. Cement lined pipes were found to be operating at low chloride conditions at the time of the study (< 140 mg/l) and it was determined that the increase in TDS to 1,200 mg/l would not increase chloride levels above the threshold level of 500 mg/l associated with damage to cement linings. Sulphate levels of 500 mg/l at the time of the study were found to be in excess of the threshold value of 300 mg/l, indicating that rising TDS levels would cause deterioration in the cement linings due to sulphate levels. It was however felt that provided pH could be controlled at levels between 6.8 and 7.2, the sulphate problems would not increase significantly. Given the above, and noting that modelling increased treatment and conveyance costs due to increased salinity is difficult, the authors predicted that no incremental treatment or corrosion costs would be experienced should TDS levels rise to 1,200 mg/l from the levels experienced during the time of the study.

In terms of the impact on salinity on the natural environment, the authors concluded that the overall costs were unknown. It was however concluded that the costs and benefits of increased salinity on angling revenue and algae (the latter resulting in increased water treatment costs) were high enough to be included in a future model to be used for assessing impacts on the natural environment.

In their review of salinity cost impacts on the ***household sector***, the Human Sciences Research Council (2000) surveyed families who had moved from low-salinity areas to Welkom and

Klerksdorp in the study area, and studied household spending patterns driven by the increase in salinity. The researchers found that the impacts of salinity, whether real or perceived, resulted in increased household expenditure in an effort to mitigate them. Depending on the residential population group concerned (township, suburban or shack dwellers) the overall costs to households of the increase in salinity was found to be between 1.3% and 2.8% of total expenditure. In terms of consumable items, most of the costs were associated with laundry and textile treatments, personal care items, cleaners and dishwashing agents. Residents thought that increased salinity caused drying of the skin and hair and the reduced foaming of soaps and detergents, leading to increased consumption of cleaning agents and the increased purchase of skin creams and hair products. The costs associated with durable items increased due to factors such as scaling (irons and kettles in township and suburban households) and the use of additional water purification devices in suburban households. Additional costs to suburban households ascribed to increasing salinity were costs related to geysers, plumbing, pools and pool filters. All three household sectors experienced increased vehicle maintenance costs. Additional monthly costs ascribed to salinity were estimated (in 2000 currency) to be R14.10/household for the informal sector, R36.39/household for the township sector and R49.38/household for the suburban sector. The researchers highlighted that the study suffered from a small sample size, which reduced statistical certainty.

Urban Econ (2000) reviewed the economic cost effects of salinity on the ***industrial sector*** for the Middle Vaal area, and identified the following primary impacts of increased salinity on the sector:

i. Increased suspended solids, contributing to deposits in boilers, heat exchanger systems, cooling tower packing and pipelines;
ii. Scaling of surfaces due to the heating of water with high total hardness or high alkalinity. It was noted that under certain conditions, calcium carbonate acts as a corrosion inhibitor by forming a protective layer over metal surfaces.

General manufacturing formulae were developed for application in various industries, with the objective of determining the costs of salinity increases to the industrial sector. In terms of this model, costs were ascribed to process water, utility water and end-product water, and increased costs due to salinity could be established by considering current and expected salinity levels. Industries were surveyed in the Welkom and Klerksdorp areas in order to obtain data for application of the model, as well as to establish attitudes and concerns as regards salinity in the area.

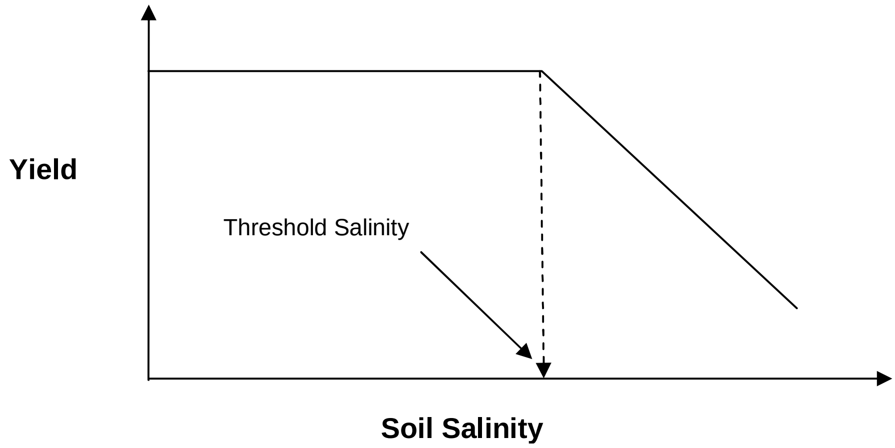
The researchers found that most industries exhibited a lack of knowledge as regards salinity measurement and impacts, and that few companies tested their water to establish salinity levels. The primary salinity-related problems were found to be corrosion and scaling of water pipes and high maintenance and service costs for boilers. Two industry categories were identified: “non-treatment” industries, which did not treat water to reduce TDS and “treatment” industries, which treated the water received to reduce TDS to meet standards required by technology. All of the industries surveyed used potable water.

The researchers found that non-treatment industries would incur limited costs due to salinity increases. Most water used in this sub-sector (50%) was for human consumption. Treatment industries were found to incur costs for treating utility, process and end-product water. Total costs to the treatment industries (in year 2000 Currency) were expected to increase from R1,838,575 at 500 mg/l TDS to R2,504,703 at 1000 mg/l TDS for the Welkom and Klerksdorp areas, based on the models developed for the study. The researchers outlined the weaknesses of the study to be the ignorance (as regards the impacts of salinity) of the users providing information for modelling and the lack of industrial diversity in the area.

Afrosearch – Index & Agtec (2000) reviewed the economic cost effects of salinity on the ***agricultural sector*** in the Middle Vaal area. The study focused on crop production, and asserted that animal production would be negligibly affected by salinisation of water supplies for the TDS range specified for the study. The authors pointed out that the impacts of salinity were not dependent on the salt content of the irrigation water alone, but also on climatic conditions, soil properties and the practices in place to manage the salt load contained in the water.

The relationship between soil salinity and crop yield, as graphically depicted by the authors, appears in Figure 1 below.

Figure 1: The General Relationship between Soil Salinity and Crop Yield



Source: Afrosearch – Index & Agtec (2000) pp 5

The graph illustrates the following variables of interest as regards the impact of salinity on yield:

i. Crop yield potential;
ii. Soil salinity;
iii. Threshold salinity, which is the salinity level above which crop yield begins to decline and;
iv. Slope of the yield curve once the threshold salinity level has been reached.

Table 1 below outlines the factors the researchers highlighted as drivers of these variables.

Table 1: Factors Influencing Crop Yield

CROP YIELD POTENTIAL	SOIL SALINITY	THRESHOLD SALINITY	SLOPE OF YIELD CURVE
Day length Climate Crop genetics Soil properties Management Cultivation techniques	Irrigation water salinity Rainfall quantity Rainfall salinity Irrigation water applied (leaching) Evapotranspiration Soil drainage Soil hydraulic conductivity Soil chemistry Cultivation techniques Irrigation systems used	Crop species Cultivar Climate Cultivation techniques Irrigation management	Crop species Cultivar Climate Plant maturity Irrigation management Type of irrigation Cultivation techniques

Source: Afrosearch-Index & Agtec (2000) pp 5

The authors considered the following three factors in their analysis:

i. The total salt effect;
ii. Specific ion toxicity and;
iii. The effect of sodium on soil properties.

The ***total salt effect*** referred to the yield reduction resulting from increased soil salinity in the root zone. While linear models were used, the authors noted that not all crops exhibit linear behaviour. Linearity was however considered appropriate for the purposes of the study, and was used to assess the financial impact (expressed as a gross margin in R/ha) of various irrigation water salinity levels on the yields of major crops such as maize, wheat, lucerne, rye grass and cabbage at different leaching fractions. The researchers defined "leaching fraction" to be "the additional quantity of water applied to maintain a specific soil salinity level". From this analysis, a number of management options were identified which farmers faced with increasing salinity could implement.

These options were:

i. The reduced yield could be accepted by farmers;
ii. Additional irrigation water could be applied (i.e. leaching fraction could be increased);
iii. Planted area could be reduced (due to limited water allocation) or production could be halted altogether;
iv. Artificial drains could be installed and;
v. Crops could be adapted to more salt-tolerant crops. This would depend on economics, since some crops could still provide higher profits, even at reduced yield.

The authors interviewed farmers to gain a sense of which options they would pursue in practice. Soil type proved a major driver of decision-making, specifically the drainage characteristics of the soil. Eighty percent of the land under irrigation drained well, and for this land, farmers indicated that they would have done the following:

i. A leaching fraction would have been applied to maintain yield;
ii. Crop selection would have been adapted should yield have deteriorated to an unprofitable level and/or;

iii. Where additional water was unavailable, farmers would have moved crops off poorer quality land and applied leaching.

For the 20% of irrigated land that did not drain well, farmers indicated that they would have done the following:

i. Artificial drainage would have been installed and;
ii. Fifty percent indicated that they would have first changed to less-sensitive crops and later on, installed drains.

In terms of ***specific ion toxicity***, the authors reviewed the impacts of sodium and chloride, noting that boron was an additional salinity-related compound that could induce toxicity effects. The authors noted that the toxic effects of sodium and chloride are more pronounced when absorbed through leaves. They therefore considered crop-specific sensitivity to foliar injury by outlining concentration ranges that were considered injurious to individual crops. The authors estimated the concentrations of individual ionic species (specifically sodium, calcium, magnesium and chloride ions) in the irrigation water for the project TDS range (200 – 1200 mg/l). They concluded that foliar injury was unlikely at the TDS range of interest.

The researchers assessed the ***effect of sodium on soil properties*** through calculation of the sodium adsorption ration (SAR), both for irrigation water alone and with the inclusion of rainwater. The exchangeable sodium percentage (ESP) was calculated using the SAR. High ESP reduces infiltration rates, causes hard setting of the soil and reduces hydraulic conductivity, all of which affect crop yield. The researchers calculated that there would be a significant increase in the ESP in the deeper subsoil near the bottom of the root zone as TDS levels in irrigation water increased from 200 mg/l to 1200 mg/l, the range specified for the study. These calculations were carried out over a range of leaching fractions (0.05 - 0.2). Guidelines outlining the impacts of SAR values on hard setting, hydraulic conductivity and infiltration showed that none of these would present significant problems to farmers over the salinity range of the study.

In quantifying economic impacts, the researchers considered the benchmark gross margin as representative of the option where the cultivation management practices remained unchanged with increasing irrigation water salinity. The study considered two other options:

i. The management option suggested by the farmers, where acceptable salinity levels at the root zone are maintained through the application of additional water and;

ii. The option of changing to less sensitive crops.

The benchmark gross margin was projected to decrease from R3,645/ha at 200 mg/l TDS to R2,958 R/ha at 1,200 mg/l TDS (in year 2000 Currency) should cultivation practices have remained unchanged. Increasing the leaching fraction to prevent yield declines would have led to a range of R3,644 at 200 mg/l TDS to R3,594.80 at 1,200 mg/l TDS. Changing to salt-tolerant crops would have resulted in a margin range of R3,746 R/ha at 200 mg/l to R3,142 R/ha at 1,200 mg/l. Alternative management options were therefore found to be a favourable means of combating irrigation water salinity increases in the study area for the chosen salinity range, particularly the use of an increased leaching fraction.

Pulles, Howard & De Lange Inc (2000) reviewed the economic cost effects of salinity on the ***mining sector*** in the Middle Vaal area, again using the study range of 200 – 1,200 mg/l TDS. These researchers modelled generic mine water circuits to assess the impacts of increasing TDS.

The circuits reviewed were:

- Evaporative cooling circuits, where TDS was indicated as impacting on treatment costs, blow down volumes and disposal costs;
- Mine service water circuits, where scaling and disposal of excess water were indicated as the primary impacts of TDS increases;
- Metallurgical plant water circuits, where TDS was indicated as impacting on flotation (treatment chemicals), electrolysis (interference with ions), gland service water, carbon elution and regeneration, reticulation piping, cooling jackets and steam generation;
- Slimes discard/irrigation circuits, which have to be maintained below a maximum TDS level and;
- Boiler and demineralisation plants, where the key issue is the need for increased chemical treatment and blow down with rising salinity.

Due to the profile of the study area (at the time of the study the area produced 80-90% of South Africa’s gold and encompassed 80-90% of mining activity in the area), only the gold mining industry was reviewed. The study involved a survey of six mines, representing 57.15% of total tonnage mined per annum in the area. Incorporated into the questionnaire used were the following management options for addressing salinity increases:

- The purchase of increased supplies of fresh water to control the water to a constant salinity;

- The treatment of the water to control to a constant salinity, holding the volume of input water constant;
- The tolerance of deterioration in water quality. In this case, the users would deal with the secondary problems (corrosion, scaling and inefficiencies) and;
- The treatment of effluents in order to meet discharge limits.

Findings of the survey are outlined in Table 2 below. The researchers concluded that the only circuits that would be significantly impacted by salinity increases would be the evaporative cooling water circuits. The study acknowledged that boilers and demineralisation plants require good quality water, but it was concluded that the incremental costs associated with increasing salinity were not significant for these process areas.

Table 2: Findings Regarding Salinity Impacts on Mine Water Circuits

EVAPORATIVE COOLING WATER	MINE SERVICE WATER	METALLURGICAL PLANT	IRRIGATION WATER	BOILER AND DEMINERALISATION PLANTS
• Scaling, fouling and corrosion; • Biocides and anti-scalants required; • Discharge to pans or metallurgical plants; • Mines will purchase more water if salinity increases.	• Scaling, corrosion, erosion, elevated chlorides; • Flocculants required; • Lime required to control pH; • Disinfectants required (treated sewage used to augment water make-up); • Discharge to dams, pans, slimes dams or process water; • Fresh water purchased to control salinity.	• No sensitive water users identified.	• All water use consumptive and no treatment practiced.	• Wide variety of demineralisation and softening plants in use; • Spent regenerants discharged to evaporation dams, sewage plants or used for cleaning – no discharge costs.

Source: Pulles, Howard & De Lange Inc (2000), pp 11-13

TDS levels in the Middle Vaal area at the time of the study were 400 – 600 mg/l. The authors evaluated savings in salinity-related costs below this level and increases in costs above this level, with the primary costs being:

i. Water treatment costs;

ii. Increased water supply costs due to reduced cycles of concentration;

iii. Water management costs, which included the costs of maintenance chemicals, staff costs and control equipment costs.

At a TDS level of 200 mg/l, savings of R5, 167,758 were estimated, while at TDS levels of 1,200 mg/l, incremental costs of R22,310,637 were estimated for the Middle Vaal study area. These costs are in Year 2000 currency. It is clear that salinity increases have a significant cost impact on the mining sector.

Urban-Econ (2000) reviewed the economic cost effects of salinity in the ***services sector.*** In terms of this study, the authors defined the services sector to comprise the recreational and business sub-sectors. In terms of recreation, no costs were determined since the salinity range of the study (200 mg/l – 1,200 mg/l) was not thought to imply any adverse health effects due to human contact. Costs related to recreation that were considered were those associated with hotels and resorts, which were thought to operate along similar principles to the rest of the services sector. In order to determine the costs, the authors surveyed the services sector in Welkom and Klerksdorp to ascertain views as regards the impact of salinity and to determine salinity impacts on individual concerns. The researchers used this information to model cost impacts of salinity for the study area. The costs identified were associated with frequent replacement of appliances and equipment, as well as increased maintenance, leading to higher operational costs. An incremental increase of R324, 913 (Year 2000 Currency) was estimated for the Middle Vaal area for a salinity increase from the levels at the time of the study (500 mg/l TDS) to 1,200 mg/l TDS.

Urban Econ Development Economists (2000), in their ***integrated report*** on the economic cost effects on salinity, highlighted that there were constraints with the data used resulting from the interviewees' inability to supply data for any conditions outside of those experienced during the course of the study. They also asserted that interviewees were generally uninformed about salinity and its potential effects. Based on salinity levels of 500 mg/l, the authors estimated total savings associated with a drop in salinity to 200 mg/l to be R80 million/annum, and total costs associated with a rise in salinity to 1,200 mg/l to be R183 million/annum for the Middle Vaal area (in 2000 Currency). They concluded that the models developed in the course of the study could be applied to areas with more economic diversity, and that useful information had been obtained on the differences between sectors as regards the economic impacts of salinity. The household sector was found to be most affected, incurring some 85% of the total incremental costs at a salinity level of 600 mg/l in the Middle Vaal area (an increase of 100 mg/l TDS). The authors concluded that a possible approach could be the selective desalination of water for the household sector.

3.1.2 The Vaalharts Long-term Salt Balance Study

Agricultural activity can lead to increased salinisation of water resources due to irrigation and land use practices. Concerns regarding a looming salinity problem in the Harts River prompted a review of the long-term salt balance of the Vaalharts Irrigation Scheme (Herold and Bailey, 1996). This study followed an earlier study commissioned by the Department of Water Affairs that concluded that between 1935 and 1984, less than 20 percent of the salt in the water supplied to Vaalharts was released via return flows to the Harts River. The study estimated that over this period, 3 million tons of salt had accumulated, and that the release of this salt would mean the addition of 100,000 tons of salt into the Lower Vaal each year. The fear was that there would be serious economic consequences for downstream users and risks for all irrigation schemes downstream of the Vaal-Harts confluence. In addition, there was a perceived threat to the Orange River given that the Lesotho Highlands Water Project would reduce dilution.

The study sought to:

i. Quantify the long-term historical macro-scale water and salt balance;
ii. Quantify the effects of sub-surface drains (installed at the scheme between 1976 and 1979 to overcome waterlogging) on return flows, TDS loads and TDS composition;
iii. Understand the underlying hydro-salinity processes and;
iv. Propose additional monitoring and field investigations to supplement available data.

The methods employed in the study were to:

i. Conduct a literature survey of similar studies;
ii. Use hydro-salinity models for simulation of the salt balance (including assessment of the impact of the sub-surface drains) and;
iii. Review available agricultural, meteorological, water quality, soils and geo-hydrological data to arrive at hypotheses as to the fate of the salt.

Soil in the area was underlain by a calcrete layer that was found between depths of 0m and 5m on average. A perched water table lay above this calcrete layer where it was impermeable. The researchers thought that where the calcrete layer was pervious, the deeper groundwater table could have risen from a depth of some 24 m to roughly 1 m below the soil surface, based on previous studies.

The study found that some 65% of total salts contained in the irrigation water were retained (compared to the 80% estimate of the DWA-commissioned study). The difference was ascribed to stream-flow gauging errors, additional data that had become available, improved estimates of water supplied before 1954 and the wet hydrological year experienced in 1987. This nevertheless confirmed that most of the TDS in the irrigation water was retained.

The hypothesis that best explained the salt accumulation was that salt was accumulating in a deep groundwater table beneath the irrigated area. This hypothesis stemmed from a few key principles and assumptions, namely:

- That the calcrete layer underlying the irrigated lands was permeable in enough places to permit deep percolation;
- That the deep groundwater table had not yet filled (implying that it could fill at some time in the future) and;
- That the deep groundwater table’s flow contribution to the Harts River is negligible relative to that from the sub-surface drains and the perched water table above the calcrete layer.

The researchers estimated return flows from the North Canal area to the Harts River to be approximately 11% for the period October 1976 to September 1991. They found that the impact of sub-surface drains on return flows was less than that of climatic fluctuations. The researchers attempted to compile a crop water balance, which would assist in assessing total irrigation losses. Total irrigation losses were defined as the sum of return flows to the river and deep percolation to groundwater storage, the latter being a potential sink for the missing salts. However, the researchers could not adequately model the inter-relationship between the processes governing infiltration, surface runoff and soil moisture storage. The authors therefore estimated total irrigation losses, comparing their results with those of other researchers, and arrived at a range of 33 – 63 Mm^3/annum, which is reflective of the degree of uncertainty associated with the study.

The researchers reviewed the long-term future salt balanced against the backdrop of several management options. They projected that in the absence of future irrigation development or water allocations, there would be little change in the mean annual TDS returned to the Harts River. However, projections based on increased development and increased allocations (which were already in progress at the time of the study and were hence more realistic) indicated an increase in the mean annual TDS load returned to the Harts River of 10%, and reduction in accumulated TDS from 65% to 59% by the end of 2030. Both of these projections assumed that the deep groundwater table had sufficient capacity to accumulate deep percolation, and hence salts. The authors noted that should this capacity not be sufficient, a balance between supply and return flow TDS would be established, resulting in a two to threefold increase in the mean annual TDS load returned to the Harts River.

3.1.3 Groundwater Contribution to Salinity in the Breede River Catchment

Groundwater in formations adjacent to the Breede River was found to be brackish or saline and a study was commissioned (Kirchner, 1995) to assess whether part of the salt load in the Breede River was derived from groundwater discharge. As salinity levels in the Breede River have increased over time, increasing amounts of water have had to be released from the Brandvlei Dam to freshen the water in the river, placing increased stress on local water resources. Water leaves the system at Secunda and via the Angora and Zanddrift Canals.

The investigation used chemical analyses from approximately 20 surface water sites and 55 groundwater sites, sampled four times at quarterly intervals. The sites were chosen from approximately 100 sites, based on representivity, chemical composition and geographical distribution. Chemical analysis from the sites was augmented with river monitoring data (EC and flow rate), borehole data (EC and water level), EC measurements at nine additional surface water sites and rainfall measurements from three stations in the area. Samples for strontium analysis were also taken.

The author highlighted that there was significant variability between aquifers as regards groundwater quality depending on borehole position, both within the aquifer and relative to recharge areas, the degree to which boreholes were fed by major fractures and whether irrigation return flow occurred.

The author pointed out that groundwater quality is a function of the geological formations with which the water is in contact. Table 3 outlines typical TDS values for water in contact with specific geological formations in the study area.

Table 3: TDS Values for Geological Formations in the Breede River Area

GEOLOGICAL FORMATION	TDS (mg/l)
Alluvium	423
Ecca Group	892
Dwyka Group	1475
Witteberg Group	1753
Bokkeveld Group	586
Table Mountain Group	92
Malmesbury Group	688

Source: Kirchner, JOG (1995), pp15, after Jolly (1990).

The study showed that chemical and stable isotope inputs and outputs were variable both in terms of sampling location and temporally, with a wide range of influencing factors such as:

- Rainfall;
- Evapotranspiration;
- Land use practices;
- Irrigation methods and practices and;
- The construction of drains.

Quantification of river recharge using ^{2}H and ^{18}O balance methods was found to be infeasible due to inaccuracies introduced by the groundwater volume relative to other variables in the system and uncertainties as regards establishment of accurate return flow volumes. The researcher highlighted that the strontium isotope ratios ($^{87}Sr/^{86}Sr$) carried the signature of the geological formations with which they were in contact, and were therefore not influenced by these uncertainties. They therefore proved a good indicator of the origin of the water found in the system, and the research team therefore used them to quantify the groundwater contribution to the run-off in the Breede River.

The findings of this analysis were as follows:

- Groundwater contribution to total flow at the lowermost weir at Secunda could vary between 3% and 34% depending on source;
- A significant proportion of the water that was found to leave the system was of Table Mountain Sandstone origin, which had a low salt content and would freshen the water in the Breede River and;
- A very small amount of water in the Breede River at Secunda and in the canal exports was derived from high-salinity Bokkeveld water.

The research team concluded that groundwater was not a major contributor to salinity in the Breede River. They observed that the highest volumes of return flows from irrigation occurred near the lower end of the study area, and that this was the area in which salinisation was increasing most rapidly. Since a more even spread of salinity increase was not observed (as would be expected from the geological disposition) this strengthened the view that groundwater of a high salt content did not enter the Breede River in large amounts.

The research team could not establish unique chemical tracers for the individual water balance components. The strontium isotope ratio method was found to be superior to the other methods attempted as regards tracing individual water components.

While this study was concerned with salinisation contributions from groundwater, the author identified other potential contributors to salinisation to be:

- Irrigation return flows (estimated at 5 – 11 m^3/ha per day, with a leaching rate of 15 – 18 kg/ha per day);
- Gypsum and fertiliser application;
- Dissolution of salt from newly developed fields (up to 0.58% salt had been found in Bokkeveld rocks) and;
- Concentration of salts through evaporation (approximately 1700 mm/annum).

3.1.4 Water and Soil Salinity Modelling in the Breede River Catchment

Moolman and de Clercq (1993) investigated the use of solute transport models in predicting root zone hydrosalinity. Three models were selected for their investigation, namely BURNS (Burns, 1974), LEACHM (Wagenet and Hutson, 1989) and TETRans (Corwin and Waggoner, 1990).

The team instrumented two irrigated vineyards in the Breede River Valley to support the study, and to gather data on soil composition and distribution, soil water content and distribution, drainage water (deep percolate) quality and chemical composition, irrigation, precipitation and evapotranspiration and other physical and chemical soil properties.

The authors conducted a literature survey, in which they reviewed the status of transport models of the unsaturated zone at the time of the study. The literature survey indicated that:

i. Wide-scale acceptance for any particular model had not been achieved;

ii. The rate of success of model application studies was not high and;

iii. Models were described as giving only approximate results.

In particular, none of the models reviewed were found able to describe the movement of chemicals under macropore flow conditions. It was further found that model selection was driven in part by:

i. Data demands, particularly for macroscale (> 10 ha) applications;

ii. The specific application of the model;

iii. The required accuracy of prediction;

iv. The availability of information and;

v. The user's knowledge of the model.

The researchers grouped the models into two general groups, a "mechanistic" group comprising models developed from first principles, and which used detailed mathematical relationships, and a "capacity" group, comprising models based on soil layer moisture capacity limits. The authors suggested that the latter group was superior for application to large areas.

The study found that for the models tested, the net flux of water moving through the soil (expressed as the ratio of evapotranspiration to irrigation, ET/I) was the most important parameter in determining the quantity of water and salt that would be leached out of the root zone. The authors asserted that accurate estimates of irrigation and evapotranspiration should therefore receive focus. The authors found that inexperienced model users could make fundamental mistakes in evaluating results, particularly when using "mechanistic" models. They also found that the water flux determined the importance of other model inputs. Where the flux was small (i.e. actual evapotranspiration was close to irrigation rate), the study showed that the rate of water movement through the soil was more important than the salt supply capacity of the soil. At greater fluxes (i.e. irrigation rates much larger than actual evapotranspiration rates), the rate of water movement became less important while the capacity of the soil to supply salt increased in importance.

In reviewing how accurately the “mechanistic” model LEACHM could simulate transport processes under micro-scale field conditions (< 1 ha), the authors found poor correlation between measured results of soil water and salt and those predicted by the model. Some of the reasons advanced for this by the authors included the fact that LEACHM was a one-dimensional model being used to model a three-dimensional situation, and that inputs to the model (e.g. wetted area) were not known with certainty, which would compromise the output from the model. From a numerical perspective, the study found that the model attempted to divide by zero and take the square root of a negative number under certain conditions, making it unstable. The authors concluded that the application of one-dimensional models to drip-irrigated, widely spaced, row-cropped fields would lead to poor results.

The three study models were evaluated at the meso-scale (1 – 10 ha) and here LEACHM was found to be superior to BURNS and TETrans models in predicting soil salt content and final ion concentrations. The two functional type models (BURNS and TETrans) predicted chloride concentrations that were very different to measured values. The improved performance of LEACHM in this study as opposed to the micro-scale study was attributed by the authors to the more dense emitter spacing patterns used, which led to more one-dimensional flow of water through the soil. Results from drip studies were better than from furrow studies (in terms of accuracy of prediction), and the authors attributed this to better control of irrigation water, and hence better quality of information input to the models employed.

The authors investigated potential uses of the models in changing surface water management strategies to decrease the salt load of deep percolate. They modelled six different salinity control measures simulated for three consecutive years to assess impacts on the salt and water flux of a hypothetical irrigated soil. The soil properties, irrigation water composition and irrigation management strategies used were all common to the Breede River, and the same rainfall and actual evapotranspiration data were used, with one exception, for each year and leaching strategy. The authors concluded that while the models do have limitations, their use as a screening tool prior to implementation of expensive field-based salinity control trials could still be valuable.

The authors conducted water balance studies in a drip irrigated vineyard, and using five different methods to calculate the leaching fraction, achieved widely varying results. Quantitative measurement of soil moisture content indicated significant losses of water from the root zone, while calculated values suggested minimal losses. The effects were ascribed to macropore and preferential flow, and it was reiterated that most water and salt transport models could not simulate these phenomena accurately. The authors concluded that water and salt balances calculated using methods that rely heavily on evapotranspiration and irrigation inputs could be highly inaccurate. They concluded further that water and salt transport models that rely heavily on irrigation and evapotranspiration inputs might be highly inaccurate as well.

3.1.5 The Impact of Geological Formations on Salinity in the Breede Valley

Greef (1990) investigated the salinity potential of soil and bedrock and the movement of groundwater in the Poesjesnels River Catchment in the Breede River Valley. The Poesjesnels River is a tributary of the Breede River, and high salt loads were found to be causing damage to crops irrigated with water from the Breede River at Bonnievale. A steady increase in salinity in the Breede River was detected from studies conducted by DWA, the CSIR and irrigation boards. The increase coincided with new irrigation development on thinner, shale soils upslope of previously developed areas on alluvial riverbank soils. The overall aim of the study was to provide data for a model of the Breede River and its tributaries to enable the effective management of future irrigation needs and return flow volumes.

The study determined that total irrigation volume in the catchment was approximately 13 Mm^3/annum, concentrated over an 8-month period from September to April. Water released from the Brandvlei Dam (in order to control salinity levels) amounted to 6.78 Mm^3/annum. Sampling and analysis showed that salinity increased as the river flowed into the central part of the valley, accompanied by a rise in pH. Salinity increased as flow diminished after the winter months. Greef found that irrigation of well-established vineyards in summer months (December to January) produced good quality return flows that helped to ameliorate increases in salinity. He calculated the average annual salt load at the lower end of the Poesjesnels River, based on flow and conductivity, to be 7,674 tons/annum. Modelling carried out estimated salt contribution to the Poesjesnels River from groundwater to be 609 tons/annum. This salt was thought to enter the river primarily through saline lateral seepage where the river intersected part of the groundwater table. The soils irrigated were calculated to yield vastly different quantities of salt based on parameters entered into the model, with Bokkeveld shale estimated to release 344.25 g salt/m^3 rainfall and irrigation, and alluvial soils releasing 77.16 g/m^3. Leaching tests showed that these soils contain far heavier loads of salt, but that these are released slowly over time. Groundwater salinity was generally found to increase with depth.

The author found the average salinity of applied irrigation water to be 312.2 mg/l, while that of return flow seepage was found to be approximately 3,000 mg/l. It was concluded that natural leaching of soil materials by irrigation water and rainfall released considerable amounts of salt into drainage lines and the Poesjesnels River. The chemical composition of the TDS released differed depending on catchment location, with more magnesium sulphate and calcium bicarbonate released in the upper part of the catchment, and sodium chloride predominating in the lower part of the catchment. The study showed that a new, deep-ploughed development on soils overlying Bokkeveld shale resulted in large TDS releases during periods of heavy rainfall and irrigation.

3.1.6 The Impact of Mining Activity on Salinity in the Lower Vet River Catchment

Herold CE ***et al*** (1996) evaluated the surface salinity status of the Lower Vet River Catchment, focusing on the portion of the catchment influenced by pollution sources in the OFS Goldfields mining area. The study area included the Sand River and the portion of the Vet River downstream of the confluence of the Vet and Sand Rivers (the lower Vet River). The Vet River flows into Bloemhof Dam, which discharges into the lower Vaal River.

The aims of the study were as follows:

i. To determine water quality requirements for recognised users;
ii. To document sources of pollution;
iii. The assess water quality monitoring systems in place at the time;
iv. To estimate diffuse source loads and;
v. To evaluate surface water quality.

The authors experienced problems with water balance information (much of the data was contradictory) and hence could not construct accurate water balances. They noted that most of the purified sewage effluent generated in the study area was reused by local mines and used to irrigate parks, gardens and sports fields. Return flows arose only from the Joel, Beatrix and Oryx mines and the Thabong Sewage Treatment Works.

In terms of user requirements, the authors used the following five broad categories of users for their analysis

1. Domestic users;
2. Recreational users;
3. Industrial users;
4. Agricultural users and;
5. The natural environment.

The study reviewed TDS and inorganic ion concentration data up to the end of September 1992 and compared the requirements of these users to the water quality measured in the catchment, using the South Africa Water Quality Guidelines (DWA, 1993). The standards used to define water quality requirements for aquaculture were used as a proxy for the requirements of the natural environment. The research team conducted a survey among these user groups to assess the impacts of salinity.

The study found the following users to be most affected by activities of the mines:

i. Residents of the town of Hoopstad, particularly users in informal settlements who do not utilise purified water for domestic purposes;
ii. Riparian irrigation farmers along the lower Vet River (below the confluence of the Sand and Vet Rivers), whose domestic water supplies may not have been purified sufficiently. In addition, the farmers that were surveyed all used sprinkler irrigation systems, implying that increased salinity would not only impact on yield but could also result in foliar damage and;
iii. Farmers using water from polluted local rivers for livestock watering. The study found that livestock watering was common to all river reaches in the study area.

It was found that groundwater had been polluted (i.e. salinisation was evident) over a large area and that a number of rivers, streams, pans and wetlands in the region had suffered severe salinisation (see Table 4 below).

The dominant ions found in polluted river water were chloride, sodium and sulphate. The median electrical conductivity of the Sand River increased from 30 to 216 mS/m from east to west across the mining area, with chloride levels rising from 18 to 390 mg/l.

Table 4: Salinised Surface Water Resources in the Lower Vet River Catchment

SURFACE RESOURCE TYPE	RESOURCES FOUND TO BE CONTAMINATED
River	Sand River, Doring River,
Stream	Mahemspruit, Theronspruit, Bosluisspruit and probably the Rietspruit and Merriespruit (latter two based on sparse data)
Pan	Dankbaar, Riet, Wolwe, Stuurmans, Doring, Blesbok, Toronto, Flamingo, Wit and Swart Pans

Source: Adapted from Herold CE et al (1996) pp ES.4

The authors identified gold mining as the main cause of salinisation of the groundwater, pans and rivers. Water pumped out of mines had TDS levels varying from 1000 to 4,500 mg/l, comprising mainly sodium and chloride. The unsuitability of this water for urban or irrigation use had led to the use of evaporation pans. The authors found that in 1992 alone, 72 Mm^3 of saline underground mine water was pumped to evaporation areas in the OFS Goldfields area. The authors asserted that it was likely that, even with sufficient evaporation capacity in terms of surface area, some of the water would have penetrated the underlying strata and reached the groundwater table and/or entered rivers.

The mines identified as being responsible for surface water contamination of the Sand River and its tributaries were the President Brand, President Steyn, Harmony, Beatrix and Oryx mines. Western Holdings and Freestate Geduld mines were found to affect the Mahemspruit while St. Helena Gold Mine was found to be discharging to the Wolwepan/Rietpan system. The research team noted the potential for seepage from these pans towards the Sand River and the impact of intermittent spillage events. The authors noted further that saline water from some mines was also discharged to natural pans and wetland systems. In addition to salinity, the study identified the following additional pollution occurrences:

i. A recently closed yeast factory had polluted the wetland system near Blesbokpan with yeast effluent;
ii. Witpan was found to suffer from occasional pollution with contaminated stormwater, and also received treated municipal effluent from the Theronia sewage treatment works;
iii. The Sand River had elevated nutrient levels throughout the mining and urban areas. The authors were unable to identify the source;

iv. Ammonia levels exceeded maximum levels for the natural environment to some extent at all points in the system, particularly in the Sand River and its tributaries in the OFS Goldfields area, but the 1 mg/l limit was not exceeded at any monitoring stations;

v. Nitrate levels were generally within target water quality user requirements, as were fluoride, pH and cyanide levels and;

vi. Phosphate levels (as P) exceeded 1 mg/l at a number of points.

The study found that the catchment monitoring system was deficient as regards coverage, flow gauging at water quality sampling points, water balance monitoring, sampling frequencies, choice of water quality variables and site identification.

The research team estimated than in the 15 years leading up to the study, pollution sources in the OFS Goldfields had contributed approximately 16,000 tons of TDS per annum to the Vet River Catchment, increasing the TDS export from the Vet River Catchment by roughly 35%. The study showed that the effect was more pronounced in wet years than in dry years. The total average TDS contribution to the Bloemhof Dam from the Vaal and Vet River systems was estimated to be 600,000 tons per annum. Long-term salinity trends in surface waters were found to have reached a plateau, thought by the authors to be due to the predominance of older, long-established mines in the region. The team noted that this situation could change as newer mines reached full production. Background surface water quality (based on the Allemanskraal and Erfenis Dams in the upper reaches of the Sand and Vet Rivers respectively) was found to be excellent and fully compliant with user requirements for salinity-related variables. The following were the concern areas highlighted by the study from a salinity perspective:

- EC levels in the Sand River increased significantly downstream of the Allemanskraal Dam;
- Harmony mine’s “waste dump” and “donga dump” streams resulted in a significant increase in salinity in the Sand River;
- In some portions of the Sand River, deterioration in water quality due to salinity increases was deemed serious enough to present an acute health threat to potential rural or informal users, who may use it for domestic purposes;
- The Sand River Canal exceeded all salinity-related water quality user requirements by wide margins most of the time, with the exception of calcium and magnesium. A farmer’s dam had been built in the stream into which the canal discharges. The water was found

to be unacceptable for domestic use, irrigation, livestock watering or the natural environment;

- The study found that the Doring River and Theronspruit had salinity levels exceeding user requirements for long periods and by wide margins. The EC level above which chronic health problems may be expected was exceeded for 68% of the time and the acute health threat limit was exceeded for 10% of the time at the sampling point immediately downstream of the Theronspruit confluence.

3.2 THEME 2: EUTROPHICATION OF SURFACE WATERS

3.2.1 A National Overview of Eutrophication in South Africa

Walmsley RD (2000) defined eutrophication as the process by which aquatic ecosystems become progressively enriched with plant nutrients over time. Walmsley explained further that the eutrophication process leads to increased production of organic material by aquatic plants (algae and weeds). Cultural eutrophication is eutrophication caused by the activities of man, and the author describes this as a “major global water resource problem”.

Walmsley’s approach was to conduct an international literature scan, to make contact with local stakeholders and specialists and then to prepare a framework for the management of eutrophication in South Africa.

The key nutrients in the eutrophication process were identified as phosphorous and nitrogen, and the optimal ratio of these nutrients in terms of plant growth was indicated to be in the range of 8:1 to 12:1 (N:P). Walmsley indicated that phosphorous was the fundamental cause of eutrophication, and that systematic elimination of phosphorous was the only practical way to combat eutrophication. It was however noted that nitrogen can become important at high levels of eutrophication, and that in the case of nitrogen-fixing cyanobacteria, nitrogen can cause significant water quality problems. The author asserted that the most severe eutrophication problems occurred where the anthropogenic nutrient inputs far exceeded the assimilative capacity of the natural environment.

The following eutrophication problems were identified by Walmsley (from Toerien, 1974 and Dunst ***et al,*** 1974):

- Increased occurrence and intensity of nuisance algal blooms, blue-green algae, toxic algae and floating and rooted aquatic macrophytes;
- Clogging of reticulation systems by filamentous benthic algae;
- Increased water treatment costs through filter clogging;
- Increased occurrence of taste and odour problems in drinking water;
- Increased de-oxygenation of bottom waters, with associated chemical effects;
- Increased fish and invertebrate mortality;
- Changes to ecological communities and loss of biodiversity;
- Increased interference in recreation activities;
- Loss of property values;

- Increased human health problems;
- Interference with agriculture (e.g. clogged irrigation systems) and;
- Undesirable aesthetic conditions.

Nutrient inputs identified included nutrients from water-borne sewage systems and from agricultural practices. Products that contained nutrients that may reach water resources were indicated as being:

- Detergents (containing phosphorous) from homes and industries;
- Foodstuffs that are part of the everyday consumer economy (e.g. meat, cereals, milk etc.);
- Fertilisers applied to agricultural land to stimulate plant productivity;
- Fossil and wood fuels, which result in nitrogen oxide emissions and;
- Animal feeds such as fishmeal, hay, grass and supplements.

Walmsley reviewed various management options, and it was concluded that the generally agreed, best practice, long-term solution to eutrophication problems was to minimise nutrients at source. It was however noted that due to the long time-frames associated with the achievement of results with this approach alone, both a long-term and short-term approach were needed, where a suite of solutions was employed.

The scan of the international extent of eutrophication highlighted that most industrialised countries have eutrophication problems. The USA, Canada, the European Union and Australia were identified as countries that had defined eutrophication strategies, whereas Africa, Asia and South America were identified as regions that did not give the problem as high a priority. Countries that had defined approaches to tackling eutrophication were said by the author to have certain common perspectives, which included the following:

- The view that cultural eutrophication was reversible;
- An acceptance that a long-term approach was needed;
- The view that government must take a lead role, and that a collaborative approach was required between government, business and communities;
- The view that the approach to eutrophication must involve a suite of actions which include technical, social and economic interventions and;

- The view that research and monitoring activities must be transparent to allow effective decision-making.

The author noted that while eutrophication was a priority water resource management problem in South Africa more than 30 years ago, it remained widespread, particularly in the more populated and industrialised areas of the country. Ongoing observed eutrophication problems in receiving water systems are noted (Chutter, 1991). The study quotes a 1975 survey by Toerien that highlights the following water resources as most seriously affected by eutrophication at the time:

- Rivers draining north of Johannesburg and Pretoria e.g. the Jukskei, Crocodile and Pienaars Rivers;
- The Shongweni Dam in Kwazulu-Natal;
- Rivers draining south of Johannesburg e.g. the Klip River and the Blesbokspruit and;
- The Buffalo River in the Eastern Cape.

Walmsley referred to a report published by the DWA Institute for Water Quality Studies, which stated that eutrophication in 2000 was as widespread as it was in 1975 in order to illustrate that the status of eutrophication had not changed significantly over this period.

Walmsley reviewed South Africa's approach to eutrophication, specifically considering the 1mg/l P special standard for effluent discharge in sensitive catchments, promulgated in 1980. The study highlighted that the standard was not applied to all of the catchments due to representations made by local authorities.

The seven "sensitive" catchments were identified as:

- The Vaal River, upstream and inclusive of Bloemhof Dam;
- The Pienaars and Crocodile Rivers, upstream of their confluence;
- The Great Olifants River, upstream and inclusive of the Loskop Dam;
- The Umgeni River, upstream of the influence of tidal water;
- The Umlaas River, upstream of its point of discharge into the sea;
- The Buffalo River, upstream and inclusive of Bridle Drift Dam and;
- The Berg River, upstream of the influence of tidal water.

Walmsley noted that the decision was taken in 1985 to limit implementation of the phosphorous standard to the Vaal River catchment up to the Barrage and the Crocodile River catchment up to the confluence of the Crocodile and Pienaars Rivers. Walmsley noted further that an additional 3 years exemption was granted to the remaining catchments up until August 1988. The author made mention of the fact that in 1988, a receiving water quality objective of 130 µg/l total phosphorous was introduced for reservoirs in the sensitive catchments and that evidence of the implementation of this standard was lacking.

Walmsley ascribed lack of progress on the eutrophication problem to issues of implementation rather than policy, citing widespread non-compliance to the 1 mg/l P standard by many wastewater treatment plants in the sensitive areas (Van Niekerk, 2000) and the lack of application of the receiving water P standard. Lack of capacity in terms of human resources has, based on the author's review of the literature, led to a regression in South Africa's ability to deal with eutrophication (Moss, 1999), which has been exacerbated by limited research and capacity building. The author asserts that a new approach to eutrophication policy, management and research is necessary in South Africa.

3.2.2 Eutrophication in the Vaal River

According to Pieterse and Janse van Vuuren (1997), the Vaal River is a eutrophic system, based on high chlorophyll-***a***, inorganic nitrogen and inorganic phosphorous concentrations as well as high primary productivity rates. Problems ascribed by the authors to eutrophication were:

i. Large phytoplankton developments with resulting aesthetic problems;
ii. Health hazards (e.g. carcinogenic trihalomethane formation upon chlorination at treatment plants);
iii. Interference with water treatment processes (clogged filters and scums) and;
iv. Problems in water distribution systems.

These issues prompted the authors to investigate the causes and consequences of the growth and decline of phytoplankton blooms in the Vaal River. The project objectives were:

- To understand the conditions responsible for the development and decline of algal blooms;
- To investigate seasonal impacts on carbon assimilation and photosynthetic characteristics ***in situ*** and relate these to environmental conditions;

- To isolate algal species into uni-algal culture and perform experiments as regards growth, metabolic rates, carbon assimilation and enzyme activity and;
- To apply (available) and develop (new) mathematical models of growth and behaviour for predictive and management purposes.

The study involved comprehensive monitoring of physical, chemical and biological parameters at various locations along the Vaal River. The study was conducted over the period from 1986 to 1993.

At Balkfontein, environmental variables measured were ***in situ*** dissolved oxygen, temperature, surface pH, atmospheric and underwater light intensity and turbidity. Total inorganic carbon available for photosynthesis was calculated using tables (Wetzel and Likens, 1979) and chlorophyll-***a*** was measured. The underwater light climate (ULC) was calculated. Data were augmented with chemical and flow data provided by DWA.

An inverse correlation was demonstrated between discharge (river flow) and TDS, with higher TDS associated with clearer water, and hence a deeper euphotic zone, which the authors believed could favour algal growth. Higher discharge was however also found to be related to higher turbidity levels. It found that on an annual basis, a positive correlation existed between chlorophyll-***a*** concentrations and discharge. Higher discharge was found to be associated with higher nutrient concentrations (nitrogen, phosphorous and silicon), which resulted in higher chlorophyll-***a*** concentrations. The algal blooms were only however apparent several weeks after high discharge levels were experienced, when turbidity decreased and light levels improved.

The authors noted that water hyacinth at Balkfontein may have contributed to reductions in turbidity and assimilation of nitrogen and phosphorous during 1991 and 1992, due to their dense root systems and the known ability of macrophytes to accumulate large quantities of nutrients from their environments.

The average values for daily rates of areal photosynthesis measured over the study period fell within the range for eutrophic water bodies. The authors noted that while several investigators had reported that turbidity and light intensity (as opposed to nutrient concentration) were the main factors controlling primary production, production levels in the Vaal River appeared to be more related to chlorophyll-***a*** concentration than to light regimes.

Between 1991 and 1993, physical, chemical and biological parameters were measured at four locations, together with identification of the algal species present. At the Barrage locality, sodium was found to be the second most dominant cation (after calcium) and the authors noted that sodium requirements are high for some species of blue-green algae. It was postulated that the higher phosphorous concentrations at the Barrage compared to the other 3 sampling locations utilised for the study - Parys Municipality, Western Transvaal Regional Water Company (near Stilfontein) and Goldfield Water at Balkfontein – could, together with the high sodium ion concentration, explain why intensive blue-green algal blooms are sometimes experienced in the Barrage vicinity. It was found that dominance of blue-green algae occurred at sodium ion concentrations above 40 mg/l. The concentration of diatoms was found to be lower at the Barrage than at the other localities sampled, and this was thought to be why silicon levels at the Barrage were higher than at other localities. Table 5 outlines the average sodium ion, silicon, dissolved inorganic phosphorous (DIP) and dissolved inorganic nitrogen (DIN) concentrations over the study period at the four sampling localities.

Table 5: Average Sodium, Silicate, DIP and DIN Concentrations at Sampling Localities in the Vaal River

SAMPLING LOCATION	SODIUM ION (Na^+) mg/l	SILICATE-SILICON (SiO_2-Si) mg/l	PHOSPHOROUS (PO_4-P) mg/l	NITROGEN (NH_4-N + NO_3-N + NO_2-N) mg/l	DIN:DIP RATIO
Barrage	48	3.4	0.155	1.472	15.9
Parys	57	2.6	0.086	1.677	48.6
Stilfontein	65	2.3	0.043	0.738	45.8
Balkfontein	68	1.7	0.04	0.3	10.3

Source: Pieterse and Janse van Vuuren (1997), pp 54-85

Elevated phosphorous levels at the Barrage were comparable to the world average in Rivers of 0.1 mg/l (after Goldman and Horne, 1983), but far lower than the levels in enriched impoundments such as Hartebeespoort Dam (approximate mean 0.35 mg/l; Robarts, 1984). The authors noted that algae and aquatic macrophytes contained nitrogen and phosphorous in the approximate ratio of 7:1, and while this differs for different organisms, it was suggested that phosphorous could be the limiting nutrient in the Vaal River. Reduced phosphorous concentrations downstream of the Barrage were ascribed to uptake by algal cells and possibly water hyacinths, which occurred frequently downstream of the Barrage at the time of the study. Average SiO_2-Si values in the Vaal River (see Table 5) were found to be significantly lower than the world average of 9 mg/l. Silicon values were also higher in the summer periods than in winter periods, and this was ascribed to the fact that silicon solubility increases directly with temperature.

The study found that at the Barrage, Parys and Balkfontein, a large number of different algal species succeeded each other within relatively short time spans. At Stilfontein a smaller number of species was found to succeed each other, suggesting more stable environmental conditions at that locality. At least 124 species and varieties belonging to seven major algal groups were identified in the Vaal River over the course of the study. Diatoms and green algae were dominant at all four sampling locations, as well as blue-green algae during certain periods. The scarceness of certain groups (e.g. Chrysophyceae), and the abundance of others (e.g. Cyanophyceae), were highlighted by the authors as an indication that the Vaal River is a polluted and eutrophic system.

The study showed that temperature was a driver in determining the specific species to bloom e.g. blue-green algae bloomed mainly in the summer months. The authors highlighted that salinity was a further major concern in the Vaal River, and that this could exacerbate algal blooms through causing flocculation of suspended material and increasing underwater light intensity. The study highlighted that phytoplankton blooms, which resulted in extreme rates of photosynthesis, also caused increases in river pH values. Application of the effluent phosphorous standard of 1 mg/l P was suggested as a relevant means of minimising the effects of eutrophication.

Modelling of algal blooms was carried out, initially using a light-temperature model, and using weekly average temperature and Total Suspended Solids (TSS) as inputs. Calculated chlorophyll-***a*** values agreed fairly well with measured values. Including silicon concentration as an input improved the accuracy of the model, but some discrepancies remained between simulated and measured values, and the authors concluded that additional factors would have to be incorporated into the model to improve accuracy.

3.3 THEME 3: TOXIC ORGANIC POLLUTANTS

3.3.1 Estrogen and Estrogen-mimicking substances

Meintjies, van der Merwe and du Preez (2000) studied estrogen and estrogen-mimicking substances in the South African water environment. The project aimed to assess the extent of pollution of the South African water environment, based on the detection of compounds most likely to occur.

The authors noted that concerns as regards these substances centred around possible effects on human reproductive systems, including reductions in sperm count and quality, testicular cancer, male breast cancer and cryptorchidism (undescended testes). Evidence was presented as regards impacts on the animal kingdom, examples of which included masculinisation of female fish, developmental abnormalities in reptiles, changes in the sexual behaviour of birds, feminisation and reproductive incompetence in turtles and endometriosis in rhesus monkeys.

The researchers noted that the chemicals implicated in causing estrogenic effects are ubiquitous, occurring in detergents, agricultural pesticides, dyestuffs, pharmaceuticals and oral contraceptives, among other products. They used databases and a literature survey to screen for likely contaminants in the South African situation, and to assess current and past levels of contamination. In all, 142 substances were identified and this list of substances was reduced through a process of elimination that included:

- Visits to industries and the Institute for Water Quality studies for guidance;
- Engagements with educational institutions, government departments, laboratories, industries, municipalities and a pharmaceutical company to determine which of these substances had already been found in South Africa;
- Identification of substances manufactured locally;
- Review of chemical characteristics and toxicological data;
- Elimination of vaguely described substances and those highly unlikely to pollute the water environment in a harmful manner and;
- Elimination of substances that could not be analysed in South Africa e.g. dioxins.

The review of past contamination showed that contamination of water resources had occurred across South Africa. Widespread contamination of surface waters with α-endosulfan, β-endosulfan, atrazine and chlorinated pesticides in the crop-growing regions of South Africa were highlighted by the review. Dichlorodiphenyl trichloroethane (DDT) contamination was also identified in areas where this substance was used to control malaria, such as in Northern Kwazulu-Natal and the Kruger National Park. Chlorinated pesticide contamination was found to correlate with the use of these substances in agricultural areas. Atrazine was found to be the most prevalent contaminant. The study found that the occurrence of estrogen and estrogen-mimicking substances in water was mainly concentrated in the Pretoria, Witwatersrand and Vereeniging areas.

The occurrence of these substances in animal tissue was found to occur mainly in the coastal areas and to a lesser extent in the northeastern areas of South Africa. Lipophilic substances such as DDT, Dichlorodiphenyl dichloroethylene (DDE) and 1,1 dichloro-2,2-bis(p-chlorophenyl)ethane (DDD) were found to contribute the most to the contamination. The authors cited the presence of more water bodies and hence more water/marine life in these areas as the reason for this geographic distribution. The researchers stressed that this geographical spread of contamination was based on a literature survey, and did not mean that areas that were not tested were not contaminated.

The study reviewed estrogen and estrogen-mimicking substances found in water and animal tissue in the USA and Europe. In the only international animal tissue/fat test cited, the blubber of a sea lion off the California coast was found to contain 253,000 – 341,000 µg/kg DDE and Polychlorinated Biphenyls (PCB's). The blubber of a dolphin sampled off the South African east cost was found to contain 0.09 – 67.18 µg/g of PCB's (equivalent to 90 – 67000 µg/kg). In terms of the international water samples tested, visual inspection of the data showed that comparisons were difficult to make, since the substances outlined in the international review differed from those in the South African review.

The authors concluded that there were many substances in the South African water environment that had the potential to disrupt human reproduction. Many of these substances were found in the Pretoria, Witwatersrand and Vereeniging area. The point was made that substances such as PCB's and DDT are lipophilic and accumulate in body fat, concentrating over a long period of time. The substances in Table 6 on the next page were the substances the authors believed were most likely to be found in the South African water environment, with results of samples analysed from grab samples taken from:

i. The Vaal River, in particular the Barrage wall and two other points 10 and 24 km upstream;

ii. The effluents of chemical manufacturers who produced any of these substances (nationally);

iii. Drinking water samples taken from taps in Windhoek, Pretoria, Johannesburg and Vereeniging and;

iv. Tithe Roodeplaat, Hartebeespoort and Boskop Dams, sampled for the presence of atrazine. The results of these tests are presented in Table 6.

Table 6: Results for Estrogen and Estrogen-mimicking Substances (Jan-Sept 1997)

CLASSIFICATION	ESTROGEN/ESTROGEN-MIMICKING SUBSTANCE	VAAL RIVER AND/OR BARRAGE	DRINKING WATER	VAAL INDUSTRY EFFLUENT	EFFLUENT FROM INDUSTRIES
Herbicide	Atrazine	X	ND	X	X
	Methoxychlor	ND	ND	ND	ND
Pesticides/Insecticides	DDT	ND	ND	ND	ND
	Endosulfan	ND	ND	ND	ND
	Malathion	ND	ND	ND	ND
	o'p' DDT	ND	ND	ND	ND
	p'p' DDT	ND	ND	ND	ND
	Endosulfan (alpha isomer)	ND	ND	ND	ND
	Endosulfan (beta isomer)	ND	ND	ND	ND
	o'p' DDE	ND	ND	ND	X
	p'p' DDE	ND	ND	ND	X
Organochlorinated pesticides	Chlordane	ND	ND	ND	ND
Polychlorinated biphenyls (PCB's)	Arochlor 1254	ND	ND	ND	X
	Arochlor 1260	ND	ND	ND	X
Phenols	Alkylphenolic compounds (4 nonylphenol)	X	ND	X	X
	Nonylphenol	X	ND	X	X
Pharmaceutical products	o'p' DDD	ND	ND	ND	X
	Synthetic estrogens - Ethinylestradiol	NT	NT	NT	NT
Endogenous estrogens	Estradiol	NT	NT	NT	NT
Miscellaneous	DDE	ND	ND	ND	X
	Dicofol	ND	ND	ND	ND
	Estrogens found in sewage water	NT	NT	NT	NT

ND = not detected; NT = could not be tested; X = detected

Adapted from Meintjies, van der Merwe and du Preez (2000) pp 31-39 and pp 44 - 47

Note that while the authors refer to 26 estrogen/estrogen-mimicking substances in the report, there appears to have been some double-counting, since certain of the compounds occur in more than one of the categories used to classify them. Even the pared down list in Table 6 has some ambiguity e.g. it is not clear how estrogens found in sewage water are different to endogenous and synthetic estrogens. It could be in this case that it involved a wider range of synthetic estrogens than ethinylestradiol but the authors did not clarify this.

Estrogens could not be tested for in water samples. While the authors found methods in the literature for the testing of estrogens in biological fluids and tissue, no references for testing for estrogens in water could be found. The tests attempted exhibited poor extraction efficiencies and had poor repeatability.

No estrogen and estrogen-mimicking substances were found in drinking water samples, leading the authors to conclude that water purification technologies employed at the time of the study removed estrogen and estrogen-mimicking substances efficiently, but that these substances could still have been present at levels below the detection limits available. Two newspaper articles were quoted in which it was reported that nonylphenol had been detected in drinking water, and the authors ascribed this anomaly to the fact that the samples reported on had been taken at different locations and at different times to that of the study.

Atrazine was found in all of the dam waters sampled, with concentrations of <0.25 μg/l in the Boskop Dam, 0.42 μg/l in the Roodeplaat Dam and 1.19 μg/l in the Hartebeespoort Dam. The authors found that atrazine concentrations correlated with agricultural activity.

From analysis of the samples, the authors asserted that contamination of South African water resources with estrogen and estrogen-mimicking substances was a fact, and highlighted that most of the substances responsible for the contamination were of agricultural or industrial origin.

3.3.2 Insecticide Contamination of Water Resources in Rural Kwa-Zulu Natal

Sereda and Meinhardt (2000) selected Makhathini Flats, Orphansi and Ndumo in Kwazulu-Natal as study areas for investigation of insecticide contamination of the water environment, on the basis that these areas are protected by a malaria control programme. DDT and deltamethrin were used for indoor spraying of dwellings in these areas at the time of the study, and this was considered a potential source of contamination. Agricultural development in these areas had also increased pesticide use.

While these substances were known to be endocrine disruptors with potentially serious consequences for animals and humans, this study was primarily prompted by concerns that their accumulation in water bodies could lead to the breeding of resistant mosquitoes, with implications for their effectiveness in the control of malaria. Cases of pyrethroid and organophosphate resistance in malaria vector Anopheles species had been detected in Kwazulu-Natal. The aims of the study were to evaluate the insecticide pollution status of the KZN water environment and to predict the possible risk of insecticide resistance development in malaria vectors.

The authors conducted a literature survey to review aspects of the chemical control of malaria. A questionnaire was designed to establish pesticide use patterns in the study area, and to assist in selecting target pesticides for analysis. A total of 214 samples, including both water and sediment, were collected and analysed for pesticide residues. Reference samples were also collected from two nature reserves. Samples were quantitatively analysed for pyrethroids and screened for the presence of organochlorines, organophosphates and carbamates.

The study found that water resources in the area were contaminated with representatives from the pyrethroid, organophosphate, organochlorine and carbamate chemical groups, including DDT and DDT metabolites. The authors considered DDT residues to be a result of illegal use in agriculture (DDT is only to be used for malaria vector control). The other insecticides detected were thought to be from both agricultural use as well as malaria vector control. Table 7 below summarises the results of the analysis of water and sediment samples.

Table 7: Insecticide Residue Detection Frequencies at Sites in Rural Kwazulu-Natal (includes reference sites)

MATRIX	NO. SAMPLES	SAMPLES CONTAINING PYRETHROIDS		SAMPLES CONTAINING ORGANO CHLORINES		SAMPLES CONTAINING ORGANO PHOSPHATES		SAMPLES CONTAINING CARBAMATES	
		No	%	No	%	No	%	No	%
SEDIMENT	128	52	40.6	73	57.03	28	21.8	46	35.9
WATER	86	11	12.8	8	9.3	39	45.3	17	19.8
TOTAL	214	63	29.4	81	37.8	67	31.3	63	29.4

Source: Sereda and Meinhardt (2003), pp 58

The game parks selected as reference sites (Tembe Elephant Park and Ndumo Game Reserve) did not meet the requirements for control sites, as both water and sediment samples from these sites were contaminated. The authors were unable to establish how contamination had occurred in the Tembe Elephant Park, since it was some distance away from agricultural activity. The Ndumo Game Reserve was in close proximity to agricultural fields located on the banks of the rivers feeding into the park, possibly explaining the contamination.

Farmer interviews in the study areas indicated a lack of practical knowledge regarding pesticide safety, disposal and risks to human health and the environment, despite the fact that many farmers had completed training courses on the safe use of pesticides. The researchers found many empty pesticide containers were used for domestic purposes and insecticide spillage was found to occur often, which was of most concern.

The researchers concluded that major selection pressure for the development of mosquito resistance existed in the study area. They noted that other researchers had shown that cross-resistance between DDT and pyrethroids was possible. The researchers expressed concern that planned agricultural development in the study area would increase insecticide usage and increase the threat of mosquito resistance. The fact that DDT is one of the 12 chemicals targeted by the Stockholm Convention on Persistent Organic Pollutants was highlighted, and that these chemicals persist in the environment, accumulate in the food chain and travel great distances. The researchers noted that these chemicals are linked to developmental defects, cancer and other serious health problems in animals and humans.

3.3.3 Pesticide Contamination of Water Resources in the Rural Western Cape

London ***et al*** (2000) investigated the presence of pesticides in rural water sources in the Western Cape over a period from 1997 to 1999. The study was motivated by the lack of data in South Africa at the time on this issue, and growing international concern regarding the links these substances had with adverse chronic health impacts. The authors noted that the adverse impacts related to environmental contamination tended to be externalised and were typically not subject to surveillance.

The study area chosen comprised the Hex River Valley, the Grabouw/Vyeboom area and the Piketberg region, based on the spread of farming activities prevalent and the high likelihood of pesticide contamination of groundwater and surface water resources. As such, these areas represented a “worst-case” scenario and the authors stressed that they were not necessarily representative of all agriculture in the region.

The choice of pesticides to be analysed for the purposes of the study was based on:

- Potential to cause adverse health effects, using the Environmental Protection Agency (EPA) and World Health Organisation (WHO) lists of drinking standards and regulations as input;
- Frequency of use in the study area;
- Likelihood of contamination, using industry expert opinion and known groundwater ubiquity scores (from Gustafson, 1989) and;
- Ability to analyse samples locally, a factor that meant that some important substances, such as aldicarb, were omitted.

A total of 31 pesticides were identified. A spectrum of groundwater and surface water resources was sampled weekly. Samples were analysed for the main pesticides of concern, endosulfan and chlorpyrifos, at the laboratories of the Peninsula Technikon (PENTECH). The State Forensic (SF) laboratories and the laboratories of the Agricultural Research Council (ARC) carried out quality assurance tests. The SF laboratories tested for all of the 31 pesticide chemicals identified. The study team conducted sampling in a manner that allowed coverage of a full year’s cycle of farming activity, and data on spraying patterns in the region, river flow, temperature, rainfall, water pH and turbidity were incorporated into the study. Sample frequency was increased for the period representing the onset of the rainy season. A summary of the spread of sampling points in each area is outlined in Table 8 below.

Table 8: Sampling Sites Used for Pesticide Analysis in the Rural Western Cape

STUDY AREA	SURFACE WATER (rivers and streams)	SURFACE IMPOUNDMENT (reservoir or dam)	DRAINS (in vineyards)	UNPURIFIED DRINKING WATER (Borehole/well)	PURIFIED DRINKING WATER (tap)
HEX RIVER VALLEY	6	3	2	1	1
GRABOUW/VYEBOOM	4	3	0	1	1
PIKETBERG	3	1	0	3	1

Source: Adapted from London et al (2000) pp 3-7

In addition to analytical testing, the study team carried out a farm survey to assess the practices of farm residents in relation to water in the Hex River and Grabouw areas. Interviews involved review of the sources of water for drinking and non-drinking purposes, contamination of water sources, drift, domestic use of pesticides and pesticide containers and knowledge of pesticide safety. In total, the team surveyed 60 farms, with questionnaires administered to 19 farm owners, 40 farm managers, 60 spray operators, 58 farm workers and 51 non-farm workers.

Finally, dietary consumption estimates were carried out based on drinking water analyses, using the basis of a 60 kg adult with water intake of 2 litres/day. Results were compared to WHO and EPA standards.

The study acknowledged the degree of uncertainty associated with measurement at very low concentrations, and used quantification limits to indicate the concentration of a pesticide in water above which results could provide a quantitative estimate with a 95% degree of confidence. To arrive at the quantification limit for a pesticide, a known standard was analysed 7 times, with the quantification limit being twice the standard deviation of the analyses. Quantification limits for the PENTECH laboratory were 0.05 μg/l for chlorpyrifos and 0.1 μg/l for endosulfan.

The findings demonstrated widespread low-level contamination of chlorpyrifos and endosulfan in the study area. Other pesticides detected in the study area are outlined in Table 9 below:

Table 9: Pesticides Other Than Chlorpyrifos and Endosulfan Detected in the Rural Western Cape

AREA	DETECTED PESTICIDES
HEX RIVER	Fenarimol, Prothiofos, Deltamethrin
PIKETBERG	Nil
GRABOUW/VYEBOOM	Iprodione, Azinphosmethyl, Penconazole

Source: Adapted from London et al pp 4-9, 4-10 and 4-15

Chlorpyrifos and Endosulfan contamination dominated, and the authors focused their analysis on these substances. In terms of frequency of detection of these two contaminants in each study area, the following pattern was observed:

Chlorpyrifos: Piketberg > Hex River > Grabouw

Endosulfan: Grabouw >> Hex River > Piketberg

Out of 382 samples, 30% AND 37% were above the European Union (EU) pesticide limit of 0.1 µg/l for chlorpyrifos and endosulfan respectively. Irrigation appeared to increase the amount of endosulfan and chlorpyrifos in water bodies, and it was found that a significant amount of pesticides entered the study area through the Berg River. Contamination coincided with crop spraying, but not strongly with rainfall.

Comparison with international studies showed that the frequency of detection in this study was comparable to a study conducted in Spain. Maximum levels found in this study were substantially higher than two studies conducted in California. The authors ascribed this to these being “worst-case” study areas, while the international studies were integrated studies representative of the target population.

Contamination of drinking water, albeit at low levels, was as an area of concern. Modelling of dietary intake levels showed however that the water sources contaminated would contribute very low proportions (generally < 1%) of Acceptable Daily Intake (ADI), which fell well within WHO guidelines specifying a range of 1 – 10% of ADI contributed by pesticides. The authors asserted that while this indicated the absence of immediate threats to human health, endocrine disrupting effects occur at far lower exposure levels than toxic effects, and that these concentrations warrant attention. It is further noted that the risk assessment procedures used did not address the toxicity of combinations of chemicals, and that farm workers may experience other routes or exposure than ingestion from water sources e.g. spray drift.

A high level of awareness was found among the communities surveyed in terms of pesticide safety, which the authors felt would support the implementation of standards and legislation in the area should these be implemented.

A broad conclusion of this study was that, since it was shown that normal farming practices e.g. irrigation are driving the entry of pesticides into water bodies, the main remedial measure would be to encourage pesticide reduction and Integrated Pest Management. A further conclusion was that in the absence of drinking water standards that included pesticides and their metabolites, the assumption that South African waters were adequately protected could be false.

3.4 THEME 4: MICROBIAL AND VIRAL WATER-RELATED DISEASES

3.4.1 DWA Guidelines on Water-related Microbial Disease

The DWA and the Water Research Commission (WRC) published guidelines on the management of water-related microbial diseases (Kühn ***et al***, 2003).

These guidelines explained that water-related diseases may be spread by bacteria, viruses and parasites, many of which may be washed into water resources during storm events. The faecal matter of humans and animals was highlighted as a particular source of pathogens. The use of indicator organisms as a means of determining if faecal pollution had occurred was explained, specifically the point that these organisms, which may not be harmful themselves, were used to indicate the potential presence of other more harmful pathogens. The guidelines highlighted that children, the elderly and immuno-compromised individuals were most vulnerable to water-borne diseases, with the latter specifically prone to potentially life-threatening cryptosporidiosis, gastroenteritis and giardiasis.

The guidelines explicitly stated that wholesome water was not necessarily free of microbes, but should contain no ***disease-causing*** micro-organisms. The following measures were proposed to ensure safe drinking water:

- Proper treatment and disposal of human, animal and plant wastes;
- Monitoring of drinking water supplies for indicator bacteria;
- Disinfection of drinking water supplies prior to distribution to the consumer and;
- Prevention of contamination of drinking water prior to use.

The guidelines stressed that water that was not tested for microbial safety should not be assumed safe. The common symptoms of microbial water-related diseases were outlined as being abdominal pain and cramps, diarrhoea (called dysentery if accompanied by blood and mucus in the stools) and circulatory shock should fluids be lost faster than they can be replaced.

The guidelines explained that water-related diseases may be characterised based on their modes of transmission as follows:

- Water-washed (water scarce) diseases, which thrive in conditions of ineffective sanitation and poor personal hygiene;
- Waterborne diseases, which are transmitted through drinking water;

- Water-based diseases which are transmitted by direct contact with water e.g. through recreational swimming and;
- Water-vectored diseases, which are transmitted by an arthropod vector, such as a mosquito, which needs water or moisture in order to breed.

The authors noted that there were literally thousands of water-related diseases, and that only a few were discussed in the guide. While the criteria used for the selection of which specific diseases were to be included in the guide were not made clear, it is assumed that these are diseases most common to the South African water environment. Important water-related diseases are described in Table 10 below, as adapted from the text.

Table 10: Overview of Important Water-related Diseases in South Africa

DISEASE	TRANSMISSION ROUTE	RESPONSIBLE ORGANISM	SYMPTOMS/COMPLICATIONS	PREVENTION/MANAGEMENT OPTIONS
Amoebic Dysentery	Water-washed	***Entamoeba histolytica***, a parasite	Bloody diarrhoea; tenderness in abdomen; nausea and weight loss. Can result in intestinal perforation; spread to other organs.	Hygiene and sanitation, clean drinking water
Bilharzia	Water-based and can be waterborne	***Schistosoma haematobium*** and ***Schistosoma mansoni***, which are parasitic flatworms	Weakness and fatigue; bloody urine in case of heavy infestation.	Avoid water contaminated with untreated sewage
Campylobacteriosis	Water-washed and waterborne	***Campylobacter jejuni***, a bacterium	Slight to severe diarrhoea, which can be bloody; abdominal cramps and fever.	Hygiene and sanitation, clean drinking water
Cholera	Water-washed and waterborne	***Vibrio cholerae***, a bacterium	Sudden diarrhoea; vomiting; massive loss of body fluids. Can lead to death within 6 hours if untreated.	Hygiene and sanitation, clean drinking water
Cryptosporidiosis	Water-washed and waterborne	***Cryptosporidium parvum***, a parasite	Watery diarrhoea and stomach pains; sometimes accompanied by vomiting and fever. Disease life threatening in those with HIV, but healthy persons recover in 1-2 weeks without treatment.	Hygiene and sanitation, clean drinking water. The parasite is generally not destroyed through chlorination, bleach treatment – boiling preferred
Gastroenteritis	Water-washed and waterborne	Wide variety of bacteria (e.g. ***E. Coli O157, Salmonella enteritis***) and viruses e.g. adenoviruses	Sudden vomiting, diarrhoea, moderate fever, stomach cramps. Life threatening to infants, the elderly and those in advanced stages of HIV infection.	Hygiene and sanitation, clean drinking water
Giardiasis	Water-washed and waterborne	***Giardia lamblia***, a parasite	Mild diarrhoeal disease; flatulence; bloating; stomach cramps. Lasts from a few days to a week typically, if longer then accompanied by weight loss.	Hygiene and sanitation, clean drinking water

Table 10 (continued): Overview of Important Water-related Diseases in South Africa

DISEASE	TRANSMISSION ROUTE	RESPONSIBLE ORGANISM	SYMPTOMS/COMPLICATIONS	PREVENTION/MANAGEMENT OPTIONS
Hepatitis A and E	Water-washed and waterborne	Hepatitis A and E viruses	Inflammation of the liver, with fatigue; loss of appetite; tender liver; jaundice; diarrhoea (sometimes), chalk-white stools.	Hygiene and sanitation, clean drinking water
Leptospirosis (Weil's Disease)	Water-based, occasionally waterborne – infection via contact with the urine of the affected animal	One or more of over 200 serotypes of the spirochaete (spiral-shaped bacteria), ***Leptospira interrogans***	Flu-like symptoms, fever, muscle aches and fatigue. In severe form, jaundice, kidney and liver failure and haemorrhagic symptoms.	Rodent control, avoidance of contact with contaminated water and sewerage
Malaria	Water-vectored	One of four types of Plasmodium, being ***P.falciparum, P.vivax, P.ovale*** and ***P.malariae.***	Intermittent headaches; aching joints; fever; sweating; cold shivers. Falciparum malaria can spread to the brain, resulting in coma and death.	Insecticides, repellents, bed-nets, prophylactic medication, drainage of puddles and stagnant waters
Poliomyelitis ("Polio")	Water-washed and waterborne, also spread by close person-to-person contact	Polio virus	Begins with flu-like symptoms, followed by stiffness in the back and neck. Damage to motor nerves leading to acute flaccid paralysis in extreme cases.	Hygiene and sanitation, clean drinking water.
Shigellosis (Shigella Dysentery)	Water-washed and waterborne	***Shigella dysenteriae*** and other ***Shigella*** species, which are bacteria	Sudden abdominal pain, cramps and diarrhoea, often with mucus and blood in the stools. Can lead to kidney failure if untreated.	Hygiene and sanitation, clean drinking water
Swimmer's itch	Water-based	Free swimming stages of blood flukes (parasitic flatworms). Only some people are allergic.	Irritating dermatitis in those allergic to the flukes.	Avoid skin contact with contaminated water, shower immediately after swimming, use of drying agents e.g. rubbing alcohol

Table 10 (continued): Overview of Important Water-related Diseases in South Africa

DISEASE	TRANSMISSION ROUTE	RESPONSIBLE ORGANISM	SYMPTOMS/COMPLICATIONS	PREVENTION/MANAGEMENT OPTIONS
Trachoma	Water-washed	***Chlamydia trachomatis***, a micro-organism	Sore, watering, red eyes. Leads to blindness in later years if untreated. Most common cause of blindness in the developing world.	Clean water required for personal hygiene, especially hand and face washing, fly control
Typhoid Fever	Water-washed and may also be waterborne	***Salmonella typhi***, a bacterium	Headache; fever; abdominal pain, with later development of bronchitis. Can lead to death from intestinal perforation or haemorrhage if left untreated.	Hygiene and sanitation, clean drinking water

Source: Adapted from Kühn et al, pp 20 - 49

3.4.2 The Geographic Spread of Water-related Disease in South Africa

Bourne and Coetzee (1996) investigated the spatial distribution of human mortality in South Africa, with the aim of quantifying the proportion of total mortality potentially due to water-related disease. The study used 1990 data. The aims of the study were to produce an atlas of mortality from potentially water-related diseases and to discuss the implications of the observed disease distributions.

The authors used data from the Central Statistical Services (now called Stats SA) and included three broad disease categories, which they defined as follows:

i. Water-borne diseases such as gastroenteritis, dysentery and cholera;
ii. Water-washed diseases (transmitted due to poor hygiene or inadequate amounts of water) such as shigellosis and;
iii. Water-mediated diseases such as malaria.

In total, 28 potentially water-related diseases were included in the study, and these were placed within the context of all other causes of mortality for each magisterial district of South Africa. The “cause of death” convention used was that of the WHO’s International Classification of Diseases (9th revision). The authors noted that there were potential problems with the data used in terms of the accuracy of the causes of death and the completeness of death registration. For example only 55% of African deaths were reported. In addition, the former homelands of Transkei, Ciskei, Venda and Bophuthatswana were not included since these areas were not considered part of South Africa at the time. These significant shortcomings require consideration when interpreting the study. Mortality among children was analysed separately on the basis that they were, according to the Reconstruction and Development Programme (RDP) of the time, to receive free health care.

The spatial distribution of water-related disease as a percentage of total mortality for each province is outlined in Table 11 on the next page. Three age categories were considered, “all ages”, which is a reflection of the total population, “0-5”, which considers all children up to 5 years old and “1-5” which excludes infants from this group.

Table 11: Spatial Distribution of Water-related Disease Mortality Relative to Total Mortality in South Africa

AGE GROUP	DISEASE	SOUTH AFRICA	WESTERN CAPE	NORTHERN CAPE	NORTHWEST PROVINCE	GAUTENG	FREE STATE	EASTERN CAPE	KWAZULU-NATAL	MPUMAL ANGA	NORTHERN PROVINCE
All ages	**Intestinal Infections**	2.87 %	1.77 %	6.00 %	6.10 %	1.28 %	8.02 %	3.51 %	2.10 %	3.29 %	1.22 %
	Viral Hepatitis	0.09 %	0.05 %	0.14 %	0.22 %	0.08 %	0.09 %	0.13 %	0.10 %	0.08 %	0.08 %
	Malaria	0.03 %	0.00 %	0.00 %	0.01 %	0.02 %	0.00 %	0.00 %	0.03 %	0.15 %	0.15 %
0-5 Years	**Intestinal Infections**	16.85 %	13.15 %	26.98 %	26.45 %	7.89 %	31.73 %	18.14 %	12.15 %	18.42 %	7.96 %
	Viral Hepatitis	0.10 %	0.07 %	0.25 %	0.07 %	0.09 %	0.03 %	0.25 %	0.09 %	0.09 %	0.00 %
	Malaria	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.12 %
1-5 Years	**Intestinal Infections**	19.41 %	12.57 %	33.23 %	29.35 %	9.37 %	38.45 %	21.56 %	13.29 %	18.90 %	7.43 %
	Viral Hepatitis	0.30 %	0.19 %	0.32 %	0.26 %	0.36 %	0.16 %	0.67 %	0.32 %	0.30 %	0.00 %
	Malaria	0.02 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.34 %

Source: Adapted from Bourne and Coetzee (1993) pp 17-47

The authors concluded that the proportion of deaths due to intestinal infections, comprising primarily ill-defined intestinal infections, was extremely high and cause for concern. This referred to deaths resulting from diarrhoeal diseases, which could be due to a number of different water-related infections. The authors noted that in many parts of the country, specifically in more rural areas, this was the first or second-ranked cause of death. While for the total population, 2.87% of all deaths was due to this cause, in the age group 0-5 years, it accounted for 16.85% of all deaths and in the group 1-5 years, for 19.41% of all deaths.

The study found that viral hepatitis caused deaths in the metropolitan areas, and in two broad bands, one running through the north west of the country and another along the eastern seaboard. The authors were unable to explain why this was so.

Malaria was restricted to the north east of the country, with a few isolated cases in Gauteng due to the movement of infected people.

The authors noted that the primary mode of transmission for intestinal infections was via the faecal - oral route. The authors ascribed the root cause of these diseases to a lack of adequate water and sanitation facilities. While not explicitly mentioned, an obvious further reason for the young being so heavily affected would be the fact that their immune systems would naturally be weaker than those of adults.

3.4.3 Sources, Survival and Transport of Water-borne Pathogens

Said ***et al*** (2005) investigated the prevalence of pathogens in surface waters in South Africa, noting that communities who used polluted surface water resources for drinking water, irrigation or recreation faced serious health and economic consequences. The authors cited human and animal wastes as the most common source of pathogenic contamination of surface water resources. The authors asserted that a successful catchment management approach to microbial pollution required an understanding of the origin, fate, survival and transport of the pathogens introduced into water bodies. In support of this broad objective, the authors investigated the possible sources, survival and clinical relevance of selected water-borne pathogens in a rural and peri-urban area, and the environmental and social determinants contributing to the transmission of water-borne diseases.

The project focused on ***Cryptosporidium parvum***, a protozoan parasite, and two bacterial pathogens ***Salmonella enterica*** and ***Vibrio cholerae***. The authors recorded the following reasons for selection of these specific organisms for the study:

i. ***Cryptosporidium parvum*** is endemic to South Africa and represents parasitic organisms that can only grow and multiply within an animal host and not within water, though they are transmitted by water. The authors noted that oocysts, which are the spore phase, could however survive for long periods in the environment and that whereas the diarrhoea caused by Cryptosporidium is self-limited in healthy individuals, AIDS patients and malnourished children generally experienced a life-threatening condition.
ii. ***Salmonella enteria*** subsp ***enterica*** is a major food and water-borne bacterial pathogen, and as a zoonotic bacterium, has a wide host range. As an organism that is equipped to survive in non-host environments, it occurs in both water and sediment. The authors noted that ***Salmonella*** was a major cause of gastroenteritis in humans.
iii. ***Vibrio cholerae*** bacteria are environmental bacterial pathogens, which spend a substantial part of their lifecycle outside human hosts, but when introduced to humans cause disease with measurable frequency. Oral ingestion of food or water contaminated with ***V. cholerae*** leads to the highly contagious disease, cholera.

The researchers determined the predominant genotype of ***Cryptosporidium parvum*** isolates obtained from patients in the larger Pretoria area through distinguishing between ***C. parvum*** genotypes in 50 samples. Oocysts were recovered from faecal samples and the ***Cryptosporidium*** oocyst wall protein was analysed using Polymerase Chain Reaction – Restriction Fragment Length Polymorphism (PCR-RFLP) analysis. Overall, genotype 1 (the human exclusive type) was detected in 40 samples, with genotype 2 (the type with the broad host range) found in the remaining 10. The authors concluded that the high incidence of genotype 1 implied that direct and indirect human transmission played a dominant role in the epidemiology of the disease caused by the parasite in the study area.

One hundred and nineteen faecal samples were collected from calves between 2 days and 8 weeks old in the Pretoria area to ascertain the prevalence of ***Cryptosporidium*** among them, an indication of prevalence in domesticated animals. In addition, 77 samples were collected from herbivores, carnivores, primates and birds at the National Zoological Gardens in Pretoria. Oocysts were present in the faeces of the calves, with the highest prevalence among animals between 1 and 2 weeks old. Shedding of oocysts was found to be seasonal, with the highest rate of shedding observed between December and February. Overall, 18.4% of the calves were found to be shedding ***Cryptosporidium*** oocysts. Of the shedding calves, 17 were diarrheic and five had asymptomatic infection. Infection rates among the calves was found to be comparable to levels reported for other countries, but the authors nevertheless stressed the importance of good management and hygiene practices to prevent spread of ***Cryptosporidium*** to other animals and aquatic environments. ***Cryptosporidium*** was not detected in any of the samples obtained from the National Zoological Gardens.

The ***Salmonella*** study was carried out in rural communities in the Vhembe region of the Limpopo Province in South Africa. During 2001 and 2003, water and sediment samples were collected over a wide area in the Vhembe region and stool specimens were obtained from the Elim and Siloam Hospitals. Food samples were also collected from various food vendors near these hospitals. The isolation of ***Salmonella*** spp was carried out on all of these samples using standard culture method, inoculating a growth medium and incubating at 37 degrees Celsius. Selective enrichment was carried out with subsequent sub-culturing of presumptive ***Salmonella*** colonies. Biochemical tests were carried out on presumptive isolates including gram staining, hydrogen sulphide production, urea hydrolysis and motility tests. Further biochemical tests were used to separate the isolates into human and environmental strains and the human-associated ***Salmonella*** isolates were confirmed using PCR. The antibiotic susceptibility of ***Salmonella*** isolates was tested using a range of commercially available antibiotics.

Of the 897 water, sediment, food and clinical samples tested, 57% (514) tested positive for the prevalence of presumptive ***Salmonella*** species using biochemical tests. Twenty five percent (133) of these samples were found to contain the human subspecies of ***Salmonella***, with 35% (46) of these samples belonging to the ***Salmonella Typhimurium*** strain and the balance being other strains.

While some resistance to antibiotics was found, resistance patterns were not indicated in human-associated ***Salmonella*** from food isolates, and human-related clinical, food, water and sediment isolates were found to be susceptible to ofloxacin and ciprofloxacin. It was noted by the authors that these are the drugs of choice for extra-intestinal and serious intestinal complications caused by human ***Salmonella***.

3.4.4 ***Salmonella*** Survival in River Sediments

The factors that influence the survival of ***Salmonella*** in fresh water sediments were investigated by Said ***et al*** (2005). Sediments were sampled from rivers in the Gauteng, Limpopo and Free State regions and presumptive ***Salmonella*** isolates were chosen for further survival testing under sterile and non-sterile conditions, conditions of varying pH and temperature and conditions of varying nutrient levels in non-sterile sediments. It was found that ***Salmonella*** could survive in sterile sediment for longer than 20 weeks, and in non-sterile sediment (where the natural microbial population was still present) for up to 8 weeks. Tests at pH levels of 5.5, 7 and 8.5 at 22 degrees Celsius had no impact on survival rates. It was shown that ***Salmonella*** can survive for extended periods in sediment at typical environmental temperatures and that the presence of additional nutrients made no significant difference to survival rates. The authors concluded that the long survival periods of ***Salmonella*** in sediments implied that the bacteria could be released into the water column during rain events or other disturbances of the sediment.

3.4.5 ***Vibrio Cholerae*** Population Dynamics in the Vaal Barrage

The population dynamics of ***Vibrio Cholerae*** in the Vaal Barrage catchment was investigated by Said ***et al*** (2005). In particular, the genetic diversity of the population was investigated, as this was felt by the authors to provide possible insights into the spread of the disease as well as possible novel epidemic strains. Environmental ***Vibrio cholerae*** isolates were obtained from Rand water, comprising strains isolated over a two-year period from 15 different sampling sites in the Vaal Barrage catchment. An enterotoxigenic strain (NTC5941) was obtained from the National Collection of Type Cultures, Public Health Laboratory Services, London. Three other ***Vibrio cholerae*** O1 clinical strains were obtained from the National Health Laboratory Services in Johannesburg. These were isolated from cholera cases in the Kwazulu-Natal and Nelspruit regions.

The ***Vibrio cholerae*** were grown on nutrient agar and sub-cultured on a fortnightly basis. DNA was extracted and a PCR technique was used to amplify DNA fragments. Polyacrylamide gel electrophoresis was used to fingerprint the different ***V.cholerae*** strains.

It was found that many of the Vaal Barrage clusters (clusters are strains with similar genetic profiles) were only distantly related to other ***Vibrio cholerae*** clusters found in the Vaal River system, indicating well established, diverse populations. Isolates from specific sampling sites were also rarely found to group closely together except where samples were taken within only a few months of each other. It was concluded that the Vaal Barrage population was made up of highly diverse clones that constantly competed, resulting in genetic shifts only perceivable within short time frames and in localised regions. The authors felt that this may have indicated high genetic flexibility of environmental ***Vibrio cholerae*** strains, and that these environmental populations could act as reservoirs for future epidemic strains. Of the clinical strains supplied by the Department of Health Laboratory, the strains from Nelspruit and Kwazulu-Natal were very similar. The NTC 5941 strain was also clustered with these clinical strains. The inclusion of an environmental isolate in the same cluster as these clinical isolates suggested to the authors that there could be relatedness between some of the enterotoxin-producing strains and environmental non-O1 and non-O139 strains.

3.4.6 Factors impacting the spread of Cholera in Kwazulu-Natal

Said ***et al*** noted that factors such as climate, geographic location, socio-economic status and the environment play a role in the dynamics of cholera. They hypothesised that climatic conditions played a significant role in the spread of cholera in Kwazulu-Natal, along with socio-economic variables. They therefore investigated how factors such as sanitation, water supply and population density, among others, exposed communities to the risk of cholera. The 2000-2004 cholera epidemic in KZN was used as a test case for the study. In particular, the KZN Cholera Dataset, compiled by the KZN Provincial Department of Health was used, along with demographic, socio-economic, geographical and climatic parameters.

It was found that the most affected areas were rural, made up of 20-60% traditional houses. The affected areas were found to have relatively high population densities of 17-99 persons/km^2. The most affected magisterial districts individually accommodated 2-3% of the provincial population, roughly 85% of whom had no form of income. The majority of the population (up to 55%) in the affected areas sourced their drinking water from rivers. Sanitation levels in the affected areas were low, with more than half of the population in some magisterial districts using pit latrines. It was also found that up to 41% of households in the affected magisterial districts did not have access to refuse services. The authors noted further that the province had the highest HIV infection rate in the country at the time of the study, which would have exacerbated the impacts of the shortage of services. In terms of climatic variables, it was noted that both the major and minor peaks in the KZN epidemic occurred just after the peak rainfall months. The initial cases of the disease and the highest number of cases coincided with the areas where there was relatively higher rainfall, high humidity and high maximum temperatures.

3.4.7 Emerging Water-related Pathogenic Threats

Venter (2003) reviewed the occurrence of emerging pathogenic threats in source and treated water in South Africa. The author noted that water-borne diseases were particularly serious because they could place an entire community at risk. It was further explained that in South Africa, less than half of the cases of gastroenteritis diagnosed can be attributed to a specific micro-organism, toxin or chemical (Schaefer, 1997). It was therefore believed that a substantial number of unattributable cases could be linked to emerging infectious disease.

The study was conducted in the Western Cape, Gauteng, Kwa-Zulu Natal and Free State areas. Emerging diseases in the context of this study were defined as diseases of infectious origin whose incidence had increased over the last two decades, or which threatened to increase in incidence in the future. Infections by bacteria such as ***E coli*** O157:H7, ***Vibrio Cholerae*** O139 and ***Bartonella*** would fall into this category, according to the author. The aims of the project were as follows:

i. To select specific examples of emerging viral, bacterial and parasitic pathogens;

ii. To establish techniques for their detection in water and;

iii. To monitor a number of source and treated water samples from different localities in South Africa for their presence.

The following emerging pathogens were proposed for this study:

- Astro and Hepatitis E virus – these were selected because the Dept. of Medical Virology at the University of Pretoria had done some preliminary work on detection methods. Astroviruses were associated with gastroenteritis in humans, while the Hepatitis E virus (HEV) was known to cause faecal-orally transmitted acute hepatitis;

- ***Campylobacter*** spp - ***Campylobacter enteritis*** is one of the major bacterial diseases transmitted by water in the developed world. The bacterium was known to be responsible for gastroenteritis;
- ***Helicobacter*** pylori – the mode of transmission was suspected to be via the faecal-oral route and;
- ***Cyclospora cayetanensis*** - it was decided to include a spore-forming parasite in the study since some of these were known to have the ability to survive a number of the common disinfection processes used for drinking water treatment. However, since propagation of ***Cyclospora cayetanensis*** was impossible at the time of the study, and finding positive stool samples would have been difficult, it was decided to focus on microsporidia.

Samples were taken from surface waters, groundwater, drinking water, wastewater and treated wastewater in the provinces earmarked for the study and sent to the Department of Medical Virology, University of Pretoria, for astroviral analysis. Samples were taken over 3 periods, March–May, July-August and October-November. Astroviruses were detected in a limited number of samples (1 surface water sample each in the Western Cape, Gauteng and the Free State and 1 wastewater sample in Kwazulu-Natal), and only during the late winter (July-August) sampling period.

Sera were collected from swine from a wide variety of areas in South Africa and analysed for anti-HEV. Using enzyme-linked immunosorbent assay (ELISA) tests, roughly 10% of the 142 samples tested positive. Further samples were gathered and tested, and overall 11.3% of the 124 samples for the Gauteng, Northern Province and Mpumalanga provinces (the focal point of the study) tested positive for anti-HEV. It was concluded that the Hepatitis E virus is endemic in the swine populations of South Africa. The author thought that this could have represented a possible animal reservoir of HEV in South Africa. Tests for detection of the virus in environmental, sewage and drinking water supplies were still being developed at the time of the study, and hence no results were available from these sources.

Various methods were assessed for the detection of ***Campylobacter*** in environmental samples. Ultimately, the author was unsuccessful in isolating ***Campylobacter*** from any of the samples taken. It was unclear as to whether this was a result of problems with the analytical procedures used or whether environmental conditions in South African water bodies were unfavourable for growth of this bacteria. The author suggested that no routine testing for ***Campylobacter*** be done, but that a proper molecular method for identifying all ***Campylobacter*** and ***Arcobacter*** species from environmental waters is developed. Identified species could then be compared with those isolated from persons suffering with illness associated with these organisms.

H.pylori was not detected in the waters sampled, though their presence was not ruled out due to shortcomings in the detection techniques available at the time of the study. None of the samples tested positive for Microsporidia.

Overall, this study showed that a great need exists for reliable and effective methods for the detection of emerging pathogens in water. In all cases however, where emerging pathogens were detected, faecal coliform data already indicated serious water problems. The author asserted that on this basis, current water quality guidelines and management procedures based on normal microbial water quality indicators should provide the necessary protection against emerging pathogens. There are however researchers who do not agree with this philosophy, one group being that of Du Preez ***et al*** below.

3.4.8 Development of Rapid Microbiological Detection and Identification Techniques

Du Preez ***et al*** (2001) conducted a study, part of which employed Polymerase Chain Reaction (PCR) technology, to:

i. Apply and optimise rapid techniques for detection of pathogenic ***Vibrio cholerae, Shigella*** spp and ***Salmonella*** spp in water;
ii. Evaluate the sensitivity of the technology for detection of enteropathogens in environmental samples and;
iii. Determine the epidemic risks associated with levels of these pathogens in water.

The authors noted that the presence of indicator organisms such as coliforms and faecal coliforms was assumed to correlate with the presence of pathogens, but that there may be cases where the indicator organisms are absent and yet pathogens may still occur. They noted further that biochemical tests lack specificity and sensitivity, and that rapid tests already developed at the time of the study were designed for analysis of clinical samples with high concentrations of pathogens. They were therefore unsuitable for environmental water sample analysis.

The authors applied the polymerase chain reaction method to the detection of ***Vibrio cholerae, Shigella*** spp and ***Salmonella*** spp in environmental water samples. To enhance the detection limit of the PCR technology, an enrichment and incubation step was included prior to PCR. A selective broth was used to overcome difficulties with growth of ***Vibrio cholerae*** and ***Shigella*** spp in environmental samples containing high concentrations of interfering bacteria. The enrichment step was found to improve both the detection limit and specificity of the technique, enabling detection of as few as 20 CFU/ml from environmental water samples. Analysis of an environmental sample using the PCR (including a hemi-nested PCR for confirmation) was achieved within 10 hours, as compared to conventional methods, which could have taken up to seven days at the time of the study.

Potential health risks associated with various levels of the pathogenic microorganisms studied were calculated. The researchers used a number of assumptions in quantifying this risk, and considered that in South Africa, many people used water directly from rivers for domestic purposes and recreation. Exposure could therefore be through drinking or accidental ingestion. A beta probability model was used to calculate the probability of infection daily and annually. The authors used the US EPA standard of one infection/10,000 individuals/year, and concluded that ingestion of a single organism (regardless of whether it was ***Salmonella, Shigella*** or ***Vibrio cholerae***) would result in a risk of infection that exceeded that risk standard. It was hence concluded that a potential health risk existed for all of these pathogens.

3.4.9 Occurrence of Pathogenic Organisms in South African Water Sources

Grabow ***et al*** (2003) investigated the incidence of ***Escherichia coli*** O157:H7 and other pathogenic strains of ***E. coli*** in water sources in South Africa. The authors noted that while ***E.coli*** are commonly found in the gastrointestinal tract of humans and are not generally associated with adverse health effects, wild type ***E.coli*** was known to cause serious health problems if it ended up in other parts of the body e.g. the urinary tract. It was further noted that normally harmless bacteria could be turned into pathogens when genes that code for virulence factors are integrated into the host genome, which was thought to occur when ***E.coli*** bacteria are themselves infected by phages. ***E.coli*** O157:H7 was thought to have been infected by phages transmitting genetic elements from ***Shigella dysenteriae***, given that the clinical symptoms of infection with this ***E. coli*** strain were similar to those caused by infection with ***Shigella dysenteriae***. The health impacts of infection were described as a bloody diarrhoeal syndrome / severe dysentery, and an example was cited by the authors of a waterborne outbreak in Walkerton, Canada, which led to 6 fatalities and over 2,000 cases of severe illness.

The authors noted that the incidence of waterborne outbreaks of diseases associated with pathogenic strains of ***E. coli*** was on the increase internationally and that domestic animals, notably cattle and pigs, served as reservoirs for the pathogens. Infected individuals were reported to excrete large quantities of the organisms, supporting concerns for potential waterborne transmission of pathogens such as ***E.coli*** O157:H7. Pathogenic ***E coli*** strains were cited as the cause of a number of diseases in humans such as diarrhoea, dysentery, renal infections, septicaemia, pneumonia and meningitis. The authors noted that no meaningful information was available on the incidence of pathogenic ***E.coli*** in wastewaters and water resources in SA at the time of the study.

The aims of the study were to:

i. Screen selected sewage and river water samples for ***E.coli*** pathogens using established methods;
ii. Optimise and establish practical molecular techniques for detection and typing of ***E.coli*** pathogens;
iii. Develop a new procedure for the isolation of ***E.coli*** O157:H7 from water and;
iv. Use this new more sensitive procedure to study the occurrence of ***E.coli*** O157:H7 in sewage and river water.

The East Rand Water Board provided raw sewage samples, and surface water samples were collected from various sites in the Vaal Barrage. ***E.coli*** O157:H7 was isolated using specific growth media, and through screening of morphological characteristics. Presumptive colonies were then confirmed using PCR and gel electrophoresis i.e. using genetic identification techniques. These procedures failed to detect ***E.coli*** O157:H7 among 1363 colonies isolated form 204 samples taken at 15 different sites in the Vaal Barrage drainage basin. The authors postulated that the screening technique, which used rainbow agar, might not have been selective enough. A high incidence (74%) of other pathogenic strains (carrying one or more of six virulence factors) of ***E.coli*** was determined.

In order to improve the isolation procedure, seeded samples of sewage, river water, ground beef and milk were used. Aliquots of pre-enriched samples were mixed with Dynabead suspension. O157-specific antibodies were used to capture ***E.coli*** O157:H7 bacteria and bind them to the beads, with the bead-bacteria complexes separated by a magnetic particle separator. Bead concentrates were then transferred to O157-selective media, after which genetic testing (PCR and electrophoresis) was used to confirm the bacteria. This was found to increase the sensitivity of the test substantially, and this new test was hence applied to environmental river water and sewage samples. The authors used settled sewage from the Daspoort, Zeekoegat and Baviaanspoort sewage treatment plants and river water samples from the Levuvhu, Pienaars and Apies Rivers. Sixteen presumptive ***E.coli*** O157H:7 isolates were identified, of which one was confirmed as being ***E. coli*** O157:H7. This was an improvement on the traditional plating test, but still highlighted to the authors that the screening techniques for ***E.coli*** O157:H7 require further development.

The project confirmed for the first time in SA the presence of a variety of ***E.coli*** pathogens in sewage-contaminated river water and ***E.coli*** O157:H7 in sewage. The incidence of ***E.coli*** O157:H7 was found to be low and not to constitute a meaningful risk to recreational and domestic consumers. The study showed that 74% of ***E.coli*** bacteria in water of the Vaal River Barrage drainage basin carried one or more toxicity factors, which was cause for concern. The extent of the risk could not be determined from this study, but the authors asserted that these bacteria were known to cause gastrointestinal disease in humans. The authors highlighted the fact that immuno-compromised individuals may be at risk. The authors concluded, on considering the costs involved, that the confirmation and typing of all ***E coli*** pathogens is expensive and not feasible for all laboratories engaged in routine water quality analysis.

3.5 THEME 5: MULTI-DIMENSIONAL WATER QUALITY PROBLEMS

This section of the report deals with water resource quality problems of a diverse nature that cannot easily be categorised within a single theme. Such problems are characterised by the involvement of a number of different contaminants and/or modes of pollutant transport, and are accompanied by a wide range of impacts.

3.5.1 A Note Concerning Point and Non-point Sources

It is opportune at this time to outline the two primary types of pollution, as categorised by the nature of their origin, these being point source and non-point source pollution. Point sources are sources of pollution that are discrete and easily identifiable. An example would be effluent that is discharged into a river through a pipe. The pipe outlet would be easily identifiable as the source of the pollution. Non-point-sources of pollution are not discrete, but diffuse. They arise from causes such as poor land use practices, or aerial deposition of pollutants. Since they are not discrete, the management of non-point sources requires a very different approach to point sources, since the causes and responsibility for the pollution may not be readily apparent.

3.5.2 Guide to Non-point Source Assessment

Pegram and Görgens (2001) developed a guide for the assessment of the impacts of non-point sources of pollution on surface waters in South Africa in support of surface water quality management. The authors defined non-point sources as “land use areas and activities that result in the mobilisation and discharge of pollution in any manner other than through a discrete or discernable conveyance”. Two main types of assessment were described, namely catchment-based assessment and source-area based assessment. Catchment-based assessment was described as being useful in the development of catchment management strategy, while area-based assessment was said to have utility for statutory non-point source control or local investigation of a particular non-point source.

The authors highlighted that non-point source pollution generally resulted from:

i. land runoff;
ii. precipitation;

iii. atmospheric deposition;
iv. drainage;
v. interflow;
vi. seepage;
vii. groundwater flow or;
viii. river course modification.

A conceptual framework describing non-point source pollution was proposed, comprising ***production*** of pollutants, ***delivery*** from the source to the surface water environment, ***transport*** through the surface water environment and ***use*** of the water. The authors outlined that non-point source assessment comprised consideration of three components, namely management goals, water quality concerns and the source area character.

Resource quality in the context of the guideline discussed here was defined in terms of four major dimensions:

- The quantity, pattern, timing, water level and assurance of instream flow;
- The physical, chemical and biological water quality characteristics;
- The character and condition of the instream and riparian habitat and;
- The characteristics, condition and distribution of aquatic biota

The authors defined “water quality” in terms of how well the physical, chemical and biological characteristics of water match the requirements for functioning of the aquatic environment and human uses and a “water quality concern” as relating to existing, threatened or perceived poor water quality.

The key water quality parameters of interest were outlined as being streamflow, sediment, nutrients, pathogens, salinity, heavy metals, toxic organics, hydrocarbons, litter/solid waste and organic matter. In terms of physical properties, temperature, appearance, odour and colour were highlighted.

It was noted that water quality effects may be localised or regional, and of a transient nature or cumulative i.e. related to long-term loads. These characteristics were cited as being of relevance to the nature of the assessment required.

Methods were outlined for the identification of water quality concerns as follows:

- Consultation with the inhabitants of a catchment;
- Screening for the effects of water quality problems using field surveys and data e.g. clinical data used to assess impacts on human health;
- Use of water quality indicators (physical, chemical, biological or ecological data) and;
- Survey of source areas for "tell-tale" signs such as erosion gullies, salinisation of irrigated fields etc.

The authors noted that the water quality impacts from non-point sources were related to climate, natural features and human activities on any land area, and that these factors work together in producing and delivering contaminants from that area to receiving waters.

The report concluded with a guide for conducting non-point source assessment and a detailed review of non-point source assessment techniques.

3.5.3 Terms of Reference for Non-point Source Management

Pegram, Görgens and Quibell (1999) outlined terms of reference for the development of strategies, procedures and guidelines to implement non-point source management under the National Water Act (Act 36 of 1998). After a review of water quality management history in South Africa, the authors arrived at the following guiding principles for an approach to non-point source management:

- The requirements of the Water Resources Classification system and the "Reserve" should be recognised;
- Special provision should be made for cases where the Resource Quality Objectives are exceeded;
- An administratively and procedurally simple (minimal "red tape") approach should be used in order to make it easy to implement;
- Decision-making should be devolved to the lowest possible level, while maintaining a national approach;
- The distinctive technological and economic characteristics of different source types should be recognised;

- The pollution management hierarchy, and principles of the ISO 14 000 series should be included;
- The need to balance development and protection should be recognised;
- Equity, sustainability and efficiency considerations should be promoted;
- Flexible economic instruments, to support statutory non-point source controls, should be incorporated;
- Opportunities for meaningful public participation should be included and;
- Clear guidelines to promote self-regulation should be provided.

The authors characterised non-point sources by sector, and these are outlined in Table 12.

Table 12: Non-point Sources of Pollution in Various Water Use Sectors

SECTOR	NON-POINT SOURCES / MANAGEMENT FOCUS AREAS
Agriculture	Soil erosion, fertiliser application, pesticide use, irrigation scheduling for salinity management, confined animal facilities.
Forestry	Soil erosion and sedimentation during harvesting period, pesticide use.
Industry	Stormwater washoff of accumulated waste or stockpiled material, atmospheric deposition of air emissions.
Mining	Stormwater washoff of accumulated waste or stockpiled material.
Residential	Depends on the level and operation of municipal services. Stormwater washoff, including during the construction and development phases of these settlements.
Transport	Stormwater washoff, washwater washoff, failure of storage facilities.
Waste Disposal	Stormwater washoff, infiltration into water resources.
Pristine areas (relatively undisturbed)	Negligible non-point source impact.

Adapted from Pegram, Görgens and Quibell (1999) pp 10 -12

The authors outlined the primary management approaches that could be followed, these being:

i. ***Persuasive approaches***, such as legal covenants/contracts between polluters and/or stakeholders, guidelines and voluntary agreements, self-regulation and advocacy, education and awareness creation;
ii. ***Statutory measures***, which comprised the issues of water use authorisation, the promulgation of regulations and the use of directives;
iii. ***Economic instruments,*** which were designed to influence decision-making behaviour through the alteration of costs and/or benefits. These included fees, penalties and pricing, and;
iv. ***Co-operative Governance,*** which entailed the involvement of various organs of state, working in concert to achieve objectives in an integrated manner.

The authors asserted that in general, statutory measures should be used to manage those non-point sources with the greatest risk of causing water-quality problems, with licensing only being required for those sources with the highest management priority. Non-statutory approaches are recommended for non-point sources with less severe impacts, while co-operative governance approaches are recommended by the authors for those non-point sources that were the mandate of authorities other than DWA.

The authors proposed a 3-point framework for statutory non-point source authorisation comprising:

i. Development of management strategies;
ii. Promulgation of sectoral statutory measures for non-point source management and;
iii. Implementation of the statutory measures, including licensing, control and enforcement.

The authors asserted that the National Water Resource Strategy (NWRS) and the Catchment Management Strategies (CMS's) provided the framework for non-point source management in South Africa and its implementation within Water Management Areas (WMA's). The determination of resource quality objectives (RQO's) and the implementation of water resource classification were seen as integral to non-point source management. The authors also noted that Water Services Development Plans (WSDP's) provided a vehicle for the management of the impacts of service provision.

It was proposed that a National Non-point Source Strategy be developed, and that every Catchment Management Strategy contain a non-point source management strategy for the WMA concerned.

3.5.4 The Contribution of Agriculture to Non-point Source Pollution

Cullis, Görgens and Rossouw (2005) conducted a study on sub-catchments in the Breede, Middle Vaal and Mgeni catchments in order to make a first-order estimate of the contribution of agriculture to non-point source pollution in South African Rivers. Areas were selected based on agricultural activity and the location of water quality sampling sites. Mean monthly, seasonal and annual net Agricultural Non-point Source (ANPS) loads were calculated based on observed water quality data. The authors defined the net ANPS load as the load after known non-agricultural non-point sources had been accounted for. Agriculture was broadly defined as irrigated, dry land and subsistence farming, forestry plantations and other unknown pollution sources such as rural settlements, transport infrastructure and activities influencing stream-flow and water quality.

The water quality variables selected for the study were:

- Salinity (measured as TDS);
- Inorganic nitrogen (as the sum of nitrite, nitrate and ammonia) and;
- Inorganic phosphorous (measured as orthophosphate).

Using daily flow and weekly concentration data, the flow weighted mean concentrations were calculated using a programme called FLUX, which fills in missing daily concentration data based on observed daily flows using regression relationships. Monthly pollution loads and flow volumes were then calculated for the period from October 1990 to September 1995.

In order to calculate diffuse background water quality levels, the researchers used observed concentrations at “least impacted” reference sites in each catchment. The reference site with the lowest concentration was used to provide an estimate of the natural monthly background concentration.

Comprehensive data on known point sources were not available for any of the three catchments. Abstractions, imports and exports were assessed from hydrology reports and

Water Resource Situation Assessment reports, with concentrations estimated from observed averages at gauges upstream or downstream of the abstraction, import or export point concerned.

The load due to urban non-point source pollution was estimated using the results of previous studies by other researchers, and modifying these to account for unique characteristics of the catchments studied.

Table 13 outlines the pollution load values used.

Table 13: Urban Non-point Source Pollution Load Values

POLLUTION CONSTITUENT	COMMERCIAL (kg/ha/a)	INDUSTRIAL (kg/ha/a)	RESIDENTIAL (kg/ha/a)
TDS	125	125	185
Total Nitrogen	7.5	7.8	3.9
Ammonia	5.6	5.8	2.9
Nitrate/Nitrite	1.9	2.0	1.0
Orthophosphate	0.28	0.21	0.13

Source: Cullis, Görgens and Rossouw (2005) pp16

Land use and area were obtained from the National Land Cover Database, and used together with the loads in Table 13 to estimate the total urban load. A mass-balance approach was then used to calculate the net ANPS load for salinity, orthophosphate and nitrogen.

A number of cases were found where negative loads were attributed to agriculture, because of over-estimation of point sources, urban NPS loads and background loads. In the case of nitrogen and phosphate, the methodology did not account for natural assimilation of these nutrients, which could explain the negative loads. In the case of negative salinity loads, the researchers attributed these to uncertainty in assumptions and results. It was concluded that the study should be viewed as useful for the assessment of trends rather than for review of absolute pollution loads. The researchers were however able to conclude that agriculture appears to have a major impact on the observed pollution loads in South African rivers.

In the Breede Catchment, it was found that agriculture was responsible for between 60% and 75% of the incremental observed mean annual salinity load in all sub-catchments. The net

ANPS unit area load of between 1,000 kg/ha/a and 1,300 kg/ha/a was described as high, and most likely due to disturbance of underlying shale through agricultural activities. Salinity loads in the Breede catchment appeared to peak with the arrival of first rains and during the months of greatest rainfall.

The net ANPS nitrogen load in the Breede Catchment was found to be significant, particularly in sub-catchments associated with table grapes under irrigation. For example, in the Hex sub-catchment a net ANPS nitrogen load of 7 kg/ha/a was calculated. This nitrogen load was thought to be associated with washoff of nutrients from fertilisers, and peaks during high-rainfall periods in winter.

Phosphate loads due to agriculture were found to be negligible in the Breede catchment. The researchers postulated that this could be due to natural assimilation and the dominance of urban washoff and point sources.

In the Middle Vaal Catchment, the agricultural contribution to salinity was found to be lower than in the Breede Catchment, but still significant in some sub-catchments. The Vet sub-catchment appeared to be most heavily impacted. While this was possible due to extensive irrigation in the area, a more likely reason for this result could have been under-estimation of the contribution of mining activity. As a percentage of total salinity load, agricultural contribution was calculated as being between 60% and 70%, similar to that found in the Breede.

Nutrient loads due to agriculture in the Middle Vaal were found to be insignificant using the mass balance approach.

The Mgeni Catchment was found to be the least impacted by agriculture of the three catchments chosen for the study. The Nagel sub-catchment was found to be the most-impacted by salinity, with an ANPS load of 89 kg/ha/a, thought to be due to the presence of sugarcane and subsistence agriculture. In terms of nutrients, agriculture was found to have more of an impact on nitrogen load in the Mgeni than in the Middle Vaal, but less so than in the Breede. The greatest net ANPS phosphate load of 0.12 kg/ha/a was found in the Nagel sub-catchment, due to the large number of feedlots in the area. ANPS loads were found to peak during the summer months, where rainfall and runoff are at their highest.

3.5.5 The Impact of Small-scale Mining on Water Quality

Small-scale mining activity has the potential to impact on water resource quality. This sector was investigated by Heath, Moffet and Banister (2004). The researchers aimed to compile an inventory of water-related impacts and develop and recommend tools to assist in environmental management for small-scale-miners.

The authors noted that Government aimed to promote small-scale mining activity as a means of creating jobs as well as promoting economic empowerment. The Small-Scale Mining Development Framework, instituted by the Department of Minerals and Energy (DME) in 1999, was cited as a means of enabling small-scale miners and alleviating technical and financial constraints in the sector. Importantly, the authors stressed that through vehicles such as the Regional Regulatory Committee and the National Steering Committee, support was provided in such a way that small-scale miners did not need to compromise environmental, health or safety standards. The authors did however highlight the challenge of attaining a balance between the preservation of high standards of environmental management and the encouragement of economic development. The rehabilitation bond paid by miners prior to the onset of mining was cited as a particular problem, since it was leading to miners abandoning sites without rehabilitating them due to rehabilitation costs being higher than the bond retained by the government.

Determination of the types of mines to be included in the study was carried out through consultation with national representatives of the then Department of Minerals and Energy and the Department of Water Affairs. The mining types selected, their characteristics and the number of operations of each type identified in South Africa are outlined in Table 14. It should be noted that the inventory of small-scale mines is not comprehensive due to a lack of available data.

The authors conducted a literature survey to better identify potential impacts and followed this up with screening site visits, out of which a survey protocol was developed. This protocol was then applied on a number of regional site surveys, which included visual observations, and the review of water quality data. Both legal and illegal mining operations were included in the study.

Table 14: Mining Types Included in a Study of the Water-related Impacts of Small-scale Mining

MINE TYPE	CHARACTERISTICS	TOTAL SA
Diamond diggings	Prospecting and mining of alluvial diamonds	19
Sand winning	All sand-winning operations from a river, dam, stream or pan, upper limit of 600,000 tons of material moved per annum.	380
Coal mining	All non-mechanised coal mining	2
Gold mining/panning	At or near-surface mining only, including prospecting and mining of magmatic reefs and alluvial gold deposits. Processing by means of gravitational and/or mechanical separation and chemical amalgamation using mercury included.	1
Clay mining	All clay mining operations, upper limit of 600,000 tons of material moved per annum.	106

Source: Adapted from Heath, Moffett and Banister (2004) pp 4 and pp 34

The literature survey conducted by the authors identified the following key environmental problems as being associated with international artisanal and small mines:

- Disposal of mercury into the environment;
- Direct dumping of effluents and tailings into rivers;
- Improperly constructed tailings dams;
- Acid mine drainage;
- Improper mine closure;
- River damage in alluvial areas and;
- Sand erosion damage at the edge of highland areas.

In the South African review, it was noted that typically, impacts were limited to the locality of the small-scale mine, with specific concerns being:

- De-vegetation and accelerated erosion of areas adjacent to the workings, leading to increased suspended sediment loads in streams and rivers;
- Instability of riverbanks due to excavation;
- Increased flood-scouring risks due to excavation of flood terraces;
- Oxidising conditions in river sediments due to excavation, leading to solubilisation of metal ions;

- Acid mine drainage, with associated pH reduction, increased metal concentrations, toxic precipitates, increased sediment loads, increased water treatment costs and increased corrosion of water distribution systems;
- Increased mercury toxicity arising from concentration of gold and;
- Wind-blown dusts from unprotected tailings and waste rock dumps entering the aquatic environment.

Regulation of small-scale mining operations was indicated as being difficult to achieve due to the remoteness of small-scale operations and a general lack of capacity. The authors asserted that small-scale miners rarely understood or adhered to standard guidelines or engaged in rehabilitation programmes. The environmental legislation relevant to small-scale mining was highlighted as comprising the National Environmental Management Act of 1998, the Minerals Act of 1991, the EIA guidelines of 1997, the Environment Conservation Act of 1989 and the Aide Memoire requirements of 1992. Water specific legislation was highlighted as being the National Water Act of 1998, and regulations on the use of water for mining and related activities, which were still in draft form at the time of the study. The use of alternative methods of regulating small-scale miners through methods such as incentives, stakeholder engagement and voluntary compliance was highlighted as important, given regulatory challenges.

Screening site-level visits were conducted at alluvial diamond mines north of Kimberley, sand-winning operations north of Pretoria, alluvial gold mining operations near Barberton in Mpumalanga and coal and clay mines in Kwazulu-Natal. The researchers were accompanied by government representatives on the visits. The observed impacts are outlined in Table 15 below.

Table 15: Water-related Impacts Observed During Screening Site Visits to Small-scale Mines

ENVIRONMENTAL IMPACT	ALLUVIAL DIAMONDS	COAL AND CLAY	ALLUVIAL GOLD PANNING	SAND-WINNING
Aesthetics	x	x	x	x
Riparian vegetation loss	x		x	x
Bank destabilisation	x		x	
Chemical contamination		x	x	
Increase in sedimentation	x		x	x
River diversion	x		x	x
Water abstraction	x	x	x	x
River bed and fauna disturbance	x		x	x
Alteration in channel hydraulics	x		x	x
Lowering of floodplain groundwater				x
Disturbance of flood attenuation				x
Ponding in floodplain	x	x	x	x
Loss of river sediments	x			x
Acid mine drainage		x		

Source: Heath, Moffett and Banister (2004) pp 42

Three different regions (the Kimberley area, Kwazulu-Natal and the Krokodilspruit) where small-scale mining was identified as having severe environmental impacts, were selected for regional site surveys, with the aim of objective assessment of the impacts of small-scale mining on water resources. A range of indices were used to assess the state of the local habitats visited, and these were found to range from “poor” to “good” in qualitative terms. Physico-chemical water quality data were measured at all the sites visited, using DWA and Umgeni Water’s monitoring station data. While none of these indicated deterioration due to small-scale mining activity, the authors noted that the sampling stations were not close enough to the mines to be useful for assessing their impact.

The authors noted that impacts were generally long-term, and that while, when viewed singly, may not be significant, when viewed cumulatively, can cause significant deterioration in water resource quality. While impacts were typically localised, the authors concluded that when many mines are concentrated in an area, impacts could be spread over a wide area e.g. large masses of silt that are washed downstream. Table 16 outlines the major water-related impacts observed during the regional site visits.

Table 16: Major Water-related Impacts Observed During Regional Site Visits

ENVIRONMENTAL IMPACT	ALLUVIAL DIAMONDS KIMBERLEY AREA	SAND WINNING KWAZULU NATAL	SAND WINNING KROKODILSPRUIT
Channel hydraulics modification	x	x	x
Bank destabilisation	x	x	x
Bed modification, causing increase in suspended solids	x	x	x
Sedimentation	x	x	x
River diversion	x	x	x
Flow modification	x	x	x
River bed disturbance	x	x	x
Reduction or removal in bank vegetative cover	x	x	x
Islands created in river	x	x	
Lowering of floodplain groundwater	x		x
Disturbance of flood attenuation areas	x		x
Solid waste dumps as no backfilling takes place	x	x	
Ponding in floodplain	x	x	x
Loss of river sediments	x	x	x
Loss of topsoil	x	x	x
Estuarine impacts		x	

Source: Heath, Moffett and Banister (2004) pp 59

Small-scale miners and local communities were interviewed in the Kimberley area and at Wolmaransstad, Cullinan and Durban. The aims of these interviews were to:

i. Determine knowledge of, and attitudes towards, environmental legislation;

ii. Identify opportunities to involve communities in rehabilitation;

iii. Establish training needs;

iv. Gauge levels of understanding of the impact of small-scale mining on the environment.

A structured questionnaire was administered to a total of 32 miners and 39 community members. Key findings related to water resource quality were as follows:

Interviews with Miners revealed that:

- Ownership of land did not promote rehabilitation;
- Miners were largely unaware of environmental legislation and the impact of their operations;
- Dependence on the river as a source of potable water did not influence the level of responsibility with which mining was carried out;
- Miners did not know where to access technical advice and support.

Interviews with local Communities revealed that:

- Communities were largely unaware of environmental legislation, impacts of small-scale mining on the environment and the consequences of not rehabilitating mines;
- There was a correlation between dependence on river water and concern for river water quality;
- Communities believed that training would improve the action taken as concerns rehabilitation.

It was found that particularly in the illegal sector, there was flagrant disregard for environmental management, health and safety and the long-term sustainability of mineral deposits and the land.

3.5.6 Health-related Pollution of the Umtata River

The Umtata River in the Eastern Cape lies in the Mzimvubu to Keiskamma Water Management Area (WMA) and supplies water to the towns of Umtata, Mqanduli, Ngqeleni, Libode and Elliotdale as well as a number of growing informal settlements. Fatoki and Muyima (2003) conducted a situation analysis of health-related water quality problems in the Umtata River. The authors asserted that surface waters were particularly vulnerable to human contamination, and that rapid demographic changes in South Africa at the time of the study, with resultant establishment of human settlements lacking appropriate sanitary infrastructure, was placing increasing pressure on water resource quality. It was further noted that people living in peri-urban settlements close to surface waters often utilised the contaminated water for drinking, recreation and irrigation, increasing the risks to human health (from Verna and Srivatava, 1990).

The aims of the study were to:

i. Identify uses and users of water from the river;
ii. Characterise the chemical and microbial composition of the river water at various sites along its reaches;
iii. Identify major sources of pollution;
iv. Identify options for improving the safety of the river water and;
v. Recommend a design for a water quality monitoring programme to support integrated catchment management in the river catchment.

The researchers used a questionnaire to obtain information on demographics, water sources and uses, the perceived quality of the water and the incidence of water-related diseases. They defined water quality in terms of taste, colour and smell, and the occurrence of diarrhoea was used as an indicator of water-related disease. The questionnaire was aimed at the members of households in the study area, and was administered at six sites, five of which were informal settlements along the riverbanks (Tabase, Kanbi, Pollar Park, Mhlahlane and Tipini) and one of which was the township of Norwood in the town of Umtata.

Physico-chemical (Temperature, pH, TDS, EC, turbidity, nitrate, phosphates, sulphates, total hardness, chloride and heavy metals) and microbiological (faecal and total coliforms) analysis of the river water was carried out on samples acquired from 10 sites, extending from a point near the source of the river until a point downstream of Tipini, the settlement furthest downstream in the study area. One of the sites was at the Umtata Dam, which supplies water to the water purification plant used to supply the town of Umtata. The sites were carefully chosen to ensure that major point and diffuse sources of pollution were captured. Sampling was carried out on a bi-weekly basis over the period of a year (1999-2000) in order to capture all four seasons. In addition to these samples, the researchers obtained tap water samples from three locations in Umtata. Table 17 outlines the sites chosen.

Table 17: Sampling Sites Used for the Umtata River Water Quality Study

SITE	DESCRIPTION
1	Near the river source
2	Downstream of Tabase settlement
3	At Kambi settlement
4	Umtata Dam
5	Downstream of the Dam
6	Downstream of Pollar Park settlement
7	At Norwood Bridge
8	Downstream of Umtata Sewage Works
9	At Tipini settlement
10	Downstream of Tipini settlement

Source: From Fatoki and Muyima (2003), pp 22

As could be expected, most respondents were either primary or secondary users of water from the Umtata River. The proportion of primary users (users who used water directly from the river) as opposed to users who received treated water from the municipality) in the six areas surveyed, the proportion of these users using the water for domestic purposes, user perceptions of water quality and the incidence of diarrhoea are outlined in Table 18 below:

Table 18: Perceptions of Water Quality and Disease Prevalence among Users of Water from the Umtata River in Various Locations

SURVEY SITE	PERCENTAGE OF PRIMARY USERS	PERCENTAGE OF DOMESTIC USERS	PERCEIVED BAD TASTE	PERCEIVED BAD SMELL	PERCEIVED BAD COLOUR	INCIDENCE OF DIARRHOEA
Tabase	100%	100%	55%	23%	72%	99%
Kanbi	64%	97%	0%	0%	0%	31%
Mhlahlane	44%	100%	6%	11%	6%	39%
Pollar Park	72%	100%	22%	56%	81%	100%
Norwood	29%	66%	40%	40%	40%	48%
Tipini	11%	95%	6%	3%	6%	49%

Source: Adapted from Fatoki and Muyima (2003), pp 69

The authors noted a high rate of domestic use of the river water, and that while many of the residents were satisfied with the quality of the water, there was a high incidence of diarrhoea among users. The authors highlighted that many of the respondents were unemployed and from the poor socio-economic group, had not had alternatives for comparison and may have been ignorant of acceptable water quality standards.

Water quality analyses indicated that the river water was turbid, had high nutrient and cadmium levels and was polluted with faecal coliforms. In general, water quality declined as the water moved from the river's upper reaches to its lower reaches. Concentrations of most contaminants were higher during the summer months, indicating that runoff during this period increased pollution levels in the river.

The authors concluded that the high turbidity values (turbidity ranged from 0.28 NTU – 1899 NTU) highlighted the known problem of donga erosion in the catchment.

Faecal and total coliform counts as high as 21,000 counts/100ml and 69,000 counts/100ml respectively were detected, indicating contamination with human and animal wastes. It was noted that in the informal settlements sanitation levels were very poor, which would have contributed to pollution of the river. The authors noted that faecal coliform counts were on average greater than 1000/100 ml in the middle reaches of the river, and greater than 3000/100 ml in the lower reaches of the river. This made the water unsuitable for full contact recreation, certainly unsuitable for direct domestic use and even unsuitable for livestock watering (DWA, 1996f specifies an upper limit of 200 counts/100 ml for this latter purpose).

Nitrate values ranged from 0.01 mg/l to 28 mg/l as N, and phosphates ranged from 0.02 mg/l to 3.81 mg/l as P. Phosphate levels were found to be high immediately downstream of the Umtata Sewage Works discharge, indicating that this was a point source contributor to nutrient levels in the river. The authors pointed out that the WHO and DWA safe limits for nitrate in domestic water were 10 mg/l at the time of the study, and that infants and pregnant mothers would be exposed to the risk of methemoglobinemia if they consumed this river water. Excessive plant growth in the river was ascribed to these high nutrient levels. In addition, the authors expressed concern about the potential for the growth of blue-green algae and the consequent release of cyanotoxins into the water.

In terms of metals, calcium, magnesium and zinc were within acceptable limits, as compared to the DWA standard applied for the study (DWA, 1996b, Quality of Domestic Water Supplies, 1998). Cadmium levels were higher than acceptable values by this standard, and ranged from 0.01 mg/l to 1.0 mg/l. Average lead concentrations ranged from 0.07 mg/l to 1.3 mg/l, far above the DWA standard (DWA, 1996b) which specified a maximum of 0.01 mg/l for lead in drinking water supplies. The authors postulated that the heavy metal contamination was due to diffuse sources, specifically waste dumps along the river banks. Cadmium levels were indicated as possibly causing kidney failure, cancers and mutagenic and teratogenic effects in users. The source of the cadmium was speculated to be either from cadmium-nickel batteries disposed of in waste dumps along the river banks or from phosphate fertilisers, in which cadmium is known to be a common impurity. The authors did not believe the lead contamination found to be of serious concern, which is surprising given the significant variance to the standard applied.

Tap water samples exhibited high turbidity, and total coliform counts exceeded DWA standards (DWA, 1996b, Quality of Domestic Water Supplies, 1998). Results for faecal coliforms and total coliforms are outlined in Table 19 below. All other parameters analysed complied with the standard. The authors concluded that there were deficiencies in the water purification processes employed.

Table 19: Bacterial Counts in Tap Water in Umtata

PARAMETER OF INTEREST	HOLIDAY INN UMTATA	SOUTHERN RIDGE	SHELL ULTRA CITY UMTATA
Faecal coliforms counts/100 ml	0	1	20
Total coliforms counts/100 ml	10	8	2

Source: Fatoki and Muyima (2003), pp 99

The pollution sources in the catchment were identified as:

- Runoff from settlements and agricultural lands;
- Effluent discharge from the Umtata Sewage Works
- Sewage discharge from the sewage ponds near the Umtata Prison
- Domestic sewage discharge from the Langeni Forest Industry and;
- Seepage from waste disposal sites situated near the river banks

These pollution sources were identified based on the status of water quality parameters as measured at the various sampling points used.

3.5.7 Impact of Urban Runoff on Water Quality in the Swartkops Estuary

Lord and Mackay (1993) evaluated the effect of urban runoff on the water quality of the Swartkops Estuary in Port Elizabeth. Uncontrolled informal settlement in and above the floodplain of the Chatty River had led to contamination by sewage at the time of the study, particularly during high-flow conditions. Additional pollution was thought to originate at the Motherwell Township, with transport to the estuary via a stormwater canal. Other known potential urban sources were yet to be investigated at the time of the study.

The aim of the project was to investigate the quantity and quality of urban runoff from Motherwell Township via the stormwater canal that drained into the estuary, and to assess the dispersion and dilution of the runoff once it had entered the estuary. Of concern was the use of the estuary for recreational purposes and the impact that this pollution could potentially have on human health and the aesthetics of the estuary.

Measurements were taken twice-weekly of a number of parameters in the canal, including flow rate, conductivity, temperature and dissolved oxygen content. Samples were collected and sent to the South Africa Bureau of Standards (SABS) lab for analysis. Parameters of interest were:

- Electrical conductivity (EC);
- pH;
- Total Suspended solids (TSS);
- Total Dissolved Solids (TDS);
- Nitrate-N, ammonia-N + Nitrate N;
- Orthophosphate-P;
- Chemical Oxygen Demand (COD) and;
- Oxygen absorption (OA).

Weekly bacteriological analysis was also carried out, comprising tests for faecal coliforms, ***E coli*** and faecal ***streptococci***. Weather conditions were noted, as were qualitative descriptions of water quality in the canal.

Two releases of Rhodamine B dye (mixed with methanol to achieve a density equivalent to that of the estuary water), one on the ebb tide and one on the flood tide, were used to determine the extent of influence of the plume from the Motherwell canal. Aerial photographs were taken of the dispersion pattern after each release, and these were later scaled in the laboratory. In addition, estuary circulation studies were conducted, using depth profiles of salinity and temperature at 11 stations between the mouth and the head of the estuary.

In addition to data acquired directly in the course of the study, the study team evaluated secondary data from various sources. The most significant information obtained from this data was confirmation that soon after Motherwell Township had been developed, a continual flow of polluted water was reaching the Swartkops estuary. This runoff contained faecal bacteria and viruses, and was nutrient-enriched.

Conclusions from data produced during the study were that dry-weather runoff was much more contaminated than wet-weather runoff, containing a greater range of faecal coliform concentrations (albeit having a similar median concentration) and higher OA, COD, ortho-phosphate-P and TDS, as well as higher pH and EC. Flow during dry weather was never zero, and could invariably be traced to blockages of the sewerage system, often due to vandalism. Pollutant loads were increased by refuse and litter dumped into the canal. The problem of dry-weather runoff was ultimately solved through the excavation of a sump below the floor of the canal, which collected the runoff and allowed it to be pumped back to the sewage treatment works. During high-flow conditions, water passed over the top of the sump and into the estuary.

Analysis of the ebb-tide pollution plume showed that after 34 minutes, it reached an area close to the bank where anglers and children paddle. Based on a vertical dispersion depth of 0.5m, it was calculated that for faecal coliform contamination of 1,000,000 faecal coliforms/100ml (a typical contamination level when the canal is polluted by sewage), the concentration of faecal coliforms in the water at the bank would be of the order of 2,000 faecal coliforms per 100 ml. This was considered unacceptable, particularly in the light of the fact that assumptions used were conservative, and true concentrations could be even higher. The flood-tide pollution plume was thinner and well-mixed.

In terms of circulation within the estuary, it was found that in dry weather the upper and middle reaches of the Swartkops Estuary are well-mixed with long residence times and limited flushing. The authors asserted that these conditions could lead to the exceeding of the assimilative capacity of the receiving water during the dry season. In the rainy season, residence times were low and adequate flushing was found to occur.

3.5.8 Water Quality Issues in the Buffalo River Catchment

O'Keeffe ***et al*** (1996) examined water quality in the Buffalo River catchment. The Buffalo River has its source in the Amatole Mountains and flows for 125 km in a south-easterly direction before discharging into the sea at East London.

The authors used the following division of the river for the purposes of the analysis contained in the study:

i. Upper reaches to King Williams Town – from the mountain stream in Montane forest down to Maden Dam and the foothill zone flowing through agricultural land downstream of Rooikrans Dam;
ii. Middle Reaches – King William's Town/Zwelitsha to Laing Dam and;
iii. Lower Reaches – downstream of Bridle Drift Dam and the estuary forming East London's harbour.

The authors noted that there had been water quality concerns prior to the study, particularly in the middle and lower reaches of the river. The specific concerns had been as regards:

- Salinity in the middle reaches of the river – the geological formations in most of the catchment comprised marine sedimentary rocks;
- Eutrophication (including nuisance algal blooms) in Laing and Bridle Drift Dams, both of which received domestic effluents and;
- Faecal contamination in Bridle Drift Dam due to broken sewers in Mdantsane.

The study aimed to assess the water quality situation using existing data, define water quality guidelines for different users, design a water quality monitoring system and make recommendations to improve water quality in the river.

The major salinity problems were found to occur in the region between King William's Town and the inflow to Laing Dam, and in the Bridle Drift Dam. The highest TDS levels (5,130 mg/l) were at the inlet to Laing Dam. While it had been feared that salinity levels were increasing over time, the authors found no long term trend to support this, finding instead that there were temporary increases during droughts, which were later reset by floods.

The authors conducted simulations using 45 years of salinity data to arrive at the contributions to salinity from point sources, diffuse sources and inflows at Laing Dam and Bridle Drift Dam. Point sources comprised discharges from industries and sewage treatment works and diffuse sources comprised runoff during wet periods. This analysis is in Table 20 below.

Table 20: Sources of Salinity in the Buffalo River Catchment

IMPOUNDMENT	CONTRIBUTION TO SALINITY FROM POINT SOURCES	CONTRIBUTION TO SALINITY FROM DIFFUSE SOURCES	CONTRIBUTION FROM INFLOWS
Laing Dam	35%	65%	0%
Bridle Drift Dam	25%	45%	30%

Source: Adapted from O'Keeffe et al (1996) pp v

Phosphate concentrations were found to be highest (15 mg/l as P) downstream of King William's Town and at the inflows of the small tributaries which flow from Mdantsane into Bridle Drift Dam. Long-term phosphate trends did not indicate a general increase in the river. The authors analysed the sources of phosphate pollution by carrying out a similar exercise to that used to determine salinity sources, with the results indicated in Table 21 below:

Table 21: Phosphate Inputs to Laing and Bridle Drift Dams in the Buffalo River Catchment

IMPOUNDMENT	CONTRIBUTION TO PHOSPHATE FROM POINT SOURCES	CONTRIBUTION TO PHOSPHATE FROM URBAN RUNOFF	CONTRIBUTION TO PHOSPHATE FROM NON-URBAN SOURCES	CONTRIBUTION FROM INFLOWS
Laing Dam	30%	62%	8%	0%
Bridle Drift Dam	8%	73%	0.13%	19%

Source: Adapted from O'Keefe et al, pp 43 - 44

Faecal bacteria counts of up to 15,000 cells/100 ml were prevalent at the tributary inflows to Bridle Drift Dam, indicating the presence of raw sewage.

The study confirmed salinity, nutrients and faecal bacteria as variables of concern. In addition, the authors reviewed other parameters and compared these to user requirements and DWA guidelines at the "no impact/ideal" and the "major impact/unacceptable" levels to identify additional potential variables of concern. At the "no impact" level, which is the most stringent requirement, all variables are of concern in the Buffalo River, since all at some time/place were found to exceed the standard. Variables found to exceed the "major impact" limits are in Table 22 below, along with an indication of the part of the river in which the non-compliance occurred.

Table 22: Water Quality Variables of Concern in the Buffalo River

VARIABLE	UPPER	MIDDLE	LOWER
Chloride		X	
COD	Insufficient data	X	X
DOC	Insufficient data	X	
Salinity		X	
Fluoride			X
Sodium		X	
Ammonium	X	X	X
Nitrates and Nitrites		X	
pH		X	
TSS	Insufficient data	X	Insufficient data
Turbidity	Insufficient data	X	X
Total Alkalinity	X	X	X

Source: Adapted from O'Keeffe et al (1996), pp 105

In addition to the parameters for which “insufficient data” are indicated, data was unavailable to evaluate the levels of boron, silicon, total phosphate and hardness.

A review of the available assimilative capacity of the river (calculated as the difference between the highest monthly 95th percentile in each season subtracted from the relevant user requirement/guideline) found considerable available assimilative capacity for most of the concern variables at the “major impact” level, particularly in the upper and lower reaches. Only the upper reaches were found to have assimilative capacity available at the “no impact” level.

In order to assess the impact of low-cost, high-density housing on water quality, the townships of Zwelitsha, Mdantsane, Ilitha, Needs Camp (a resettlement camp) and the traditional village of Mlakalaka were investigated. The aim was to evaluate the effects of diffuse runoff from these areas on the river. The study team conducted interviews to assess water use, waste disposal and demographics in these areas. Deficiencies were discovered in water and sanitation as well as refuse disposal services. Only 56% of households had waterborne sanitation. Of the balance, 28% used pit latrines, 6% used the bucket system and 9% had no access to sanitation of any kind. Only 24% of households had taps in their houses, with the balance using standpipes in the road or taps outside on their properties. Rubbish collection services were found to be poor to non-existent, with much of the rubbish disposed of on the catchment and washed into the river during rainy periods. The traditional village was found to produce 2.5 times as much phosphate per person due to livestock. In the upper catchment, population density was of the order of 10 people/km^2, but township areas contained up to 1000 people/km^2.

The overall conclusions of the authors were as follows:

i. Water quality problems in the catchment were a result of overpopulation and over-development in a relatively small catchment with inadequate water resources;
ii. These problems were exacerbated by:
    - political division of the catchment (at the time the catchment was divided between South Africa and the then Ciskei);
    - The catchment geology, which resulted in increased salinity levels and;
    - The position of the two largest dams being immediately downstream of large townships.

The authors expressed concern that the problems of increasing population growth, naturally high salinity and the positions of the dams were likely to persist, and that these factors needed to be considered in managing water quality in the river.

An important argument made by the authors was that the use of Receiving Water Quality Objectives (RWQO's) was acceptable for conservative elements such as the major ions, but unsuitable for predicting the effects of nutrients, which cause secondary problems such as algal blooms. The authors pointed out that blooms result from a suite of conditions, and that phosphate loads alone were a poor indicator of their likelihood.

3.5.9 Water Quality Measurement and Modelling in the Berg River Catchment

The Berg River lies in the Western Cape and has its origins in the Jonkershoek and Franschoek mountains. It is roughly 270 km long and flows in a north-westerly direction to the sea, where it discharges at Laaiplek. It is an important source of water to the City of Cape Town and various other agricultural and domestic users in the catchment.

Görgens and de Clercq (2006) conducted studies of the Riviersonderend-Berg River (RSE-BR) System together with a team of researchers, with two underlying themes:

i. Development of decision support and information management software for general water quality management in a river system with diverse components and human impacts and;
ii. Water-quality research in the form of field-scale process studies and large-scale soils data interpretation and mapping, with a strong focus on salinisation processes.

The study team combined a suite of water quality models with a user interface so that modelling results could be presented and interpreted visually. A two dimensional hydrodynamic and water quality model (CE-QUAL-W2) was used to simulate the flow pattern and constituent profiles in a proposed impoundment in the system, Skuifraam Dam. The Skuifraam Dam was proposed for the upper reaches of the upper Berg River, just downstream of the confluence of the Berg River and the Wolwekloof Rivers. The dam was meant to capture flood flows and transfer water to the Theewaterskloof Dam or directly to Cape Town via the Jonkershoek Tunnel, and was planned to have a full supply capacity of 168 Mm^3. DUFLOW, a one dimensional hydrodynamic river flow and water quality model was used to simulate the river.

The authors defined "model" in the context of the study to mean, "the computational hydraulic and water quality software used", with some models supported by "sub-models or algorithms that describe the mathematical equations that represent water quality processes". The authors asserted that their aim as regards hydrodynamic river water quality modelling was to describe and understand interactions between the hydraulics of the river and the chemical and biological water quality characteristics of the river.

The team conducted a review of the water quality status of the Berg River main stem, in order to allow compilation of a minimum group of water quality variables of concern. The authors noted that Fourier and Görgens (1977) had indicated that salinity increases of the river could be the result of increasing irrigation along the river, and that Bath (1989) had concluded that 80% of the annual phosphorous was contributed by diffuse sources. Reference was made to a previous study by Ninham Shand that showed that the Skuifraam Dam would have relatively small effects on the salinity of the lower reaches of the river.

The following variables of concern were considered for the study:

iii. pH;
iv. salinity;
v. phosphate;
vi. temperature and;
vii. oxygen.

The authors noted that pH influences physical, chemical and biological processes in the system. The surface waters in the upper Berg River catchment were found to be acidic. This was thought to be due to tributaries on the eastern bank of the river, which drained areas with Table Mountain Sandstone as main geological formation. The soils were acidic and low in salts. The water of the Berg River was found to become more alkaline downstream with more acidic water at the origin of the river. The acidic water (pH of < 6.5 regularly found) was said to have a tendency of dissolving the cement lining of water distribution networks (aggression) and lime treatment was found to be necessary to raise the pH of municipal water supplies, increasing treatment costs. It was found that pH trends had moved upwards since 1989 when DWA introduced an improved sample preservation procedure.

Electrical conductivity (EC) was taken as the measure of salinity for the study. High salinity was found to occur in the rivers draining the Malmesbury Shales (Doring, Fish, Sand, Matjies, Sout and Morreesburg Rivers). This water was unsuitable for irrigation and it was asserted that if this water were used, it would lead to yield losses. The tributaries draining the Table Mountain series as dominant geological formation showed low TDS concentration, but the water of the Berg River became more saline further downstream due to runoff from the Malmesbury Shales. Trends indicated that salinity had increased slightly over the years in the lower reaches of the river. Salinity was also been shown to be seasonal, increasing during the low-flow summer months due to increased irrigation return flows.

Phosphates were selected as the indicator of nutrient status for the study, and an increase in phosphate concentrations at all sampling stations was clearly seen for the period 1992-1998. Algal growth was not found to be a problem except at Misverstand Weir, where chlorophyll-***a*** levels were found to be higher than at other points in the river. Phosphate levels ranging from 0.01 mg/l (as PO4) to 0.06 mg/l were reported here. Increasing phosphate levels in the system were ascribed to increasing land use and irrigation.

The following are the conclusions reached and the modelling activities carried out:

- Salinity levels in the lower reaches of the Berg River catchment were excessive, and nutrient levels were increasing, with intermittent high nutrient levels;
- The tributaries of the Berg River were introducing most of the salinity, due to irrigation return flows and the geology of the region downstream of Paarl/Wellington (where Sandstone formations gave way to Malmesbury shale);
- DUFLOW was found to be suitable for flow modelling, and it was possible to make adjustments to parameters in the model to deal with instability;
- The DUFLOW model was found to be very flexible, allowing the user to change water quality algorithms (which was done for phosphate in this study) or add additional water quality processes (which was done in this study for TDS, COD and temperature) as required. The temperature algorithms in the original model proved satisfactory;
- A limitation of the DUFLOW model was that it did not allow the input of diffuse pollution loads, making it difficult to distinguish between point and non-point sources (all diffuse loads had to be entered as point sources);

- Problems with input data impacted on the accuracy of results, with errors introduced at the beginning of the flow calculations (i.e. in the upper reaches of the river) carried through all the way to the end boundary;
- DUFLOW was successfully used for scenario analysis, and linked to CE-QUAL-W2 (using the outputs of the latter as inputs to DUFLOW as upstream boundary conditions) to investigate 3 different scenarios successfully. DUFLOW was found to be capable of predicting the outcomes of different water management scenarios;
- The scenario analysis showed that the downstream summer temperature would change considerably (a drop of 10 degrees Celsius) if Skuifraam Dam were to be built in the upper reaches of the Berg River. The authors thought that this change could have significant ecological impacts;
- The modelling of phosphate was an area where improvement could be gained if data on suspended solids and algae production had been included. This data was not available at the time of the study;
- In terms of modelling of the impoundment, it was found that in the absence of site-specific meteorological data, regional meteorological data could be successfully used;
- Heat transfer within the reservoir could not be adequately modelled due to a lack of stream temperature data;
- The CE-QUAL-W2 model required data on sediment oxygen demand (SOD) which was not readily available and had to be estimated for the study from previous studies. The model was found to be very sensitive for this parameter and it was included in scenario testing.

The study showed that models could successfully be employed to assess various scenarios and management options for complex catchments. While it is acknowledged that all models have shortcomings, the authors suggested that ongoing improvement of available data (both in extent and accuracy) and ongoing refinement of modelling approaches would result in tools that could be used for integrated management of catchments.

3.5.10 The Vaal River System Water Quality Study

The Vaal River System is considered by Government to be the most important water resource in the country, supporting some 60% of South Africa's economy and 45% of the local population (DWA, 2008). The Department of Water Affairs has commissioned extensive studies to examine the extent of the available water resource, taking various growth scenarios into account, as well as the water quality challenges in the system. Water quality issues are to be addressed through an Integrated Water Quality Management Plan (IWQMP)

Water quality in the Vaal River System was assessed by examining available water quality data for the Vaal River main stem and major tributaries and using an initial set of Resource Water Quality Objectives, variables of concern were identified. Three major water quality challenges were identified through this process:

i. High salinity levels, particularly between the Vaal Barrage and Bloemhof Dam due to urbanisation, return flows from WWTW's, industrial discharges and mine dewatering discharges;
ii. Eutrophication, specifically in the Vaal Dam, Vaal Barrage and Bloemhof Dam due to WWTW effluent discharges and the management and maintenance of sewerage systems. High phosphorous levels are identified as a problem;
iii. Microbiological water quality, related to WWTW effluent discharges that have been improperly disinfected and problems with sewerage system management and maintenance. While the Vaal main stem meets the full water contact standard for recreational purposes, microbiological "hot spots" are identified in some of the tributaries close to the discharge points for WWTW's.

Salinity levels in the Grootdraai Dam have been identified as being under threat from mining, in particular decants from closed mines in the catchment. This will affect users, both in the agricultural sector as well as power generation, a major user.

Eutrophication problems have negatively affected the performance of the Midvaal and Sedibeng water purification plants, with additional treatments necessary to deal with colour and odour problems.

3.5.11 Drinking Water Quality in the Western Cape

In January 2009, the DWA Directorate: Planning and Information conducted a preliminary analysis of the quality of drinking water in the Western Cape for the 2008 year. Data for this review was extracted from the Electronic Water Quality Management System (eWQMS), into which all Water Service Authorities (WSA's) are required to capture drinking water quality (and effluent discharge) data.

It was noted that the Western Cape has 30 WSA's, with both local and district municipalities designated as WSA's. The WSA's reviewed in the study were:

Beaufort West Municipality ; Bergrivier Municipality ; Bitou Municipality ; Breede River Winelands Municipality ; Breede Valley Municipality ; Cape Agulhas Municipality ; Cape Winelands District Municipality ; Cederberg Municipality ; Central Karoo District Municipality ; City of Cape Town ; Drakenstein Municipality ; Eden District Municipality ; George Municipality ; Hessequa Municipality ; Kannaland Municipality ; Knysna Municipality ; Laingsburg Municipality ; Matzikama Municipality ; Mossel Bay Municipality ; Oudtshoorn Municipality ; Overberg District Municipality ; Overberg Water ; Overstrand Municipality ; Prince Albert Municipality ; Saldanha Bay Municipality ; Stellenbosch Municipality ; Swartland Municipality ; Swellendam Municipality ; Theewaterskloof Municipality ;
West Coast District Municipality ; Witzenberg Municipality

The analysis examined detailed results for the month of December 2008 using the following criteria:

i. Percentage characterization of water quality against national standards/limits for December 2008;
ii. Points failing Maximum Allowable Limits for December 2008 and;
iii. Percentage failure for SANS 241 (i.e. the drinking-water quality standard) minimum required parameters for December 2008.

Drinking-water quality compliance for the last 12 months (i.e. January to December 2008) was also undertaken.

A review of the frequency with which data was loaded over the period January 2007 to December 2008 revealed that the amount of data loaded by the WSA's varied significantly from month to month. Monthly data submissions ranged from a low of 63% to a maximum of 93%. In terms of legislative compliance, WSA's were required to monitor water quality monthly. If data submissions reflected the analyses actually carried out, this would suggest that certain WSA's were not legally compliant. For December 2008, it was found that only 22 out of the 30 WSA's had loaded data, down from 27 WSA's the month before.

Seventeen health-related failures against the SANS 241:2006 drinking water quality standards were found for the month of December 2008. These failures centred around three issues:

i. A violation of the ***Escherichia coli*** health risk level of 1 count/100 ml
ii. A violation of the faecal coliform health risk level of 10 counts/100 ml and;
iii. A violation of the aluminium health risk indicator of 300-500 µg/l.

The details of the WSA's involved and the number of samples violating these standards in the month of December 2008 are outlined in Table 23 below:

Table 23: Health-related Failures at WSA's in the Western Cape in December 2008

WATER SERVICES AUTHORITY	NO. OF E.COLI FAILURES	NO. OF FAECAL COLIFORM FAILURES	NO. OF ALUMINIUM FAILURES
Bergrivier Municipality	1	0	0
Breede River Winelands Municipality	0	0	3
Eden District Municipality	2	0	0
George Municipality	0	0	1
Knysna Municipality	0	0	3
Laingsburg Municipality	1	0	0
Stellenbosch Municipality	0	2	0
Swellendam Municipality	0	0	1
Theewaterskloof Municipality	0	0	3

Source: Adapted from DWA (2008) pp 7

The authors noted that residual aluminium levels were a function of process control, since the source of the aluminium was the alum used for coagulation during the water treatment process.

It was further noted that this analysis was based on the data entered, and that if this was used as a basis, not all analyses required may physically have been carried out.

The authors evaluated the performance of the WSA's against the minimum SANS:241 (2006) parameters specified, which were indicated as: ***E.coli*** and/or faecal coliforms, pH, electrical conductivity (EC), turbidity, aluminium and free chlorine residual. These results are summarised in Table 24 below:

Table 24: Overview of Compliance to Minimum Parameters at WSA's in the Western Cape for December 2008

PARAMETER	STANDARD	COMPLIANCE IN WC
E. coli	SANS: Microbiological safety column 5	98.5% compliant
Faecal coliforms	SANS: Microbiological safety column 5	98.3% compliant
pH	SANS:Physical, Organoleptic, Chemical Class 1	96.8% compliant
Electrical conductivity	SANS:Physical, Organoleptic, Chemical Class 1	99.7% compliant
Turbidity	SANS:Physical, Organoleptic, Chemical Class 1	68.1% complaint
Aluminium	SANS:Physical, Organoleptic, Chemical Class 1	85.7% compliant
Free chlorine residual	WHO: Recommended network FCR (0.2 – 0.5 mg/l)	Average of 0.3 mg/l in WC, but ranges from 0 mg/l to 1.1 mg/l at individual WSA's

Source: Adapted from DWA (2008) pp 8 – 15

The authors noted that there were numerous failures during the month of December 2008, and that not all municipalities were monitoring water quality according to the minimum parameters that are to be monitored monthly according to SANS: 241 (2006). A full SANS: 241 (2006) analysis is required from each WSA at least annually. The authors assessed whether this was being carried out based on data loaded into eWQMS and what the levels of compliance to the standards were where data had been entered. Table 25 on the following page compares the Western Cape to the rest of South Africa in terms of total samples analysed for each parameter and, where samples have been taken, the level of compliance to the standard.

Table 25: Sampling Frequency and Performance Against the Full SANS:241 Standard in the Western Cape (Jan-Dec 2008)

PARAMETER	CATEGORY	TOTAL SAMPLES SA	COMPLIANCE % SA	TOTAL SAMPLES WC	COMPLIANCE % WC	WSA's NOT REPORTING IN WC
Faecal coliforms	H	14463	98	1438	99	16
E.coli	H	51731	96	8593	98	0
Total coliforms	O	51181	90	9920	94	0
Colour	A	19376	91	2507	78	4
Electrical Conductivity	A	40734	98	8300	100	3
Odour	A	4543	99	0	-	30
pH	AO	49978	99	9037	98	0
Taste	A	1648	99	0	-	30
TDS	A	11286	98	1495	100	9
Turbidity	AO, Indirect health	50742	77	9092	78	0
Aluminium	H	8977	92	1738	83	8
Ammonia	O	4680	99	436	99	20
Antimony	H	525	100	0	-	30
Arsenic	H	959	91	0	-	30
Cadmium	H	2510	98	0	-	30
Calcium	AO	10548	97	1921	100	8
Chloride	A	12252	97	2035	98	9
Chromium	H	2468	100	0	-	30
Cobalt	H	2303	100	0	-	30
Copper	H	2841	100	57	100	29
Cyanide (recoverable)	H	64	100	0	-	30
Dissolved Organic Carbon	AH	1551	100	0	-	30
Fluoride	H	13025	97	1061	100	11
Iron	AO	13563	89	2442	83	4
Lead	H	2601	97	0	-	30
Magnesium	AH	9368	98	1725	100	9
Manganese	A	9651	95	2074	96	5
Mercury	H	718	28	0	-	30
Nickel	H	2392	100	0	-	30
Nitrates	H	8550	93	184	100	20
Nitrates and Nitrites	H	3356	99	887	100	13
Phenols	AH	488	100	0	-	30
Potassium	OH	6904	100	836	100	19
Selenium	H	1150	98	0	-	30
Sodium	AH	7244	99	849	99	17
Sulphate	H	10869	99	1336	100	11
Total THM's	H	2058	64	9	100	29
Vanadium	H	1980	100	0	-	30
Zinc	AH	3073	100	446	100	20

*A= aesthetic, O = operational and H = health

Source: Adapted from DWA (2008) pp 16 - 32

Overall conclusions of the study were as follows:

- Consistent monitoring on a monthly basis is not occurring at some WSA's;
- Some parameters were not measured at all by WSA's in the Western Cape, specifically several heavy metals, arsenic, odour, taste, dissolved organic carbon and phenols.
- Where monitoring does occur, not all WSA's are monitoring the minimum parameters to be monitored in terms of SANS : 241;
- None of the WSA's in the Western Cape had entered data for a full SANS : 241 (2006) analysis in 2008;
- Numerous drinking water quality failures had occurred, highlighting the need for intervention;
- The most significant water quality problems in the Western Cape relative to the national situation were:
  - Control of iron levels;
  - Control of aluminium levels;
  - Colour problems and;
  - Bacteria
- The Western Cape performed better than the rest of the country in terms of THM levels, but this is based on a very small number of samples (9). All of these samples were analysed at one municipality, Stellenbosch.
- At the national level, it is apparent by the range of sampling frequencies indicated for the various parameters that consistent compliance to sampling frequencies is not being achieved.
- In terms of national drinking water quality, the following parameters are of concern:
  - E.coli, faecal coliforms and total coliforms
  - Turbidity, which while an aesthetic issue, can result in indirect health issues due to the impact turbidity could have on disinfection effectiveness;
  - Aluminium levels, which are related to alum dosing;
  - Arsenic levels;
  - Other heavy metals, particularly mercury, where compliance nationally is at a level of just 28%;
  - Nitrate levels and;

- Trihalomethanes, which may result from issues concerning raw water quality e.g. algal blooms, but may also be related to purification processes e.g. the use of pre-chlorination upstream of sand filtration.

It is clear therefore that drinking water quality in the Western Cape and at the national level is cause for concern.

3.6 THEME 6: OTHER WATER QUALITY PROBLEMS

The reports reviewed generally cover the key water quality challenges facing South Africa, but there are important issues that either are covered only in a cursory fashion or are absent altogether. It is therefore necessary to include some detail concerning these issues, if only to provide additional context for the review. Selected reports on what is believed to be the most important issues not sufficiently covered by the core report list have therefore been included below. The issues addressed are acid mine drainage, drinking water quality, solid litter and dissolved oxygen levels.

3.6.1 Acid Mine Drainage (AMD)

Acid mine drainage is associated mainly with gold and coal mining, where pyrite is oxidised due to bacterial action to produce sulphuric acid. Acid mine drainage is associated with increased salinity, reduced pH, increased metals concentration (WRC, 2008) and has a major, multi-dimensional impact on water resources. The National Water Act (1998), in Chapter 3, Part 4, deals with pollution prevention, particularly resulting from land-based activities, and accompanying regulations deal specifically with pollution of water resources due to mining activities. The regulatory environment thus already deals with AMD, and hence the recommendations considered will deal with management responses to the problem.

Hodgson ***et al*** (2007) studied various coal mines in Mpumalanga with a view to assessing their impacts on water quality and determining appropriate management practices for minimising this impact. The researchers highlighted that total decants from coal mines were eventually expected to reach 360 ML/day, since mines eventually fill up with water. The importance of life cycle management was stressed, rather than an approach that focused on remediation only. The flooding of mines immediately after mining was completed was highlighted as a good management practice to reduce AMD, since this excluded air and activated the base potential of the remaining coal. Flushing after flooding was considered a good practice, but it was highlighted that treatment may be necessary to reduce salt discharges to the environment.

Based on this study, a recommendation deemed useful in the context of this review is for best practice guidelines for management and control of AMD to be developed, addressing the life cycle of mines. In time these practices may be incorporated into regulations;

3.6.2 Radionuclide Pollution

Wade ***et al*** (2002) conducted a Tier 1 Risk Assessment of selected radionuclides in sediments of the Mooi River catchment. The study built on earlier work that showed that significant concentrations of water-borne radionuclides were associated with mine water discharge into the river system. Radionuclides hence may be associated with acid mine drainage from gold mines.

The researchers found that radionuclides had indeed accumulated in sediments of the Mooi River catchment, and may be remobilised by perturbation of TDS, pH or oxidation potential. A number of dams were identified as having higher U-238 levels than that stipulated in the Nuclear Energy Act (1993), implying that these sites be regulated.

Winde et al (2004) investigated gold tailings as a potential source of water-borne contamination of water resources, and found that pH and redox potential of the receiving waters were important factors influencing the mobilisation of uranium. It was noted that dissolved metals are more highly mobile than metal precipitates, and likely to pass through less sophisticated water purification plants and into drinking water. The researchers found, through chemical analysis of water and sediment samples from the Koekemoerspruit, that gold and uranium tailings dams are indeed sources of uranium and heavy metal contamination. The potential for uranium contamination was found to have increased due to mines not pursuing the purification and sale of uranium, due to unattractive market prices for the mineral, since quantities of uranium in slimes dams had consequently increased. Low pH was found to prevent immobilisation of uranium, promoting its transport, rather than to be resulting in mobilisation of uranium that had previously been incorporated into sediment.

3.6.3 Drinking Water Safety

The review of drinking water quality in the Western Cape highlighted a national problem as regards compliance to the frequency of measurement of important water quality parameters. A recommendation regarding the auditing and compliance of all WSA's nationally in terms of measurement and reporting is therefore an obvious inclusion to the consolidated list of water quality recommendations. The Western Cape study cannot however be used to draw definitive national conclusions as to the status of purification plants, and makes no recommendations, not even for the Western Cape.

Given the status of raw water in South Africa, it is vital that water purification plants operate optimally. Mackintosh and Jack (2008) conducted a study on drinking water quality failures in non-metropolitan areas in the Free State, Eastern Cape and Western Cape. The authors consider the study areas chosen to be broadly representative of South Africa. Detailed recommendations were not made, but a more detailed analysis of challenges was undertaken. The key issues identified were:

i. A lack of capacity at purification plants, both in terms of numbers of staff and the skills of existing staff;
ii. Most purification plants were not able to cope with demand. Reservoir cleaning was being neglected due to inadequate storage capacity;
iii. Reduced availability of surface water was leading to rising turbidity levels at the intake works and the overexploitation of groundwater resources, the latter without proper treatment;
iv. Maintenance of purification plants was not being carried out effectively;
v. Only basic treatment technologies were employed, which may not be appropriate given raw water quality challenges.

Taking the above and the Western Cape study into account, the following recommendations are proposed for inclusion:

i. Compliance to SANS 241 measurement standards to be enforced at all WSA's;
ii. Action plans for each WSA to be formulated to address water quality deficiencies, and a monitoring programme to be implemented to assess progress;
iii. A national audit of water purification skills at individual WSA's to be undertaken and a strategy to address skill gaps to be formulated;

iv. Preventive maintenance programmes for all purification plants to be developed and implemented;

v. The capacity of individual plants to be reconciled to demand, and investments planned to enable the requisite capacity to be installed.

3.6.4 Solid Litter

Solid litter enters waterways either directly or via stormwater drainage infrastructure, and can have a negative impact on the aquatic environment and interfere with the operation of stormwater systems. Solid litter is also a problem in terms of aesthetics, and can affect recreational opportunities. None of the core reports reviewed dealt with this issue in any detail.

Marais and Armitage (2004) proposed strategies for source controls, which are aimed at preventing litter entering stormwater systems by addressing the problem at source. The authors assert that an integrated approach encompassing planning controls, source controls and structural controls is ultimately required, and that the suite of options pursued would depend on unique catchment characteristics. Planning controls would typically entail issues of land-use planning and urban design, while structural controls would comprise measures such as litter traps and stormwater treatment.

The source controls proposed in this study entail:

i. Educational campaigns to bring about increased public awareness about the litter problem;

ii. Waste reduction to reduce the volume of waste generated;

iii. Cleansing operations to prevent the waste entering the environment and;

iv. Law enforcement to ensure compliance.

Given that this problem lends itself to local solutions, a relevant recommendation in the context of this study would be that all catchment management plans and strategies are to contain a specific, integrated strategy for the management of solid litter.

3.6.5 Dissolved oxygen

Dissolved oxygen is essential to support fish, zooplankton and invertebrates. Water polluted with organic matter, e.g. partially treated sewage effluent can be deficient with oxygen. Oxygen is also depleted when algae die and decompose. The sources of oxygen include rainfall, air ingress in flowing water, including at hydraulic structures such as weirs, and photosynthesis by algae and aquatic plants. None of the source materials reviewed dealt with the issue of dissolved oxygen levels in any detail.

Fatoki et al (2003) reviewed water quality in the Keiskamma River and the impoundment immediately downstream, including a review of dissolved oxygen levels. The authors asserted that a minimum level of 5 mg/l dissolved oxygen was required in order to prevent adverse effects on aquatic life, and found levels in the Keiskamma River to be far below this level. The root cause was attributed to discharges from a local wastewater treatment works that increased Biological Oxygen Demand (BOD) to levels in excess of twice the maximum stipulated by EU guidelines. While this report made no recommendations, what is clear is that oxygen depletion is closely related to issues regarding nutrient enrichment. On this basis, recommendations proposed by other researchers to address eutrophication problems and non-point source pollution are considered adequate for the resolution of the oxygen depletion problem as well.

4. REVIEW OF CATCHMENT INFORMATION SOURCED FROM THE DWA WEBSITE

4.1 REVIEW OF CATCHMENT MANAGEMENT PLANS

South Africa is divided into 19 Water Management Areas (WMA's), each of which will ultimately be overseen from a water management perspective by a Catchment Management Agency (CMA). The role of CMA's is to protect, develop, conserve, manage and control water resources in defined WMA's. In terms of the National Water Act (Act no. 36 of 1998), each CMA must produce a Catchment Management Strategy, which must align to the National Water Resources Strategy and which will include issues regarding the allocation of water to users. A WMA may comprise a number of individual catchments and sub-catchments, and plans to address water quality problems in these catchments and sub-catchments inform the overall Catchment Management Strategy in individual WMA's. From a water quality perspective, Catchment Management Plans would typically specify water resource quality objectives for various river reaches in the catchment, and specify strategies to ensure that these objectives are achieved. CMP's are therefore a subset of Catchment Management Strategies.

A search of the DWA website yielded two documents that could be viewed as components of Catchment management Plans: The Diep River Catchment Water Quality Situation Assessment and the Wasbank River Catchment Water Quality Management Strategy. In order to augment these sources of information and conduct a more comprehensive review of the geographical spread of water quality problems, the water quality component of the situation assessments conducted for each Water Management Area were reviewed. These are available on the DWA website for 18 of the 19 WMA's. The review of these sources of information follows.

4.1.1 The Diep River Catchment Management Plan

The Diep River rises in the Riebeeck-Kasteel Mountains in the South-western Cape region and flows in a south-westerly direction for roughly 65 km before discharging into Table Bay. A situation assessment of the Diep River Catchment was conducted (Mafejane A ***et al***, 2000). The authors reviewed water quality in the Diep River and its tributaries using DWA user-specific guidelines, and examined the point and non-point sources of pollution in the catchment.

Salinity was found to be a problem in the catchment, largely because of local geology. High salt levels in surface waters and groundwater were found to make the water unsuitable for domestic use and even uses such as livestock watering in places.

Nutrient loading was found to be high (both nitrogen and phosphorous), in part due to intensive agricultural activity in the upper reaches of the catchment and due to point discharges from wastewater treatment plants. Faecal contamination of the estuary and the coastal/surf zone were found to pose a health risk to recreational users. Possible sources of faecal pollution were highlighted as being urban runoff, discharges from wastewater treatment plants, agricultural runoff and leaking sewers.

Ecosystem integrity in the catchment was compromised, with all bio-monitoring sites bar one being found to display “deteriorated quality” status and the remaining site found to be “moderately impaired”. The causes of decline in ecosystem integrity were attributed by the authors to point and non-point source pollution, increased use of limited water resources and the characteristics of the river mouth, which closes during the dry season and does not permit marine animals into the estuary. Exotic plant species were also found in the riparian zone.

The authors found that rapid, uncontrolled development was taking place in the lower parts of the catchment, and it was felt that this was having a negative impact on water quality.

4.1.2 The Wasbank River Catchment Management Plan

The Wasbank River Catchment is situated in northern Kwazulu-Natal and is part of the Tugela WMA. It originates in the Biggarsberg and extends to the confluence of the Sundays River. A water quality management strategy was developed for the Wasbank River Catchment (DWA, 2000) after a situation assessment revealed that this sub-catchment of the Sundays River Catchment was severely impacted.

The principal water quality problem was found to be that of excessive salinity, principally due to coal mining activity, and chiefly comprising sulphate and sodium contamination. It was also felt by DWA that the influx of people to the catchment at the time of the study could potentially have a negative impact on water quality due to an increase in informal settlements. Calcium and magnesium levels were found to be problematic in the lower reaches of the river, while fluoride, ammonium, nitrate and chloride were found to exceed user requirements at times. Heavy metal pollution was found to negligible, while pH problems were restricted to the high end of the pH scale (> 8.5 units). High ***E.coli*** counts were detected at some measuring points, indicating risks to informal users who use river water for domestic purposes. As regards bio-monitoring, the instream habitat was generally found to be in good condition, but it was thought that it could be improved further with better management of the riparian surrounds. In particular, sediment released from the riparian environment due to land-use practices was of concern.

A comprehensive stakeholder engagement process was undertaken in order to establish a list of users of the resource and their requirements, and to ensure the involvement of stakeholders in the implementation of solutions. Water Quality Objectives (WQO's) were arrived at through engagement with stakeholders, review of existing national standards and arrival at a balance between ideal user requirements and other factors in the catchment i.e. a pragmatic approach was followed. The final WQO's were agreed to by all users in the catchment. An action plan was developed to ensure sustainable achievement of these water quality objectives, and systems were established for sustainable management of the catchment, including a water quality monitoring programme and a multi-stakeholder forum.

4.2 REVIEW OF WATER RESOURCE SITUATION ASSESSMENTS

The scope of the water quality issues reviewed in the 18 WMA Situation Assessments reviewed was not comprehensive, but did address the following parameters:

4.2.1 Mineralogical surface water quality

This parameter was expressed in terms of TDS and was based on data obtained from the DWA water quality data base. It was assumed that if the water quality met requirements for irrigation and domestic use, it would be acceptable to remaining users.

4.2.2 Mineralogical groundwater quality

TDS and potability were used as indicators of mineralogical quality for groundwater. Data was obtained from WRC Project K5/841 (Simonic, 2000), which included a potability study based on chloride, fluoride, magnesium, calcium, nitrate, potassium, sodium and sulphate. Potability was based on the DWA standard, Quality of Domestic Water Supplies, Volume I (DWA, 1998), with "ideal", "good" and "marginal" quality classes considered potable, and "poor" and "unacceptable" classes considered not potable. Where no data was available, approximations were made using work carried out by Vegter (1995). The results of the potability tests were difficult to present in this report since they were presented graphically as a percentage potability figure at the quaternary catchment level for each WMA. The percentage groundwater potability should therefore be viewed as a subjective assessment derived from this graphical approach i.e. an estimate.

4.2.3 The risk of microbial contamination of surface water

Surface water risks were estimated using a screening method, which used a simple weighting system to assess risks based on land-use practices, population density and degree of sanitation provision. A map was constructed for the whole of South Africa, and this was then used to estimate the risks in each WMA. These risks were not verified using water quality data due to this data not being available.

4.2.4 The risk of microbial contamination of groundwater

The DRASTIC method, which uses a weighting and rating technique that considers geological and geo-hydrological factors in estimating aquifer vulnerability, was used to assess the vulnerability of aquifers in each WMA to microbial contamination. The map of surface water faecal contamination was then superimposed on the aquifer vulnerability map to arrive at an assessment of potential faecal contamination of groundwater in each WMA. Verification using microbiological data was not carried out due to a lack of data.

4.2.5 Sediment yields

Sediment yields were calculated for each quaternary catchment in each WMA using a theoretical approach e.g. erodibility indices. In addition, data from DWA reservoir basin surveys was used to calculate sediment yields. Only the DWA reservoir basin studies are included here, since not all the situation assessments contained the theoretical calculation method. The basin studies are furthermore considered more accurate, since they involved physical measurements of accumulated sediment.

4.2.6 Miscellaneous WMA-specific water quality concerns

Known water quality problems outside of the issues above were reviewed at a desktop level for each WMA in the situation assessments. These assessments were not comprehensive, and relied on reports and studies that were carried out by other researchers/ study teams in the various WMA's. Hence, where an appropriate study that may have dealt with other real water quality issues in a WMA was not carried out, the issue would not have been raised in the situation assessment. The value of these assessments is however that they do provide an indication of the geographical spread of certain water quality issues, which is important in gaining a sense of the magnitude of the risks associated with these water quality problems. The Situation Assessments were available for 18 of the 19 WMA's, with the only exception being the Lower Vaal WMA. The findings of the situation assessments are summarised in Table 26 below.

Table 26: Summary of Water Quality Issues Identified in WMA Situation Assessments

WMA	SURFACE WATER SALINITY	GROUND WATER SALINITY	GROUND WATER POTABILITY	SURFACE WATER FAECAL POLLUTION RISKS	GROUND WATER FAECAL POLLUTION RISKS	OBSERVED SEDIMENT YIELDS (tons/km^2/a)	OTHER WQ ISSUES
Crocodile West and Marico	Good, but limited data.	Moderately affected, with a few high salinity areas.	>50%	Some missing data, many medium to high risk areas.	Roughly half the WMA has medium or high risk	21-256	Extensive eutrophication
Upper Vaal	Heavily impacted by mining and industry	Heavily impacted by mining	> 50%	No to Low risk	Low to medium risk	4-195	Eutrophication. Widespread salinity due to atmospheric deposition, mining and industrial discharge.
Middle Vaal	Limited data. Severe mining and irrigation impacts.	Mainly moderately impacted	>50%	Limited data, some areas of high risk.	Large areas of medium risk	5-275	Radionuclides from gold mining. Elevated manganese levels. Eutrophication.
Olifants	Marginal to ideal	Varies, high in Elands and Middle Olifants catchments	>50%	High risk in former Lebowa homeland area	Large areas of medium to high risk	20-121	Low pH, elevated iron, manganese, sulphate and aluminium due to mining. Heavy metal (chrome and vanadium) pollution.
Usutu to Mhlatuze	Generally good, some impacts from mining and agriculture	Mainly good to ideal, with some poor quality close to coast	>50%	Large area of high risk close to Mozambique border	Band of high risk along eastern coastline	5-446	None identified.

Table 26: Summary of Water Quality Issues Identified in WMA Situation Assessments (Continued)

WMA	SURFACE	GROUND	GROUND	SURFACE	GROUND	OBSERVED	OTHER WQ

	WATER SALINITY	WATER SALINITY	WATER POTABILITY	WATER FAECAL POLLUTION RISKS	WATER FAECAL POLLUTION RISKS	SEDIMENT YIELDS (tons/km^2/a)	ISSUES
Thukela	Generally good with some minor impacts from coal mining	Generally good, with some marginal sub-catchments	Not available	Significant areas of medium to high risk	Low risk, with a small area of medium risk	29-426	Suspected contamination of the Thukela estuary due to paper mill return flows
Mzimvubu to Keiskamma	Limited data. Generally good	Generally good with some poor and unacceptable areas	<50%	Extensive areas of medium to high risk	Most of the WMA is if medium risk	12-1071	Elevated iron and manganese levels due to the Ochre soils. Elevated arsenic levels from cattle dips. Eutrophication.
Lower Orange	Very limited data	Marginal to completely unacceptable	<50%	Limited data. Low risk where data is available.	Mainly low to medium risk, with some high risk areas in the east.	4-52	Eutrophication. Microbiological contamination in some canals. Elevated aluminium levels.
Upper Orange	Limited data, generally good	Generally good to marginal	> 50%	Limited data, low risk where data available	Mainly low to medium risk	26-350	Severe sedimentation upstream of Gariep and Vanderkloof Dams. Eutrophication.

Table 26: Summary of Water Quality Issues Identified in WMA Situation Assessments (Continued)

WMA	SURFACE WATER SALINITY	GROUND WATER SALINITY	GROUND WATER POTABILITY	SURFACE WATER FAECAL POLLUTION RISKS	GROUND WATER FAECAL POLLUTION RISKS	OBSERVED SEDIMENT YIELDS (tons/km^2/a)	OTHER WQ ISSUES
Luvuvhu Letaba	Mainly marginal	Mainly marginal, with some good and ideal quaternary catchments.	>50%	Large areas of medium to high risk.	Large areas of medium to high risk	25-357	No major problems aside from ammonia, nitrate, iron concentrations and pH problems in the Mutale River.
Inkomati	Mainly ideal to good	Mainly ideal to good, with some marginal areas.	Not available	Limited data. Roughly equal spread of low, medium and high risk.	Mainly medium risk, with some low risk and a small number of high-risk quaternary catchments.	30-566	Potential salinity increases from Ngodwana paper mill.
Mvoti to Umzimkulu	Generally good	Ideal to good, with a few marginal areas	>50%	Balance between low and medium risk areas, with a few high risk zones	Mainly low risk with some limited areas of medium risk	10-723	Limited monitoring in heavily industrialised areas.
Fish to Tsitsikamma	Variable, ranging from ideal to totally unacceptable.	Mainly poor to unacceptable	<50%	Limited data. Mainly low to medium risk where data exists.	Mainly medium risk	4-496	Nutrient enrichment. Pesticide residues. Hypersalinity. Localised microbial pollution from informal settlements. Elevated iron, manganese and DOC.

Table 26: Summary of Water Quality Issues Identified in WMA Situation Assessments (Continued)

WMA	SURFACE WATER SALINITY	GROUND WATER SALINITY	GROUND WATER POTABILITY	SURFACE WATER FAECAL POLLUTION RISKS	GROUND WATER FAECAL POLLUTION RISKS	OBSERVED SEDIMENT YIELDS (tons/km^2/a)	OTHER WQ ISSUES
Limpopo	Mainly marginal with a few good areas	Mainly marginal	>50%	Variable risk from low to high	Mainly low to medium risk	6-119	Groundwater contamination with ***E-coli***, fluoride and nitrates.
Olifants Doring	Ranges from ideal to unacceptable	Ranges from ideal to unacceptable	<50%	Limited data. Low risk where data exists.	Low to medium risk	17-134	Salinity driven by geology and agriculture. Some nutrient enrichment.
Gouritz	Limited data. Ranges from ideal to unacceptable.	Mainly marginal, with areas of good, poor and unacceptable quality.	>50%	Limited data, mainly medium risk where data exists.	Mainly medium risk	1-169	Limited information. ***E.coli*** and nutrients.
Breede River	Varies from ideal to completely unacceptable	Ranges from good to completely unacceptable	<50%	Limited data. Mainly low risk	Mainly medium to high risk	1-269	Pesticide residues. High turbidity. Nutrient enrichment. Low pH in headwaters.
Berg	Varies from ideal to completely unacceptable	Mainly marginal and poor, with some unacceptable areas	<50%	Mainly low risk	Mainly medium and high risk	54-310	Acidity, nutrient enrichment and pesticide residues.

Source: Individual WMA Water Resource Situation Assessments (please see references)

5. IDENTIFICATION, EVALUATION AND PRIORITISATION OF KEY WATER QUALITY RISKS

What follows is a list of the key water quality risks identified by this review, an overview of the root causes of each risk, a summary of the typical consequences for different user groups and an indication of the prevalence of each risk.

5.1 Salinity

Salinity was found to be a problem afflicting surface and groundwater in most WMA's and is most likely the most widespread water quality problem in South Africa.

The root causes of salinity increases were generally described as the following:

i. Leaching from geological formations due to irrigation, with the extent of contamination driven largely by the characteristics of the formation involved (Kirchner, 1995);
ii. Land use practices, specifically where underlying geology is disturbed by agricultural or mining activities (e.g. Herold and Bailey, 1996, Kirchner, 1995 and Greef, 1990) and mining (Herold et al, 1996);
iii. Point discharges from industrial and mining activities (DWA, 2008);
iv. Non-point source pollution from evaporation pans used in the gold mining industry (Herold et al, 1996) and from mine decants;
v. Aerial deposition of pollutants from activities such as power generation (Pitman, Bailey and Beater, 2002)

Salinity affects all user groups, with the magnitude of the impact dependent on the level of contamination as well as the specific ionic species involved.

5.1.1 Health-related consequences of salinity

High salinity levels pose health risks to domestic consumers as well as livestock, and cause foliar injury to plants. The specific health impacts are related to the ionic composition of the contaminants. At the concentrations typically prevalent in South African water resources, it is probably fair to say that health impacts are moderate.

5.1.2 Economic consequences of salinity

As shown by the Middle Vaal salinity study, high salinity imposes costs on all user groups, particularly the household sector (due to the costs of personal care products, soaps and detergents and home appliance purchases), industries that treat incoming water for salinity and the agricultural sector, where crop yields are negatively impacted. In mining, the biggest impacts were found to be those associated with evaporative cooling circuits, where more water was required due to increased blow down volumes, and increased treatment chemicals were necessary. In the services sector, the primary impact of rising salinity was found to be an increase in replacement frequency for appliances and increased maintenance costs.

5.1.3 Environmental consequences of salinity

The impact of salinity on the environment depends on concentration and ionic composition, and at extremely high levels of salinity, the environment could be modified. Increased TDS tends to increase water clarity and hence the depth of the euphotic zone, which affects algae growth. The health of fish and aquatic organisms is also negatively impacted at high salinity levels. High sodium levels were found to increase the dominance of blue-green algae at concentrations above 40 mg/l in the Vaal River (Pieterse and Janse van Vuuren,1997) demonstrating the influence of ionic composition.

5.2 Eutrophication

Both the WMA situation assessments and the WRC reports have shown that eutrophication is a widespread problem in South Africa. It is furthermore a problem that has been in existence for some time, and is not showing any signs of abating (Walmsley (2000).

Eutrophication arises when nutrient levels (specifically levels of phosphorous and nitrogen) exceed the assimilative capacity of watercourses, the root causes being largely (After Walmsley, 2000):

i. Point source discharges from wastewater treatment works, particularly where phosphorous levels are high due to insufficient treatment;
ii. Maintenance and management problems associated with sewerage infrastructure;
iii. Urban runoff, particularly where sanitation services are lacking or inadequate;
iv. Agricultural runoff, both from livestock wastes and due to fertiliser inputs and animal feeds;

v. Nutrient inputs from domestic wastes such as detergents as well as certain foods;
vi. Nitrogen is also contributed by the burning of fossil fuels and wood.

5.2.1 Health-related consequences of eutrophication

Certain types of algae produce toxins with serious human and animal health consequences. The cyanotoxins produced by blue-green algae are known to be carcinogenic for example, and these may be carried through into purified drinking water, or absorbed by aquatic organisms and passed up the food chain. Vulnerable groups that use raw water for domestic purposes are exposed to heightened risk. Eutrophication can also lead to the production of trihalomethanes during chlorination in water purification plants. THM's are known carcinogens. The health-related impacts of the root causes of eutrophication, which include exposure to pathogens, are considered elsewhere.

5.2.2 Economic consequences of eutrophication

Eutrophication imposes economic costs on many user groups. In agriculture, algae and aquatic macrophytes interfere with the operation of irrigation and conveyance systems. Eutrophication can impact negatively on the recreational value of water and reduce water resource yields through increased evapotranspiration losses from floating and rooted macrophytes. Water purification costs are also increased, both for water Service Authorities as well as for industrial users that treat their own water. The impact of eutrophication on aesthetics may also affect property values.

5.2.3 Environmental consequences of eutrophication

Eutrophication leads to significant modification of water quality due to the physical and chemical changes that accompany the growth of algae and macrophytes. Rooted macrophytes can modify streamflow conditions, and together with algae, impact on predation. While algae can increase dissolved oxygen levels due to photosynthesis, the death of algae populations depletes oxygen levels and has been known to result in fish kills. The ionic composition of water resources can be altered, together with nutrient levels as a result of the metabolism of algae populations.

5.3 Estrogen and estrogen-mimicking substances

Estrogen and estrogen-mimicking substances were shown in the reports reviewed to be prevalent in a wide range of household, pharmaceutical, industrial and agricultural products. High incidence of contamination is indicated in crop-growing areas of South Africa, in areas where malaria is controlled and in the Pretoria, Johannesburg (Witwatersrand) and Vereeniging areas. The fact that aldicarb and dioxins were excluded from the review suggests a wider prevalence than indicated, since these substances are used and produced by certain sectors of the South African economy.

The root causes of contamination, based on this review, are:

- Point discharges from industries that manufacture these substances;
- Household effluents;
- Some insecticides and herbicides used in the agricultural sector;
- Aerial deposition of substances produced through combustion, such as dioxins;
- Effluents from industries which produce these substances as by-products e.g. dioxins, furans and polychlorinated biphenyls are produced during chlorine and chlorine dioxide bleaching of pulp in the pulp and paper industry.

5.3.1 Health-related consequences of estrogen and estrogen-mimicking substances

Estrogen and estrogen-mimicking substances have severe endocrine effects on humans and animals, mimicking hormones and impacting on sexual development. Toxic effects include carcinogenicity.

5.3.2 Economic consequences of estrogen and estrogen-mimicking substances

The economic impacts of these substances are all related to their impacts on human and animal health. These are addressed elsewhere.

5.3.3 Environmental consequences of estrogen and estrogen-mimicking substances

The environmental consequences of pollution of water resources with these substances are their impact on animal reproduction and their propensity to cause birth defects. Local populations in affected areas could be reduced in number due to fatalities and a reduction in their ability to compete. Importantly, many of these substances are bio-accumulators, becoming more concentrated in receiving tissues over time with ongoing exposure. Many of them also tend to be persistent in the environment.

5.4 Pesticides/Insecticides

Pesticide/insecticide contamination is generally restricted to rural environments in South Africa, though it must be said that a review of the impact of household pesticides was not conducted as part of this study.

The root causes of contamination of water resources are:

i. Crop spraying in agricultural environments, with pollution of water resources arising from irrigation washoff and spray drift (Sereda and Meinhardt, 2000);
ii. Lack of practical knowledge by farmers as regards pesticide safety and disposal and the risks posed to human health and the environment;
iii. Over-use of pesticides/insecticides as opposed to an integrated pest management approach.

The consequences of pesticide contamination are human and animal-health related, comprising endocrine and toxic effects, and they have similar effects as estrogen and estrogen-mimicking substances (in fact some pesticides are estrogen-mimicking substances).

5.5 Bacterial and Viral Pathogens

Bacterial and viral pathogens are a widespread problem in South Africa, as shown by the studies reviewed. Surface water risks regarding faecal contamination are at least at a medium level within catchments in 12 of the 18 WMA's reviewed, and all WMA's reviewed exhibited risks of groundwater contamination based on aquifer vulnerability.

The root causes of microbial and viral pathogens in water resources may be summarised as:

i. Poor water and sanitation provision;
ii. Discharges of poorly disinfected treated sewage from wastewater treatment works;
iii. Discharges of raw sewage;
iv. Urban runoff;
v. Agricultural runoff, specifically from livestock and facilities such as feedlots;
vi. Harbouring of microbes in sediments, with suspension in the water column during storm events or other disturbances;

vii. Storage in animal reservoirs, with subsequent pollution of water resources;

viii. Potential infection of environmental strains by phages, leading to development of virulence factors.

5.5.1 Health-related consequences of bacterial and viral pathogens

Health-related consequences of water-borne pathogens are generally in the form of diarrhoea and dysentery, in some cases leading to fatality. Bourne and Coetzee (1996) found that mortality as a result of water-related diseases was widespread, and that mortality as a result of water-related diseases comprised almost 3% of all deaths in South Africa in 1990. It is generally the poor, the immune-compromised, the young and the elderly that are most at risk.

5.5.2 Economic consequences of bacterial and viral pathogens

Heavy pollution can affect the cost of disinfection at water purification plants. Irrigation with contaminated water can also affect the economic value of crops, and prevent access to markets. There are also costs associated with the productivity losses that accompany illness.

5.5.3 Environmental consequences of bacterial and viral pathogens

The environmental consequences of bacterial and viral pathogens are limited to those organisms that affect both animals and humans. None of these is considered to have serious environmental impacts, based on the studies reviewed.

5.6 Suspended Solids

Suspended solids are a problem in evidence in most WMA's, as indicated by the sediment yields in Table 26. It receives special mention as a particular problem in the Upper Orange WMA, and is highlighted in the review of water quality problems in the Umtata River (Fatoki and Muyima, 2003) and as a consequence of small-scale mining (Heath, Moffet and Banister, 2004). O Keefe ***et al*** (1996) also reported turbidity problems in the Buffalo River.

The root causes of suspended solids problems in water resources are generally related to land use practices, particularly those involving removal of natural vegetation. In the case of agriculture, farming practices can have an impact e.g. the use of mulching can assist in reducing erosion. Mining is shown to have a serious impact over the entire life cycle of the mining process, including at the end of a mine's life, when rehabilitation becomes critically important. Activities in the instream and riparian zones are of particular importance in terms of their impact on erosion. Urbanisation also contributes to erosion as developments replace natural vegetation, and also due to the extensive disturbances during the building phase.

5.6.1 Health-related consequences of suspended solids

In themselves, suspended solids are not responsible for serious health effects. While they do harbour pathogens and other harmful substances such as heavy metals, these are reviewed elsewhere.

5.6.2 Economic consequences of suspended solids

High levels of suspended solids can increase water purification costs for Water Services Authorities and for industrial abstractors and mines. Suspended solids also reduce the effective capacity of impoundments.

5.6.3 Environmental consequences of suspended solids

Filter feeders are particularly affected, and ecological changes could also occur due to the impacts on predation, as predators find it more difficult to see their prey.

5.7 Heavy metals

The review material did not carry extensive coverage of heavy metal contamination in South African water resources, aside from cadmium and lead pollution identified in the Umtata River (Fatoki and Muyima, 2003). The WMA situation assessments did however indicate a number of cases of metal pollution involving heavy metals and other metals. Included here are radionuclides arising from gold mining in the Middle Vaal WMA, chrome and vanadium pollution in the Olifants WMA, arsenic in the Mzimvubu to Keiskamma WMA and several cases of iron and manganese pollution. The number of failures in treated water at WSA's nationally also suggests that heavy metal pollution in raw water is potentially widespread.

Heavy metals form a natural part of the geology, and may be leached into water resources through natural processes. It is however when the geology is disturbed that contamination is promoted, and also when natural resources are beneficiated in industrial processes. The root causes of heavy metal pollution are the generally the following:

i. Leaching from mine wastes such as tailings stockpiles and dams;

ii. Aerial deposition. For example, mercury is deposited on land and in water resources as a consequence of coal combustion;
iii. Mobilisation due to changes in redox potential arising from problems such as acid mine drainage.
iv. Industrial effluents may contain heavy metals, which may be components of some of the process aids and raw materials used.

5.7.1 Health-related consequences of heavy metals

Heavy metals are bio-accumulators, toxic at high concentrations, carcinogenic and also result in neurological defects.

5.7.2 Economic consequences of heavy metals

Heavy metals can increase water treatment costs. They can also interfere with chemical and biochemical processes in some industries, impacting on product quality and yields. In agriculture, livestock health can be affected with economic consequences.

5.7.3 Environmental consequences of heavy metals

Heavy metals affect the health of animals, in some cases leading to death, and pollution can affect population dynamics.

5.8 Acid Mine Drainage (AMD)

Acid mine drainage primarily arises from gold and coal mining activities, and is hence geographically restricted to these mining areas. It is specifically mentioned as a concern in the Olifants WMA Situation Assessment, and by Hodgson ***et al*** (2007), who estimate that discharges from Mpumalanga's coal mines will eventually reach 360 ML/day. Hence while the problem may initially be localised, the destructive capacity of AMD can be substantial.

The root causes of AMD are to do with the oxidation of pyrite in coal and gold mining. There are management actions that can be taken to alleviate AMD, specifically the exclusion of air through mine flooding at the end of the life of the mine.

5.8.1 Health-related consequences of AMD

The health-related consequences of AMD are a combination of the impacts of increased salinity and heavy metals contamination, including radionuclide contamination.

5.8.2 Economic consequences of AMD

The economic consequences of AMD are similar to those for salinity and heavy metal pollution. They include costs to users that are associated with water treatment.

5.8.3 Environmental consequences of AMD

The consequences of AMD include increased salinity, the mobilisation of heavy metals (including radionuclides) and reduced pH, all of which impact negatively on the aquatic environment as well as on animals and birds using the affected resource.

5.9 Solid Litter

The review did not contain sufficient information to evaluate the national extent of the solid litter problem.

The root causes of solid litter pollution involve issues of education and capacity building in communities and issues of service delivery.

Solid litter pollution can affect the instream and riparian habitat through the transport of pathogens and interference with natural streamflow. Municipal stormwater infrastructure can also be impacted.

5.10 Dissolved Oxygen

The review did not contain sufficient information to evaluate the national extent of the dissolved oxygen problem.

The root causes of low dissolved oxygen levels in surface water resources are related to the presence of organic materials arising from the following sources:

i. Discharges of effluents from wastewater treatment works;
ii. Discharges of raw and partially treated sewage;

iii. Discharges of industrial wastes containing organic materials, typically from agro-processing facilities;

iv. Discharges of domestic wastes and leaching from landfills;

Low oxygen levels also arise from secondary effects of the above, for example the death of algae, or the impact that algae have on dissolved oxygen levels at night (during the day algae increase the dissolved oxygen level due to photosynthesis)

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The consequences of low oxygen levels are firstly on aquatic life, which is negatively impacted at dissolved oxygen levels below 5 mg/l (Fatoki, Gogwana and Ogunfowokan, 2003). This is then followed by impacts on water quality due to the impact on the natural assimilative capacity of the water resource.

6. PRIORITISATION OF WATER QUALITY CHALLENGES

6.1 Overview and Methodology

The identified water quality risks will be arranged in descending order of importance in this section of the review. Recommendations relevant to each risk will then be clustered in the same order in order to produce a consolidated list of recommendations in priority order, as required by the terms of reference.

The quantification of risk is typically carried out through the assessment of the impact (i.e. the consequence) of each individual risk and its probability of occurrence. The data available in the reports reviewed is not comprehensive enough to enable an assessment of risk exposure, but an analogous approach will be used to prioritise the identified water quality challenges. Instead of probability of occurrence, an indication of the national prevalence of each identified risk (based on data from the review) will be used, together with a measure of the human-health, economic, social and environmental consequences.

6.2 Prioritisation of Water Quality Risks

Consequence and prevalence for each identified risk were assessed using quantitative ranking scales. Consequences were considered with respect to three major dimensions, the consequences to human health, the consequences to the environment and the socio-economic consequences. The ranking scale used for consequence is contained in Table 27 below.

Table 27: Ranking Scale Used to Assess Consequences of Water Quality Challenges

RANKING	HUMAN HEALTH	ENVIRONMENT	ECONOMIC
5	Possible fatality due to ongoing exposure.	Irreversible damage to environment, even if source of pollution is removed.	Costs likely to affect livelihoods of vulnerable users.
4	Long-term impact on human health, not necessarily leading to fatality.	Visible, measurable environmental damage, possibly accompanied by local species loss.	Significant cost impacts on users.
3	Observable disease that impacts on productivity.	Measurable impacts on plant and animal health.	Measurable cost impacts that may be permanent or sporadic.
2	Limited impact on human health.	Limited impact on the environment.	Limited cost impacts.
1	No measurable impact on human health.	No measurable impact on the environment.	No measurable impact on the costs to users.

The prevalence of individual water quality risks is assessed using the following ranking scale:
1 = little evidence of prevalence;
2 = prevalent in limited areas;
3 = evidence of prevalence in a number of locations, but not present at a regional scale;
4 = evidence of regional prevalence or in a few closely-related regions but not at national scale;
5 = evidence of prevalence on a national scale, or in a number of widely dispersed regions, with potential for development of a national footprint;

Based on these ranking scales, the evidence presented in the reports can now be used to arrive at a criticality ranking for each identified risk by taking the product of the consequence and the prevalence of each risk. Solid litter, dissolved oxygen and radionuclides were parameters that were excluded from this assessment due to the data available from the review being insufficient. Recommendations pertinent to these issues are included at the end of the priority list.

Table 28: Priority Ranking of Water Quality Risks

RISK	PREVALENCE RANKING	HEALTH-RELATED RANKING	ECONOMIC RANKING	ENVIRONMENTAL RANKING	OVERALL RANK
Eutrophication	4	5	4	4	320
Heavy metals	4	5	4	3	240
Acid mine drainage	4	5	4	3	240
Salinity	5	3	4	3	180
Suspended solids	5	2	4	4	160
Bacterial and viral pathogens	5	5	2	3	150
Estrogen and estrogen-mimicking substances	5	5	2	3	150
Pesticides/insecticides	4	5	2	3	120

Economic impacts on users do not include medical costs arising from health-related impacts.

7. CONSOLIDATED RECOMMENDATIONS AIMED AT ADDRESSING WATER QUALITY CHALLENGES IN SOUTH AFRICA

7.1 Overview and Methodology

The authors of the reports reviewed in this study made various recommendations. These recommendations address specific problems or risks identified in the course of carrying out the research covered in each report. The recommendations, outlined in detail in Appendix 1, vary widely in terms of:

i. The level of detail they entail;
ii. The geographic scope of their applicability i.e. some apply to local environments while others are applicable at the national or policy level;
iii. Their relevance, given their age – some of the recommendations are from studies that are over a decade old. The relevance of these studies, particularly those entailing operational management type issues is questionable;
iv. Their practical relevance to the stakeholders who commissioned this study – this applies particularly to those studies which are focused on research, and whose recommendations are aimed at promoting further research on the study topic;

It should be clear from the above, and from a first-hand review of the recommendations outlined in Appendix 1 that many of the recommendations are not in a form that is suitable for the purposes of this study. The recommendations therefore were converted to a suitable form using the following approach:

i. Recommendations pitched at a policy level were presented in their original form;
ii. Situational recommendations dealing with operational issues in local environments were excluded;
iii. Recommendations dealing with specific research topics were considered to be outside the scope of this review and were hence excluded;
iv. Where recommendations were not made, but were deemed necessary, recommendations were proposed;
v. Similar recommendations were clustered together and used to synthesise policy-level recommendations suitable for discussion.

7.2 Consolidated List of Recommendations

Table 29: Recommendations Regarding Eutrophication

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
1.	The national eutrophication problem to be quantified in terms of its extent, trends, the sources of nutrients and the extent of nutrient enrichment of aquatic systems and the social and economic costs of the problem; Implement nutrient source monitoring plans; A eutrophication monitoring information system to be developed and managed.	A national eutrophication monitoring system to be developed and implemented.
2.	A National Eutrophication Strategy to be established within the National Water Resource Strategy; A Eutrophication Strategy to be established within each Catchment Management Strategy; Land-based control measures to be incorporated into eutrophication policy; A eutrophication workshop to be held to develop cooperative structures, identify research gaps and priorities and develop a programme of action.	A National Eutrophication Strategy, developed with input from all stakeholders, is to be established within the NWRS. This strategy is to take due consideration of the impact of land use practices on eutrophication, and each CMA must develop a Eutrophication Strategy for its respective WMA that is aligned to this National Eutrophication Strategy.

Table 29 (continued): Recommendations Regarding Eutrophication

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
3.	Manage formal and informal settlements to prevent faecal pollution; Water supplies and sanitary facilities in the squatter section in Zwelitsha to be upgraded; Breakages in the sewer and reticulation systems in Mdantsane to be controlled and mended Low flows from the four streams in Mdantsane to be intercepted by means of weirs and diverted to the sewage works in order to prevent spillages from Mdantsane entering Bridle Drift dam; Amenities (sanitation facilities) to be provided to all rural and peri-urban settlements on the banks of the Umtata River.	All formal and informal settlements are to be provided with adequate sanitation facilities that are inspected and maintained regularly.
4.	Implement flow manipulation to manage algal blooms in the middle reaches of the Vaal River.	Investigate and implement opportunities for flow manipulation in rivers affected by eutrophication.
5.	Eutrophication concepts to be incorporated within the National Classification System for aquatic ecosystems; Resource management objectives that include eutrophication problem criteria to be set.	Eutrophication concepts to be incorporated within the National Classification System for aquatic ecosystems and resource management objectives that include eutrophication problem criteria to be set.

Table 29 (continued): Recommendations Regarding Eutrophication

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION

6.	Audit Wastewater Treatment Works in the Vaal; Permits to be implemented for discharges of treated and untreated sewage; Implement a WWTP upgrade and retrofit project in hotspot areas in the Vaal; All existing sewage treatment works in the Buffalo River catchment to be upgraded to comply with the 1 mg/l P effluent standard;	All Wastewater Treatment Works nationally to be audited to ascertain their permit status, compliance to operational standard practice, performance levels (particularly sterility and phosphorous level of discharge) and technological capabilities. Upgrade and retrofit projects are to be planned and implemented where required, with progress reported centrally.
7.	A long-term eutrophication research and capacity building programme to support other eutrophication-related activities to be established; Eutrophication management guidelines to be developed; Farmers, particularly those in high-risk catchments, to be made aware of the impacts of their activities on pollution levels, and encouraged to take action to reduce these impacts; Education of rural community on river pollution and the need for a clean and hygienic environment; Information days to inform local people of the consequences and financial implications caused by vandalism to their sewage and reticulation systems to be organised	Design and implement a eutrophication capacity building programme to assist and educate all water user groups in affected catchments as to their contribution to eutrophication and the actions they can take to minimise this impact.

Table 29 (continued): Recommendations Regarding Eutrophication

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION

8.	Implement nutrient balances and a nutrient model from Vaal Barrage to Bloemhof Dam and apply this model to investigate alternative eutrophication control strategies; Additional investigations into environmental variables are carried out to allow improvement of the mathematical model developed for algal growth predictions in the Vaal.	A model to be developed that can be applied nationally (in local catchments) to project expected algal growth patterns based on nutrient status.

Table 30: Recommendations Regarding Heavy Metal Contamination

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
9.	Waste sites along the river banks to be removed and relocated to more appropriate locations; Rubbish dumps next to the river to be monitored to assess the effect of leachates on water quality during rainfall events. If they are found to be contributing to water quality deterioration they are to be removed or sealed;	A national policy regarding the location and management of waste sites in close proximity to water resources to be developed and implemented.
10*.	Investigate the reasons for high levels of non-compliance nationally to SANS: 241 drinking water heavy metals specifications.	Investigate the reasons for high levels of non-compliance nationally to SANS: 241 drinking water heavy metals specifications.

*Synthesised from the Western Cape Drinking Water Study (DWA, 2008)

Table 31: Recommendations Regarding Acid Mine Drainage

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
11.*	Best practice guidelines for management and control of AMD to be developed, addressing the life cycle of mines.	Best practice guidelines for management and control of AMD, addressing the life cycle of mines, to be developed and disseminated.
12.*	Mining regulations regarding impacts on water quality to be implemented.	Mining regulations regarding impacts on water quality to be implemented.

* These recommendations have been synthesised from findings contained in the Mpumalanga coal mines study (Hodgson et al (2007)

Table 32: Recommendations Regarding Salinity

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
13.	Continue with the dilution of the Vaal Barrage water with releases from the Vaal Dam.	Continue with the dilution of the Vaal Barrage water with releases from the Vaal Dam.
14.	Implement a waste discharge charge in the Vaal, with revenues to be used to compensate downstream users for “dis-benefit”.	Implement a waste discharge charge in the Vaal, with revenues to be used to compensate downstream users for “dis-benefit”.

Table 32 (Continued): Recommendations Regarding Salinity

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
15.	Implement an upgraded water quality monitoring system in the Vaal; Water quality monitoring systems to be improved in the OFS Goldfields region;	Implement an upgraded water quality monitoring system in the Vaal River System.
16.	Evaluation of the impact of increased TDS export from the Vet River on Bloemhof Dam and the downstream river system to be carried out.	Evaluation of the impact of increased TDS export from the Vet River on Bloemhof Dam and the downstream river system to be carried out.
17.	Implement targeted saline effluent treatment schemes in the Vaal; Differential desalination to be considered as an option in the Middle Vaal, since the household sector was found to bear high costs, with lower costs borne by other sectors;	Identify and implement opportunities to employ desalination of discharges and treated water in all areas impacted by high salinity, in order to reduce the impacts of salinity on users.
18.	All dischargers in the Vaal River System to reduce TDS load by 50-60% by 2014.	All dischargers in the Vaal River System to reduce TDS load by 50-60% by 2014.
19.	Remediation of historical mining operations; Rehabilitation bonds to be increased by the DME such that they are sufficient to cover projected costs; Responsibilities for rehabilitation need to be clarified in the cases of State and privately owned land; Hands-on training as regards rehabilitation to be provided to small-scale miners.	Quantify the extent of the mine remediation problem, identify the root causes for inadequate remediation of mining operations and implement a project to correct the problem.

Table 32 (Continued): Recommendations Regarding Salinity

NO	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
20.	Uncontrolled development of new irrigation areas that entail the deep ripping of thin Bokkeveld shales to be restricted.	Land use practices that have increase the salinity of water resources to be controlled.
21.	The effect of a doubling or trebling of the Vaalharts irrigation return flow TDS on the Vaal River to be urgently assessed; The existing flow and water quality monitoring system at the Vaalharts scheme to be improved; A new intensive TDS monitoring system to be employed to allow close monitoring of the potential threat of sudden increases in salinity in the Vaal River; A detailed study to be done to verify groundwater storage states, groundwater quality and percolation rates and the processes governing the behaviour of the Vaalharts system. The aim should be to predict when TDS loads returned to the Harts River are likely to increase and to what level they will rise; An improved irrigation model to be developed for the Vaalharts scheme that integrates soil chemistry, groundwater modelling, irrigation practices and advanced crop water modelling and infiltration/surface runoff/soil moisture processes.	The risks of a sudden salinity increase in the Vaal River due to salt retention in the Vaalharts scheme to be assessed and a detailed response plan to be developed and implemented.

Table 32 (Continued): Recommendations Regarding Salinity

NO	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION

22.	Catchment Management Plan to be formulated for the OFS Goldfields region and the downstream portions of the Sand-Vet River system; Development of a catchment management programme for the Umtata River catchment.	Catchment management Plans for all catchments to be expedited, beginning with priority catchments.
23.	As an interim measure, public warnings to be posted against drinking water from the worst affected river reaches, specifically the Sand River Canal, the Sand River downstream of this canal, the Doring River and the Theronspruit.	Warning signs to be placed at all sites nationally where salinity levels pose a risk to human health.

Table 33: Recommendations Regarding Suspended Solids

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
24.	Implement land use strategies for afforestation and erosion control; A land use policy to be implemented to prevent soil erosion in the upper and middle reaches of the Umtata river.	Each CMA to develop and implement catchment-based land use strategies and policies to control the level of suspended solids in surface water resources.
25.	Illegal small-scale mining to be addressed, since these operations show disregard for environmental standards.	Illegal small-scale mining to be addressed, since these operations show disregard for environmental standards.

Table 33 (Continued): Recommendations Regarding Suspended Solids

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
26.	Small scale miners and communities to be trained on environmental management and health and safety.	Small scale miners and communities to be trained on environmental management and health and safety, including the impacts of mining activities on

		water quality.
27.	Ongoing health and safety and environmental monitoring of small-scale miners by the DME (now Department of Mining) required; Capacity of regulators with regards to small-scale mining to be increased.	Ongoing environmental monitoring of small-scale miners required to ensure that water quality impacts are minimised.
28.	Tax relief and incentives must be promoted for environmentally acceptable mining.	Tax relief and incentives must be promoted for environmentally acceptable mining, specifically including water quality impacts.

Table 34: Recommendations Regarding Bacterial and Viral Pathogens

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
29.	An interdisciplinary working group representing research councils in the medical and water fields as well as the government departments of Health and Water Affairs and the agency responsible for water and sanitation provision should be established to look into the extremely	Multidisciplinary task team to be established to determine the root causes of the high prevalence of mortality from intestinal infectious diseases, propose solutions and oversee their

	high prevalence of mortality from intestinal infectious diseases.	implementation.
30.	Ongoing surveillance of mortality due to intestinal infectious diseases should be carried out.	Ongoing surveillance of national mortality due to intestinal infectious diseases to be carried out.
31.	Identify microbiological hotspots requiring urgent attention.	Microbiological hotspots requiring urgent attention in different parts of the country to be identified and action plans developed together with responsible local authorities.

Note that while it may appear that there are a limited number of recommendations to address bacterial and viral pathogens, many of the root causes of these problems are dealt with through the recommendations that address the eutrophication problem.

Table 35: Recommendations Regarding Estrogen and Estrogen-mimicking Substance

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
37.	Dioxins to be taken into consideration for future investigations.	National capability to analyse samples for dioxins and aldicarb to be established, and these substances to be included in future studies on estrogen and estrogen-mimicking substances.

38.		National prevalence of estrogen and estrogen-mimicking substances in water resources, including drinking water, to be mapped and monitored on an ongoing basis.

Table 36: Recommendations Regarding Pesticides/Insecticides

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
32.	Established international health-based standards (e.g. those developed by the WHO and the EPA) to be adopted by DWA in order to afford a level of protection consistent with the provisions of the South African Constitution; Risk assessment in relation to pesticides to include exposure through	Established international health-based standards (e.g. those developed by the WHO and the EPA) to be adopted by DWA in order to afford a level of protection consistent with the provisions of the South African Constitution.

	a number of pathways, to recognise farm workers' additional exposures and vulnerability factors, should take account of cumulative impacts and should be used to set water standards for drinking and other uses.	
33.	A representative sample of all agricultural areas to be mapped in order to characterise the overall state of water pollution due to pesticides; Continuous monitoring of insecticide residues in the study area to be carried out and coordinated with the National River health Programme; DWA to actively pursue surveillance and monitoring methodologies to protect water supplies from pollution by pesticides; Assessment of the impacts of the use of pesticides in the Umtata River catchment; Data in support of surveillance activities on farms to be effectively captured, in particular toxic release inventories and pesticide use inventories.	A national pesticide monitoring programme to be established to determine, on an ongoing basis, the extent and impacts of pesticide pollution.

Table 36 (continued): Recommendations Regarding Pesticides/Insecticides

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
34.	Policy measures that seek to avoid potential contamination of environmental media and reduce leaching to be encouraged (e.g. integrated pest management, containment liners at mixing sites, training, pesticide reduction); Strict control on the use and distribution of pesticides to be established (Departments of Agriculture and Health) More rigorous policy-based standards to be considered, within the framework of an appropriate national multi-stakeholder process e.g. the National Chemicals Profile;	Holistic policy measures governing the use of pesticides to be developed and implemented in order to minimise the impacts on water resource quality and human health.

	Alternative control measures to chemical control in agriculture and in the malaria control programme to be investigated.	
35.	Communication network to be established between the agricultural sector, the health sector and scientists for the planning and implementation of intervention actions; Workshop a strategic plan for further water related environmental research, development of a decision support system for insecticide use in the study area and the establishment of a policy on pesticide use in malaria areas if necessary (WRC and ARC-PPRI).	Input from the agricultural sector, the health sector, scientists and specialists to be obtained in devising and planning interventions for affected areas, and in the determination of policy.

Table 36 (continued): Recommendations Regarding Pesticides/Insecticides

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
36.	Local government capacity to implement monitoring of pesticides to be audited and strengthened, particularly in rural areas; Practical guidelines for water monitoring for pesticides to be developed for all personnel charged with inspection and enforcement functions; Health, safety and environment training to be provided to employers and employees in farming communities, particularly as regards the empowerment of rural residents in terms of protecting themselves and their communities from the adverse consequences of unintended pollution with pesticides; Training module on pesticide use in the emerging farming sector to be developed and implemented in the study area Rural communities to be provided with simple, cost-effective tools to	A capacity building programme for pesticide monitoring and management targeting all stakeholders to be developed and implemented.

	undertake pesticide monitoring of their own water supplies; Information on safety aspects and the potential impacts of pesticides on human and environmental health to be developed and disseminated in the study area;	

Table 37: Other Recommendations: Non-point Source Management

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
39.	A National Non-point Source Strategy (NNPSS) to be developed as part of the National Water Resource Strategy (NWRS), setting out DWA's intentions for non-point source management in South Africa over the next five years and the requirements of water management institutions, sectors and stakeholders; The National Non-point Source Strategy to be supported by procedures and guides for regulatory personnel for the promulgation of statutory and non-point source management measures and the implementation of non-statutory non-point source management approaches; Generic registration, licensing and water use charging processes (outlined in the Business Process Models as part of WARMS) to be interpreted in order to identify the elements that are important for non-point source management; An implementation plan for the NNPSS to be developed.	A National Non-point Source Strategy (NNPSS) to be developed as part of the National Water Resource Strategy (NWRS).

Table 38: Other Recommendations: Capacity Building

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
40.	Build water quality management capacity among stakeholders in the Wasbank River Catchment.	Appropriate water quality unit standards to be developed in conjunction with the e-SETA in order to facilitate structured implementation of capacity building as required by the NWRS.

Table 39: Other Recommendations: Water Quality management Systems

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
41.	DWA to reinstate the POLMON database in order to improve the state of available data on known point sources of pollution; More detailed studies into pollution sources in significant catchments to be carried out, beginning with catchments with known salinity and nutrient problems; Water quality monitoring points were proposed for the Umtata River in order to ensure that the safety of the water (from a health perspective) may be monitored; Improve the monitoring system for point and non-point sources along the Berg River catchment; Systematic water quality monitoring should be continued throughout the country, paying particular attention to temperature and nutrient data sampling; A water quality data-patching package to allow estimation of pollutant loads from deficient data to be developed. Modelling of water quality issues in South Africa's important agricultural catchments to be carried out; Gather site-specific meteorological data specifically for important impoundments and proposed impoundments (particularly Skuifraam Dam in terms of this study).	National water quality data, pollution source data and pollution modelling needs to be assessed and a programme implemented to ensure that water quality management in all catchments is adequately supported.

Table 40: Other Recommendations: Drinking Water Quality*

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
42.	Compliance to SANS 241 measurement standards to be enforced at all WSA's.	Compliance to SANS 241 measurement standards to be enforced at all WSA's.
43.	Action plans for each WSA to be formulated to address water quality deficiencies, and a monitoring programme to be implemented to assess progress.	Action plans for each WSA to be formulated to address water quality deficiencies, and a monitoring programme to be implemented to assess progress.
44.	A national audit of water purification skills at individual WSA's to be undertaken and a strategy to address skill gaps to be formulated.	A national audit of water purification skills at individual WSA's to be undertaken and a strategy to address skill gaps to be formulated.
45.	Preventive maintenance programmes for all purification plants to be developed and implemented.	Preventive maintenance programmes for all purification plants to be developed and implemented.
46.	The capacity of individual plants to be reconciled to demand, and investments planned to enable the requisite capacity to be installed.	The capacity of individual plants to be reconciled to demand, and investments planned to enable the requisite capacity to be installed.

*All recommendations in Table 40 have been synthesised based on the Western Cape drinking water study, which did not propose recommendations and Mackintosh and Jack (2008), a study considered more representative of the national situation. Hence "clustered" and "final" recommendations are identical.

Table 41: Other Recommendations: Solid Litter

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
47.	All CMA's to produce an integrated strategy as part of the Catchment management Strategy for the management of solid litter.	All CMA's to produce an integrated strategy as part of the Catchment management Strategy for the management of solid litter.

Table 42: Other Recommendations: Radionuclides

NO.	CLUSTERED RECOMMENDATIONS	FINAL RECOMMENDATION
48.	The extent of radionuclide contamination of South African surface and groundwater resources, both in the form of dissolved metals and immobilised contaminants in sediment to be determined and risks to human and animal health to be assessed.	The extent of radionuclide contamination of South African surface and groundwater resources, both in the form of dissolved metals and immobilised contaminants in sediment to be determined and risks to human and animal health to be assessed.

8. CONCLUSIONS AND RECOMMENDATIONS

This review has shown that South African water resources face a number of water quality challenges, most of which are the result of human activity. These challenges have been arranged in order of priority to comply with the terms of reference of this study.

It is clear that none of these risks or challenges should be considered in isolation, since solutions aimed at any single water quality problem could have impacts on other problems. As an example, actions taken to improve service delivery regarding sanitation would reduce the risks of the spread of dangerous pathogens, but would also assist in reducing eutrophication as well as oxygen depletion. What this shows is that while a priority order has been arrived at, the approach used was simplistic, and it is difficult to arrange these water quality challenges in order of importance due to the significant overlap between both the root causes of these problems as well as the approaches that could be used to solve them. A further important conclusion is that addressing the causes of these problems requires widespread and extensive engagement due to the range of stakeholders involved in the causes of each problem, and the stakeholders potentially responsible for the implementation of the final integrated solutions.

The methodology employed in conducting this study presented some difficulties, since the approaches used for investigation and analysis varied widely between the researchers and authors that compiled the source material. Some studies dealt with singular issues e.g. salinity, but where this was the case, this was generally conducted for a specific geographic region. Other reports dealt with a wide range of problems in selected geographical regions. Where national studies were conducted e.g. the study on estrogen and estrogen mimicking substances, the data appeared incomplete. It was therefore challenging to use these diverse sources of information to compile a coherent review of the key challenges. While some studies produced holistic and detailed recommendations, others merely stated the problem without proposing solutions. Recommendations therefore had to be synthesised in some cases.

The most significant issue that was not covered in any detail by the source material was that of radionuclide pollution, which is predominantly associated with gold mining. The fact that the drinking water studies indicated widespread non-compliance with SANS:241 standards as regards heavy metals indicates that should radionuclide contamination be a widespread phenomenon, drinking water may be at risk from radionuclide contamination. In addition, livestock and plant crops could be at risk of contamination, potentially resulting in multiple ingestion pathways. It is recommended that further study be conducted in this area as a matter of urgency.

A number of themes emerge from a review of the consolidated list of recommendations. These are the following:

- Strategies to address specific water quality problems are required. These strategies could be developed within the National water Resources Strategy, but should then be translated into catchment-level strategies, or integrated into catmint management plans.

- The need for a multi-stakeholder, and possibly sector-based approach is apparent. This is a complementary approach to that of strategies aimed at specific challenges, mentioned above. As an example, the proliferation of informal settlements with attendant water quality challenges is an issue requiring input from a range of national Government Departments as well as Local Government, along with other stakeholders. By the same token, as issue such as salinity affects all water use groups, and is in part, caused by diverse business sectors such as mining, irrigated agriculture and manufacturing. It is only in engaging with these sectors to assess and address the underlying drivers of these problems that they can be solved.

- Systems for the measurement of water quality appear to be deficient. Many of the studies contained comments on a lack of sufficient water quality data, both in terms of the measurement of parameters as well as the recording of pollution sources. This is a potential hindrance to the implementation of approaches that require ongoing feedback, an example being the Waste Discharge Charge System.

- Skills in the area of water quality management appear to be lacking and an integrated capacity building strategy is most likely required. Such a strategy should begin with a detailed needs analysis, followed by the design of the appropriate solutions, which could include training, community awareness programmes, coaching and mentoring. Capacity gaps appear to exist among all stakeholders and at all levels, and while capacity building is already an element of the NWRS, a more detailed and holistic strategy is required.

- The impacts on (and of) water quality resulting from service delivery challenges in water and sanitation are shown to be very serious, widespread and multi-dimensional. The problems are both in the area of service delivery roll-out as well as in the operation of existing services. It is clear that even in developed metros, compliance to measurement and reporting standards is poor, exposing consumers of treated drinking water to unnecessary risk. Compliance to nutrient standards, even in sensitive catchments, appears poor, leading to eutrophication and potential oxygen depletion problems. An unacceptably high prevalence of mortality from water-related intestinal diseases indicates that poorly serviced informal settlements and problems associated with existing infrastructure, while not the only source of pathogens, are exacting a heavy toll in terms of the spread of bacterial and viral pathogens.

Despite some of the identified shortcomings of this study, it is concluded that it does provide a useful assessment of the primary water quality challenges in South Africa. It is therefore proposed that the stakeholders debate the consolidated recommendations and that those deemed feasible for implementation be developed further with the requisite implementation agents. An important part of this process would be an assessment of whether some of the recommendations are indeed already in the process of implementation, which could be the case given that an assessment of current initiatives was not part of the scope of this study.

8. APPENDIX 1 – RECOMMENDATIONS EXTRACTED DIRECTLY FROM REPORTS

Table 43: Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE/S ADDRESSED	INCLUDED?
Afrosearch-Index & Agtec (2000). The Economic Cost Effects of Salinity, Agricultural Sector	Recommendations were not made. Recommendations were however made in the integrated report.	Salinity	No
Bourne DE and Coetzee N (1996). An atlas of potentially water-related diseases in South Africa Volume 1	An interdisciplinary working group representing research councils in the medical and water fields as well as the government departments of Health and Water Affairs and the agency responsible for water and sanitation provision should be established to look into the extremely high prevalence of mortality from intestinal infectious diseases.	Pathogens	Yes
Bourne DE and Coetzee N (1996). An atlas of potentially water-related diseases in South Africa Volume 1	Ongoing surveillance of mortality due to intestinal infectious diseases should be carried out.	Pathogens	Yes
Cullis J, Görgens A and Rossouw N (2005). First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments: Salinity, Nitrogen and Phosphorous	DWA to reinstate the POLMON database in order to improve the state of available data on known point sources of pollution;	Deficiencies in water quality data	Yes
Cullis J, Görgens A and Rossouw N (2005). First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments: Salinity, Nitrogen and Phosphorous	WRC to encourage continuing work to determine natural background water quality conditions and run-off loads associated with particular land-use types;	Salinity And eutrophication	No. Research.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Cullis J, Görgens A and Rossouw N (2005). First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments: Salinity, Nitrogen and Phosphorous	Modelling of water quality issues in South Africa's important agricultural catchments to be carried out;	Water quality modelling	Yes
Cullis J, Görgens A and Rossouw N (2005). First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments: Salinity, Nitrogen and Phosphorous	More detailed studies into pollution sources in significant catchments to be carried out, beginning with catchments with known salinity and nutrient problems;	Deficiencies in water quality data	Yes
Cullis J, Görgens A and Rossouw N (2005). First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments: Salinity, Nitrogen and Phosphorous	Farmers, particularly those in high-risk catchments, to be made aware of the impacts of their activities on pollution levels, and encouraged to take action to reduce these impacts and;	Salinity and eutrophication	Yes
Cullis J, Görgens A and Rossouw N (2005). First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments: Salinity, Nitrogen and Phosphorous	DWA to move towards the system used to manage point and non-point source pollution in the USA, that of Total Maximum Daily Load (TMDL), which requires a high degree of monitoring of point sources and the modelling of significant catchments.	Salinity and eutrophication	No. Need to focus on measurement problems first.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Assess pollution sources (particularly salinity) through monitoring of TDS and determination of flow;	Salinity	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Implement land use strategies for afforestation and erosion control;	Suspended solids	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Manage formal and informal settlements to prevent faecal pollution;	Pathogens and eutrophication	Yes
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Refine Resource Water Quality Objectives for the Wasbank River;	Integrated catchment management	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Set compliance requirements for sewage works (both formal and informal settlements), waste disposal sites, mining operations (both abandoned and operational);	Statutory compliance	No. Local issue
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Control residual water quality impacts e.g. treatment options	Integrated catchment management	No. Local issue.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Continue with the dilution of the Vaal Barrage water with releases from the Vaal Dam.	Salinity	Yes. Local issue, but of national importance.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement a waste discharge charge, with revenues to be used to compensate downstream users for “dis-benefit”.	Salinity	Yes. Local issue but of national importance.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement an upgraded water quality monitoring system.	Salinity	Yes. Local issue but of national importance.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement targeted saline effluent treatment schemes.	Salinity	Yes. Local issue but of national importance.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement flow manipulation to manage algal blooms in the middle reaches of the Vaal River	Eutrophication	Yes. Local issue but of national importance.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Audit Wastewater Treatment Works	Eutrophication, microbiological pollution	Yes. Translate to national.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Identify microbiological hotspots requiring urgent attention.	Microbiological contamination	Yes. Translate to national.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Remediation of historical mining operations;	Salinity and suspended solids	Yes. Translate to national.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Ensure adequate surface water flow by removing alien vegetation, quantifying and assessing water and land use, implementing land use strategies to reduce polluted runoff, re-evaluating catchment hydrology and determining the basic human needs Reserve and the ecological Reserve;	Integrated catchment management	No. Too general.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Build water quality management capacity among stakeholders	Capacity building	Yes. Translate to national.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Integrate future development with the WQMS	Integrated catchment management	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Develop and calibrate a water quality simulation model;	Water quality modelling	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Assess management actions before implementation using cost-benefit analysis and water quality modelling	Water quality modelling	No. Local issue.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Maintain and revise the WQMS on an ongoing basis	Integrated catchment management	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Continual monitoring of water quality (chemical, bacteriological and biological);	Deficient water quality data	No. Local issue, self-evident.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Control pollution sources through water use licence applications and Integrated Waste and Water Management Plans.	General	No. This is routinely done.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement nutrient source monitoring plans.	Eutrophication.	Yes. Yes translate to national.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement an upgraded monitoring and reporting plan.	Deficiencies in water quality data	Yes. Translate to national.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement a WWTP upgrade and retrofit project in hotspot areas	Eutrophication and microbiological contamination.	Yes. Translate to national.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Implement nutrient balances and a nutrient model from Vaal Barrage to Bloemhof Dam	Eutrophication.	Yes. Local issue but of national importance.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	Apply nutrient model to investigate alternative eutrophication control strategies.	Eutrophication	Yes. Local issue but of national importance.
Department of Water Affairs, South Africa (2008), Strategy to Supply the Growing Water Demands from the Vaal System, DWA Directorate: National Water Resource Planning.	All dischargers to reduce TDS load by 50-60% by 2014	Salinity	Yes. Local issue but of national importance.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Maintain awareness and communication regarding the WQMS;	Stakeholder engagement	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Evaluate and monitor implementation of the system	Integrated catchment management	No. Local issue.
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Audit water use licences and compliance requirements	Statutory compliance	No. This is a routine function of Government.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Department of Water Affairs, South Africa (2000). Water Quality Management Strategy, Wasbank River Catchment. Final Report.	Audit achievement of instream water quality objectives	Integrated catchment management	No. Local issue.
Department of Water Affairs (2009). Drinking Water Quality Status in the Western Cape: 2008. Chief Directorate: Water Services, Directorate: Planning and Information.	No specific recommendations were made, except to highlight that intervention and remedial measures were required, with the optimisation of disinfection mentioned as an example.	Drinking water quality problems	No
Du Preez M et al (2001). Enteropathogens in water; rapid detection techniques, occurrence in South African waters and evaluation of epidemic risks (health-related). Report No. 741/1/01. Water Research Commission.	Future research is required involving hemi-nested PCR technology	Research – water related disease	No
Du Preez M et al (2001). Enteropathogens in water; rapid detection techniques, occurrence in South African waters and evaluation of epidemic risks (health	A more comprehensive set of environmental samples should be tested for the presence of Vibrio cholerae and Shigella spp. using the hemi-nested method and;	Research – water related disease	No
Du Preez M et al (2001). Enteropathogens in water; rapid detection techniques, occurrence in South African waters and evaluation of epidemic risks (health	The hemi-nested method should be refined to serve as a direct test method and not as a confirmation step only	Research – water related disease	No
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Water quality monitoring points were proposed for the Umtata River in order to ensure that the safety of the water (from a health perspective) may be monitored;	Deficient water quality data	Yes. Translate to national since evident in many of the studies.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Turbidity, nitrates, phosphates, total coliforms and faecal coliforms were proposed for biweekly measurement at each point;	Deficient water quality data	No. Local issue.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Heavy metals (particularly cadmium) were proposed for six monthly measurement at the proposed sampling points;	Deficient water quality data	No. Local issue.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	All point sources were proposed for quarterly monitoring;	Deficient water quality data	No. Local issue.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Amenities (sanitation facilities) to be provided to all rural and peri-urban settlements on the river banks	Pathogens	Yes. Translate to national.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	A land use policy to be implemented to prevent soil erosion in the upper and middle reaches of the river	Suspended solids	Yes. Translate to national i.e. for all CMA's.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Permits to be implemented for discharges of treated and untreated sewage	Pathogens and eutrophication	Yes. Translate to national.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Waste sites along the river banks to be removed and relocated to more appropriate locations	Heavy metal pollution	Yes. Translate to national.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Education of rural community on river pollution and the need for a clean and hygienic environment;	Pathogens and eutrophication	Yes. Translate to national.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Introduction of a bio-monitoring programme for the river	Water quality data	No. Local issue.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Investigation into the source of cadmium pollution and its health-related impacts on the rural community in the catchment	Heavy metal pollution	No. Local issue.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Development of a catchment management programme for the Umtata River catchment and	Integrated catchment management	Yes. Translate to national.
Fatoki OS and Muyima NYO (2003). Situation Analysis of the Health-related water quality problems in the Umtata River. Report No. 1067/1/03. Water Research Commission	Assessment of the impacts of the use of pesticides in the catchment	Pesticide pollution of rural water sources	Yes. Translate to national.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science, University of Stellenbosch. Report No. TT 252/06. Water Research Commission.	Improve the monitoring system for point and non-point sources along the Berg River catchment	Deficient water quality data	Yes. Translate to national.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Link the hydrodynamic river model to a catchment model to estimate water quality loads from un-gauged areas	Water quality modelling NR	No. A research-type issue.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Empirically explore the oxygen mass balance in the Berg River by taking grab samples over a longer period and incorporating COD discharges of the point sources into the river	Research- water quality modelling	No. A research-type issue.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Study different algorithms relating to oxygen and adapt these according to the specific river in the catchment to which they are best suited	Research – water quality modelling	No. A research-type issue.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Investigate the ecological impact of the projected temperature changes expected to accompany the incorporation of the Skuifraam Dam in the upper reaches of the catchment	Research – water quality modelling	No. Local issue.
Grabow WOK et al (2003). Occurrence in Water Sources of ***E.coli*** O157:H7 and Other Pathogenic ***E.coli*** Strains. Report No. 1068/1/03. Water Research Commission.	Research to be conducted into the incidence of E coli pathogens in animal reservoirs, notably cattle but also other animals such as pigs.	Research - Water-related disease	No
Grabow WOK et al (2003). Occurrence in Water Sources of ***E.coli*** O157:H7 and Other Pathogenic ***E.coli*** Strains. Report No. 1068/1/03. Water Research Commission.	Research to be conducted into the incidence of pathogenic E coli infections among humans in South Africa.	Research Water-related disease	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Grabow WOK et al (2003). Occurrence in Water Sources of ***E.coli*** O157:H7 and Other Pathogenic ***E.coli*** Strains. Report No. 1068/1/03. Water Research Commission.	Research to be conducted into phages that transmit the genetic elements coding for toxicity factors to harmless E coli bacteria.	Research - Water-related disease	No
Greef GJ (1990). Detailed Geohydrological Investigations in the Poesjesnels River Catchment in the Breede River Valley with Special Reference to Mineralisation. Report to the Water Research Commission by the Geology Department, University of Stellenbosch. Report No. 120/1/90. Water Research Commission	The release of salts following agricultural development in the study area to be investigated through an experiment.	Research - Salinity	No
Greef GJ (1990). Detailed Geohydrological Investigations in the Poesjesnels River Catchment in the Breede River Valley with Special Reference to Mineralisation. Report to the Water Research Commission by the Geology Department, University of Stellenbosch. Report No. 120/1/90. Water Research Commission	The volume of high quality water stored in the Sandstone mountain watershed and its potential for exploitation using horizontal boreholes to be assessed – this water could be used for low-TDS irrigation and could dilute return flows, improving water quality in the Breë River.	Research - Salinity	No
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Include data on suspended solids and algae production in order to better simulate and understand phosphorous concentration patterns in the Berg River	Research – water quality modelling	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Integrate a catchment model into the Water Quality Information System developed in the study so that tributary inputs can be provided and the DUFLOW model can be developed for scenario analysis, supporting decision-making for integrated water management;	Research – water quality modelling	No
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Continue with systematic meteorological data monitoring throughout the country.	Deficient water quality data	No. No action necessary.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Gather site-specific meteorological data specifically for important impoundments and proposed impoundments (particularly Skuifraam Dam in terms of this study).	Deficient water quality data	Yes.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Systematic water quality monitoring should be continued throughout the country, paying particular attention to temperature and nutrient data sampling.	Deficient water quality data	Yes. Translate to national.
Görgens AHM and de Clercq WP (Editors) (2006). Research on Berg River Water Management. Summary of Water Quality Information System and Soil Quality Studies. Departments of Civil Engineering and Soil Science	Retain the relevance of impoundment modelling for water quality impacts by maintaining contact between researchers/modellers and the developers of the models in use e.g. CE-QUAL-W2.	Water quality modelling	No.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Grabow WOK et al (2003). Occurrence in Water Sources of ***E.coli*** O157:H7 and Other Pathogenic ***E.coli*** Strains. Report No. 1068/1/03. Water Research Commission.	Research to be conducted into improved procedures for recovery of E coli O157:H7 from water.	Research - Water-related disease	No
Grabow WOK et al (2003). Occurrence in Water Sources of ***E.coli*** O157:H7 and Other Pathogenic ***E.coli*** Strains. Report No. 1068/1/03. Water Research Commission.	Research to be conducted into the incidence and behaviour of E coli pathogens in sewage and in raw and treated water supplies.	Research - Water-related disease	No
Greef GJ (1990). Detailed Geohydrological Investigations in the Poesjesnels River Catchment in the Breede River Valley with Special Reference to Mineralisation. Report to the Water Research Commission by the Geology Department, University of Stellenbosch. Report No. 120/1/90. Water Research Commission	Uncontrolled development of new irrigation areas that entail the deep ripping of thin Bokkeveld shales to be restricted .	Salinity	Yes. Translate to national.
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Illegal small-scale mining to be addressed, since these operations show disregard for environmental standards	Suspended solids and salinity	Yes.
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Public involvement in the decisions around environmental issues to be increased	Stakeholder engagement	No. Too general.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Greater emphasis to be placed on regional approaches to "water security" and economic development e.g. pilot scale projects using District Councils as partners	Integrated catchment management	No.
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Small scale miners and communities to be trained on environmental management and health and safety	Suspended solids and salinity	Yes
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Ongoing health and safety and environmental monitoring of small-scale miners by the DME (now Department of Mining) required;	Suspended solids and salinity	Yes
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Capacity of regulators with regards to small-scale mining to be increased	Suspended solids and salinity	Yes
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Rehabilitation bonds to be increased by the DME such that they are sufficient to cover projected costs	Salinity	Yes
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Regulations to be consistently applied to both small and large-scale mines and between regional offices of DME and DWA (DM and DWEA);	Regulatory compliance	No. This is a relevant issue, but too broad.
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Hands-on training as regards rehabilitation to be provided to small-scale miners.	Capacity building	Yes
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Responsibilities for rehabilitation need to be clarified in the cases of State and privately owned land.	Suspended solids and salinity	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Loans for small-scale mining should be made available.	Suspended solids and salinity	No. Not really a water quality issue.
Heath R, Moffett M and Banister S (2004). Water related impacts of small-scale mining. Report No. 1150/1/04. Water Research Commission.	Tax relief and incentives must be promoted for environmentally acceptable mining.	Suspended solids and salinity	Yes
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	The effect of a doubling or trebling of the Vaalharts irrigation return flow TDS on the Vaal River to be urgently assessed	Salinity	Yes. Local issue but of national importance.
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	The existing flow and water quality monitoring system at the Vaalharts scheme to be improved	Salinity	Yes. Local issue but of national importance.
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	A new intensive TDS monitoring system to be employed to allow close monitoring of the potential threat of sudden increases in salinity in the Vaal River.	Salinity	Yes. Local issue but of national importance.
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	A detailed study to be done to verify groundwater storage states, groundwater quality and percolation rates and the processes governing the behaviour of the Vaalharts system. The aim should be to predict when TDS loads returned to the Harts River are likely to increase and to what level they will rise.	Salinity	Yes. Local issue, but of national importance.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	An improved irrigation model to be developed that integrates soil chemistry, groundwater modelling, irrigation practices and advanced crop water modelling and infiltration/surface runoff/soil moisture processes.	Salinity	No. Research-type issue.
Herold CE et al (1996). Lower Vet River Water Quality Situation Analysis with Special Reference to the OFS Goldfields. Stewart Scott Incorporated. Report No. 523/1/96. Water Research Commission.	Catchment Management Plan to be formulated for the OFS Goldfields region and the downstream portions of the Sand-Vet River system.	Salinity	Yes. Translate to a plan for the Vaal River System.
Herold CE et al (1996). Lower Vet River Water Quality Situation Analysis with Special Reference to the OFS Goldfields. Stewart Scott Incorporated. Report No. 523/1/96. Water Research Commission.	Water quality monitoring systems to be improved in the OFS Goldfields region.	Salinity	Yes. Translate to a plan for the Vaal River System.
Herold CE et al (1996). Lower Vet River Water Quality Situation Analysis with Special Reference to the OFS Goldfields. Stewart Scott Incorporated. Report No. 523/1/96. Water Research Commission.	Water quality requirements of users to be determined, including those of the natural environment.	Salinity	No. This was done recently as part of the Vaal River System study.
Herold CE et al (1996). Lower Vet River Water Quality Situation Analysis with Special Reference to the OFS Goldfields. Stewart Scott Incorporated. Report No. 523/1/96. Water Research Commission.	Complete and reliable salt balances constructed for all surface water storage facilities in the OFS Goldfields area.	Salinity	No. Does not address an outcome.
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	The salt balance of irrigated lands along the lower Sand and Vet Rivers to be investigated.	Salinity	No. Does not address an outcome.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	As an interim measure, public warnings to be posted against drinking water from the worst affected river reaches, specifically the Sand River Canal, the Sand River downstream of this canal, the Doring River and the Theronspruit.	Salinity	Yes. Translate to national.
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	Evaluation of the impact of increased TDS export from the Vet River on Bloemhof Dam and the downstream river system to be carried out	Salinity	Yes. Local issue, but of national importance.
Herold CE, Bailey AK (1996). Long Term Salt Balance of the Vaalharts Irrigation Scheme. Report No. 420/1/96. Water Research Commission.	A water quality data-patching package to allow estimation of pollutant loads from deficient data to be developed	Deficient water quality data	Yes. Change to reflect that the data is to be fixed.
Human Sciences Research Council (2000). The Economic Cost Effects of Salinity, Household Sector, Volume II. Report No. 634/1/00. Water Research Commission.	No recommendations were made as part of this study. Recommendations are in the integrated report.	Salinity	No
Kirchner JOG (1995). Investigation into the Contribution of Groundwater to the Salt Load of the Breede River, using Natural Isotopes and Chemical Tracers. Report No. 344/1/95. Water Research Commission.	The strontium isotope ratio method should be tested further for its applicability as regards groundwater fingerprinting;	Research - Salinity	No
Kirchner JOG (1995). Investigation into the Contribution of Groundwater to the Salt Load of the Breede River, using Natural Isotopes and Chemical Tracers. Report No. 344/1/95. Water Research Commission.	Water conductivity and chemical quality survey samples are only to be taken after sufficiently long pumping of boreholes to avoid problems associated with stratification.	Research - Salinity	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Kirchner JOG (1995). Investigation into the Contribution of Groundwater to the Salt Load of the Breede River, using Natural Isotopes and Chemical Tracers. Report No. 344/1/95. Water Research Commission.	Strontium ratio to be determined once or twice during the dry season to ensure a more representative figure for the calculated ground-water contribution, which was based on only one set of samples for this study	Research - Salinity	No
Kühn A et al (2003). Management of Water-related Microbial Diseases. Volume 1 – What is the problem? – Disease Characteristics. Report No. TT 175/03. Water Research Commission.	This is a guide and does not contain recommendations.	Pathogens	No
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	DWA to actively pursue surveillance and monitoring methodologies to protect water supplies from pollution by pesticides	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Local government capacity to implement monitoring to be audited and strengthened, particularly in rural areas	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Rural communities to be provided with simple, cost-effective tools to undertake monitoring of their own water supplies	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Practical guidelines for water monitoring for pesticides to be developed for all personnel charged with inspection and enforcement functions.	Pesticide pollution of rural water sources	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Data in support of surveillance activities on farms to be effectively captured, in particular toxic release inventories and pesticide use inventories;	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	A representative sample of all agricultural areas to be mapped in order to characterise the overall state of water pollution due to pesticides;	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Established international health-based standards (e.g. those developed by the WHO and the EPA) to be adopted by DWA in order to afford a level of protection consistent with the provisions of the South African Constitution.	Pesticide pollution of rural water resources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	More rigorous policy-based standards to be considered, within the framework of an appropriate national multi-stakeholder process e.g. the National Chemicals Profile.	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Risk assessment in relation to pesticides to include exposure through a number of pathways, to recognise farm workers' additional exposures and vulnerability factors, should take account of cumulative impacts and should be used to set water standards for drinking and other uses	Pesticide pollution of rural water sources	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Analytical methods used to measure pesticide exposures to be improved, specifically: (i) The utility of Solid Phase Micro Extraction (SPME) fibres to be assessed for possible adoption as part of a monitoring programme; (ii) Methods involving lower levels of detection to be explored; (iii) Traditional GC pesticide analytical methods to be supplemented with alternative methods e.g. bioassays and immunoassays	Research - Pesticide pollution of rural water sources	No
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Policy measures that seek to avoid potential contamination of environmental media and reduce leaching to be encouraged (e.g. integrated pest management, containment liners at mixing sites, training, pesticide reduction);	Pesticide pollution of rural water sources	Yes
Kühn A et al (2003). Management of Water-related Microbial Diseases. Volume 1 – What is the problem? – Disease Characteristics. Report No. TT 175/03. Water Research Commission.	Research directed at identification of the farming activities to be changed to reduce pesticide contamination to be encouraged;	Pesticide pollution of rural water sources	Yes
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Health, safety and environment training to be provided to employers and employees in farming communities, particularly as regards the empowerment of rural residents in terms of protecting themselves and their communities from the adverse consequences of unintended pollution with pesticides.	Pesticide pollution of rural water sources	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
London L ***et al*** (2000). The Quality of Surface and Groundwater in the Rural Western Cape with Regard to Pesticides. Report No. 795/1/00. Water Research Commission.	Research into the impact of safety training on the health of farm workers and employers to be conducted.	Research - Pesticide pollution of rural water sources	No
Lord DA and Mackay HM (1993). The Effect of Urban Runoff on the Water Quality of the Swartkops Estuary. Report to the Water Research Commission by the Department of Oceanography, University of Port Elizabeth. Report No. 324/1/93. Water Research Commission.	No recommendations are made apart from a proposal for additional research.	Pathogens	Yes. The lessons regarding sewerage system maintenance to be used.
Meintjies E, van der Merwe L and du Preez JL (2000). Qualitative and Quantitative Evaluation of Estrogen and Estrogen-mimicking Substances in the Water Environment. Report No. 742/1/00. Water Research Commission.	Cause and effect and in vivo studies to determine the levels at which estrogen and estrogen-mimicking substances have a measurable effect on the human reproductive status as determined using animals to be undertaken.	Research - Estrogen and estrogen-mimicking substances	No
Meintjies E, van der Merwe L and du Preez JL (2000). Qualitative and Quantitative Evaluation of Estrogen and Estrogen-mimicking Substances in the Water Environment. Report No. 742/1/00. Water Research Commission.	Dioxins to be taken into consideration for future investigations	Estrogen and estrogen-mimicking substances	Yes
Meintjies E, van der Merwe L and du Preez JL (2000). Qualitative and Quantitative Evaluation of Estrogen and Estrogen-mimicking Substances in the Water Environment. Report No. 742/1/00. Water Research Commission.	The extent and levels of estrogenic compounds in sewage effluent to be determined and combined with animal studies by measuring the vitellogenin levels of fish species placed in cages in the sewage effluents in order to determine the relative potencies of these substances.	Research - Estrogen and estrogen-mimicking substances	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Meintjies E, van der Merwe L and du Preez JL (2000). Qualitative and Quantitative Evaluation of Estrogen and Estrogen-mimicking Substances in the Water Environment. Report No. 742/1/00. Water Research Commission.	New methods of detection to be developed or existing methods optimised in order to improve the limits of detection of estrogen and estrogen-mimicking substances.	Estrogen and estrogen-mimicking substances	No. Research.
Moolman JH, De Clercq WP (1993). Data Acquisition and Evaluation of Soil Conditions in Irrigated Fields in the Breede River Valley. Department of Soil and Agricultural Water Science University of Stellenbosch. Report No. 196/2/93. Water Research Commission.	The monitoring of soil conditions in selected irrigation fields to continue, in order to increase and improve data used to validate water and salt transport models of the unsaturated zone;	Research - Salinity	No
Moolman JH, De Clercq WP (1993). Data Acquisition and Evaluation of Soil Conditions in Irrigated Fields in the Breede River Valley. Department of Soil and Agricultural Water Science University of Stellenbosch. Report No. 196/2/93. Water Research Commission.	A study involving the comparison of two sophisticated mechanistic models (LEACHM and another model capable of simulating the chemistry of all the major ions found in agricultural soils) to be conducted and	Research - salinity	No
Moolman JH, De Clercq WP (1993). Data Acquisition and Evaluation of Soil Conditions in Irrigated Fields in the Breede River Valley. Department of Soil and Agricultural Water Science University of Stellenbosch. Report No. 196/2/93. Water Research Commission.	A two- and three-dimensional model that can simulate the transport of water and chemical processes in drip-irrigated fields to be developed.	Research - salinity	No
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	All existing sewage treatment works in the Buffalo River catchment to be upgraded to comply with the 1 mg/l P effluent standard;	Eutrophication	Yes. Translate to national.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Water supplies and sanitary facilities in the squatter section in Zwelitsha to be upgraded.	Pathogens and eutrophication	Yes. Translate to national.
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Breakages in the sewer and reticulation systems in Mdantsane to be controlled and mended	Pathogens and eutrophication	Yes. Translate to national.
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Low flows from the four streams in Mdantsane to be intercepted by means of weirs and diverted to the sewage works in order to prevent spillages from Mdantsane entering Bridle Drift dam.	Pathogens and eutrophication	Yes. Translate to a national recommendation re runoff from settlements.
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Water from Wriggleswade Dam to be used to improve conditions in the Yellowwoods River and to dilute saline water in Laing Dam (subject to investigation of effects on nutrient processes at the inflow to Laing dam and a cost-benefit analysis).	Salinity	No. Local issue.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Rubbish dumps next to the river to be monitored to assess the effect of leachates on water quality during rainfall events. If they are found to be contributing to water quality deterioration they are to be removed or sealed;	Pathogens, heavy metal pollution	Yes. Translate to national together with similar recommendation on Umtata River.
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Impact of runoff from the Textile and Tannery irrigated effluent during rainfall events to be ascertained;	Salinity	No. Local issue.
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Water supplies and sanitary facilities in the squatter section in Zwelitsha to be upgraded.	Pathogens and eutrophication	Yes. Translate to national.
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Gauging weir and associated water chemistry sampling site to be installed upstream of the inflow to Bridle Drift Dam to allow calibration of the hydrological model used for assessing loads flowing into the reservoir	Deficient water quality data	No. Local issue.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
O'Keeffe JH ***et al*** (1996). A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high density urban development on water quality (Volume I). Report No. 405/1/96. Water Research Commission.	Information days to inform local people of the consequences and financial implications caused by vandalism to their sewage and reticulation systems to be organised	Pathogens and eutrophication	Yes. Translate to national.
Pegram GC and Görgens AHM (2001). A Guide to Non-point Source Assessment. Report No. TT142/01. Water Research Commission.	A National Non-point Source Research and Development Programme to be formalised as an outcome from a strategic research planning process facilitated by the WRC	Non-point source pollution	No. See recommendation on NNPS Strategy.
Pegram GC and Görgens AHM (2001). A Guide to Non-point Source Assessment. Report No. TT142/01. Water Research Commission.	The National Non-Point Source Research and Development Programme to have research, technology transfer, capacity building and management policy development themes	Non-point source pollution	No. See recommendation on NNPS Strategy.
Pegram GC and Görgens AHM (2001). A Guide to Non-point Source Assessment. Report No. TT142/01. Water Research Commission.	The National Non-point Source Research and Development Programme to focus on: • Establishment of a limited set of representative catchments to be monitored (as far as possible) using DWA monitoring points over a five-year period; • Use of these catchments for problem-tree analyses of the non-point source causative chain, followed by conceptual development of management frameworks and protocols for each representative causative chain;	Non-point source pollution	No. See recommendation on NNPS Strategy.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Pegram GC and Görgens AHM (2001). A Guide to Non-point Source Assessment. Report No. TT142/01. Water Research Commission.	The National Non-point Source Research and Development Programme to focus on: • Non-point source-related modelling and; • Development of non-point source load "potential" mapping procedures using the latest national land-use mapping and Geographic Information System (GIS) -based integration procedures	Non-point source pollution	No. See recommendation on NNPS Strategy.
Pegram G, Görgens A and Quibell G (1999). A Framework for Implementing Non-point Source Management Under the National Water Act A Discussion Paper. WRC Report No. TT 115/99. DWA Report No. WQP 0.1	A National Non-point Source Strategy (NNPSS) to be developed as part of the National Water Resource Strategy (NWRS), setting out DWA's intentions for non-point source management in South Africa over the next five years and the requirements of water management institutions, sectors and stakeholders	Non-point source pollution	Yes
Pegram G, Görgens A and Quibell G (1999). A Framework for Implementing Non-point Source Management Under the National Water Act A Discussion Paper. WRC Report No. TT 115/99. DWA Report No. WQP 0.1	The National Non-point Source Strategy to be supported by procedures and guides for regulatory personnel for the promulgation of statutory and non-point source management measures and the implementation of non-statutory non-point source management approaches;	Non-point source pollution	Yes
Pegram G, Görgens A and Quibell G (1999). A Framework for Implementing Non-point Source Management Under the National Water Act A Discussion Paper. WRC Report No. TT 115/99. DWA Report No. WQP 0.1	Generic registration, licensing and water use charging processes (outlined in the ***Business Process Models*** as part of WARMS) to be interpreted in order to identify the elements that are important for non-point source management.	Non-point source pollution	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Pegram G, Görgens A and Quibell G (1999). A Framework for Implementing Non-point Source Management Under the National Water Act A Discussion Paper. WRC Report No. TT 115/99. DWA Report No. WQP 0.1	The proposed NNPSS to focus on: • Identification of implications of the NWRS for the NNPSS; • Identification of the requirements of the water resource classification system and determination of resource quality objectives, in terms of non-point source management; • Development of the relationship between the NNPSS and other components of the NWRS, particularly resource protection, point source management and water pricing strategies; • Revision and refinement of the proposed framework for non-point source management; • Exploration of which non-point source management options are appropriate under different conditions, including persuasion, regulation, pricing and co-operative governance; • Detailing of considerations for adoption of alternative statutory measures for non-point source control, including general authorisations, regulations, water use licensing and directives; • Fostering and implementation of co-operative governance arrangements; • Development of regional considerations for non-point source management and; • Specification of requirements for a non-point source management strategy within a Water Management Area (WMA) as part of every catchment management strategy (CMS).	Non-point source pollution	No. This to be part of the development of the strategy. These detailed recommendations may be used as input, but are too detailed at this stage.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Pegram G, Görgens A and Quibell G (1999). A Framework for Implementing Non-point Source Management Under the National Water Act A Discussion Paper. WRC Report No. TT 115/99. DWA Report No. WQP 0.1	An implementation plan for the NNPSS to be developed	Non-point source pollution	Yes
Pieterse AJH and Janse van Vuuren A (1997). An Investigation into Phytoplankton Blooms in the Vaal River and the Environmental Variables Responsible for their Development and Decline.	While not explicitly termed a recommendation, the researchers did suggest that additional investigations into environmental variables be carried out to allow improvement of the mathematical model developed for algal growth predictions. The model was highlighted as being useful as a planning tool in water resource management and for further study of algal blooms. This was primarily an investigative study, and did not produce overarching recommendations.	Research - Eutrophication	Yes. Translate into a national recommendation regarding development of a generic eutrophication model.
Pulles, Howard and de Lange Inc (2000). The Economic Cost Effects of Salinity, Mining Sector, Volume IV. Report No. 634/3/00. Water Research Commission.	No recommendations are made. Recommendations are covered in the integrated report.	Salinity	No
Said M ***et al*** (2005). Origin, fate and clinical relevance of water-borne pathogens present in surface waters. Report No. 1398/1/05. Water Research Commission.	Research into the virulence factors that can help predict the pathogenic capabilities of pathogens detected in the environment.	Research - Pathogens	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Said M ***et al*** (2005). Origin, fate and clinical relevance of water-borne pathogens present in surface waters. Report No. 1398/1/05. Water Research Commission.	Research into the fate of enteric pathogens in aquatic and terrestrial environments	Research - Pathogens	No
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Research regarding insecticide residues and their behaviour in the water environment to be continued in the study area	Research - Insecticide pollution of rural water sources	No. Covered by earlier national recommendations concerning determination of the national pesticide footprint.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Detailed half-life studies of important insecticides such as DDT and pyrethroids under local environmental conditions to be conducted;	Research - Insecticide pollution of rural water sources	No
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Alternative control measures to chemical control in agriculture and in the malaria control programme to be investigated	Pesticide pollution of rural water sources	Yes
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Information on the patterns of insecticide use in the study area to be regularly updated	Pesticide pollution of rural water sources	No. Local issue.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Study on mechanisms of insecticide resistance and cross-resistance in malaria vectors to be carried out	Malaria prevention – not a water quality issue	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Communication network to be established between the agricultural sector, the health sector and scientists for the planning and implementation of intervention actions;	Pesticide pollution of rural water sources	Yes
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Continuous monitoring of insecticide residues in the study area to be carried out and coordinated with the National River health Programme;	Pesticide pollution of rural water sources	Yes, but integrated into the national recommendation.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Strict control on the use and distribution of pesticides to be established (Departments of Agriculture and Health)	Pesticide pollution of rural water sources	Yes
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Training module on pesticide use in the emerging farming sector to be developed and implemented in the study area	Pesticide pollution of rural water sources	Yes. Translate into national. Ensure training is outcomes-based.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Information on safety aspects and the potential impacts of pesticides on human and environmental health to be developed and disseminated in the study area;	Pesticide pollution of rural water sources	Yes, translate into national.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Sources of pesticides in conservation areas to be identified and corrective steps taken to prevent environmental contamination of these areas (DEAT and Department of Agriculture).	Pesticide pollution of rural water sources	No. Local issue.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Resistance monitoring in malaria vectors to be conducted and a strategy developed to manage the development of resistance to insecticides used for anti-malaria spraying (Department of Health, Department of Agriculture and relevant research institutions).	Malaria prevention.	No. Not a water quality issue.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	A decision support system for insecticide use in the study area to be developed (Departments of Agriculture and Health, Agricultural Research Council – Plant Protection Research Institute) and;	Pesticide pollution of rural water sources	No. Research-type issue.
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Establish technology transfer mechanisms to share knowledge gained on the project and build capacity and awareness for extension officers, farmers and communities in the study area.	Pesticide pollution of rural water sources	No. Project-specific.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Sereda BL and Meinhardt HR (2003). Insecticide Contamination of the Water Environment in Malaria Endemic Areas of Kwazulu Natal (South Africa). Report No. 1119/1/03. Water Research Commission.	Workshop a strategic plan for further water related environmental research, development of a decision support system for insecticide use in the study area and the establishment of a policy on pesticide use in malaria areas if necessary (WRC and ARC-PPRI).	Pesticide pollution of rural water sources	Yes. Focus on the need for a policy i.e. workshop this.
University of Cape Town, Africon, Afridev (2000). The Economic Cost Effects of Salinity Water Quality Analysis, Feeder Systems and the Natural Environment Volume VII. Report No. 634/6/00. Water Research Commission.	No recommendations were made. Recommendations are in the integrated report.	Salinity	No
Urban-Econ (2000). The Economic Cost Effects of Salinity, Services Sector, Volume VI. WRC Report No. 634/5/00	No recommendations were made. Recommendations are in the integrated report.	Salinity	No
Urban-Econ (2000). The Economic Cost Effects of Salinity, Industrial Sector, Volume V. Report No. 634/4/00. Water Research Commission.	No recommendations were made. Recommendations are covered in the integrated report	Salinity	No
Urban-Econ Development Economists (2000). The Economic Cost Effects of Salinity Integrated Report. Report No. TT 123/000. Water Research Commission.	Differential desalination to be considered as an option in the study area, since the household sector was found to bear high costs, with lower costs borne by other sectors;	Salinity	Yes. Translate to national.
Urban-Econ Development Economists (2000). The Economic Cost Effects of Salinity Integrated Report. Report No. TT 123/000. Water Research Commission.	The generic model developed in the course of the study should be applied to a more diversified economic area e.g. Gauteng, since the study area was dominated by the mining and services sectors;	Salinity	No. Research-type issue.

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Urban-Econ Development Economists (2000). The Economic Cost Effects of Salinity Integrated Report. Report No. TT 123/000. Water Research Commission.	A salinity awareness campaign to be introduced among users in the study area, since decisions taken could reduce the costs of salinity;	Salinity	No. Project-specific issue.
Urban-Econ Development Economists (2000). The Economic Cost Effects of Salinity Integrated Report. Report No. TT 123/000. Water Research Commission.	The specialised database established in the course of the study to be refined and made more comprehensive through engagement with users in the study area, increasing the robustness of the model and making the model easier to apply elsewhere and;	Salinity	No. Project-specific issue.
Urban-Econ Development Economists (2000). The Economic Cost Effects of Salinity Integrated Report. Report No. TT 123/000. Water Research Commission.	Future study populations to be made aware of the problems associated with salinity in advance to allow more accurate cost estimates and possibly more correct reporting of behaviour.	Research – salinity	No.
Van Ginkel CE et al (1996). A Situation Analysis of Water Quality in the Catchment of the Buffalo River, Eastern Cape, with Special Emphasis on the Impacts of Low Cost, High Density Urban Development on Water Quality. Volume II. Appendices. Institute for Water Research, Rhodes University and Division of Water, Environment and Forest Technology, CSIR. Report No. 405/2/96. Water Research Commission.	Covered by O'Keeffe JH ***et al*** (1996) above	N/A	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Venter SN (2003). The Occurrence of Emerging Viral, Bacterial and Parasitic Pathogens in Source and Treated Water in South Africa. Report No. 1031/1/03. Water Research Commission.	Further research required to assess actual risks of infection by astroviruses from water bodies;	Research - Water -related disease	No
Venter SN (2003). The Occurrence of Emerging Viral, Bacterial and Parasitic Pathogens in Source and Treated Water in South Africa. Report No. 1031/1/03. Water Research Commission.	Molecular techniques for the detection and comparison of Hepatitis E virus in the stool and water samples to be developed	Research - Water-related disease	No
Venter SN (2003). The Occurrence of Emerging Viral, Bacterial and Parasitic Pathogens in Source and Treated Water in South Africa. Report No. 1031/1/03. Water Research Commission.	Use of enrichment media for the testing of environmental samples for the presence of ***Campylobacter*** to be refined;	Research - Water-related disease	No
Venter SN (2003). The Occurrence of Emerging Viral, Bacterial and Parasitic Pathogens in Source and Treated Water in South Africa. Report No. 1031/1/03. Water Research Commission.	Molecular method for identification of all Campylobacter and Arcobacter species from environmental waters to be developed;	Research - Water related disease	No
Venter SN (2003). The Occurrence of Emerging Viral, Bacterial and Parasitic Pathogens in Source and Treated Water in South Africa. Report No. 1031/1/03. Water Research Commission.	Effective isolation method for ***H.pylori*** based on culturing procedures to be researched and;	Research - Water related disease	No
Venter SN (2003). The Occurrence of Emerging Viral, Bacterial and Parasitic Pathogens in Source and Treated Water in South Africa. Report No. 1031/1/03. Water Research Commission.	Effective method for the preparation of environmental samples to be analysed for the presence of microsporidia spores using tissue culture to be developed.	Research - Water-related disease	No

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	A National Eutrophication Strategy to be established within the National Water Resource Strategy.	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	A Eutrophication Strategy to be established within each Catchment Management Strategy.	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	Eutrophication concepts to be incorporated within the National Classification System for aquatic ecosystems;	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	Resource management objectives that include eutrophication problem criteria to be set	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	Land-based control measures to be incorporated into eutrophication policy;	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	Eutrophication management guidelines to be developed;	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	A eutrophication monitoring information system to be developed and managed;	Eutrophication	Yes

Table 43 (continued): Extraction and Categorisation of Recommendations from Water Quality Reports

REFERENCE	RECOMMENDATION	CORE ISSUE ADDRESSED	INCLUDED?
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	A long-term eutrophication research and capacity building programme to support other eutrophication-related activities to be established;	Eutrophication	No. This is an issue that would be debated for inclusion in the strategy.
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	Co-operative governance and commitment of all parties on eutrophication management and control fostered;	Eutrophication	No. Too general.
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	The national eutrophication problem to be quantified in terms of its extent, trends, the sources of nutrients and the extent of nutrient enrichment of aquatic systems and the social and economic costs of the problem	Eutrophication	Yes
Walmsley, RD (2000). A Review and Discussion Document Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. Report No. KV129/00. Water Research Commission.	A eutrophication workshop to be held to develop cooperative structures, identify research gaps and priorities and develop a programme of action.	Eutrophication	Yes

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