NATIONAL WATER RESOURCE QUALITY STATUS REPORT:

INORGANIC CHEMICAL WATER QUALITY OF SURFACE WATER RESOURCES IN SOUTH AFRICA - THE BIG PICTURE

1. PURPOSE OF THE STUDY

The aim of this report is to provide information on the major inorganic chemical water quality constituents of surface waters across South Africa to water resource managers, scientists, decision-makers, and the public. It is intended to provide an overview of the status of the chemical water quality of surface water resources according to the water quality requirements of two water user sectors, namely, domestic water use and irrigated agriculture water use.

2. INTRODUCTION AND BACKGROUND

Water is an excellent solvent and transport medium for particulates, and as such it tends to become contaminated both by natural processes such as erosion, and dissolution of salts geologically present in soils, as well as by man-induced processes and wastes. The latter are both natural e.g. the contamination of runoff water with excreta, as well as artificial, such as the contamination of water with industrial effluents and synthetic chemicals such as pesticide residues.

Water can thus be contaminated by a whole host of substances including:

- Physical soil and clay particles and organic detritus from storm runoff.
- Microorganisms, such as bacteria, viruses, and parasites, from the soil and environment and animal and human wastes.
- Chemical constituents, which can be subdivided into (a) major inorganic chemical salts (such as sodium, chloride, calcium, sulphate, etc.), (b) minor inorganic chemical salts (such as ammonia, fluoride, phosphate and trace metals such as iron, manganese, copper, etc.) and (c) organic substances such as pesticide residues, for example.
- Radioactive substances (which usually occur only in minute concentrations under natural conditions).

The Constitution of South Africa guarantees everyone a right of access to water and a right to an environment that is not harmful to their health or well-being. Section 24 of the Bill of Rights states that:

"Everyone has the right
(a) to an environment that is not harmful to their health or well-being; and
(b) to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that
(i) prevent pollution and ecological degradation;
(ii) promote conservation; and
(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."

The Department of Water Affairs and Forestry, as a custodian of the water resources of South Africa must manage and ensure efficient, equitable and sustainable use of our limited water resources. It is, therefore, the responsibility of the Department to support sustainable operations of potable water and sanitation systems, to monitor and evaluate access to services and to provide the national resource management function with resource quality and technical information.

Status reporting is an obligation of the Department of Water Affairs and Forestry in terms of the National Water Act (Act 36 of 1998). A comprehensive status report would cover a range of water quality problems, including:

- inorganic chemical water quality (major ions and trace metals),
- trophic status of water resources,
- microbiological water quality,
- organic chemical water quality,
- aquatic ecosystem health, and
- radioactivity levels in water resources.

In the broader perspective, status reporting should ideally be carried out on a regular basis for surface water, groundwater and estuaries.

2.1 National Water Quality Monitoring Programmes

DWAF has had a national monitoring programme (the so-called Chemical or Salinity monitoring programme) in place since the early 1970's, as well as established assessment procedures for assessing the inorganic chemical water quality of surface waters. For this programme, samples are regularly collected at approximately1 600 monitoring stations on rivers, at a frequency that varies from weekly to monthly sampling.

A Trophic Status Monitoring Programme is conducted on a much smaller scale for selected South African impoundments that are managed by the Department of Water Affairs. The design of a more extensive Eutrophication Monitoring Programme has been completed and the Trophic Status Programme will be integrated with this programme as soon as it becomes operational.

A national microbiological water quality monitoring programme has been designed and is currently being implemented. At present only a limited sampling network exists and work is underway to extend this network, however, it will be several years before it can provide a national indication of the microbiological water quality.

Organic surface water resource quality sampling occurs for a very small number of sampling sites and no national network is feasible at present because of the costs of sampling and analysis. Initiatives are underway to develop a National Toxicants Monitoring Programme that will include monitoring of organic and heavy metal pollutants. Radioactivity monitoring is done at a regional level only where such problems exist.

This report concentrates mainly on the status of water quality in South Africa, as reflected in predominantly the mineral salt composition. Mineral salts arise both naturally from soil erosion and washout of salts naturally present in the soil, as well as the contribution from human settlements and activities. Land use activities include both domestic (e.g. leading to nutrient enrichment or eutrophication) and industrial (e.g. the contamination of surface waters by acid mine drainage water containing constituents such as sulphate arising from the accelerated oxidation of sulphur bearing minerals in exposed rock consequent to mining operations).

In addition to the information on the major inorganic water quality constituents, information is also given in this report on the nutrient status of selected impoundments that are monitored in South Africa as reflected in the so-called trophic status of the water bodies.

This report does not deal with the microbiological status of the water resources, as this information is not yet readily available. However, as a general rule it must be assumed that all surface water has the potential for microbiological contamination, and needs to be disinfected before drinking.

3. ASSESSMENT METHODOLOGY

3.1 Assessment Basis

Water quality is assessed on the basis of its fitness for use by the domestic and irrigated agriculture water user sectors. These are the two user groups that generally have the most stringent requirements for water quality (with the possible exception of the aquatic environment). Agriculture often does not have the opportunity to pretreat the water to individual requirements before using it. Industry either has similar requirements to those of the above two water users or has the ability to conduct the necessary treatment of the raw water for it to be suitable for their purposes (*e.g.* industries with specific water quality requirements).

The water quality constituents selected for this study are largely limited to those of relevance to domestic and irrigated agriculture water use. The two sets of water quality constituents used as indicators for these water user sectors are reflected in Table 3.1.

Table 3.1 Water quality constituents used in the assessment of fitness-for-use for domestic and irrigated agriculture water use

Domestic Use	Irrigated Agriculture Use
Nitrate +Nitrite as N (NO_3+NO_2 (as N))	Chloride (Cl)
Ammonia as N (NH_4 (as N))	Electrical Conductivity (EC)
pH	pH
Potassium (K)	Boron (B)
Total Dissolved Salts (TDS)	Sodium Adsorption Ratio (Ca; Na; Mg)
Fluoride (F)	
Turbidity	
Sodium (Na)	
Magnesium (Mg)	
Chloride (Cl)	
Calcium (Ca)	
Sulphate (SO_4)	

The assessment classification system used for the assessment of the suitability of water for domestic purposes is based on that described in the Assessment Guide for the quality of Domestic Water Supplies (DWAF, DOH and WRC, 1998) and the water quality guidelines presented in the South African Water Quality Guidelines (DWAF, 1996a and DWAF, 1996b, for irrigated agriculture).

Water quality guidelines or criteria are scientific and technical information provided for a particular water quality constituent in the form of numerical data and/or narrative descriptions of its effects on the fitness of water for a particular use or on the health of aquatic ecosystems.

The two sets of water quality constituents were used as indicators for the relevant water user sectors and the motivation for including these indicators are presented below (DWAF, DOH and WRC, 1998; DWAF, 1996a; DWAF 1996b). The indicators can be linked to specific problems that may be associated with specific land uses and activities. These water quality problems include salination (measured by TDS), acidification by mines and atmospheric deposition and potential toxicity (measured by pH), the impact of erosion (measured by turbidity), nutrient and other problems associated with sewage treatment works and excess fertiliser application in agriculture (measured by constituents such as NH_4 and NO_3+NO_2).

The water quality constituents selected for the assessment of fitness for domestic use have been divided into two groups (Domestic Use – "Health" and Domestic Use – "Salinity") for map representation reasons; primarily since there are too many constituents to be presented clearly on one diagram. The "Health" set includes those variables where there may be a more health-related impact on domestic users, while those constituents in the "Salinity" set are most often those that have an aesthetic (taste and/or scaling) effect on domestic users. The properties of these indicators are described in more detail in the Tables below.

The assessment classification system used for the assessment of the suitability of water for domestic purposes is based on that described in the Assessment Guide for the quality of Domestic Water Supplies (DWAF, DOH and WRC, 1998) and the South African Water Quality Guidelines: Domestic Use (DWAF, 1996a) and for irrigation agriculture, the South African Water Quality Guidelines - Agricultural Use: Irrigation (DWAF, 1996b). The classification system that describes the effects of the different classes of water on the various domestic uses is presented below (Table 3.2 and Table 3.3).

Table 3.2 Domestic "Health" Set: Water quality constituents relevant to the health of domestic water users (DWAF, 1996a and DWAF, DOH and WRC, 1998)

Constituent	Range	Colour Classification	Suitability for Domestic Use
TDS (mg.ℓ$^{-1}$) The TDS concentration provides a measure of the salination of water. It can be enhanced by, for example, excessive use of fertilisers or by the discharge of industrial waste products into a water body or river. TDS also affects the taste of the water, and at high concentrations does not slake thirst.	0 – 450	Blue **Very good water quality**	No health effects.
	450 – 1000	Green **Good water quality**	Insignificant effect on sensitive groups.
	1000 – 2400	Yellow **Fair water quality**	Slight possibility of salt overload in sensitive groups and a slightly salty taste.
	2400 – 3400	Red **Poor water quality**	Possible health risk to all individuals and a salty taste.
	> 3400	Purple **Not acceptable water quality**	Increasing risk of dehydration and a very salty taste.
NO_3+NO_2 (as N) (mg. ℓ$^{-1}$) Nitrate plus nitrite is common in groundwater samples, particularly in areas of intensive agricultural activity, or where pit latrines are used. Severe toxic effects are possible in infants (DWAF, DOH and WRC, 1998).	0 – 6.0	Blue **Very good water quality**	Negligible health effects.
	6.0 – 10.0	Green **Good water quality**	Insignificant risk.
	10.0 – 20.0	Yellow **Fair water quality**	Slight chronic risk of blue baby syndrome to some babies.
	20.0 – 40.0	Red **Poor water quality**	Possible chronic risk to some babies.
	> 40.0	Purple **Not acceptable water quality**	Increasing acute health risk to babies.
NH_4 (as N) (mg. ℓ$^{-1}$)* Ammonium may be indicative of organic waste in the water or excess runoff from fertilised agricultural lands. High concentrations of ammonia can give rise to nitrite that is potentially toxic to infants (DWAF, 1996a).	0 – 1.0	Blue **Very good water quality**	No health or aesthetic effects.
	1.0 – 2.0	Green **Good water quality**	Possible taste and odour complaints.
	2.0 – 10.0	Yellow **Fair water quality**	Consumer complaints of objectionable taste and odour. Disinfection by chlorine can be compromised.
	> 10.0	Red **Poor water quality**	Danger of formation of nitrite. Chlorination is severely compromised.
pH The pH value has a marked effect on the taste of the water and also indicates possible corrosion problems (DWAF, DOH and WRC, 1998).	< 3.0	Brown **Not acceptable water quality**	Acid burns.
	< 4.0	Red **Poor water quality**	Severe irritation of mucous membranes.
	4.0 – 4.5	Salmon **Fair water quality**	Irritation of mucous membranes.
	4.5 – 5.0	Yellow **Good water quality**	Mild irritation of mucous membranes.
	5.0 – 9.5	Blue **Very good water quality**	No health effects.
	9.5 – 10.0	Light blue **Good water quality**	Mild irritation of mucous membranes.
	10.0 – 10.5	Light pink **Fair water quality**	Irritation of mucous membranes.
	10.5 – 11.0	Pink **Poor water quality**	Severe irritation of mucous membranes.
	> 11.0	Purple **Not acceptable water quality**	Alkali burns.
F (mg. ℓ$^{-1}$) Fluoride (F) is often elevated in groundwater in hot, arid areas and can cause damage to the skeleton and mark teeth (DWAF, DOH and WRC, 1998).	< 0.7	Blue **Very good water quality**	No health effects.
	0.7 – 1.0	Green **Good water quality**	Insignificant health effects on sensitive groups and insignificant tooth staining.
	1.0 – 1.5	Yellow **Fair water quality**	Increasing effects in sensitive groups and tooth staining.
	1.5 – 3.5	Red **Poor water quality**	Possible health effects in all individuals and marked tooth staining.
	> 3.5	Purple **Not acceptable water quality**	Increasing risk of skeletal damage.

* Ammonium guideline only sourced from DWAF (1996a)

Table 3.3 Domestic "Salinity" Set: Constituents of concern and water quality guidelines to assess the suitability for domestic use (DWAF, 1996a and DWAF, DOH and WRC, 1998)

Constituent	Range	Colour Classification	Suitability for Domestic Use
Ca (mg. ℓ$^{-1}$) Calcium can cause scaling in electrical appliances and reduce the lathering properties of soap.	0 – 80	Blue **Very good water quality**	No health effects.
	80 – 150	Green **Good water quality**	Insignificant effects.
	150 – 300	Yellow **Fair water quality**	Increased effects in sensitive groups only.
	> 300	Red **Poor water quality**	Chronic health effects in sensitive groups only.
Mg (mg. ℓ$^{-1}$) Magnesium (Mg) affects the taste of water, being bitter at high concentrations (DWAF, DOH and WRC, 1998).	0 – 70	Blue **Very good water quality**	No health effects.
	70 – 100	Green **Good quality water**	Insignificant health effects in sensitive groups only.
	100 – 200	Yellow **Fair water quality**	Increasing effects in sensitive groups only.
	200- 400	Red **Poor water quality**	Potential diarrhoea in all new users (some adaptation is possible).
	> 400	Purple **Not acceptable water quality**	Diarrhoea in all individuals.
SO_4 (mg. ℓ$^{-1}$) Sulphate is particularly common in mining areas and may cause diarrhoea, particularly in users not accustomed to drinking water with high sulphate levels (DWAF, DOH and WRC, 1998). It also affects the taste of the water.	0 – 200	Blue **Very good water quality**	No health effects.
	200 – 400	Green **Good water quality**	Insignificant health effects.
	400 – 600	Yellow **Fair water quality**	Slight chance of diarrhoea in sensitive groups, but disappears with adaptation.
	600 – 1000	Red **Poor water quality**	Possibility of diarrhoea. Poor adaptation in sensitive individuals.
	> 1000	Purple **Not acceptable water quality**	High chance of diarrhoea. No adaptation.
Cl (mg. ℓ$^{-1}$) Chloride is often elevated in hot, arid areas and may cause nausea and vomiting at very high concentrations (DWAF, DOH and WRC, 1998). It also affects the taste of water at higher concentrations.	0 – 100	Blue **Very good water quality**	No health effects.
	100 – 200	Green **Good water quality**	Insignificant health effects.
	200 – 600	Yellow **Fair water quality**	Increasing health risk to sensitive groups.
	600 – 1200	Red **Poor water quality**	Possible long-term health effects.
	> 1200	Purple **Not acceptable water quality**	Dehydration in infants, nausea and vomiting.
Na (mg. ℓ$^{-1}$) Sodium affects the taste of water.	0 – 100	Blue **Very good water quality**	Negligible health effects.
	100 – 200	Green **Good water quality**	Insignificant health effects.
	200 – 400	Yellow **Fair water quality**	Slight risk to some sensitive groups.
	400 – 1000	Red **Poor water quality**	Possible health risk, particularly in sensitive groups.
	> 1000	Purple **Not acceptable water quality**	Definite health risk.
K (mg. ℓ$^{-1}$) Potassium affects the taste of water and may also be bitter at high concentrations (DWAF, DOH and WRC, 1998).	0 – 25	Blue **Very good water quality**	Negligible health effects.
	25 – 50	Green **Good water quality**	Insignificant health effects.
	50 – 100	Yellow **Fair water quality**	Slight risk to some sensitive groups.
	100 – 500	Red **Poor water quality**	Possible health effects.
	> 500	Purple **Not acceptable water quality**	Definite health risk to all individuals.

The effects of the different classes of water on irrigated agriculture are listed in Table 3.4.

Table 3.4 Water quality guidelines applicable to the Irrigated Agriculture Use (DWAF, 1996b)

Constituent	Range	Colour Classification	Suitability for Irrigated Agriculture
SAR The Sodium Adsorption Ratio is an index of the potential of a given irrigation water to induce sodic soil conditions. Negative effects associated with soil sodicity include: reduced crop yield and quality as a result of sodium uptake through the roots of sodium sensitive plants; and impaired soil physical conditions (reduced soil permeability) (DWAF, 1996b).	≤ 2.0 TWQR	Blue **Very good water quality**	Should prevent sodium toxicity from developing, provided that water is applied to the soil surface, limiting sodium uptake through the roots.
	2.0 – 8.0	Green **Good water quality**	The most sodium-sensitive crops absorb toxic levels of sodium through roots. Crops vary in sensitivity.
	8.0 – 15.0	Yellow **Fair water quality**	Sodium-sensitive crops absorb toxic levels of sodium through roots. Crops vary in sensitivity.
	> 15.0	Red **Poor water quality**	All sodium-sensitive crops absorb toxic levels of sodium through root uptake. A number of economically important crops can be irrigated without sodium toxicity developing.
EC (mS.m^{-1}) Electrical Conductivity is increased when increasing levels of salt are present in the irrigation water, which introduces salt into the soil profile. When little or no leaching of the salt takes place from the soil profile, salt accumulates and saline soil is formed (DWAF, 1996b). Yield is reduced in crops that are sensitive to soil salinity.	≤ 40 TWQR	Blue **Very good water quality**	Should ensure that salt-sensitive crops can be grown without yield decreases when using low frequency irrigation systems.
	40 – 90	Green **Good water quality**	A 95% relative yield of moderately salt-sensitive crops can be maintained by using a low frequency irrigation system.
	90 – 270	Yellow **Fair water quality**	A 90 % relative yield of moderately salt-tolerant crops can be maintained by using a low frequency irrigation system.
	270 – 540	Red **Poor water quality**	An 80 % relative yield of moderately salt-tolerant crops can be maintained by using a low frequency irrigation system.
	> 540	Purple **Not acceptable water quality**	These waters can still be used for irrigation of selected crops provided sound irrigation management is practised and yield decreases are acceptable.
pH The pH value of water does not have direct consequences except at the extremes (DWAF, 1996b). The adverse effects of pH result from the solubilisation of toxic heavy metals and the protonation or deprotonation of other ions.	< 6.5	Red **Not Very good water quality (acid)**	Increasing problems with foliar damage.
	6.5 – 8.4 TWQR	Blue **Very good water quality**	Should not cause foliar damage
	> 8.4	Purple **Not Very good water quality (alkali)**	Increasing problems with foliar damage
Cl (mg. ℓ$^{-1}$) Chloride is an essential plant micronutrient and is relatively non-toxic to most crops (DWAF, 1996b). However, when the accumulated chloride concentration in leaves exceeds the crop's tolerance, injury symptoms develop in the form of leaf burn that affect crop production (DWAF, 1996b).	< 100 TWQR	Blue **Very good water quality**	Should prevent accumulation of chloride to toxic levels in all but the most sensitive plants.
	100 – 175	Green **Good water quality**	Crops sensitive to foliar absorption accumulate toxic levels of chloride when foliage is wetted.
	175 – 350	Yellow **Fair water quality**	Crops moderately sensitive to foliar absorption accumulate toxic levels of chloride when foliage is wetted.
	350 – 700	Red **Poor water quality**	Crops moderately sensitive to foliar absorption increasingly accumulate toxic levels of chloride when foliage is wetted.
	> 700	Purple **Not acceptable water quality**	Crops tolerant to foliar absorption increasingly accumulate toxic levels of chloride when foliage is wetted.
B (mg. ℓ$^{-1}$) Boron is an essential plant nutrient that is toxic to plant growth at low concentrations (DWAF, 1996b). Boron tends to be found in association with saline conditions.	< 0.5 TWQR	Blue **Very good water quality**	Should prevent accumulation of boron to toxic levels (through root uptake) in all but the most sensitive plants.
	0.5 – 1.0	Green **Good water quality**	Crops very sensitive to boron accumulate toxic levels (through root uptake). Plants start to display symptoms of foliar injury and/or yield decreases.
	1.0 – 2.0	Yellow **Fair water quality**	Crops sensitive to boron accumulate toxic levels and start to display foliar injury and/or yield decreases.
	2.0 – 4.0	Red **Poor water quality**	Crops moderately sensitive to boron accumulate toxic levels and start to display foliar injury and/or yield decreases.
	> 4.0	Purple **Not acceptable water quality**	Crops moderately tolerant to boron accumulate toxic levels and start to display foliar injury and/or yield decreases.

3.2 Land Cover

Land cover and land use is known to affect water quality. The human activities conducted on land adjacent to rivers and water bodies have an impact on the water quality in a number of ways. Disturbing the land cover may result in erosion and, therefore, increase turbidity, the discharge of treated and untreated wastes into rivers increases the nutrient and ammonia levels, and the diffuse release of excess fertilisers applied to agricultural fields entering rivers and water bodies affects the nutrient balance, amongst other impacts. The geology and natural plant growth also have an impact on water quality and may result in elevated levels of various constituents even in the absence of disturbance by human intervention.

A vast range of land cover types is evident over South Africa (Map 1 and Table 3.5). This would lead one to believe that the water quality would also reflect this complexity by exhibiting a range of specific water quality problems and characteristics. Appendix 8.2 presents the four most dominant (by aerial extent) land cover types in each of the 19 Water Management Areas (WMAs). This information may be of interest to certain readers of this report.

The land cover types reflected in Map 1, Table 3.5 and Appendix 8.2 are extensive and certain effects can be expected of various land cover and land use types. For example:

- Mining and quarries can be expected to be associated with deterioration in water quality due to the exposure of elements previously covered by soil or deep underground to rainfall and runoff. Specific types of mining would be expected to be associated with elevated levels of specific water quality constituents, such as sulphate in the case of coal mining.
- Cultivated lands can also be expected to be associated with specific water quality perturbations, such as: increased turbidity due to increased soil erosion of exposed land; and increased nutrient and salt concentrations due to return flows of fertiliser-carrying irrigation water. If herbicides and pesticides were used, then these could also be expected to make their way into water courses after rain or irrigation events (these substances are not included in this study).
- Various types of degraded lands are often a result of unsustainable human and livestock pressure on the land, with associated increases in turbidity due to the surface cover being removed and then rainfall and runoff carrying the soil to the nearest water course.
- Urban or built-up areas are often associated with increased levels of nutrients and other pollutants.
- Bush, shrub, herb, forest and grassland, if natural and undisturbed, would not be expected to be a reason for water quality perturbations since the vegetation cover should shield the soil from the erosive effects of rainfall and the ground cover should also protect the soil surface.
- Plantations may be associated with higher levels of nutrients if the plantations are fertilised and also higher turbidity levels since there is implicit disturbance in the planting, tending and harvesting of plantations.

The land cover in the vicinity of each sample site (based on Map 1) is presented in Table 3.5.

Map 1 Land cover of South Africa (after Fairbanks *et al.,* 2000)