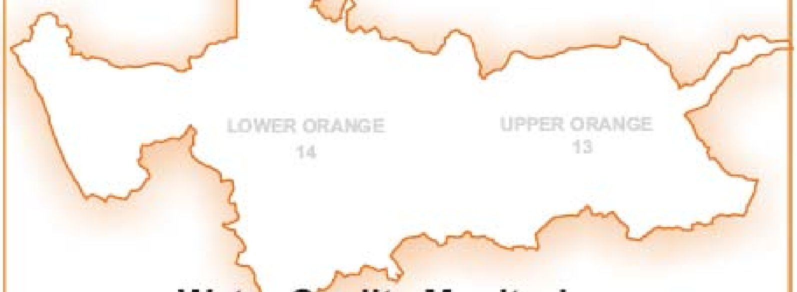
Water Resource Planning Systems

Water Quality Planning

Orange River: Assessment of Water Quality Data Requirements for Water Quality Planning Purposes



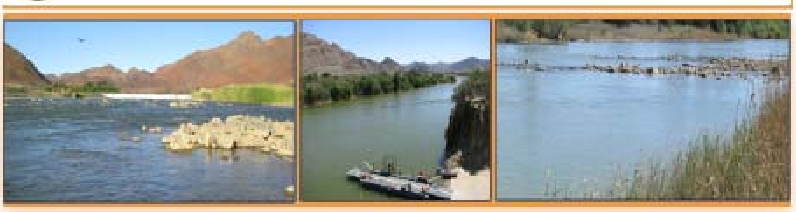
Water Quality Monitoring and Status Quo: Upper and Lower Orange Water Management Areas (WMAs 13 and 14)

Report No:. 3
(P RSA D000/00/8009/1)

June 2009

Final

water & forestry
Department:
Water Affairs & Forestry
REPUBLIC OF SOUTH AFRICA



DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Water Resource Planning Systems

Orange River: Assessment of Water Quality Data Requirements for Water Quality Planning Purposes

Water Quality Monitoring and Status Quo: Upper and Lower Orange Water Management Areas
(WMAs 13 and 14)

Report No.: 3
(P RSA D000/00/8009/1)

June 2009

Final

Published by

Department of Water Affairs and Forestry
Private Bag X313
PRETORIA, 0001
Republic of South Africa

Tel: (012) 336 7500/ +27 12 336 7500
Fax: (012) 336 6731/ +27 12 336 6731

ISBN No. 978-0-621-38690-5

This report should be cited as:

Department of Water Affairs and Forestry (DWAF), 2009. Directorate Water Resource Planning Systems: Water Quality Planning. Orange River: Assessment of water quality data requirements for planning purposes. Water Quality Monitoring and Status Quo Assessment. Report No. 3 (P RSA D000/00/8009/1). ISBN No. 978-0-621-38690-5, Pretoria, South Africa.

DOCUMENT INDEX

Reports as part of this project:

REPORT NUMBER	REPORT TITLE
1*	Overview: Overarching Catchment Context: Upper and Lower Orange Water Management Areas (WMAs 13 and 14)
2.1*	Desktop Catchment Assessment Study: Upper Orange Water Management Area (WMA 13)
2.2*	Desktop Catchment Assessment Study: Lower Orange Water Management Area (WMA 14)
3**	Water Quality Monitoring and Status Quo: Upper and Lower Orange Water Management Areas (WMAs 13 and 14)
4.1*	Catchment Visioning: Upper Orange Water Management Area (WMA 13)
4.2*	Catchment Visioning: Lower Orange Water Management Area (WMA 14)
5**	Resource Water Quality Objectives (RWQOs): Upper and Lower Orange Water Management Areas (WMAs 13 and 14)
6**	Towards A Monitoring programme: Upper and Lower Orange Water Management Areas (WMAs 13 and 14)

* Reports produced by the Directorate, Water Resource Planning Systems, Sub-Directorate Water Quality Planning as part of the study titled *"Development of an Integrated Water Quality Management Strategy for the Upper and Lower Orange River Water Management Areas".*

** Reports produced by Zitholele Consulting on behalf of the Department of Water Affairs and Forestry as part of the study titled *"Assessment of Water Quality Data Requirements for Water Quality Planning Purposes in the Upper and Lower Orange Water Management Areas".*

APPROVAL

TITLE:	Orange River: Assessment of water quality data requirements for planning purposes: Water Quality Monitoring and Status Quo.
DATE:	June 2009
AUTHOR:	J C Roos
REVIEWERS:	R Stassen, S Boshoff and J J van Wyk
LEAD CONSULTANT:	Zitholele Consulting
FILE NO.:	14/2/D000/21/2
REPORT NO.:	P RSA D000/00/8009/1
FORMAT:	MS Word and PDF
WEB ADDRESS:	www.dwaf.gov.za

Approved for Zitholele Consulting:

Ms Priya Moodley
Study Manager

Approved for the Department of Water Affairs and Forestry by:

Mr Jurgo van Wyk
Project Manager: Water Quality Planning

Mr Pieter Viljoen
Deputy Director: Water Quality Planning

Dr Beason Mwaka
Director: Water Resource Planning Systems

ACKNOWLEDGEMENTS

The following individuals are thanked for their contributions to the document:

Project Management Committee

Jurgo van Wyk	Department of Water Affairs & Forestry	Project Manager
Retha Stassen	Department of Water Affairs & Forestry	Project Co-ordinator
Samantha Boshoff	Department of Water Affairs & Forestry	Project Co-ordinator
Priya Moodley	Zitholele Consulting	Study Manager
Jan Roos	Water Quality Consultants	Co-study leader and technical task leader
Pieter Viljoen	Department of Water Affairs & Forestry	Project Director
Seef Rademeyer	Department of Water Affairs & Forestry	Member
Mariette Swart	Department of Water Affairs & Forestry	Member
Mike Mokgwabone	Department of Water Affairs & Forestry	Member
Sam Dywili	Department of Water Affairs & Forestry	Member
Henry Abbott	Department of Water Affairs & Forestry	Member
Willem Grobler	Department of Water Affairs & Forestry	Member
Peter Pyke	Department of Water Affairs & Forestry	Member
Lerato Bapela	Department of Water Affairs & Forestry	Member
Thokozani Mbhele	Department of Water Affairs & Forestry	Member
Lorraine Fick	Department of Water Affairs & Forestry	Member
Salagae Modukanele	Department of Water Affairs & Forestry	Member
Rodrick Schwab	Department of Water Affairs & Forestry	Member
Sebastian Jooste	Department of Water Affairs & Forestry	Member
Ramogale Sekwele	Department of Water Affairs & Forestry	Member
Dragana Ristic	Department of Water Affairs & Forestry	Member
Barbara Weston	Department of Water Affairs & Forestry	Member
Wendy Ralekoa	Department of Water Affairs & Forestry	Member

EXECUTIVE SUMMARY

The Orange River system is of great importance to South Africa because of the heavy reliance of the South African national economy on water from this particular catchment.

The Orange-Senqu River basin spans four Southern African countries (Botswana, Lesotho, Namibia and South Africa) and is one of the largest river basins in Southern Africa. The relatively scarce surface and groundwater resources in the Orange-Senqu basin are critical for the sustainable social and economic development of each country. Existing patterns of land and water use have reached the point where great care is needed to ensure that the scarce and vulnerable water resources are not over-exploited.

The aim of this study was to undertake a water quality assessment of the Orange River (Upper and Lower Orange Water Management areas) to determine the current status, and to provide recommendations for future planning and strategy development activities.

The study included once-off summer and winter monitoring (field surveys) of 38 identified sites for selected water quality variables for the Orange and Caledon Rivers with major tributaries (the snapshot assessment). The water quality variables analysed included:

- *In situ* measurements of pH, Secchi depth, temperature & dissolved oxygen, and electrical conductivity.
- Chemical water quality parameters, including total dissolved salts, alkalinity, mineral ions (HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, F^-, Si & SO_4^{2-}), nutrients [nitrogen (NO_3^{2-} & NH_4^+) and phosphorus (PO_4^{3-}) and TP], dissolved organic carbon (DOC), and metals (Al, As, Cd, Cu, Fe, Mn, Pb, V, and Zn).
- Physical parameters: Turbidity and total suspended solids (TSS).
- Biological parameters: Algal biomass (Chl-*a*), identification and enumeration of phytoplankton species and diatoms analyses.
- Microbiological parameters: Total coliforms, which is indicative of the general hygienic quality of the water and *E. coli* which is used to evaluate the quality of the water.

Historical data on physico-chemical parameters as well as hydrological data were also obtained from Resource Quality Services (RQS), Department of Water Affairs and Forestry (DWAF) for the monitoring sites on the Orange and Caledon Rivers and some major tributaries registered in the National Chemical Monitoring Programme. Where available, analysis of historical data (as on WMS and other sources) and comparison to once-off snapshot monitoring results was done. A desktop assessment of the water quality of Lesotho was undertaken. Water quality data from monitoring sites on the Senqu River (upper Orange River) were obtained from the Department of Water Affairs (DWA) in Maseru, Lesotho. The data were analysed and compared with the downstream sites on the Orange River within South Africa.

MAIN FINDINGS:

Current Water Quality Status

- ♦ The water quality and quantity in the uppermost reaches of the Orange River, above Gariep Dam, is still in a fairly natural state and show minor changes over the past 35 years.

- ♦ The water in the uppermost reach is moderately soft, relatively low in salt concentrations, but generally high in suspended solids and turbidity.

- ♦ The water quality in the upper Orange River was suitable for domestic use, recreational use and irrigation with low TDS and low SAR (sodium adsorption ratio).

- ♦ The concentration of total suspended solids (TSS) and turbidity in the upper Orange River are high because of soil erosion, but fluctuate seasonally. However, the TSS in the Orange River in and downstream of the major dams, has decreased extensively (up to 97 %) during the past 35 years, which has decreased the turbidity, therefore increases the underwater light regime and the potential for algal blooms.

- ♦ The pH values in the whole Orange River were high (median, 8.1); generally increase downstream and occasionally exceeds the upper limit for irrigation of 8.4.

- ♦ The overall dissolved salt concentrations in the Orange River are increasing significantly (in space and time), especially in the Lower Orange (below Marksdrift), that occasionally exceeds 500 mg/ℓ, with negative consequences for the river's ecosystem as well as for crop production further downstream.

- ♦ The dissolved oxygen (DO) concentration (daytime) in the surface water of the Orange River were high (mean, >90 %) in the whole river during both snapshot surveys. The increasing trend downstream is ascribed to the higher chlorophyll-*a* concentrations downstream.

- ♦ The *E. coli* concentrations in the Orange River were during the snapshot surveys, generally low (<130 cfu/100 mℓ) and suitable for full contact (swimming) recreational use, although many complaints of poor performing sewage works were received.

- ♦ The mean phosphate concentrations in the Orange River were moderately and more or less the same in the whole river (30 ± 10 µg/ℓ).

- ♦ The dissolved inorganic nitrogen (DIN) concentrations have decreased at most of the sites during the past 15 years. DIN also declined significantly from upstream to downstream (spatially), in particular from Vanderkloof Dam (mean, 0.547 mg/ℓ) to Alexander Bay (mean, 0.169 mg/ℓ). The decrease is probably because of high denitrification processes, biogenic assimilation, sediment burial, and limited inflows that can replenish the nitrogen in the lower Orange River.

- High N:P ratios (>14) in the Upper Orange River, indicate that phosphorus is potentially limited. However, the N:P ratios drop significantly from Prieska (median, 28) to less than 7 at Pella and downstream that indicate a switch to N limitation in the lower end of the river.

- Silicon retention has been observed in the Orange River basin with very low concentrations (average 2.75 mg/ℓ) at Alexander Bay. The temporal and spatial silica decline in the Orange River is mainly due to dam constructions, lower suspended solids; biogenic uptake followed by Si burial, and could also effects the coastal biogeochemical cycles and food web structure.

- The mean chlorophyll-*a* concentrations (algal biomass) in the Gariep and Vanderkloof Dams were low (<5 µg/ℓ) and fall in the range of oligotrophic systems, but the Chl-*a* concentrations, and blooms, were much higher at Upington and Pella (mean 17 µg/ℓ) corresponding to mesotrophic water bodies. Generally high Chl-*a* concentrations (up to 40 µg/ℓ) were recorded in the Lower Orange River (Pella to Alexander Bay) during the snapshot surveys.

- The concentration of some metals, Al, Cd, Cu and Pb, were occasionally unacceptable high and potentially harmful for human health and for the aquatic environment – the reason for the high metal concentrations at Upington, Neusberg weir, Pella, and Vioolsdrift are unclear and should be investigated further. Mining activities in the area could be a potential source of some of the metals observed.

- The water quality in the Lower Orange River was occasionally above the target water quality range (ideal) for irrigation especially because of high salts and high pH values.

- Some of the water withdrawn for irrigation is returned to the river environment for reuse, but its quality is seriously degraded with considerably higher salts and nutrient concentrations and evidently contributes significantly to the salts load in the Orange River.

- However, the contribution of DIN concentrations from irrigation return flows to the Orange River is apparently low; in fact the DIN concentrations decrease continuously from Vanderkloof Dam downstream to Alexander Bay. Even in the intensive irrigation areas, no significant increases in the DIN concentrations were observed. The possible impact of return flows on groundwater should be investigated.

- Water quality data (1999 to 2008) from DWA, Maseru for five sampling stations on the Senqu River in Lesotho, in general don't match the results discussed in this report. Most of the concentrations are not viable values and cannot be accepted. Therefore, water quality results from DWA, Lesotho were rejected as unrealistic and unreliable and not useable to make any scientific conclusion.

Flow Regulation Impacts

- The controlled releases of water from the major storage dams (Gariep and Vanderkloof) have improved the reliability of supply to water users along the lower reaches of the Orange-Senqu River in South Africa and Namibia with the result that the river no longer experiences periods of zero flow.

- However, dams are a principal threat to freshwater diversity and that threat is largely mediated through loss of habitat frequently involving modifications to the natural flow regime and to blockage of migrations.

- The construction of the dams have also homogenized the flow regimes, chiefly through modification of the magnitude and timing of ecologically critical high and low flows. It also has greatly dampened the seasonal and interannual stream flow variability of the Orange River, thereby altering natural dynamics in ecologically important flows.

- The Orange is a highly regulated river. River regulation modifies the sediment regime of a river through retention of material within the reservoirs (dams) and through modification of downstream erosion and deposition processes.

- Sediment concentrations in the Orange River declined following 1971 (after dam construction); the dams trapped large amounts of sediments and dramatically altered the transport patterns of suspended sediments downstream in the river.

- Phytoplankton abundance and production are controlled by stream flow. This is related to residence time, channel depth, and dilution rate and affects water transparency and sedimentation.

- River regulation has increased the risk of algal blooms through the combination of low flows and weir pools that create stratified conditions favourable for algal growth.

- The algal blooms in the Orange River are probably not primarily driven by nutrients, but are caused by changes in physical conditions, *i.e.* lower stream flow, lower TSS and higher light availability because of clearer water.

- The Lesotho Highlands Water Project has resulted in large volumes (770 Mm^3/a) of low salinity water being diverted from the Orange River into the Vaal River catchment. This has lead to an increase in salt levels in the Gariep and Vanderkloof dams.

- The implementation of the new Polihali Dam (second phase of the LHWP) in Lesotho will influence (reduce) the flow of water into the Gariep and Vanderkloof dams, which in turn will have a negative influence on water quality and availability in the lower reaches of the Orange River.

- Flow regulation and increased salinity are recognised as the two main factors that have impacted (and continue to impact) negatively on the environmental health of the lower Orange River.

Low Flows

- The water volume flow has been much reduced in the Lower Orange River, as has the frequency, duration and magnitude of flooding.

- Water availability in the Orange River catchment is already at a critical stage (<1 000 m^3/p/a).

- All stream flows are not equal; the natural flow in the river after rain has a total different effect on the water quality and environment compared to an unnatural controlled release of water from a dam. The natural seasonal inverse relationship between stream flow and dissolved salts as seen in the upper Orange is not applicable to the unnatural releases of water from the storage dams, which shows no seasonal variation.

- Inter- and intra-catchment water transfer schemes, river diversions (primarily for irrigation), and evapotranspiration have reduced the natural stream flow in the lower Orange River (below Marksdrift) to half or less than the natural levels, e.g. from about 350 m^3/s to 150 m^3/s at Upington.

- The total virgin mean annual discharge (VMAD) of the Orange River has decreased dramatically, for example, at Vioolsdrift the VMAD of some 13 000 million m^3 (1940s) has been reduced by 60 % to approximately 5 000 Mm^3 today.

- Lower stream flow increases the susceptibility of the river to pollution because it will reduce its capacity to attenuate and degrade wastes, will concentrate pollutants and increase salinity, as the dilution effects of the Orange River will be reduced.

- The lack of flow variability and the overall reduction in water volume poses a serious threat to the integrity of the river mouth Ramsar wetland.

Major Tributaries

- The annual stream flow in the three major tributaries to the upper Orange River, namely, Caledon River, Kornetspruit and Kraai River are very similar, *i.e*. 558, 583, and 652 Mm^3 respectively.

- The general water quality in Kornetspruit and Kraai River was good. Sterkspruit was polluted with sewage effluent indicated by high *E. coli* counts, high DOC concentration, and high nutrient (N & P) concentrations.

- The Seekoei River's salt and nutrient concentrations are high but are considered to represent natural conditions, although the stream flow in the river has decreased dramatically and indicates over-extraction and/or damming of the water.

- The water quality in the Riet and Vaal River was poor, especially due to high dissolved salts.

- The pollution levels are unacceptably high in the Stormbergspruit at Burgersdorp. The high nutrients (N & P) and faecal coliforms contamination indicate that poorly treated sewage has been entering the system since 1992.

- The water quality in the Caledon River is highly variable but in general is in a fair condition, however, pollution levels (nutrients and faecal contamination) at Ficksburg and Maseru is a matter of concern.

- The Caledon River is characterized by extreme seasonal fluctuations in turbidity (min. 0.5; max. 10 000 NTU) and with a mean value of 400 NTU (at Kommissiedrift) is probably the most turbid river in South Africa.

- The Little Caledon at Golden Gate is in terms of water quality in a very good condition, but shows signs of deterioration (higher salts and nutrients) downstream at the confluence with the Caledon River.

- The water quality in Meulspruit was good and moderate in Leeu River, with relatively high nitrogen concentrations, but low SAR values – ideal for irrigation.

- Moperispruit was characterised by relatively high salts concentrations (especially Cl), with a low diatom SPI score (8.3, poor quality), but with a SAR of 2.01 still acceptable for irrigation.

- Grootspruit (close to Fouriesburg) showed signs of sewage pollution with faecal contamination, nutrient enrichment and high periphyton growth on rocks associated with high pH and dissolved oxygen concentrations. Relatively high dissolved salts and metals were recorded, however, a high diatom score (SPI) indicate good water quality.

<u>Monitoring and Research Needs:</u>

The status assessment task also identified certain gaps in the current monitoring system. Amongst these were the discontinuation of sampling at strategic sites, poor sampling frequency, and important variables that were not measured. New monitoring sites are also proposed. These are addressed in the monitoring report, No. 6.

In future, additional inter- and intra-basin water transfer schemes will be needed to meet the growing demands for water in the Orange-Senqu and neighbouring basins, as well as to meet international and Southern African Development Community (SADC) obligations to share water equitably, thus increase the pressure on the aquatic ecosystem with potential devastating effects. In addition, climate change may result in increased precipitation variability and a resultant increased frequency in flood and drought events.

Research needs were identified and an integrated water resources management process for the Orange River is proposed for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

%PTV	Percentage of pollution tolerant valves (diatoms)
µg/ℓ	Microgram per litre
AEV	Acute Effect Value
AMSL	Above mean sea level
CEV	Chronic Effect Value
Cfu	Colony forming units (bacterial count unit)
Chl-*a*	Chlorophyll-*a*
DIN	Dissolved inorganic nitrogen (NO_3-N + NO_2-N + NH_4-N)
DIP	Dissolved inorganic phosphorus (PO_4-P)
DMS	Dissolved major salts
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DTEC	Department of Tourism, Environment and Conservation
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
E. coli	*Escherichia coli* (bacteria, indicator of faecal pollution)
GEMS	Global Environment Monitoring System – United Nations
GGP	Gross Geographic Product
GPS	Global Positioning System
IBT	Inter-basin Transfer
IGS	Institute for Groundwater Studies
IWRM	Integrated water resources management
Kjel N	Kjeldahl Nitrogen
LHWP	Lesotho Highlands Water Project
LOR	Lower Orange River
mg/ℓ	Milligrams per litre
Mm^3	Million cubic metres
m^3/s	Cubic metres per second (1 000 litres per second)
m^3/p/a	Cubic meters per person per annum
N:P	Nitrogen to Phosphorus ratio
NCMP	National Chemical Monitoring Programme
NEPAD	New Partnership for Africa's Development
NMMP	National Microbial Monitoring Programme
NTU	Nephelometric turbidity units
ORASECOM	Orange-Senqu River Commission
RHP	River Health Programme
RWQO	Resource Water Quality Objective

RQS	Resource Quality Services
SA	South Africa
SADC	Southern African Development Community
SADC-HYCOS	The Southern African Development Community Hydrological Cycle Observing System
SAR	Sodium Adsorption ratio
SAWQGs	South African Water Quality Guidelines
Si	Silicon
SiO_2	Silica or silicon dioxide
SPI	Specific pollution sensitivity index (diatoms)
TAL	Total Alkalinity
TDS	Total dissolved solids
TN	Total nitrogen (Kjeldahl Nitrogen + NO_3-N +NO_2-N)
TP	Total Phosphorus
TSS	Total suspended solids
TWQR	Target Water Quality Range
UFS	University of the Free State
VMAD	Virgin mean annual discharge
WMA	Water Management Area
WMS	Water Management System
WRYM	Water Resources Yield Model
WUA	Water Users Association

1 INTRODUCTION

1.1 Background

South Africa is a water stressed country (<1 700 m^3 per person annually) and will probably face water scarcity (<1 000 m^3/p/a) by 2025 (GEO-2000, 1999). Increased stresses on the world's water are affecting quality, quantity and availability. Therefore the need to protect and not pollute valuable freshwater resources cannot be overemphasised. Rising demand for increasingly scarce water resources is leading to growing concerns about future access to water, particularly where water resources are shared by two or more countries.

The availability of water and its physical, chemical, and biological composition affect the ability of aquatic environments to sustain healthy ecosystems; as water quality and quantity are eroded, organisms suffer and ecosystem services may be lost. Moreover, an abundant supply of clean, usable water is a basic requirement for many of the fundamental uses of water on which humans depend (UNEP-GEMS, 2006).

Rivers are the most important freshwater resource for man. Social, economic and political development has, in the past, been largely related to the availability and distribution of freshwater contained in riverine systems (Chapman, 1996).

The Orange River (also known as the Gariep River) is the largest and longest river in South Africa. At almost one million square kilometres the Orange-Senqu River catchment is the largest basin south of the Zambezi and stretches over four countries – South Africa, Lesotho, Botswana and Namibia (**Figure 1**). About 60 % of the 1 000 000 km^2 area of the Orange River catchment lies in South Africa. The remainder falls within Namibia (25 %) and Botswana (13 %), completely encapsulating Lesotho (2 %). It originates as the Senqu River in the Maluti Mountains in the highlands of Lesotho, from where it drains westward to cut through the dry Richtersveld Mountains (Augrabies Falls), before it discharges into the Atlantic Ocean at Alexander Bay (**Figure 1**).

The Orange River system is of great importance to South Africa since it drains about 48 % of the total area of the country and the natural flow represents more than 22 % of the country's surface water resources. South Africa has a high economic dependence on the Orange, with a staggering 100 % of the gross geographic product (GGP) of Gauteng Province being dependent on inter-basin transfers (IBTs) involving the Orange system (Basson *et al*., 1997). The fact that the Gauteng Province is 100 % reliant on IBT water, all of which is channeled through the Vaal River system, illustrates the strategic importance of the Orange River basin, given the heavy reliance of the South African national economy on water from this particular basin (Turton, 2005).

1.2 Climate

The mean annual rainfall for the catchment is about 400 mm per year, with a high degree of variability from approximately 2 000 mm per year in Lesotho to about 50 mm per year at the Orange River mouth. Over 50 % of the area of the Orange River Basin can be classified as hyper-arid to semi-arid, with aridity increasing to the west (UNEP, 2005). The two driest WMAs in SA are the Lower Orange and Lower Vaal as both are located in the semi-desert on the far western side of the country (Stat SA, 2008). Runoff extremes have been recorded between 26 000 million m^3/a and as little as 1 100 m^3/a due to climatic variations (Conley & Van Niekerk, 1998).

Potential evaporation is equally variable, from 1 200 mm per year in Lesotho to 3 500 mm per year at the river mouth (UNEP, 2005). The calculated evaporation losses from the Orange River ranged from 575 million m^3/a at an annual low flow release rate of 50 m^3/s to 989 million m^3/a at an annual release rate of 400 m^3/s (McKenzie & Craig, 2001).

Some major features of the Orange River Systems are listed in **Table 1**.

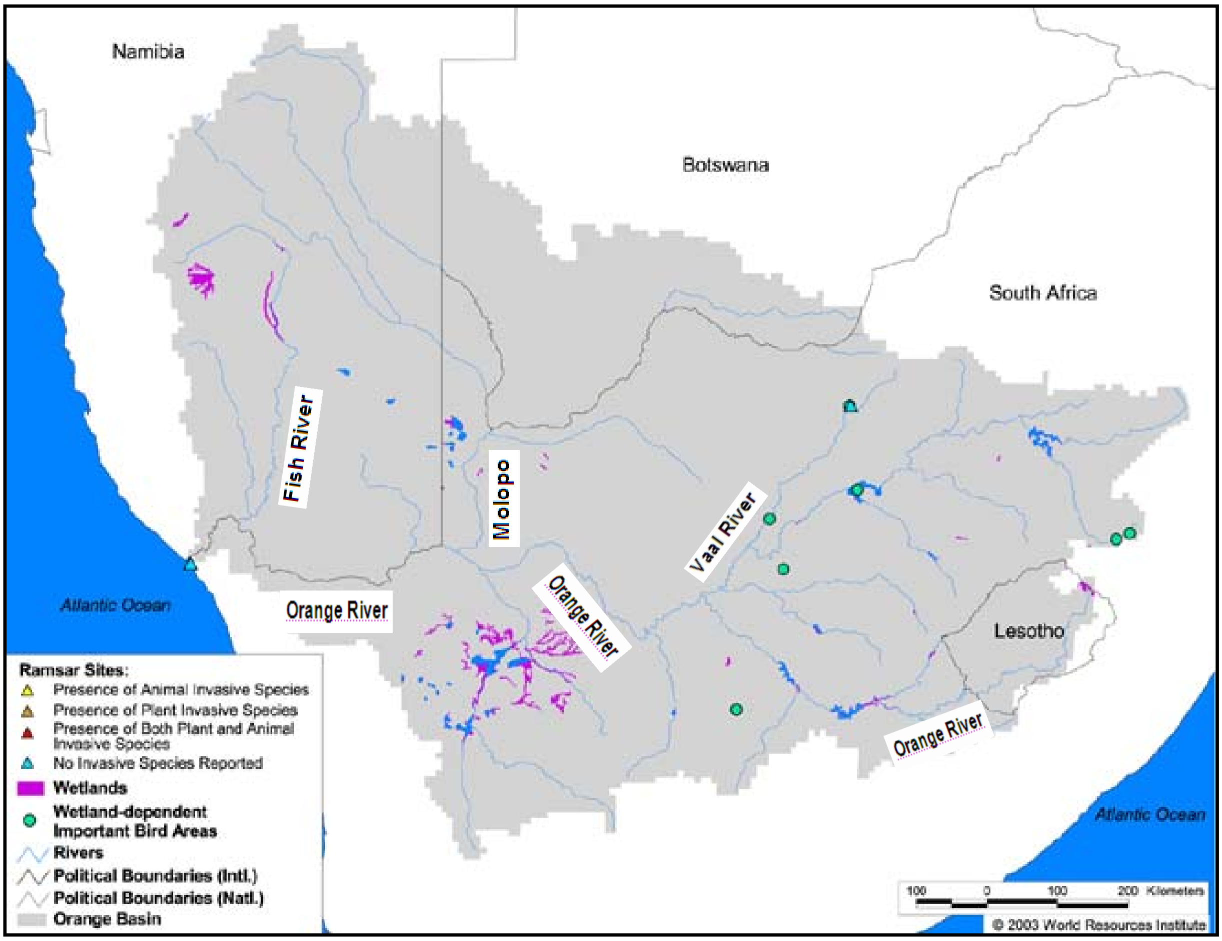


Figure 1: Orange-Senqu River basin shared with four other countries – modified from Earth Trends 2002, World Resources Institute.

1.3 Water Resources

The surface water resources, which naturally occur in the WMA (together with inflows from Lesotho), are already well developed, and with a high degree of utilization. The natural water resources of the Orange River basin are estimated to be in the order of 12 000 million m^3/annum (Mm^3/a), although less than half of the available water is currently abstracted by various developments in the Orange and Vaal basins. Approximately 4 000 Mm^3/a of the natural runoff originates in the Lesotho Highlands, and approximately 800 Mm^3/a originates from the contributing catchment downstream of the Orange-Vaal Rivers' confluence. The remaining 6 500 Mm^3/a originates from the areas contributing to the Vaal, Caledon, Kraai and Middle Orange Rivers.

The Vaal River is a major and very important tributary of the Orange River, and is regarded as being a river basin in its own right and provides Gauteng with all its water. Extensive water resource developments have taken place upstream of this confluence, including several large dams and inter-basin transfer schemes. Results from the Water Resources Yield Model (WRYM) showed that at 2005 development level, on average, 1 680 Mm^3/a enters the Orange River from the Vaal River catchment (DWAF, 2008b).

Table 1: Major features of the Orange River Catchment (Earle *et al.*, 2005; Earth Trends, 2002, Revenga *et al.*, 2000; UNEP, 2005 & Wikipedia, Website).

Total catchment area (km^2)	1 000 000
River length (km)	2 200*; 2 415#
Area rainfall (mm/a)	Average, 330; (range: <50 to >2,000)
Average annual discharge (million m^3)	11 500
Arid	77 %
Evaporation – potential (mm/a)	1 200 to 3 500
Population	22 million (year 2004)
Population density	22 persons/km^2
Water demand	Total = 6.5 km^3/a; (Agriculture 64 %, urban supply 23 %, rural supply 6 %, mining and other 7 %)
Major dams	5 (Gariep, Vanderkloof, Sterkfontein, Vaal and Katse Dam) – total storage 20 412 Mm^3
Water availability	<1 000 m^3 per capita – scarcity
Total fish species	24
Fish endemics	7
Threatened fish species	2
Endemic bird species	2
Protected area	5 %
Wetlands	1 %
Ramsar sites	4 (Barberspan, Blesbokspruit, Seekoeivlei and Orange River Mouth)

* Wikipedia; # own measurements

The bulk of the surface water in the Lower Orange WMA is therefore found in the main stem of the Orange River, with virtually all coming from the Upper Orange WMA. Most of the run-off generated in the Lower Orange WMA comes from the Fish River in Namibia and is only entering the main Orange River close to the River mouth.

1.4 Topography

The Orange River length is reported in the literature to be between 1 900 to 2 300 km. However, the river length was calculated to be 2 415 km from a detailed measurement in Google Earth and Garmin MapSource (**Figure 2**). This would place the Orange River as the 44th longest river in the world (Wikipedia, Website).

The mountainous topography in Lesotho results in a sharp river slope with an average of about 3.9 m/km for the first 400 km, but from the South African boarder to Upington bridge the flat topography results in a moderate low slope of about 0.55 m/km, followed by the lower reach (Upington to river mouth) where the river drops on average with 1.04 m/km, including the Augrabies falls.

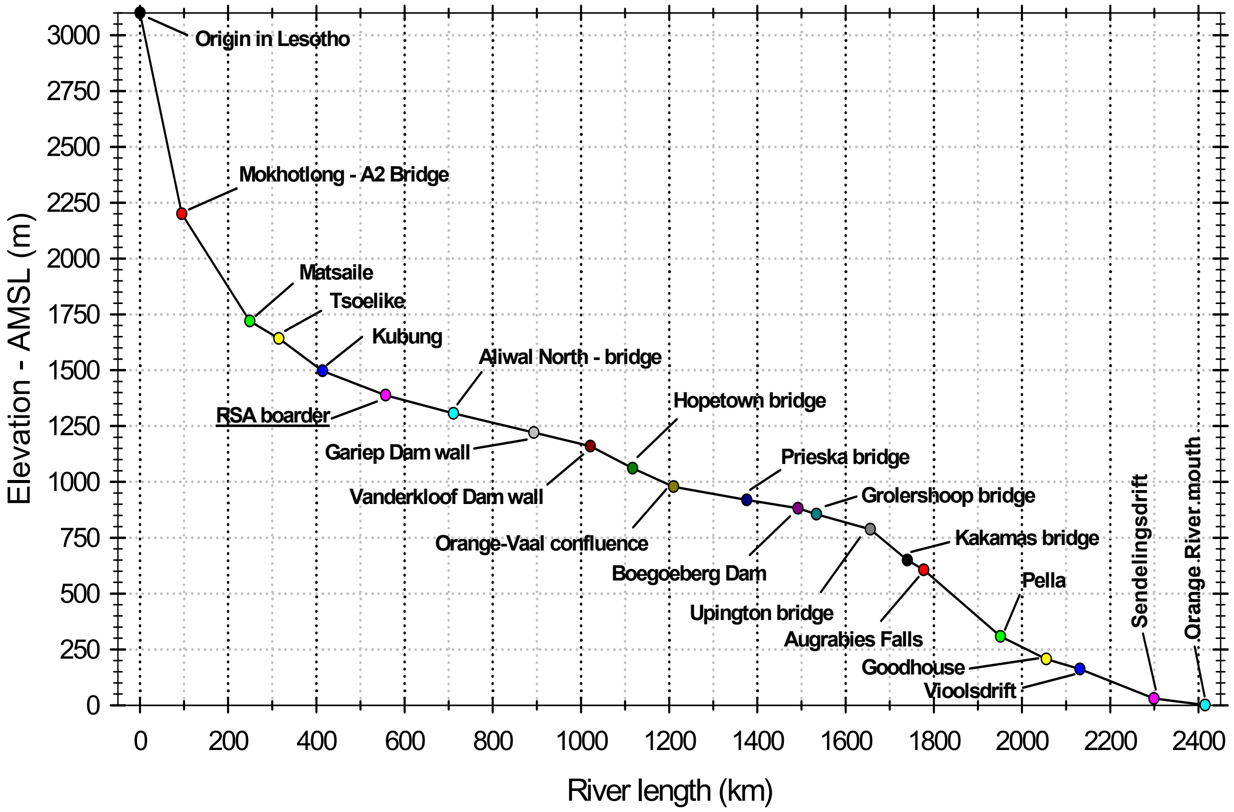


Figure 2: Altitude profile of the Orange River. Measurements were made in Google Earth and MapSource (Garmin).

1.5 Geology

The geology of the Orange River Basin is dominated by the consolidated sedimentary rocks of the Karoo succession, the volcanic extrusives of the Lesotho Highlands, dolomite successions and Kalahari sand cover. Of these, only the Kalahari sands contain water in primary openings. Groundwater is contained mainly in fractures and larger dissolution openings (UNEP, 2005). For the South African part of the Orange River Basin, hydrogeological information can be obtained from Vegter (1995; 2001).

1.6 Development of the Orange River

The Orange River basin is the most developed of all the rivers in Southern Africa, with at least twenty-nine dams having a storage capacity of more than 12 x 10^6 m^3 (Turton, 2005). The Orange River (together with its main tributary the Vaal River) is controlled through storage reservoirs in the upper WMA and in Lesotho, with limited regulation capacity in the Lower Orange WMA. The main storage dams are Gariep and Vanderkloof.

The construction of the Gariep and Vanderkloof Dams in the Orange River made a great contribution towards the establishment and maintenance of irrigated crops throughout large sections of the Orange River, however, with a negative impact on the environment.

Large-scale infrastructural development (dams, etc.) and water abstraction in the catchment results in only half of the 11 500 million m^3 annual runoff reaching the Orange River estuary in the west – see section 9.1. Until today most of the Orange's water is used for irrigation farming, *i.e.* about 2 160 Mm^3/a to irrigate approximately 180 000 ha. Water is also used for the generation of hydropower at Gariep and Vanderkloof dams. As the power is essentially generated with water released for other purposes, this is not regarded as an additional requirement for water (Basson *et al.*, 1997). However, the unnatural regulation of flows in the river has numerous effects on the physical, chemical and biological characteristics of the Orange River.

The Orange River provides a significant resource to the Northern Cape Province, and is used for industrial, agricultural, recreational and domestic purposes. While most of the Province is unsuitable for dry land cropping, the Orange River Valley, especially at Upington, Keimoes and Kakamas, is intensively cultivated grape and fruit growing country. The Vaalharts Irrigation Scheme near Warrenton produces wheat, fruit, peanuts, maize and cotton (DTEC, 2005).

The major user of the Northern Cape's freshwater resources is the irrigated agriculture sector, which requires 1 129 million cubic meters per annum (Mm^3/a). The greatest volume of water required for the irrigated agriculture sector is in the Lower Orange WMA where intensive cultivation of fruit trees and grape vines takes place. Water resources are highly valued in this area and contribute significantly to sustaining the agricultural economy.

In the lower Orange River (LOR), the largest primary contributions to the economy are made by mining and agriculture. Mining activities consists mainly of extract in of alluvial diamonds and a variety of minerals (zinc, etc.). Extensive irrigation occurs at locations along the LOR, where the tendency has increasingly towards growing high value orchard crops. Sheep and other livestock farming are found where the climate is favourable (ARTP JMB, 2008).

The recreational use of the LOR has gained in intensity over the past twenty years. The rafting and canoeing industry in this remote area has developed into an extremely popular experience for tourists (ARTP JMB, 2008).

The Lower Orange WMA has one of the highest uses of water yet receives the second lowest amount of rainfall. This can hinder economic development in the area as the deficit in water available has to be augmented from another WMA that has a surplus (Stats SA, 2008).

Groundwater is an extremely valuable source in both WMAs and in particular in the Lower Orange WMA where approximately 60 % of water used in the tributary catchments (large areas) is from groundwater, although volume is significantly lower than that of surface water resources.

1.7 Estuary and conservation areas

Among the more valued natural resources in the river basin is a transboundary Ramsar protected wetland at the mouth of the Orange River. Important nature conservation areas include the Kgalagadi Transfrontier Park, the Ai-Ais-Richtersveld Transfrontier Park, and the Augrabies Falls National Park. A review of biodiversity information by Revenga *et al* (2000) shows that a total of 24 fish species are found in the basin, of which seven are endemic, two of which are threatened with extinction. Some major features of the Orange River Systems are listed in **Table 1**.

The estuary of Orange is proclaimed a Ramsar site by both South Africa and Namibia and is regarded as the sixth most important coastal wetland in southern Africa in terms of the number of birds supported, at times as high as 26 000 individuals from up to 57 species (DWAF, Website). However, in September 1995, Orange River mouth wetland was placed on the Montreux Record (a record of Ramsar sites where changes in ecological character have occurred, are occurring or are likely to occur) following the collapse of the salt marsh component of the estuary (Earle *et al*., 2005).

1.8 Transfer schemes

The Orange is a recipient basin for three IBTs; a donor basin for three IBTs; with four intra-basin transfers also in existence (Turton, 2005). Through a number of dams and transfer schemes, water is moved in and out of the Orange River.

These include:

- The Orange River project: transfer of water from the Caledon and Orange Rivers to the Modder and Riet Rivers of the Free State (~268 Mm^3/a).
- The Orange-Fish tunnel project (completed in 1975) that supplements flow (620 Mm^3/a) in the Great Fish and Sundays Rivers of the Eastern Cape (Pallett, 1997).
- The Lesotho Highland Water scheme (Phase 1A), that transfers water from the headwaters of the Orange River to the Vaal River (770 Mm^3/a).
- The transfer of 52 Mm^3/a from the Orange River to the Lower Vaal (at Douglas), mainly for irrigation and domestic use.
- The transfer of water (10 Mm^3/a) from the Orange River to the Buffels catchment, mainly for industrial and domestic use (Basson *et al.*, 1997).

1.9 Shared Watercourse

The Orange River is one of South Africa's four main rivers which are shared with other countries. Namibia and South Africa share a 600 km border along the lower, western reaches of the Orange River before it flows into the Atlantic Ocean. This represents an important challenge for integrated resource management between the two countries (DTEC, 2005).

At the regional level, Southern African Development Community (SADC) Water Sector Coordination Unit deals with regional water issues and co-ordination. At sub-regional level, South Africa is also a member of the Orange-Senqu River Commission (ORASECOM) that facilitates implementation of the SADC Protocol on Shared Watercourses whose objective is to promote integrated water resources management. This commission was established in 2000 by four watercourse states namely, the Kingdom of Lesotho and the Republics of Botswana, Namibia and South Africa.

The relatively scarce surface and groundwater resources in the Orange-Senqu Basin are critical for the sustainable social and economic development of each country. Existing patterns of land and water use have reached the point where great care is needed to ensure that the scarce and vulnerable water resources are not over-exploited. In addition to the existing patterns of water use, the prospects of long-term changes caused by both natural and human activities pose several medium- and long-term threats to the integrity of the Basin and to the future development aspirations of each Basin State.

1.10 Aim of study

The ultimate aim of this study was to provide a scientific basis for managing human's external environment and for sustainable utilisation of natural resources. Thus, the final objective of this study was to make a contribution towards the scientific basis for the control of water quality and resource management of the Orange River ecosystem.

2 ISSUES AND CONCERNS

A number of studies that were previously carried out for Orange River System catchment area are of relevance and have been consulted in this study. In terms of the previous studies reviewed, the major concerns and key issues identified in the Orange River from the literature include (Inception Report; DWAF, 2008a):

ISSUES/CONCERNS	DETAILS
Soil erosion and wetland degradation	High degree of soil erosion experienced in Lesotho (~2 % of top-soil/annum). Wetlands are seriously degraded.
Increasing siltation	High sediment load in Caledon as a result of the soil erosion in the upper regions, mainly in Lesotho. Siltation of dams is occurring, e.g. Welbedacht Dam, Lower Orange, diamond mining activities. Because of the silt retention capacity of the two major dams in the Orange, silt and sediment loads in the lower Orange have been considerably reduced.
Increased loads of salts (salinity)	Increase in time and space. Ascribed to irrigation return flow and reduced flows. Special concern, between Boegoeberg Dam and Kakamas – regularly exceeds 500 mg/ℓ TDS. Salinity problems in Lower Riet River are observed. Impact on sustainability of agriculture is a concern. Salinisation of irrigated soil could lead to greater salt loads on the river, ultimately to the point where quality may be impaired and the uses of the water restricted. The salt load from the Vaal River needs to be taken into account in the sitting of future dams.
Eutrophication	Serious cyanobacterial blooms in lower Orange since 2000; aesthetic problems; toxic species in central and lower Orange.
Pest blackflies	Outbreaks of pest blackflies (*Simulium chutteri*) – from Hopetown to Sendelingsdrift. Major outbreaks of *Simulium chutteri*, have resulted in annual losses to livestock farmers. These outbreaks are ascribed to the artificial flow regime and it is considered that other flow regimes may contribute to their amelioration (Palmer *et al.*, 2007).
Reduced flow	Enhance salinity and eutrophication; formation of sandbars in the river mouth.
Environmental threats	Threats to the Orange River estuary Ramsar site at the mouth – loss of inflow of water and sediment. Blackflies chemical control.
Conservation of representative ecosystems	There are parts of the Orange River in reasonably natural condition which represent ecosystem types not conserved anywhere. Areas of particular conservation importance include:

ISSUES/CONCERNS	DETAILS
	- Archaeological sites near the confluence with the Vaal River. - The Ai/Ais Transfrontier National Park including the Richtersveld National Park. - Orange River Mouth = RAMSAR wetland. - Augrabies Falls National Park
Species conservation	*Barbus hospes*, the fish found only in the Orange River downstream of Augrabies Falls, is the known species, which should be considered of special conservation importance.
Conservation of the river estuary	The Orange River estuary has been ranked as the sixth most important coastal wetland in South Africa. It is an important resting site on the migration route of many aquatic bird species.
Turbidity	The Orange River is a turbid river. The growth of benthic algae and phytoplankton, which include important nuisance organisms, is limited by light availability, which is restricted by the turbidity. New dams, or an increase in the salinity of the water (with which flocculation and sedimentation of suspended solids is associated), or both factors acting together, could reduce the turbidity allowing blooms of algae and phytoplankton.
Groundwater pollution	Groundwater pollution around many of the smaller towns and urbanised areas are becoming a growing concern. This is related to poor and inadequate sanitation systems. In the Lower Orange WMA groundwater contamination (with radioactivity and nitrates) are emerging as key issues and further investigation is needed.
Microbiological pollution	Due the large number of sewage effluent discharges microbiological pollution and increase in health risks is growing in the Orange River. Much of the outbreaks are localised, however, the situation is becoming symptomatic of the general decline in microbiological quality.
Impact of irrigation	Huge volumes of irrigation return flows enter the Orange River. These return flows have a major impact on the water quality. The extent of the impact is not well understood.
Reed encroachment	Reed encroachment of the channel in the middle reaches of the Orange River has been considerable, subsequent to the regulation of flow by the Gariep and Vanderkloof Dams.
Other key issues in Upper Orange WMA	Hydropower turbines impact negatively on some users. In turn, upstream transfers of water negatively impact on the water availability for power generation.

ISSUES/CONCERNS	DETAILS
	Over-exploitation of groundwater is experienced in localized areas. A need exists for increased future transfers of water to the Upper Vaal and to Port Elizabeth in the Fish to Tsitsikamma WMA. Flood management at Gariep and Vanderkloof Dams, in concert with flood management along the Vaal River, is of major importance with respect to the protection of developments along the Lower Orange River. Developments in Lesotho and increased transfers of water out of the WMA can have a major impact on water availability in the Upper Orange WMA.
Other key issues in Lower Orange WMA	The arid climate of the region and limited potential of water resources which naturally occur in the WMA. Surface and groundwater are already fully developed and utilized. The virtual total dependence of the Lower Orange WMA on water released from the Upper Orange WMA, and the dominant influence of water utilization in upstream WMA on water resource management in the Lower Orange WMA. Concerns about water quality in the Orange River as a result of upstream activities (transfers and urban, industrial, mining and irrigation return flows) and possible future developments. Insufficient measurement, monitoring and control of water used by irrigation, which is by far the largest water use sector in the WMA. Water use efficiency by irrigation is also subject to improvement. Inefficient management of releases from Vanderkloof Dam and the lack of control structures to facilitate this. The sharing of releases from Vanderkloof Dam with Namibia as well as joint responsibility by South Africa with respect to the management of the estuary. Need for poverty relief and availability of water (approval in principle) for settlement of emerging irrigation farmers. Implementation of efficient flood management measures in co-operation with upstream WMA.

3 AIM OF THE PROJECT

The **aim of this project** is undertake a water quality assessment of the Orange River (Upper and Lower Orange Water Management areas):

- To determine the current status,
- To undertake a desktop assessment of the water quality of Lesotho
- To develop a monitoring programme if necessary
- To provide future monitoring requirements and preliminary RWQOs, and
- To provide recommendations for future planning and strategy development activities.

The overall objective of the project is to:

Create a clearer picture of the current water quality status and data requirements of the Orange River and in doing so identify the water quality "hot spots" and issues/aspects that have an impact on the overarching planning and management of the system.

The study includes seven tasks, with this report forming the deliverables for task 2 and 3 as well as aspects of task 6 and 7 (**Figure 3**).

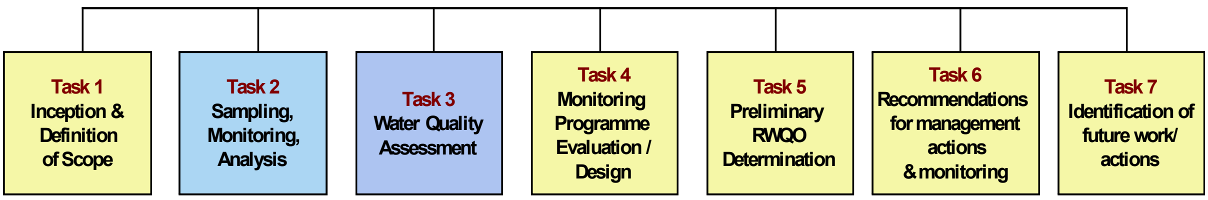


Figure 3: Study tasks

3.1 The water quality assessment task

The water quality assessment task 3 included:

Review and assessment of results of previous studies, reports, available data/information available for the Orange River System, in order to understand/identify changes, trends, water quality issues.

Desktop assessment of the water quality data from Lesotho.

Statistical analysis and graphs to draw scientific conclusions based on sampling data interpretation and results undertaken in snapshot water quality surveys (Task 2).

3.2 Sampling, monitoring and analysis

Task 3 was preceded by once-off summer and winter monitoring (field surveys) of identified sites for selected water quality variables for the Orange River (the snapshot assessment). Two snapshot surveys were undertaken to assess the water quality in the whole Orange River (excluding Lesotho), the Caledon River and the major tributaries of these two rivers (Task 2).

The water quality variables analysed at all the sites included:

- *In situ* measurements of pH, Secchi depth, temperature & dissolved oxygen, and electrical conductivity.
- Chemical water quality parameters, including total dissolved salts, alkalinity, mineral ions (HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, F^-, Si & SO_4^{2-}), nutrients [nitrogen (NO_3^{2-} & NH_4^+) and phosphorus (PO_4^{3-}) and TP], dissolved organic carbon (DOC), and metals (Al, As, Cd, Cu, Fe, Mn, Pb, V, and Zn).
- Physical parameters: Turbidity and total suspended solids (TSS).
- Biological parameters: Algal biomass (Chl-*a*), identification and enumeration of phytoplankton species, and diatoms analyses.
- Microbiological parameters: Total coliforms, which is indicative of the general hygienic quality of the water and *E. coli* which is used to evaluate the quality of the water.

See chapter 4 (study area) for more detail on the 38 sampling sites and chapter 5 (Materials and methods) for more detail on the snapshot surveys, *in situ* measurements, sampling procedures, laboratory analyses, and the diatom index.

Finally, task 2 and 3 included the documentation of results and findings, drawing of conclusions and making specific recommendations on the water quality of the Orange River System based on all of the above. Thus, task 6 and 7, *i.e.* making recommendations for management actions and monitoring as well as identification of future work/actions are addressed in the three main reports – Report 3, 5 and 6.

4 STUDY AREA

The Orange River rises in the Drakensberg mountains in Lesotho, flows westward through South Africa to the Atlantic ocean at Alexander Bay. The Orange River basin is divided into five Water Management Areas (*i.e.* Upper, Middle, & Lower Vaal WMAs and Upper & Lower Orange WMAs). This report focuses on the Upper and Lower WMAs. The Orange River forms a green strip in an otherwise arid but beautiful landscape, and also forms the border between South Africa and Namibia over a distance of approximately 550 km to the west.

The study area for this project includes the Upper and Lower Orange Water Management areas (WMA 13 & WMA 14) with 38 sampling sites. See **Tables 2, 3** and **4** for a detailed description of the sites on the Orange River, Caledon River and major tributaries as well as **Figures 4, 5** and **6** for the spatial orientation. Twenty one of the sites are on the Orange River main stem (level 1), including the two major dams, 5 on major tributaries (level 2) of the Orange; 5 on the Caledon River and 7 on tributaries of the Caledon River.

These sites were based primarily on existing DWAF water quality monitoring stations. New sites that were added as a result of meetings with DWAF's regional offices (Free State and Northern Cape) and of this study are indicated in **Table 2**.

The monitoring sites on the Orange River main stem (level 1) were numbered (coded) from upstream to downstream, *i.e.* from OS1 to OS19 (OS for Orange System). The tributaries (level 2) were denoted as OS (Orange System), L2 (level 2) followed by the numeric order, e.g. OSL2/1.

The DWAF monitoring site downstream of the confluence of the Orange and Vaal River (OS7) was at Irene (D7H012), but was unfortunately discontinued (data only from 1989 – 1997). Katlani was proposed as an alternative site, but during snapshot 1 it was clear that the accessibility to the river was poor. Therefore, during snapshot survey 2, the farm De Hoek was identified as a suitable site – see **Figure A16** in Appendix A.

The Caledon River is a major and important tributary of the Orange River, and is regarded as being a river catchment in its own right with a separate system code, *i.e.* CS (Caledon System). The Caledon tributaries (level 2) were denoted as CS (Caledon System), L2 (level 2) followed by the site number, e.g. CSL2/1.

The summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Orange and Caledon Rivers as well as tributaries are in **Tables C1 – C20** in Appendix C.

Table 2: Sampling sites – Upper Orange River – snapshot field trips (2008).

Upper Orange WMA 13					
SITE NO	**SAMPLE CODE**	**SA HYDRO SITE ID NO**	**LOCATION OF SITE – DESCRIPTION**	**GPS CO-ORDINATES**	**OTHER INFO**
1	**OSL2/1**	D1H006	**Kornetspruit** at Maghaleen	S30.16003; E27.40145	Elevation, 1 428 m; WMS D15, Data: 1975 – '07 (859 samples)
2	**OSL2/2**	New site	**Sterkspruit** (at R382 crossing)	S30.52694; E27.37484	Elevation, 1 444 m; Crossing with road R392
3	**OS1**	D1H009	Orange River (OR) at **Oranjedraai;** at Lesotho border	S30.33772; E27.36277	Elevation, 1 392 m; WMS D12, 1972- '07 (911)
4	**OSL2/3**	D1H011	**Kraai River** at Roodewal	S30.73707; E26.78440	Elevation, 1 299 m; WMS D13, 1967 – (1002)
5	**OS2**	D1H003	OR at **Aliwal North** (Road bridge)	S30.68612; E26.70600	Elevation: 1 310 m; D14, Data 1972- '07 (1800+)
6	**OS3**	New site	**Orange River** at Saamwerk – upstream Gariep Dam	S30.57622; E26.45638	Weir at Saamwerk farm, Elevation, 1 279 m; D14.
7	**OSL2/4**	D1H001	**Stormbergspruit** at Burgersdorp (Wonderboomspruit at diepkloof)	S31.00109; E26.35314	Elevation, 1 379 m; below weir; WMS D14, 1975 – '07 (729)
8	**OSD1**	D3R002	**Gariep Dam** on OR: near dam wall	S30.60794; E25.50465	Elevation: 1 273 m WMS D34, 1971- '07 (1 106)
9	**OS4**	D3H013	OR at **Roodepoort**; ds of Gariep Dam (OR at Waschbank – Iron bridge)	S30.58487; E25.42084 (S30.62062; E25.46511)	Elevation: 1 195 m WMS D34, 1976 – '07 (973)
10	**OSL2/5**	D3H015	**Seekoei River** at De Eerste Poort	S30.53480; E24.96250	Elevation: 1 214 m WMS D32, 1981 – '07 (341)
11	**OSD2**	D3R003	**Vanderkloof Dam**, near dam wall	S29.99447; E24.73524	Elevation: 1 169 m WMS D31; 1979 – '07 (255)
12	**OS5**	D3H012	Orange River at **Dooren Kuilen**; below Vanderkloof Dam	S29.99141; E24.72414	Elevation: 1 083 m WMS D33, 1980 – '07 (450)
13	**OS6**	D3H008	OR **at Marksdrift**	S29.16201; E23.69447	Elevation: 980 m D33, 1966- '07 (875); GEMS site;

Table 3: Sampling sites – Caledon River and tributaries – snapshot field trips (2008).

Upper Orange WMA – Caledon River					
SITE NO	**SAMPLE CODE**	**SA HYDRO SITE ID NO**	**LOCATION OF SITE – DESCRIPTION**	**GPS CO-ORDINATES**	**OTHER INFO**
14	**CSL2/1**	New site	**Little Caledon** River (close to Golden Gate)	S28.49980; E28.58196	Elevation, 1 824 m; On Road R712 crossing
15	**CSL2/2**	D2H012	**Little Caledon River** at The Poplars; confluence with Caledon River	S28.69477; E28.23486	Elev., 1 603m; D20, 1971 – (443);
16	**CS1**	New site	**Caledon River** at **confluence** (with Little Caledon)	S28.69363; E28.23445	Elev., 1603 m; at border post
17	**CSL2/3**	New site	**Grootspruit** at R26 road bridge	S28.68026; E28.13996	Elev., 1 594m; At R26 bridge
18	**CS2**	D2H035	**Caledon River** d/s from **Ficksburg**	S28.90409; E27.83084	Elev., 1 536m; D20
19	**CSL2/4**	New site	**Meulspruit** above Meulspruit Dam	S28.83528; E27.83340	Elev., 1 565m;
20	**CSL2/5**	New site	**Moperispruit** at R26 road bridge	S28.96011; E27.56664	Elev., 1 538m;
21	**CS3**	New site (Old D2H011)	**Caledon** downstream **Maseru** (Maseru Lesotho)	S29.38042; E27.41203	Elev., 1 470m; D20
22	**CSL2/6**	New site	**Leeu River** at Hobhouse	S29.52155; E27.13577	Elev., 1 460 m; At R26
23	**CS4**	New Site (Old D2H001)	**Caledon** at Tienfontein pump station (at Jammersdrift)	S29.78357; E26.90998	Elev., 1 409 m; D20
24	**CS5**	D2H036	Caledon River at **Kommissiedrift** at N6 crossing	S30.27994; E26.65427	Elev., 1 323 m; D20; 1993 – 2007; difficult access

Table 4: Sampling sites – Lower Orange River – snapshot field trips (2008).

Lower Orange River WMA 14					
SITE NO	**SAMPLE CODE**	**SA HYDRO SITE ID NO**	**LOCATION OF SITE – DESCRIPTION**	**GPS CO-ORDINATES**	**OTHER INFO**
25	**VS21**	New site	**Vaal River** at **Douglas bridge**	S29.04885; E23.76822	Elevation: 977 m
26	**OS7**	New site (Old D7H012)	**Orange River** at De Hoek (Orange River at Irene; D7H012)	S29.21069; E23.51447	At Irene Data 1989 – 1997
27	**OS8**	D7H002	OR at **Prieska** at bridge	S29.65700; E22.74415	Elevation: 918 m D72, 1977 - 2001 (386)
28	**OS9**	D7H008	OR at **Boegoeberg Dam** – Reserve/Zeekoebaart	S29.02625; E22.18608	Elevation: 973 m D73, 1966 – 2007 (629)
29	**OS10**	New site	OR at **Gifkloof** weir	S28.43884; E21.404153	Elevation: 805 m New
30	**OS11**	D7H005	OR at **Upington Water Works**	S28.45259; E21.25994	Elevation: 791 m D73, 1965 – (3742)
31	**OS12**	D7H004	OR at **Kanon Island** – right side	S28.63543; E21.09020	Elevation: 768 m D73, 1971 – (88)
32	**OS13**	D7H016	OR at **Neusberg** weir (North canal)	S28.77481; E20.74558	Elevation: 678 m D73, 1995 – 07 (378)
33	**OS14**	New site	OR at **Blouputs**	S28.51409; E20.18518	Elevation: 437 m Below Augrabies water fall
34	**OS15**	D8H008	OR at **Pella** Mission	S28.96443; E19.15276	Elevation: 301 m D80, 1980 – (214)
35	**OS16**	D8H003	OR at **Vioolsdrift**	S28.76208; E17.72631	Elev: 167 m; D80, 1965 – (1032); GEMS site; CA 850 530 km^2
36	**OS17**	New site (Old D8H006)	OR at **Sendelingsdrift** (Richtersveld Rosh Pinah)	S28.12288; E16.89032	Elevation: 32 m By Richtersveld
37	**OS18**	D8H007	OR at Korridor / **Brand Kaross**	S28.48570; E16.69444	Elevation: 16 m D80, 1971 – 2001 (407)
38	**OS19**	D8H012	OR at **Alexander Bay**/ Ernest Oppenheimer Bridge	S28.56689; E16.50728	Elevation: 9 m D80, 1965 – 2003 (216) At Dunvlei

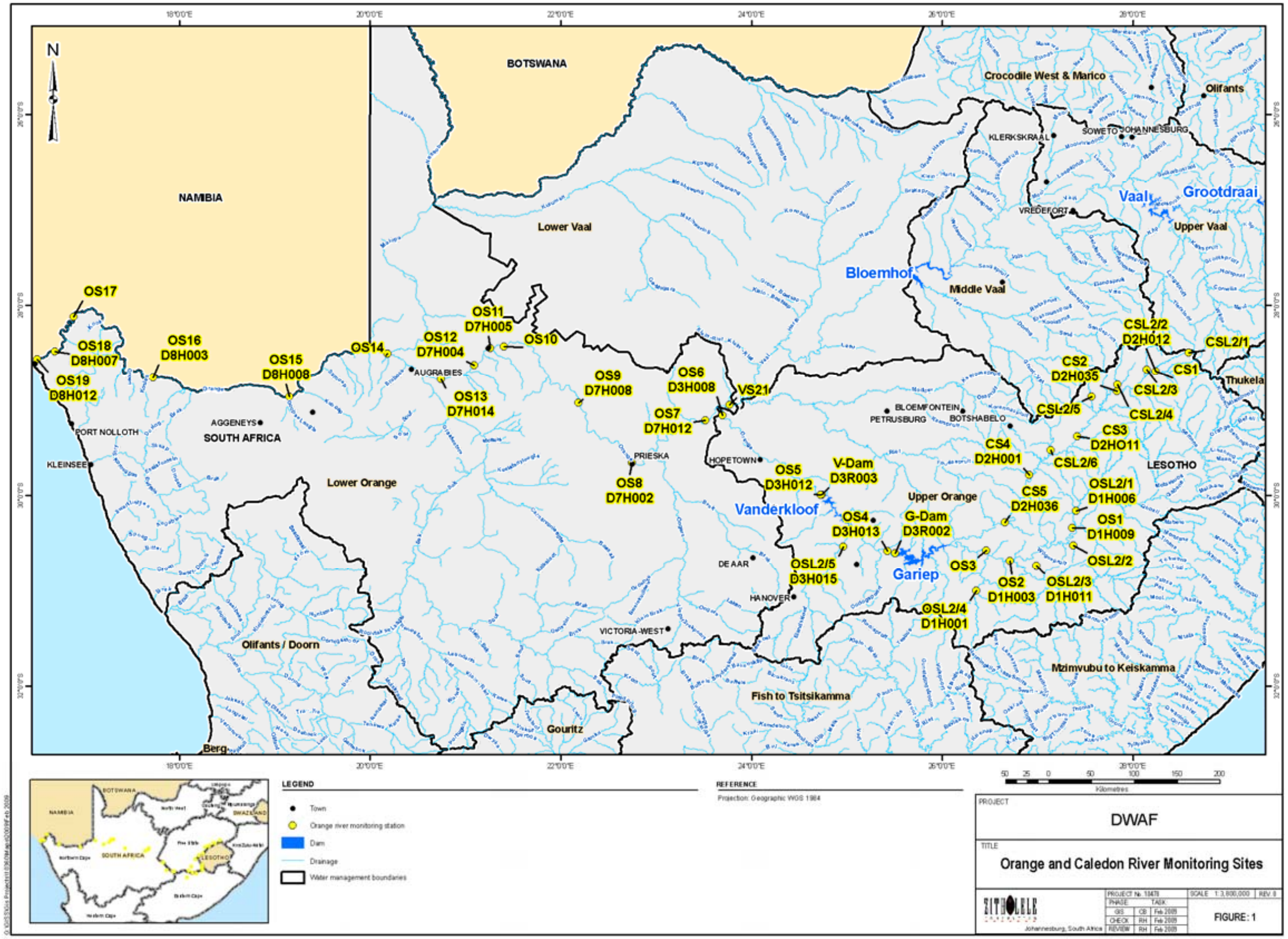


Figure 4: Upper and Lower Orange Water Management Areas with monitoring sites.

4.1 Upper Orange River Catchment Area (WMA 13)

The Upper Orange Water Management Area stretches from its origin in Lesotho to its confluence with the Vaal River at Douglas, including the tertiary drainage regions C51, C52, D11 to D18, D21 to D24, D31, D32, D34 and D35. Major rivers include the Modder, Riet, Kraai, Caledon and Orange.

The Upper Orange: Upstream of the South Africa/Lesotho border, this section of the Orange River is also known as the Senqu River which originates high in the Maluti Mountains. The Upper Orange/Senqu area covers the Orange River basin upstream of the South Africa/Lesotho border and therefore includes the Lesotho Highlands Water Project (LHWP).

The monitoring sites on the Upper Orange River main stem are: OS1 at Oranjedraai, OS2 Aliwal North, OS3 Saamwerk – new site, OS4 Roodepoort, OS5 Dooren Kuilen and OS6 Marksdrift. The main tributaries are: Kornetspruit, Sterkspruit, Kraai River, Stormbergspruit, and Seekoei River (**Figure 5**).

Sites on the Caledon River, main stem, are: CS1 at confluence with Little Caledon River, CS2 at Ficksburg, CS3 at Maseru, CS4 at Tienfontein, and CS5 at Kommissiedrift. The tributaries are: Little Caledon River, Grootspruit, Meulspruit, Moperispruit, and Leeu River.

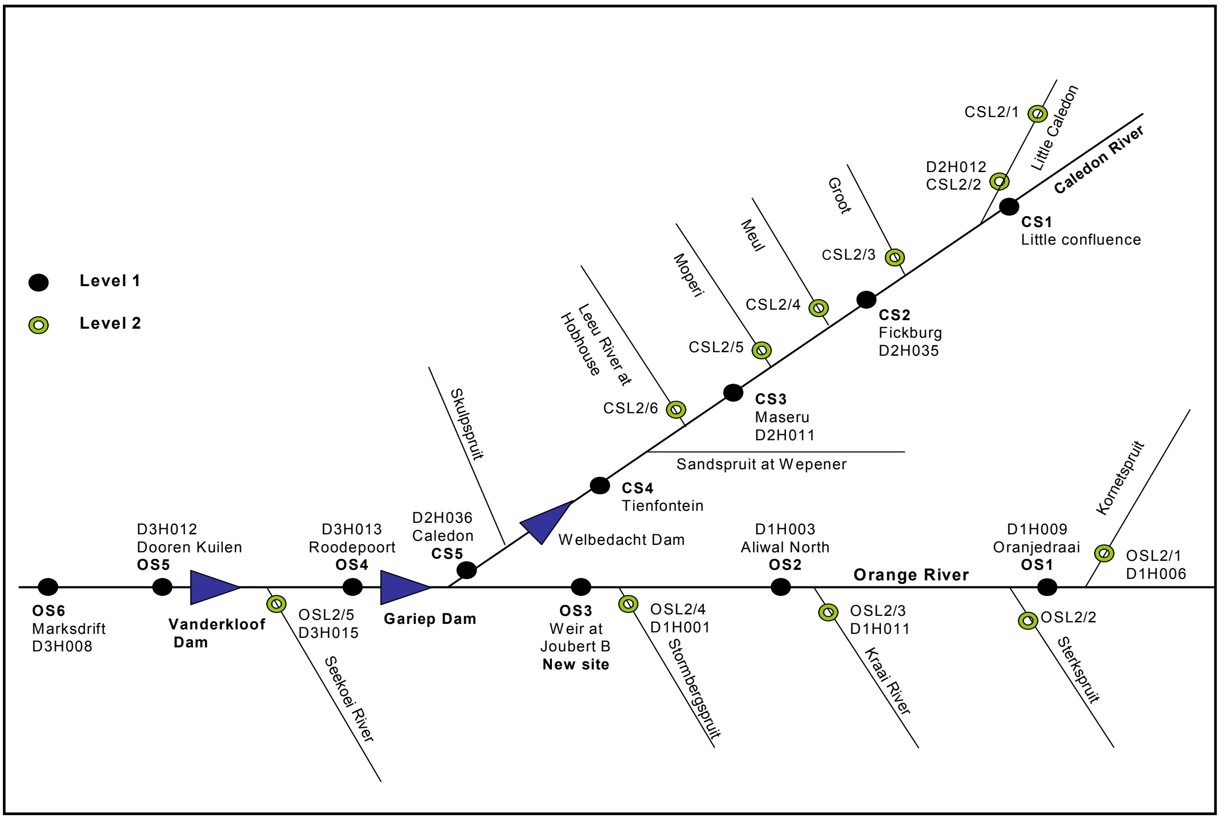


Figure 5: Line diagram of Upper Orange WMA with monitoring sites – level 1 and 2.

4.2 Lower Orange Water Management Area (WMA 14)

The Lower Orange refers to the stretch of Orange River between the Orange-Vaal confluence and Alexander Bay or Oranjemund where the river meets the Atlantic Ocean. Major rivers include the Ongers, Hartbees, Molopo (non-perennial), Fish and Orange.

Boundary description: Primary drainage region D (excluding tertiary drainage region F60), tertiary drainage regions D33, D42 (excluding portions of quaternary catchments D42C and D42D), D51 to D58, D61, D62, D71 to D73 (excluding quaternary catchment D73A and portions of D73B, D73C, D73D and D73E), D81, D82, and quaternary catchment C92C.

There are 13 monitoring sites on the lower Orange River, *i.e.* from OS7 at Katlani (close to Douglas) to OS19 at Alexander Bay, and 1 site on the Vaal River (VS21) at Douglas (new site) are shown in **Figure 6.**

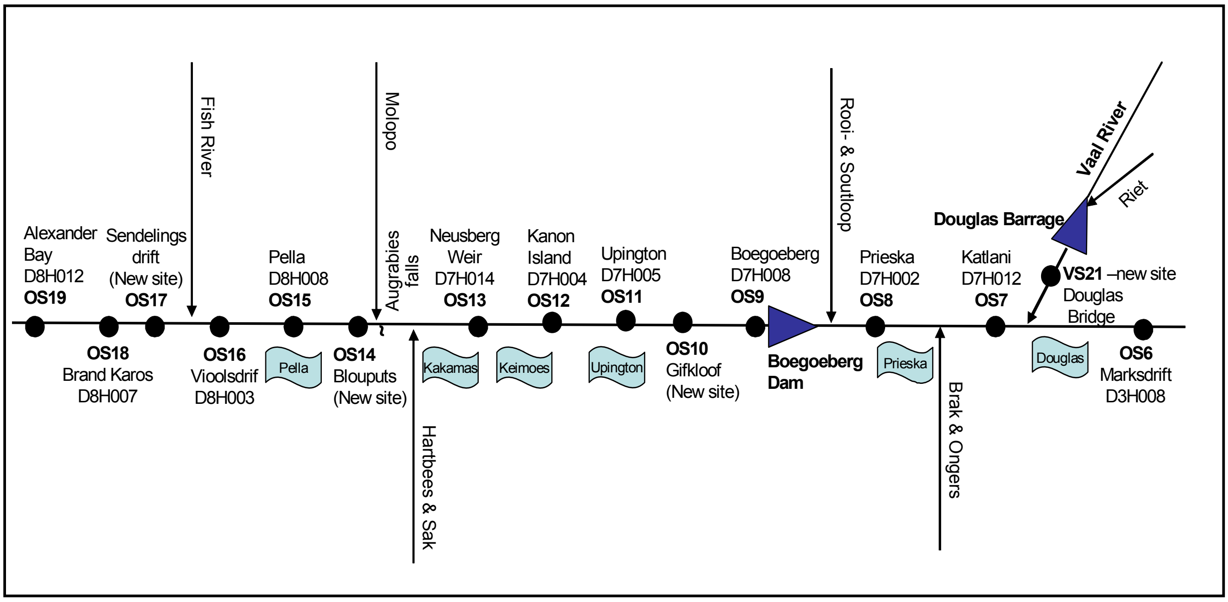


Figure 6: Line diagram of Lower Orange WMA with monitoring sites.

5 MATERIALS AND METHODS

5.1 Historical data

The historical data on physico-chemical parameters as well as hydrological data were obtained from Resource Quality Services (RQS), Department of Water Affairs and Forestry (DWAF) for the monitoring sites on the Orange and Caledon Rivers and some major tributaries registered in the National Chemical Monitoring Programme (see **Figures 4, 5** and **6**). Where available, analysis of historical data (as on WMS and other sources) and comparison to once-off snapshot monitoring results was done.

Water quality data from monitoring sites on the Senqu River (upper Orange River) were obtained from the Department of Water Affairs in Maseru, Lesotho. The data were analysed and compared with the downstream sites on the Orange River within South Africa.

Software used for data manipulation includes Microsoft Office Excel for basic statistical analyses and SigmaPlot 8.0 was used for graphical presentations, regression and trend analyses. In the box and whiskers plots, the box represents 50 % of the data and the whiskers represent the 10^{th} and 90^{th} percentile. The 5^{th} and 95^{th} percentile outliers are indicated by the lower and upper dots. The median values are indicated by a solid line and the mean values as a dashed line in the boxes.

5.2 Snapshot Surveys

Two snapshot surveys were undertaken to assess the water quality in the study area including the whole Orange River (excluding Lesotho), the Caledon River and major tributaries of these rivers. Field trips were planned to include 'high flow conditions' around March 2008 after rainy season and 'low flow conditions' around August 2008.

Snapshot survey 1 stretched over three weeks with water samples collected from 38 different sites and a distance of more than 3 000 km being covered, *i.e*. week 1 (20 – 25 April), week 2 (5 May to 10 May), and week 3 (1 – 6 June, 2008).

Snapshot survey 2, with slightly fewer sampling points because of time and money constraints, was conducted over 2 weeks, *i.e*. 24 – 29 August and 14 – 19 September, 2008. Chapter 4 (Study area) includes more detail on the monitoring sites.

Sampling was done according to prescribed methods for the different variables. Subsurface water samples were collected in new 500 mℓ plastic bottles. No preservation of water samples was done for chemical analyses but sample bottles were placed in cooler box with ice. The water samples were usually couriered the following day to the laboratory for analyses.

Same-day chlorophyll-*a* filtration (GF/C filters) and ethanol extraction was done on the samples. Microbiological samples (sampled in 100 mℓ sterilised glass bottles) were kept on ice and analysed within 48 h. Bacteriological analyses included total coliforms, which is indicative of the general hygienic quality of the water and *E. coli* which is used to evaluate the quality of the water.

Diatom samples were collected according to the standard methods described by Taylor *et al*., 2005. Samples were mainly collected from stones and if not available, then from either instream vegetation or riparian vegetation suspended in the river channel. The diatom analyses were done by Dr. Jonathan Taylor from the University of North-West, Potchefstroom.

Algal samples were preserved in 2 % formaldehyde and diatom samples in ethanol (10 mℓ alcohol in 100 mℓ samples).

GPS coordinates were taken in the field to be within 5 – 10 m accuracy. On site pictures were also taken – see Appendix A and B.

5.2.1 *In situ* measurements

On site measurements that were done include *in situ* measurements of pH, Secchi depth, temperature, dissolved oxygen, and electrical conductivity.

pH is a measure of the amount of hydrogen ions (H^+) in a solution. Since these values (H^+) are very low and involve negative powers of 10, it is customary to use the pH scale, where: $pH = -log_{10} [H^+]$. The pH scale is a logarithmic one, thus, if the measurement scale is not linear, arithmetic means may give a false value. Therefore pH values are reported as a median and not as a mean.

5.2.2 Laboratory analyses

Water samples were couriered to the Institute for Ground Water studies (IGS) (an accredited laboratory) at the University of the Free State (UFS) for laboratory analyses. Chemical water quality parameters, including total dissolved salts, alkalinity, mineral ions (HCO_3^-, Ca_2^+, Mg^{2+}, Na^+, K^+, Cl^-, F^-, Br^-, Si & SO_4^{2-}), nutrients [nitrogen (NO_3-N & NH_4-N) and phosphorus (PO_4-P) and TP], dissolved organic carbon (DOC), and metals (Al, As, Cd, Cu, Fe, Mn, Pb, V, and Zn) were analysed.

The dissolved inorganic nitrogen (DIN) was calculated by the summations of the NO_3 + NO_2-N + NH_4-N concentrations. Reference to nitrate usually also includes nitrite (NO_2-N).

Standard Methods were used for all the above-mentioned chemical and biological assessments. Phytoplankton chlorophyll-*a* concentrations, enumeration and identification were done at the Centre for Environmental Management laboratory, UFS.

5.2.3 Diatom Index

Diatom indices function in the following manner: In a sample from a body of water with a particular level or concentration of determinant (e.g. phosphorus), diatom taxa with their optimum close to that level will be most abundant. Therefore an estimate of the level of that determinant in the sample can be made from the average of the pollution sensitivity of all the taxa in that sample, each weighted by its abundance. This means that a taxon that is found frequently in a sample has more influence on the result than one that is rare. A further refinement is the provision of an ‘indicator value’ which is included to give greater weight to those taxa which are good indicators of particular environmental conditions.

In practice, use of diatom indices involves making a list of the taxa present in a sample, along with a measure of their abundance. The index is expressed as the mean of the pollution sensitivity of the taxa in the sample, weighted by the abundance of each taxon. The indicator value acts to further increase the influence of certain species. The Specific Pollution sensitivity Index (SPI) used in this report was developed and refined over a period of 20 years in France and has been tested in South Africa for 6 years and was found to accurately reflect water quality (Taylor *et al*., 2005).

Interpretation of the Specific Pollution sensitivity Index (SPI) scores is as follows:
>17, high quality;
>13 to 17, good quality;
>9 to 13, moderate quality;
5 to 9, poor quality and
<5 bad quality.

Preparation and enumeration were done according to Taylor *et al*. (2005). Index scores were calculated using OMNIDIA ver. 4.2., database updated March 2006. The index used in the assessment is known as the Specific Pollution sensitivity Index (SPI). In addition the percentage of pollution tolerant valves (%PTV) is given.

All slides and material are archived in the Diatom Collection of the North-West University, should any material be required for independent verification of these results.

6 RESULTS AND DISCUSSION OF HISTORICAL DATA

The quality of surface water or groundwater at any point in a catchment reflects the combined effect of many physical, chemical, and biological processes that affect water as it moves along hydrologic pathways over, under, and through the land. The chemical composition of water varies depending on the nature of the solids, liquids, and gases that are either generated internally (*in situ*) or with which the water interacts (Peters & Meybeck, 2000).

However, water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter. Rather, it is variable in both time and space and requires routine monitoring to detect spatial patterns and changes over time (UNEP-GEMS, 2006).

The Department of Water Affairs and Forestry (DWAF) has a comprehensive data basis for monitoring sites all over the country (National Chemical Monitoring Programme: NCMP). Using long-term chemical data and runoff, an investigation was made of the spatial (downstream) and temporal (time) variability of parameters and stream flow in the Orange and Caledon River as well as major tributaries.

The parameters usually include: Ca, Cl, DMS (dissolved major salts), EC (electrical conductivity), F, Hardness-Total, K, Kjeldahl N, Mg, Na, NH_3, NH_4, NO_3+NO_2, pH, PO_4, SAR (Sodium Adsorption Ratio), Si, SO_4, TSS (Total suspended solids), TAL (Total Alkalinity), and turbidity.

The major concerns in the Orange River are changes in the flow regime, salinisation and eutrophication, therefore, the main focus of this study will be on the stream flow (discharge), major dissolved salts, nutrient (N & P), and algal biomass (chlorophyll-*a*). Metals concentrations were limited, but also discussed where available. However, all the other variables measured at a monitoring site are briefly reported on with the associated graphs are shown in Appendix A and B.

6.1 Desktop assessment of water quality data from Lesotho:

The origin and part of the upper Orange River (known as the Senqu) is in Lesotho, South Africa's neighbour country (**Figure 1**). Water quality data of the Senqu River was obtained from Lesotho's Department of Water Affairs (DWA) to assess possible downstream changes from Lesotho to South Africa.

The data was for five sampling stations (Phahameng, elevation 2 000 m to Seaka, elevation 1 415 m) with up to 23 basic parameters for the period 1999 to 2008. The number of observations were limited and ranged from only 2 at Ha Mohlapiso to 19 at Seaka.

In general the results from DWA, Lesotho, don't match the results discussed in this report. For example, the average calcium concentration for the 5 sites was extremely high at 118.4 mg/ℓ compared to the average of 18.5 mg/ℓ at Oranjedraai (first downstream site in SA) (**Figure 7**). The highest Ca concentration measured in the Orange River was 64.7 mg/ℓ, based on thousands of readings over a period of 30 years.

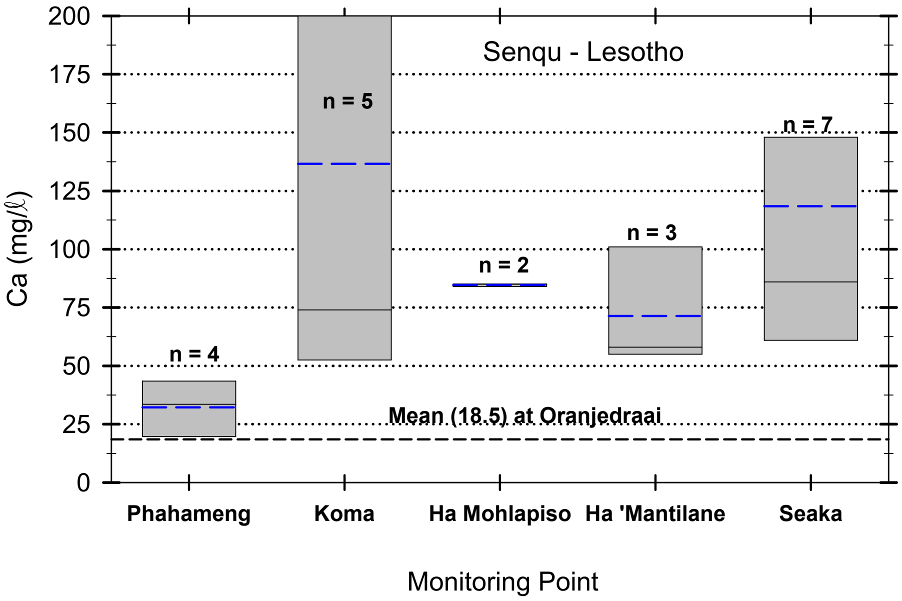


Figure 7: Box plot of spatial variation of Calcium concentrations (mg/ℓ) in the Senqu River at various monitoring sites (1999 – 2007). The mean concentrations are indicated by the dashed line and the median by the solid line in the box (Data: DWA, Lesotho).

If one compares the Calcium concentrations with the TDS concentrations (that is supposed to include the calcium), the calcium alone was on several occasions higher than the TDS which is impossible (**Figure 8**).

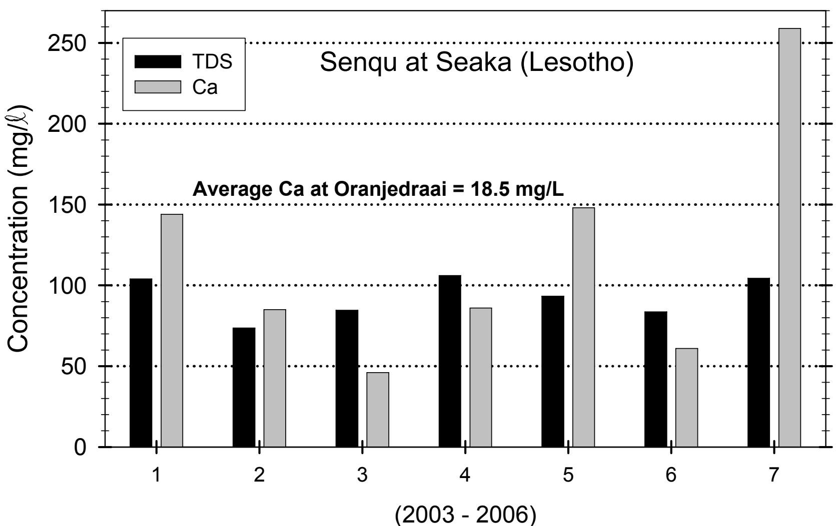


Figure 8: Variation of total dissolved salts (TDS) and Calcium concentrations (mg/ℓ) in the Senqu River at Seaka (2003 – 2007) (Data: DWA, Lesotho).

The nutrient concentrations were also unrealistically high, e.g. the average ammonium concentrations ranged between 0.52 and 1.0 mg/ℓ (**Figure 9 A**) that is an order higher than at Oranjedraai (0.051 mg/ℓ); first South African site.

The average phosphate concentration was 0.23 mg/ℓ, which is comparable to eutrophic systems (**Figure 9 B**). The mean phosphate concentration (DIP) at Oranjedraai was only 0.046 mg/ℓ (**Table C4** – Appendix C).

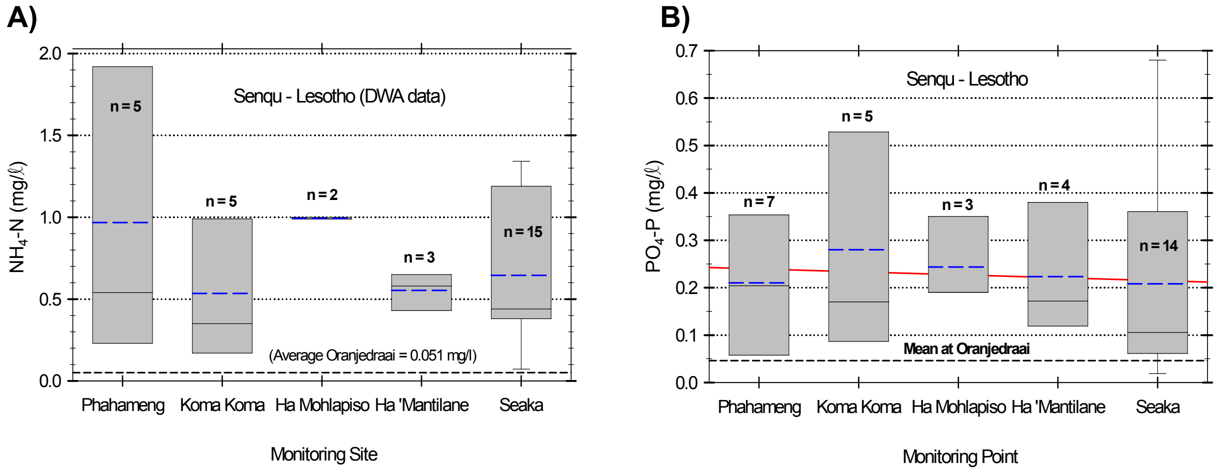


Figure 9: Box plot of spatial variation of A) ammonium (NH_4-N) and B) phosphate (PO_4-P) concentrations (mg/ℓ) in the Senqu River at various monitoring sites (1999 – 2007) (Data DWA, Lesotho).

Most of the other parameters were also questionable. For example, the dissolved oxygen concentration ranged between 0.01 and 3.6 mg/ℓ (mean 1.10) which is unrealistic for the Orange River; these concentrations would only be found in a seriously polluted river.

The silica concentrations at Seaka ranged between 0.0 and 126.2 mg/ℓ (mean, 20.3 mg/ℓ) and at Phahameng between 0.02 and 1.5 mg/ℓ (mean, 0.43 mg/ℓ). These concentrations are not viable values and cannot be accepted.

Therefore, the water quality results from DWA (Lesotho) that were scrutinized are rejected as unrealistic and unreliable and not useable to make any scientific conclusion.

A) MONITORING SITES ON THE UPPER ORANGE RIVER: LEVEL 1

6.2 OS1 – Oranjedraai – D1H009 (S30.33772; E27.36277)

Oranjedraai is the first flow gauging station and monitoring site within South Africa's border, managed by the DWAF. This site is about 550 km downstream from the origin of the river in the Drakensberg (Lesotho) and represents a fairly un-impacted site with natural characteristics.

The site is downstream of the confluence of the Senqu and Makhaleng Rivers with a catchment area of 24 550 km^2, of which 96.8 % is within Lesotho's national territory. The river width at Oranjedraai is approximately 170 m (**Figure A1** – Appendix A).

The historical chemical data set at Oranjedraai is good with biweekly sampling from 1975 to 2007, with approximately 585 measurements (n ≈ 585).

6.2.1 Stream flow (discharge)

Hydrological characteristics of rivers are determined by current velocity and stream flow. The current velocity of the river water is the distance traveled per unit time given as m/s or cm/s. The stream flow or discharge is determined from the velocity multiplied by the cross-sectional area of a river (m^3/s). Stream flow and water velocity have been proved to be important variables influencing water chemistry and river phytoplankton.

Although not technically a measure of water quality, stream flow is an important parameter to monitor because of its direct influence on the chemical composition of a riverine environment and it's receiving waters. Stream flow is directly related to the amount of water moving from a catchment into a stream channel and can be defined as the volume of water that moves over a designated point in a river over a fixed period of time, usually expressed as cubic meters per second (m^3/s) or cubic meters per annum (m^3/a).

The stream flow (monthly averages) at Oranjedraai were highly variable and ranged between 1.68 and 934.2 m^3/s (mean, 126.6 m^3/s, *i.e.* about 3 990 million m^3/a) (**Figure 10**). Thus, about 60 % of the water resources generally associated with the Upper Orange WMA, originate from the Senqu River in Lesotho.

The average flow-rate was fairly constant during the past 35 years, but a show a slight decrease during the last 10 years (see trend line (red) in **Figure 10**), which could be ascribed to the inter-basin transfer of 770 Mm^3/a (~24 m^3/s) to the Vaal River system.

The stream flow clearly follows a seasonal pattern with high flows during summer months (November – March) and low flows during winter (May – July). The stream flow usually peaks during February and the lowest flow is usually observed during July (**Figure 11**).

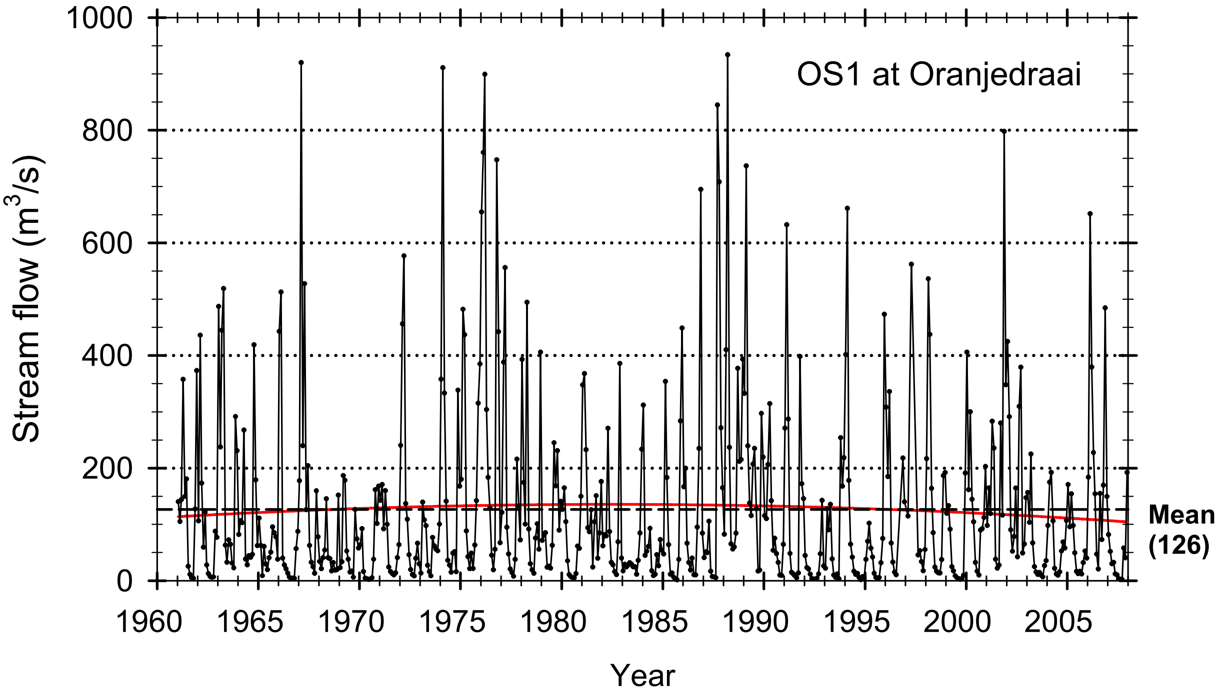


Figure 10: Temporal variation of stream flow (mean monthly, m^3/s) in the Orange River at Oranjedraai (OS1), (1961 – 2007).

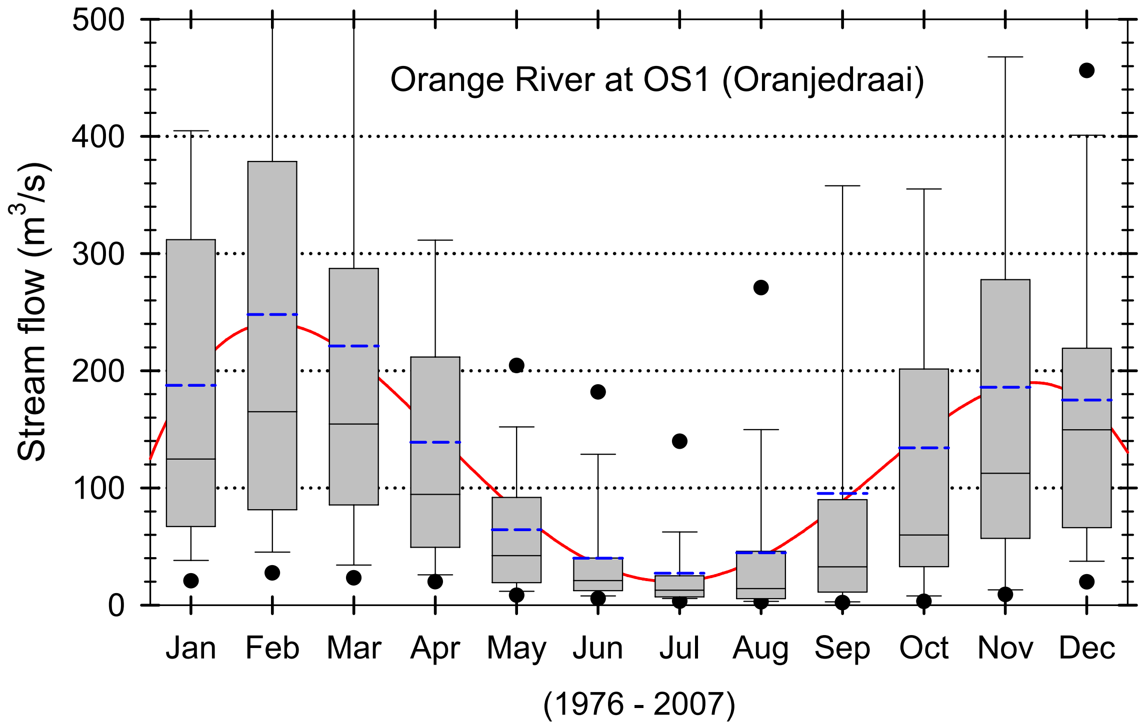


Figure 11: Box and whiskers plot of the seasonal variation of stream flow (m^3/s) in the Orange River at Oranjedraai (1961 – 2007). The box represents 50 % of the data with the whiskers represents the 10th and 90th percentile. The 5th and 95th percentile outliers are indicated by the lower and upper dots. The median values are indicated by a solid line and the mean values as a dashed line in the boxes.

6.2.2 Turbidity

Turbidity refers to water clarity. Turbidity influences the quantity and the quality of light penetrating water as well as the biota and the transport of chemicals. The greater the amount of suspended solids in the water, the murkier or muddier it appears, and the higher the measured turbidity. The majority of particles transported by rivers are carried in suspension. Turbidity is measured in Nephelometric turbidity units (NTU).

The most severe ecological problem in the upper reaches of the Orange River is the high degree of soil erosion experienced in Lesotho. Approximately two percent of top-soil is lost in the country each year with adverse effects on habitats as well as agricultural productivity (Earl *et al.*, 2005).

The Orange River is known as a very turbid river and ranked as the most turbid river in Africa (Bremner *et al.*, 1990). Most Orange River suspended sediment is produced upstream of the Caledon-Orange confluence (Bremner *et al.*, 1990). The majority of the Orange River suspended load is derived from erosion of Karoo sedimentary bedrock and soils (cf. **Figure 12**). The suspended river sediment are dominated by 40 to 60 weight % fine silt with sand, coarse silt and clay each varying between 10 and 20 % (Compton & Maake, 2007). However, sediment loads downstream in the Orange River have decreased significantly during the past 35 years – see 6.5.3, 6.8.3 and 6.13.3.

Figure 12: A major erosional gully (donga) outside the town of Sterkspruit close to Oranjedraai.

The turbidity at Oranjedraai ranged between 0.5 NTU (very clear) and 4 000 NTU (very muddy), with a mean of 161 NTU and a median of 14.5 NTU (**Figure 13**). The high turbidity is primarily caused by high erosion and associated high suspended solids, which ranged between 2.5 and 9 844 mg/ℓ (mean 995 mg/ℓ) – see **Table C4** in Appendix C.

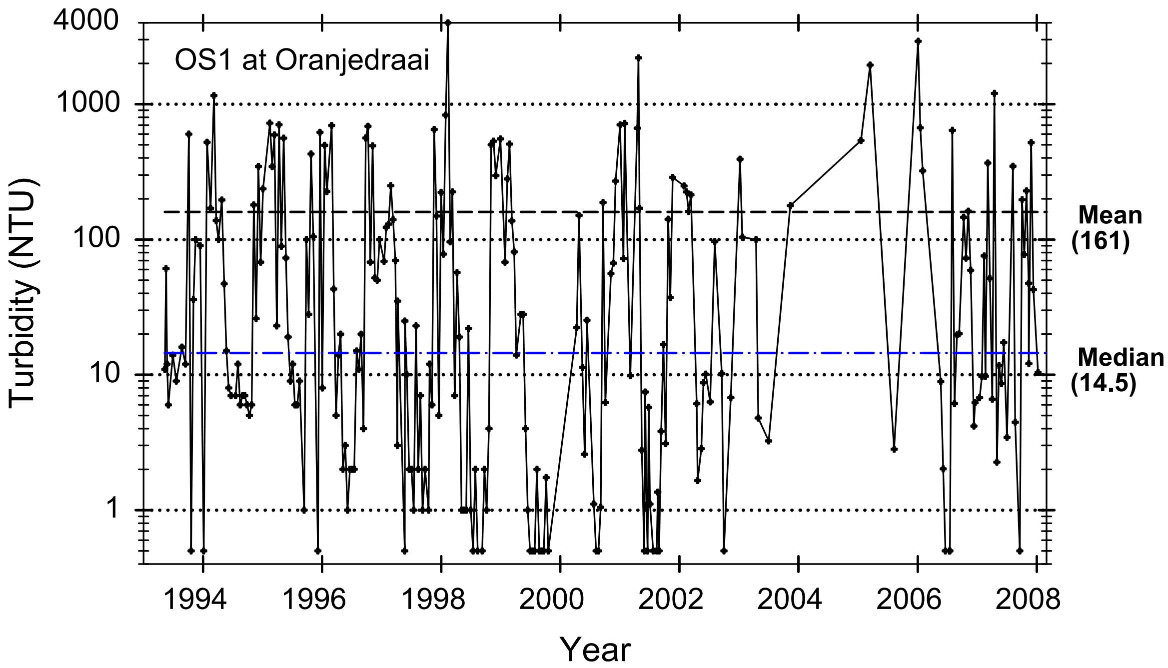


Figure 13: Temporal variation of turbidity (NTU) in the Orange River at Oranjedraai (1993 – 2007). Note the log scale on y-axis.

6.2.3 pH

The pH is an important variable in water quality assessment, as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world (UNEP-GEMS, 2006).

The pH values at Oranjedraai (and other sites downstream) show distinct differences for the period before and after 1998, *i.e.* a median of 7.12 (1976 – 1988) and 8.0 (1989 – 2007) respectively (**Figure 14**). However, the difference is ascribed to a methodological artefact, *i.e.* no real change with time because in 1988/89 the DWAF method for pH determination was changed (Hughes, 2005). This has resulted in DWAF pH values recorded after 1988/89 being on average about 0.5 pH units higher than before the change. Users are cautioned against using DWAF pH data from before 1988/89 to characterise reference conditions and then comparing it to pH data recorded in recent times to characterise the present status (Hughes, 2005). Therefore, we will only focus and report on pH values recorded after 1988.

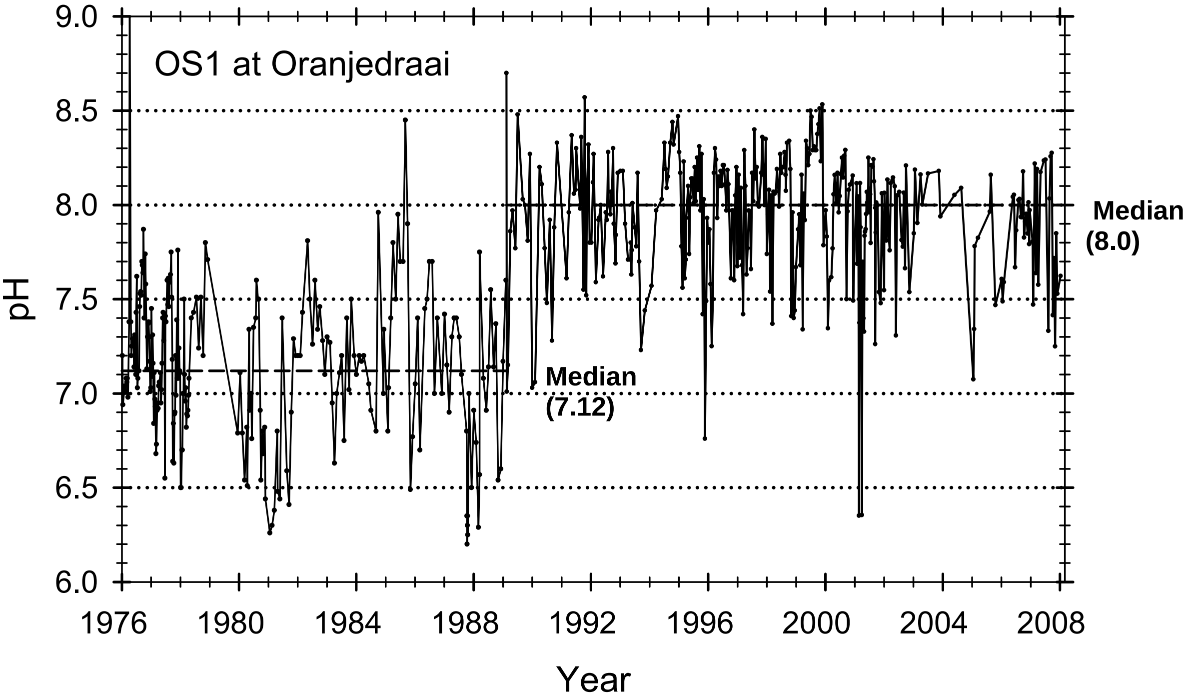


Figure 14: Temporal variation of pH in the Orange River at Oranjedraai (1993 – 2007).

6.2.4 Dissolved major salts (DMS)

Salinity is an indication of the concentration of dissolved salts in a body of water. The level of salinity in aquatic systems is important to aquatic plants and animals as species can survive only within certain salinity ranges. Salinisation is the process by which the concentration of total dissolved solids in inland waters is increased.

The dissolved major salt concentrations at Oranjedraai were relatively low (mean, 133 mg/ℓ) that ranged between 56 and 460 mg/ℓ and shows a slight increasing trend with time (solid line in **Figure 15**), which could be partially ascribed to the water abstraction in the headwaters – see discussion in **6.5.1**.

The average TDS concentration in natural river water is 99.6 mg/ℓ, with an average of 121 mg/ℓ in Africa Rivers (Wetzel, 2001). While the mean TDS concentration in the polluted Vaal River, main tributary of the Orange, was 502 mg/ℓ (see **7.2** Snapshot results and **Figure 146**).

Annual and seasonal cycles in stream flow, as depicted in **Figure 16**, drive fluxes in suspended and dissolved materials in rivers and streams and the rate of delivery of these materials to points further downstream. Thus, the dissolved salts display a seasonal pattern with an inverse relation with flow (**Figure 16**).

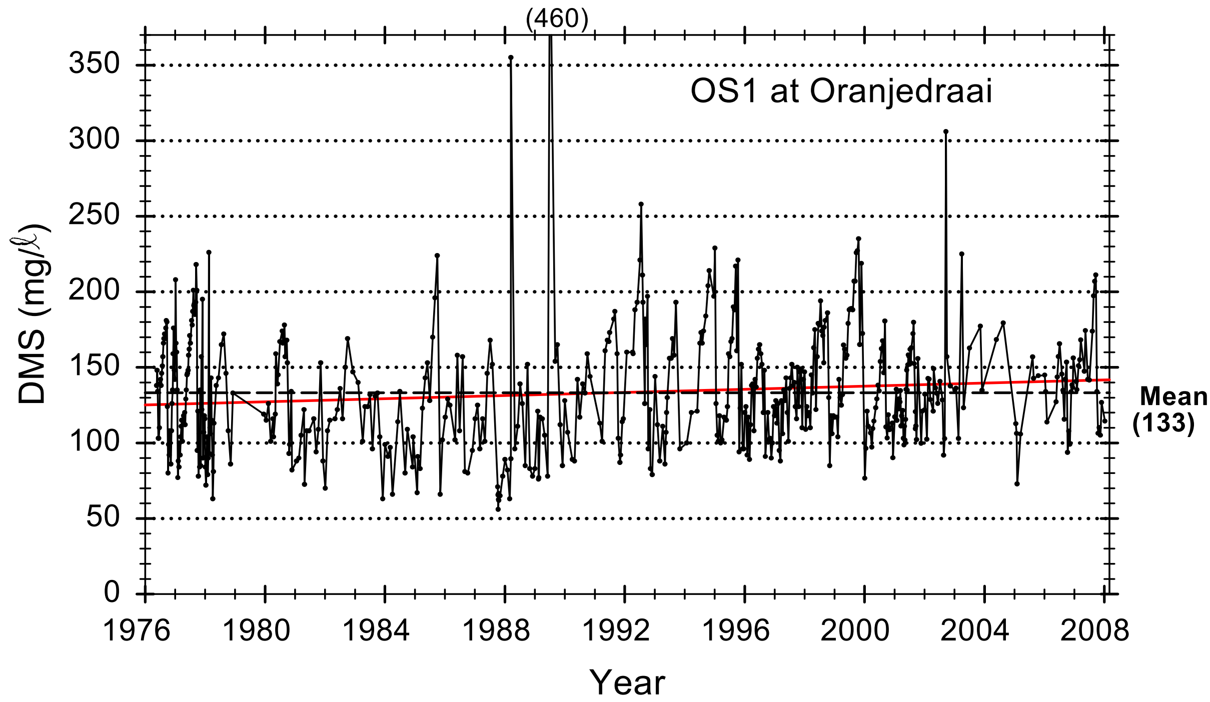


Figure 15: Temporal variation of dissolved major salt concentrations (DMS, mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007).

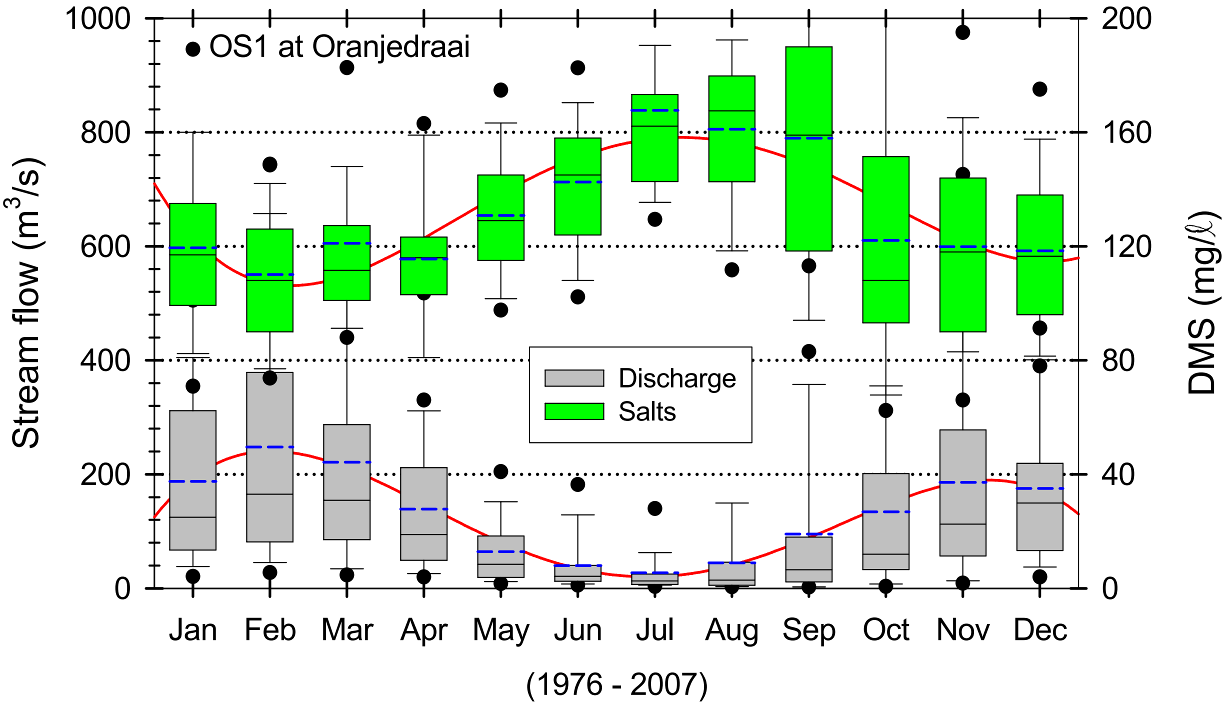


Figure 16: Box and whiskers plot of seasonal variation of stream flow (discharge, m^3/s) and dissolved major salt concentrations (DMS, mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007).

In catchments where human interference is negligible, chemical weathering assumes a major role in influencing water composition. The mean dissolved ionic composition of the Orange River water at Oranjedraai is illustrated as a pie chart in **Figure 17**. The order of ionic prominence in the Upper Orange River was:

$HCO_3^- > Ca^{2+} > SO_4^{2-} > Mg^{2+} > Na^+ > Cl^- > K^+$.

The concentration of major anions shows proportions of $HCO_3^- > SO_4^{2-} > Cl^-$ and the cations of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. The cation and anion proportions in the Orange River are the same as the proportions illustrated in most freshwater (Wetzel, 2001).

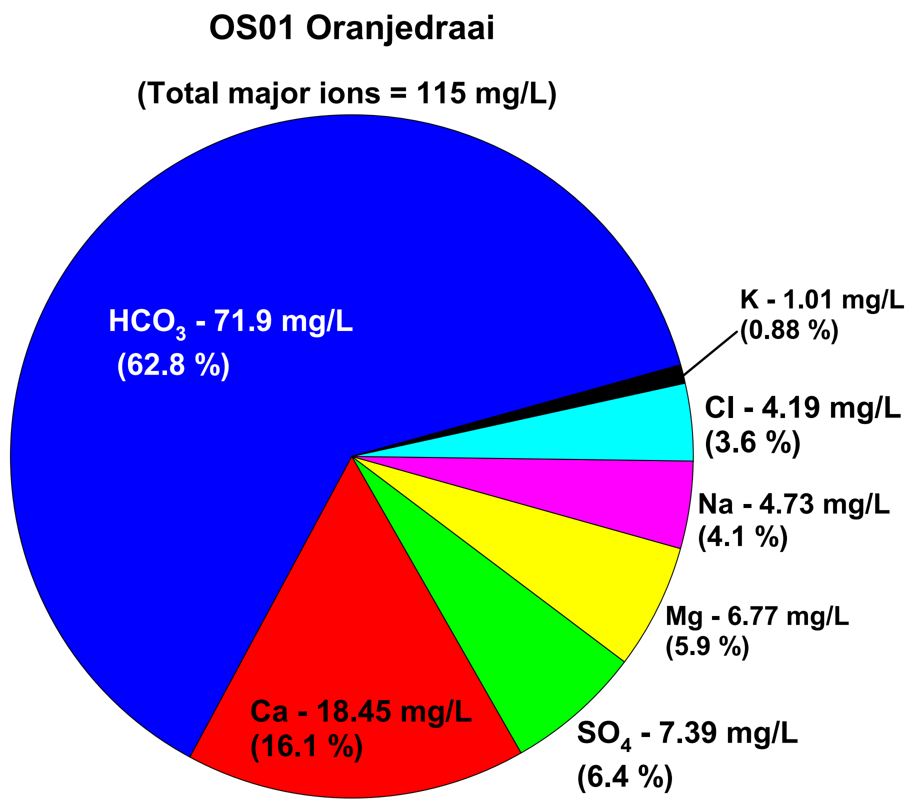


Figure 17: Pie chart of the ionic composition (averages) in the Orange River at Oranjedraai (1976 – 2007).

Nevertheless, the origin of different ions is different in nature and does not necessarily show any correlation with each other. For example, at Oranjedraai, a plot of Mg concentrations versus SO_4 concentrations shows no significant correlation with each other (**Figure 18**). However, anthropogenic activities can change the correlation significantly – cf. **Figure 69.**

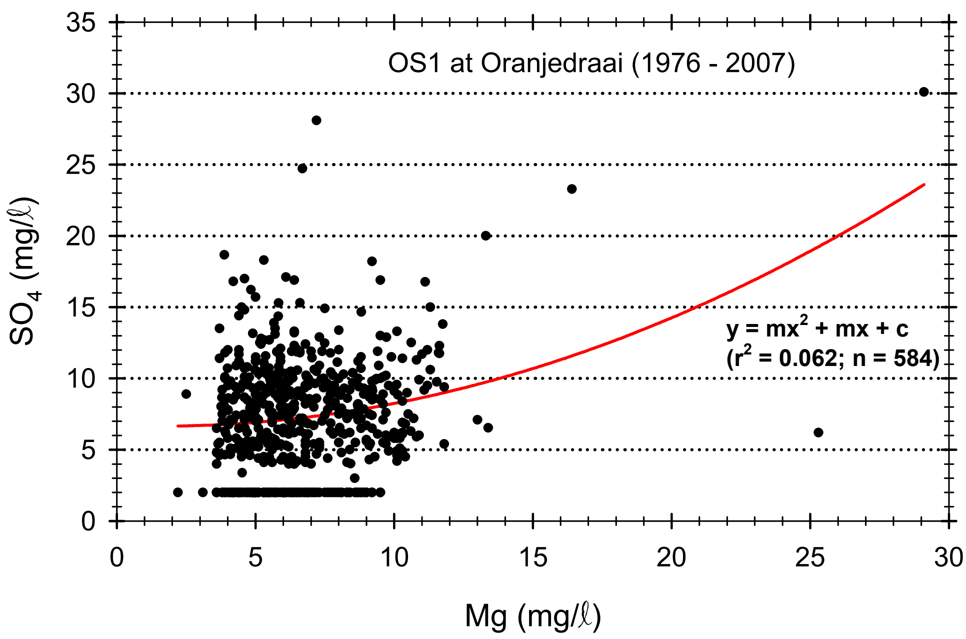


Figure 18: Scatter chart of magnesium vs. sulphate concentrations (mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007).

Because the Orange River is a relatively big river with little human impact at Oranjedraai, most of the salts concentrations fluctuated in a relatively narrow range, for example the calcium concentrations ranged mostly between 10 and 30 mg/ℓ (mean, 18.5 mg/ℓ) with no significant trend or change in concentration observed during the past 32 years (**Figure 19**). This indicates that the river is very stable with a high resilience. The mean Ca concentration of 18.45 mg/ℓ is slightly higher than the median concentration of 13 mg/ℓ found in Africa's rivers and lakes (Wetzel, 2001).

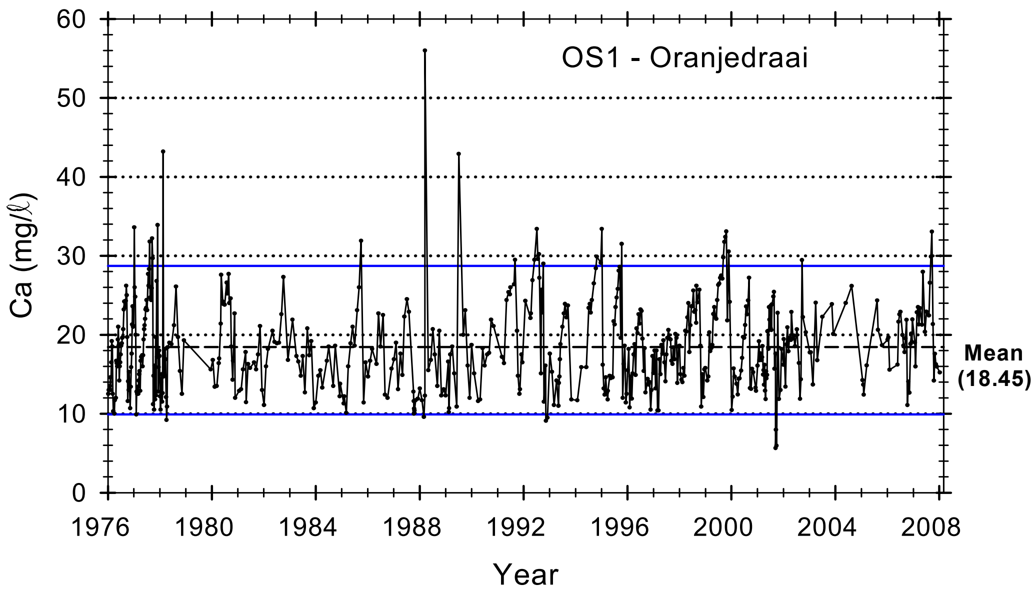


Figure 19: Temporal variation of calcium (Ca) concentrations (mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007). The solid lines (blue) represent the standard deviation.

6.2.5 Total hardness

The hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts. The general range and overall mean hardness in the Orange River at Oranjedraai of 75.2 mg/ℓ falls in the range of moderately soft water systems (Kunin, 1972) (**Figure 20**).

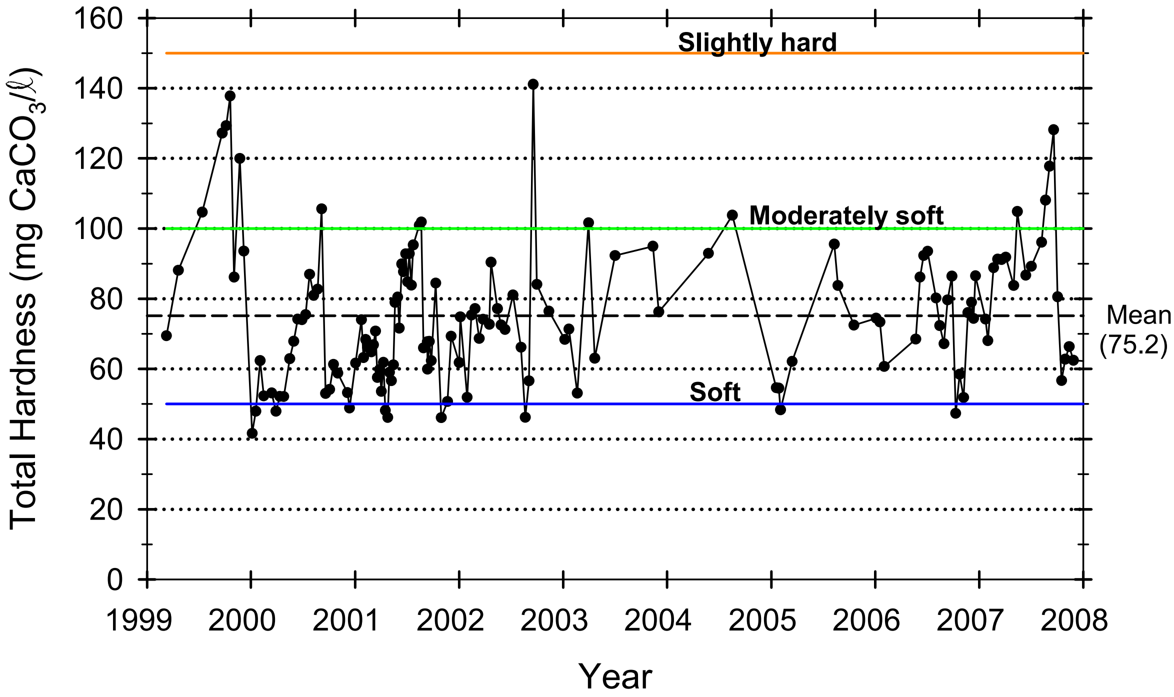


Figure 20: Temporal variation of total hardness (mg $CaCO_3$/ℓ) in the Orange River at Oranjedraai (1999 – 2007).

6.2.6 Nutrients

Inorganic nutrients are elements essential to life and provide the chemical constituents on which the entire food web is based. The major nutrients (macronutrients), required for metabolism and growth of organisms include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, magnesium, and calcium. Catchment nutrient loads are the principal drivers of ecological processes in receiving waters.

In aquatic systems, nitrogen (N) and phosphorus (P) are the two nutrients that most commonly limit maximum biomass of algae and aquatic plants (primary producers), which occurs when concentrations in the surrounding environment are below requirements for optimal growth of algae, plants and bacteria (UNEP-GEMS, 2006). Productivity of aquatic ecosystems can, therefore, be managed by regulating direct or indirect inputs of N and P with the aim of either reducing or increasing primary production.

Phosphorus and nitrogen are considered to be the primary drivers of eutrophication of aquatic ecosystems, where increased nutrient concentrations lead to increased primary productivity. Rivers and streams are major routes of transfer of nitrogen and phosphorus, and they integrate point and non-point sources of nutrients. Some systems are naturally eutrophic, whereas others have become eutrophic as a result of human activities ('anthropogenic or cultural eutrophication') through factors such as runoff from agricultural lands containing fertilizers and the discharge of municipal waste into rivers and lakes.

Aquatic ecosystems can be classified into trophic state, which provides an indication of a system's potential for biomass growth of primary producers. Trophic states are usually defined as oligotrophic (low productivity), mesotrophic (intermediate productivity), and eutrophic (high productivity). Ultra-oligotrophic and hyper-eutrophic (hypertrophic) states represent opposite extremes in the trophic status classifications of aquatic environments. Although there are many methods for classifying systems into trophic state, a common approach examines concentrations of nutrients across many systems and separates systems according to their rank in the range of nutrient concentrations (Dodds *et al*., 1998).

6.2.6.1 Phosphate (PO_4-P)

Phosphorus is present in natural waters primarily as phosphates, which can be separated into inorganic and organic phosphates. Inorganic phosphorus, as orthophosphate (PO_4^{3-}), is biologically available to primary producers that rely on phosphorus for production and has been demonstrated to be an important nutrient limiting maximum biomass of these organisms in many inland systems (UNEP-GEMS, 2006). Phosphate is usually the limiting factor in algal growth and therefore, controls the primary productivity of a water body (Chapman, 1996).

Natural sources of P are mainly the weathering of phosphorus-bearing rocks and the decomposition of organic matter. Phosphorus generally enters aquatic ecosystems sorbed to soil particles that are eroded into lakes, streams and rivers. Domestic wastewater (particularly those containing detergents), sewage discharges, industrial effluents and fertiliser run-off contribute to elevated levels of P in surface waters.

Phosphorus in rivers and streams are retained by adsorption onto streambed sediments, sedimentation, and via uptake by algae and aquatic macrophytes. The adsorption onto bottom sediments is considered to be the major mechanism of P retention (Wetzel, 2001).

High concentrations of phosphates can indicate the presence of pollution and are largely responsible for eutrophic conditions. The eutrophication threshold of P is 40 µg/ℓ and of N is 900 µg/ℓ for rivers and stream in the US (USEPA, 2000).

The phosphate concentrations in the Orange River at Oranjedraai were relatively high (mean 42 µg/ℓ), and show an increasing trend with time (**Figure 21**). The increasing trend indicates possible nutrient pollution from agricultural activities and/or sewage contamination in Lesotho.

Phosphate concentrations in natural waters are low, between 1 and 24 µg/ℓ (Meybeck, 1982). The most common natural concentration (corresponding to the median value obtained for 60 major rivers) in rivers is 10 µg/ℓ (Chapman, 1996). However, the mean phosphate concentration in the Katse Dam (upper catchment area of the Orange River (1996 – 1999), considered to be pristine, was also high at 66 µg/ℓ (Roos, 2000). Therefore, the relatively high phosphate concentrations at Oranjedraai are considered to be largely natural.

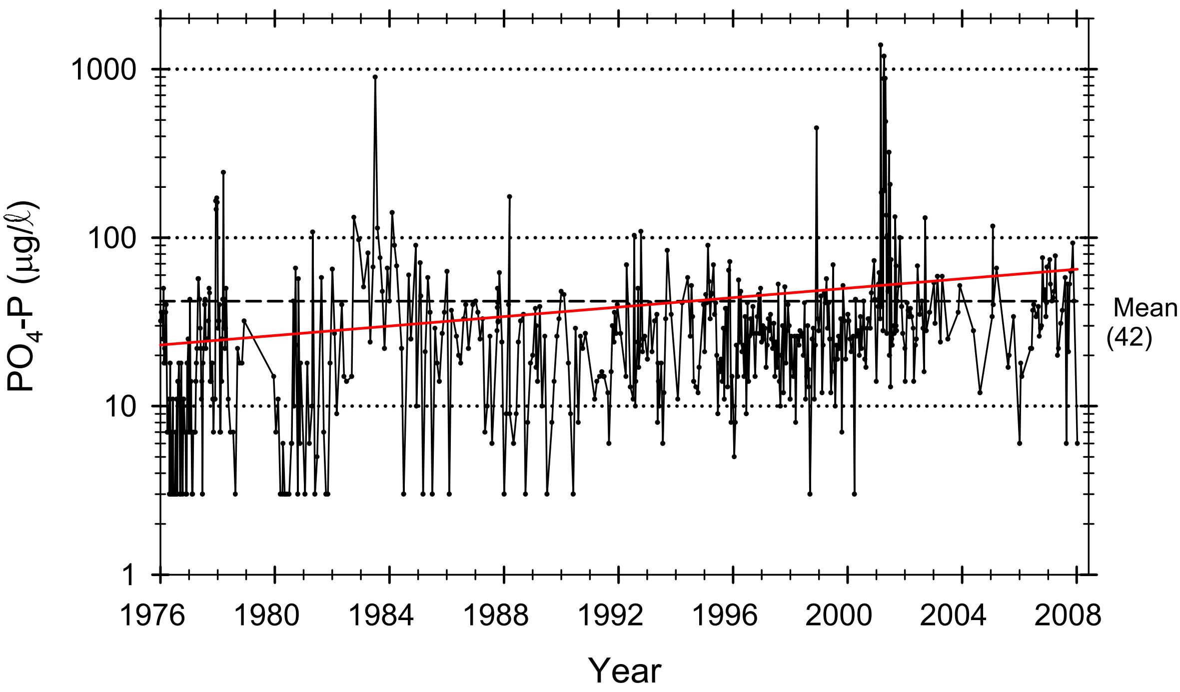


Figure 21: Temporal variation of phosphate concentration (PO_4-P, µg/ℓ) in the Orange River at Oranjedraai (1976 – 2007). Note the log scale on y-axis.

6.2.7 Dissolved inorganic nitrogen (DIN)

Nitrogen occurs in water in a variety of inorganic and organic forms and the concentration of each form is primarily mediated by biological activity. Nitrogen fixation, performed by cyanobacteria and certain bacteria, converts dissolved molecular N_2 to ammonium (NH_4^+). Aerobic bacteria convert NH_4^+ to nitrate (NO_3^-) and nitrite (NO_2^-) through nitrification, and anaerobic and facultative bacteria convert NO_3^- and NO_2^- to N_2 gas through denitrification. Primary producers assimilate inorganic N as NH_4^+ and NO_3^-, and organic N is returned to the inorganic nutrient pool through bacterial decomposition and excretion of NH_4^+ and amino acids by living organisms.

Ammonium (NH_4) occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by microorganisms and from gas exchange with the atmosphere. Unpolluted waters contain small amounts of ammonium, usually <0.1 mg/ℓ as nitrogen (Chapman, 1996).

The dissolved inorganic nitrogen (DIN = NH_4-N + NO_3-N + NO_2-N) concentrations at Oranjedraai were generally low (mean, 0.348 mg/ℓ) (**Figure 22**), which is lower than the median DIN content in non-polluted areas of 0.450 mg/ℓ (Meybeck, 1982), but much higher than the 0.12 mg/ℓ in unpolluted rivers. DIN was dominated by nitrate (mean, 0.30 mg/ℓ) and only 15 % was present as ammonium (0.051 mg/ℓ).

The NH_4 concentrations in major unpolluted rivers usually vary between 0.007 and 0.040 mg/ℓ (Meybeck, 1982). The NH_4-N concentrations in the Orange River at Oranjedraai were generally low (mean, 0.051 mg/ℓ) and ranged between 0.015 and 0.710 mg/ℓ (Appendix C, **Table C3**).

The DIN concentrations at Oranjedraai fall in the range of mesotrophic systems. However, the DIN concentration shows a decreasing trend with time (**Figure 22**). The DIN concentration in uncontaminated rivers is generally variable from 0.1 to 0.80 mg/ℓ, with the mean at 0.45 mg/ℓ (Meybeck, 1982).

The decreasing trend is ascribed to denitrification of nitrate (NO_3 to N_2 gas that escapes into the atmosphere), which is thought to be an important process in rivers. Similar observation was made in the Vaal River (Roos, 2007) – see section **6.7.2**.

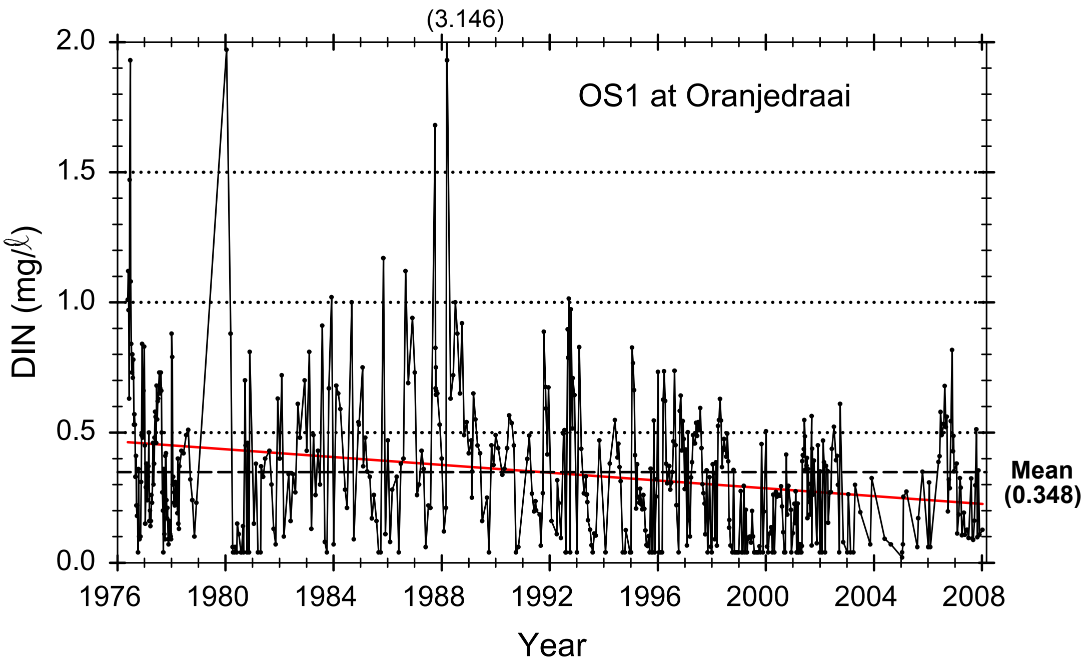


Figure 22: Temporal variation of dissolved inorganic nitrogen concentration (DIN, mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007).

6.2.8 Silica (SiO_2)

Silica or silicon dioxide (SiO_2) is widespread and always present in surface and groundwater. About 60 % of the rocks and soils of the earth's crust consist of silica. It exists in water in dissolved, suspended and colloidal states. Reactive silicon mainly arises from chemical weathering of siliceous minerals (Chapman, 1996).

Silica is a key micronutrient in diatom production, a very common algal group, and is taken up during the early growing season. Silica is also an essential element for certain aquatic plants (principally diatoms). It is taken up during cell growth and released during decomposition and decay giving rise to seasonal fluctuations in concentrations, particularly in lakes. The requirement for silica makes it an ecologically important environmental variable for chrysophytes and diatoms.

Dissolved silica (SiO_2) usually occurs in moderate abundance in freshwaters. The silica concentration of rivers and lakes usually varies within the range 1 – 30 mg/ℓ. The mean silica concentration for World Rivers is 13.1 mg/ℓ (Wetzel, 2001).

The dissolved SiO_2 concentration in the Orange River at Oranjedraai ranged between 3.67 and 11.46 mg/ℓ (mean 8.63 mg/ℓ; **Figure 23**). This mean is lower than the mean of World Rivers of 13.1 mg/ℓ, but much higher than the average silica concentration in 21 South African impoundments of 5.2 mg/ℓ (calculated from data by Walmsley & Butty, 1980).

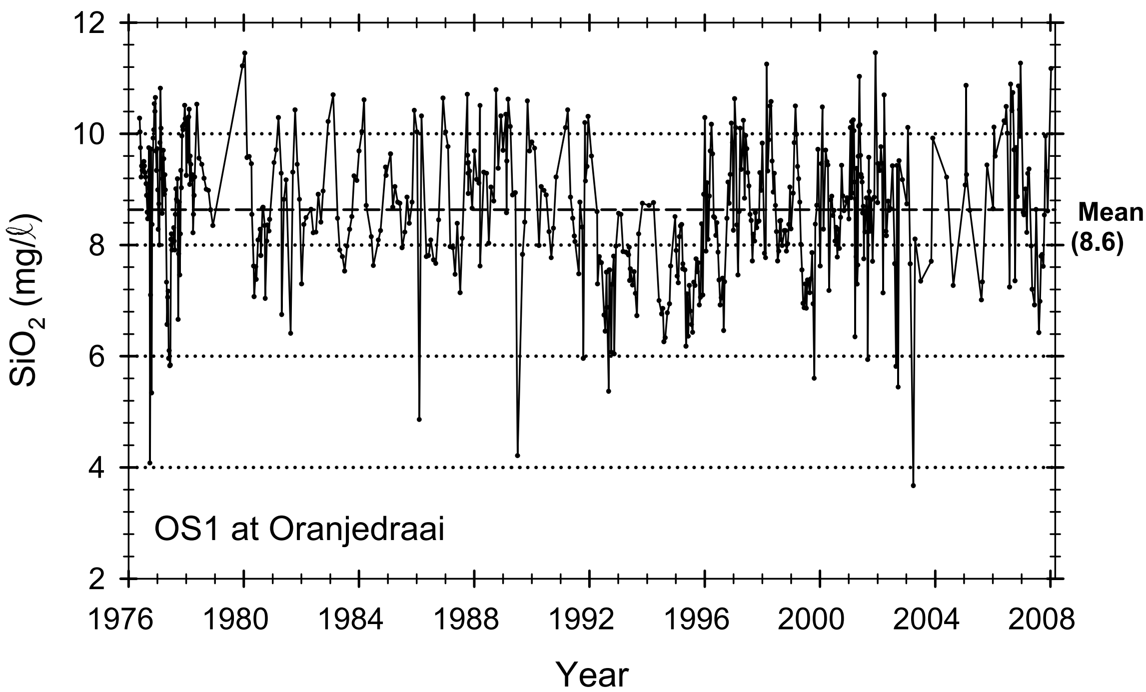


Figure 23: Temporal variation of dissolved silica concentration (SiO_2, mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007).

6.2.9 Other parameters

Additional graphs of other parameters are shown in Appendix A, **Figure A2**, and briefly discussed below.

The electrical conductivity (EC) of the water is proportional to the dissolved salts, and ranged between 7.8 and 51.0 mS/m (mean, 16.8 mS/m) (**Table C1** in Appendix C).

6.2.9.1 Magnesium (Mg):

Magnesium is common in natural waters as Mg^{2+}, and along with calcium, is a main contributor to water hardness. However, the demands for Mg in metabolism are minor in comparison to quantities generally available in freshwaters (Horne & Goldman, 1994).

Mg concentrations in the Orange River at Oranjedraai were moderate; it ranged between 2.20 and 29.1 mg/ℓ with mean at 6.77 mg/ℓ. This value is comparable to the median Mg concentration of 5.0 mg/ℓ in Africa's rivers and lakes. The Mg concentration shows, like all the salts, a seasonal pattern, but no significant trend with time (**Figure A2 A**).

6.2.9.2 Sodium (Na):

All natural waters contain some sodium since sodium salts are highly water-soluble and it is one of the most abundant elements on earth. It is found in the ionic form (Na^+) and in plant and animal matter – it is an essential element for living organisms. Increased concentrations in surface waters may arise from sewage, industrial and mining effluents.

Sodium is commonly measured where the water is to be used for drinking or agricultural purposes, particularly irrigation. Elevated Na in certain soil types can degrade soil structure thereby restricting water movement and affecting plant growth.

The Na concentrations at Oranjedraai were low and ranged between 1.0 and 22.35 mg/ℓ (mean 4.67 mg/ℓ) compared to the median Na concentration in Africa's rivers and lakes of 18 mg/ℓ.

6.2.9.3 Potassium (K):

Potassium (as K^+) is found in low concentrations in natural waters, since rocks that contain potassium are relatively resistant to weathering. Potassium is usually found in the ionic form and the salts are highly soluble. It is readily incorporated into mineral structures and accumulated by aquatic biota as it is an essential nutritional element. Concentrations in natural waters are usually less than 10 mg/ℓ (Chapman, 1996). Nevertheless, K is rarely considered to have an important influence on the ecology of algae.

Potassium in the Orange River at Oranjedraai demonstrates little seasonal variation, indicating the conservative nature of K, with concentrations that ranged between 0.15 and 12.4 mg/ℓ (mean 1.01 mg/ℓ) (**Figure A2 C**). The most common natural concentration of K in rivers is 1.0 mg/ℓ and the median K concentration for Africa's rivers and lakes is 4 mg/ℓ (Meybeck & Helmer, 1989).

6.2.9.4 Sulphate (SO_4)

The most frequently encountered form of sulphur in freshwaters is anion sulphate (SO_4^{2-}) in combination with common cations (positively charged ions), as well as hydrogen sulphide (H_2S). Sulphur is important in protein structure, but rarely limits the growth or distribution of the aquatic biota (Horne & Goldman, 1994).

The impacts of SO_4 concentration in water is associated with the cation that sulphate associates. If the cation is Magnesium, this will induce diarrhoea if the water is consumed by both humans and animals (DWAF, South African Water Quality Guidelines, 1996).

The most common natural sulphate concentration in rivers is 4.8 mg/ℓ (Chapman, 1996). The sulphate concentration at Oranjedraai was higher and ranged between 2.0 mg/ℓ and 30.10 mg/ℓ (mean 7.39 mg/ℓ).

The sulphate concentration shows an increasing trend, but was fairly stable during the last 15 years at about 10 mg/ℓ (**Figure A2 E**).

6.2.9.5 Chloride (Cl)

Most chlorine occurs as chloride (Cl^-) in solution. In pristine freshwaters chloride concentrations are usually lower than 10 mg/ℓ and sometimes less than 2 mg/ℓ. Chlorides do not appear to limit algal production directly in nature but, as sodium chloride, may play a major part in determinating the types of algae that can grow in the water (Lund, 1965).

The mean chloride concentration in the Orange River at Oranjedraai was low at 4.2 mg/ℓ (ranged between 1.0 and 22.35 mg/ℓ) and very close to the most common natural concentration of Cl in rivers of 3.9 mg/ℓ (Chapman, 1996). A value of 39.8 mg/ℓ (7/3/1989) was rejected as an outlier.

Higher Cl concentrations can occur near sewage and other waste outlets. As chloride is frequently associated with sewage, it is often incorporated into assessments as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies. However, the Cl concentration at Oranjedraai showed no significant increase with time (**Figure A2 C**).

6.2.9.6 Fluoride (F):

Traces of fluoride (<1 mg/ℓ) occur in many aquatic ecosystems, whilst higher concentrations (often >10 mg/ℓ) can be found in groundwaters derived from igneous rocks. Fluoride reacts rapidly with calcium and phosphate ions to form insoluble complexes, which tend to settle out of the water-column.

Fluoride concentrations in natural waters vary from 0.05 to 100 mg/ℓ, although in most situations they are less than 0.1 mg/ℓ (Chapman, 1996). F concentration between 0.6 and 1.5 mg/ℓ in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. However, dental fluorosis ('mottled enamel') is a sign of chronic fluoride poisoning (F >1.5 mg/ℓ) in children under six to seven years of age.

The mean F concentration at Oranjedraai of 0.13 mg/ℓ (**Figure A2 D**), is much lower than the mean concentration of 0.26 mg/ℓ usually found in freshwaters (Wetzel, 2001), but falls within the target water quality range (TWQR) for aquatic ecosystems of ≤ 0.75 mg/ℓ (DWAF, 1996).

6.2.9.7 Sodium Adsorption Ratio (SAR):

The SAR is an index of the potential of water to induce sodic soil conditions, and is calculated from the sodium, calcium and magnesium concentrations in the water. Thus, the SAR is used to evaluate the suitability of water for irrigation. The ratio estimates the degree to which sodium will be adsorbed by the soil. High values of SAR imply that the sodium in the irrigation water may replace the calcium and magnesium ions in the soil, potentially causing damage to the soil structure.

The target water quality range for SAR to prevent loss of crop yield and quality is ≤ 2.0 and ≤1.5 to preserve the soils physical conditions (DWAF, 1996). The mean SAR at Oranjedraai was very low at 0.24 (min. 0.07; max. 1.15) and within the TWQR for irrigation water (**Figure A2 G**).

6.2.9.8 Total Alkalinity (TAL):

Alkalinity is the acid-neutralising capacity of water and is usually expressed as mg $CaCO_3$/ℓ. The alkalinity of water is controlled by the sum of the titratable bases. It is mostly taken as an indication of the concentration of carbonate, bicarbonate and hydroxide, but may include contributions from borate, phosphates, silicates and other basic compounds.

At high pH values (8 – 9; as in Orange River), the bicarbonate ion (HCO_3^-) is the predominant form. Water of low alkalinity (<20 mg/ℓ as $CaCO_3$) has a low buffering capacity and can, therefore, be susceptible to alterations in pH (sensitive to acidification), for example from atmospheric, acidic deposition (UNEP-GEMS, 2006).

The mean alkalinity value in the Orange River at Oranjedraai was moderate (mean 71.9 mg/ℓ) and showed a seasonal variation (**Figure A2 H**). Waters of low alkalinity (<20 mg/ℓ) are considered to be less suitable for fish culture due to the associated unstable water chemistry. However, the alkalinity values in Orange River are within the target water quality range (20 – 100 mg/ℓ) for aquaculture production and the health of fish (DWAF, 1996).

Because bicarbonate (HCO_3) dominates the salt composition (**Figure 17**), therefore, a statistically significant correlation was demonstrated between the total alkalinity and the major dissolved salts. Ninety-six per cent of the variation of alkalinity was associated with the variation of DMS (**Figure 24**). Similar linear correlations were illustrated in other systems (Chapman, 1996).

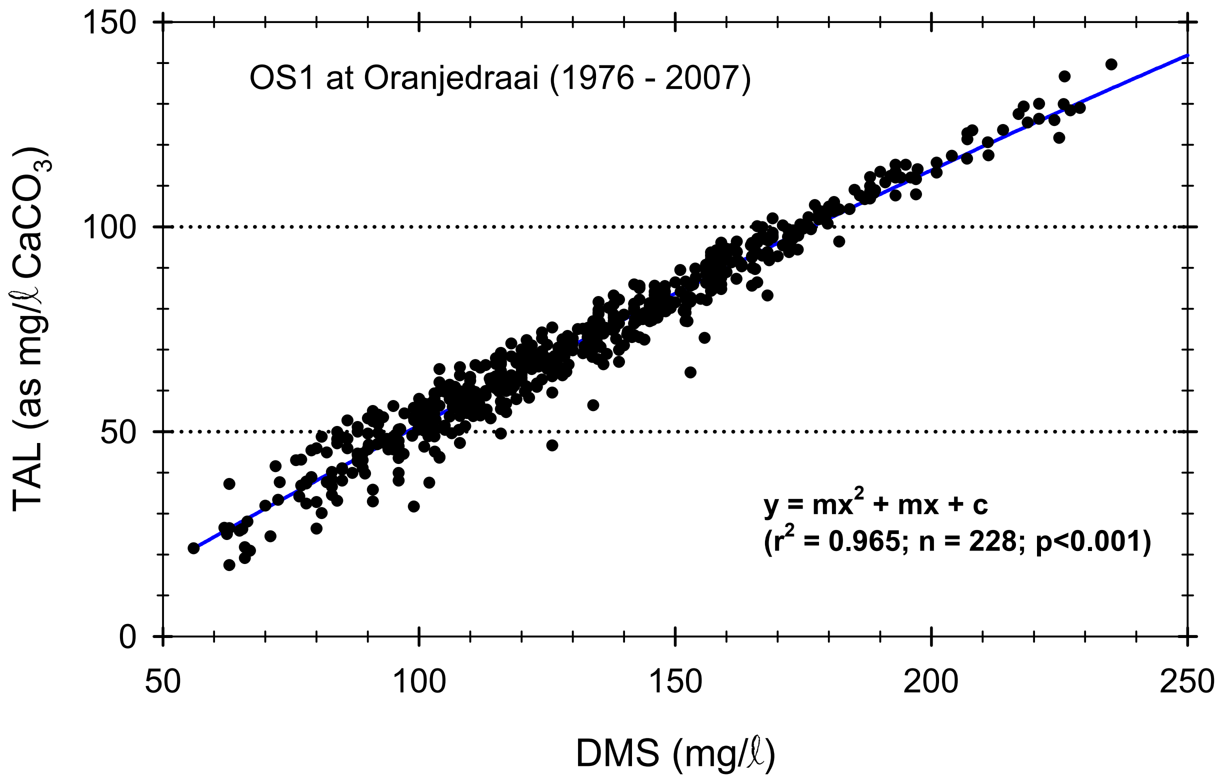


Figure 24: Scatter plot of major dissolved salts (DMS) vs. total alkalinity (TAL) in the Orange River at Oranjedraai (1976 – 2007).

6.3 OS2 – Aliwal North – D1H003 (S30.68612; E26.70600)

Aliwal North is a medium size town in the Eastern Cape Province. The monitoring site is at the old Steel bridge (General Hertzog Bridge) in town and about 145 km (river length) downstream of Oranjedraai (**Figure A3**).

6.3.1 Stream flow

The annual stream flow ranged between 971 and 14 822 millions m^3 with the average at 4 750 Mm^3 (~150 m^3/s), which is 760 Mm^3/a higher than at Oranjedraai. The higher stream flow at Aliwal North originates mainly from the Kraai River tributary with a mean stream flow of 652 Mm^3/a, *i.e.* 20.7 m^3/s.

A second order trend line indicate a fairly constant annual stream flow at Aliwal North of approximately 5 000 millions m^3 during the past 68 years (**Figure A4 A** – Appendix A).

6.3.2 Total suspended solids (TSS)

Limited data on suspended solids are available for the Orange River, whilst it an important characteristic of the river. Unfortunately, TSS data is only available from 1968 to 1986 at Aliwal North (**Figure 25**) and turbidity measurements started in 1992; therefore, no correlation between these two variables could be determined.

The transport of river borne sediment from the continental land mass to the world's oceans is a fundamental feature of the geology and biogeochemistry of our planet. The TSS concentration is a measure of the amount of material suspended in water. Suspended matter consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, phytoplankton and other microscopic organisms.

Suspended particles in rivers can compromise biotic integrity and degrade water quality, but they also represent an important part of the food webs and nutrient cycles of lotic ecosystems (Dodds & Whiles, 2004). In many freshwater systems, transparency and light penetration are mainly controlled by the concentration of particulate material in the water. The type and concentration of suspended matter controls the turbidity and transparency of the water.

The Orange River is one of the world's most turbid; delivering 60 million tons of sediment each year to the western margin of South Africa. Much of this sediment is believed to be from soil erosion, an increasing environmental threat to sustainability in southern Africa (Compton & Maake, 2007).

The concentration of suspended solids increases with the stream flow of sediment washed into rivers due to rainfall and resuspension of deposited sediment. As flow decreases, the suspended solids settle out, the rate of which depends on particle size and the hydrodynamics of the water body.

The mean TSS at Aliwal North was very high (1 235 mg/ℓ), which is comparable with the Ganges/Brahmaputra River with 1 700 mg/ℓ, lower than the Nile which (before the construction of the Aswan Dam) carried 3 700 mg/ℓ, but much higher than the Mississippi with 360 mg/ℓ (Degens *et al.*, 1991). The most common natural TSS concentration in rivers is only 150 mg/ℓ (Chapman, 1996).

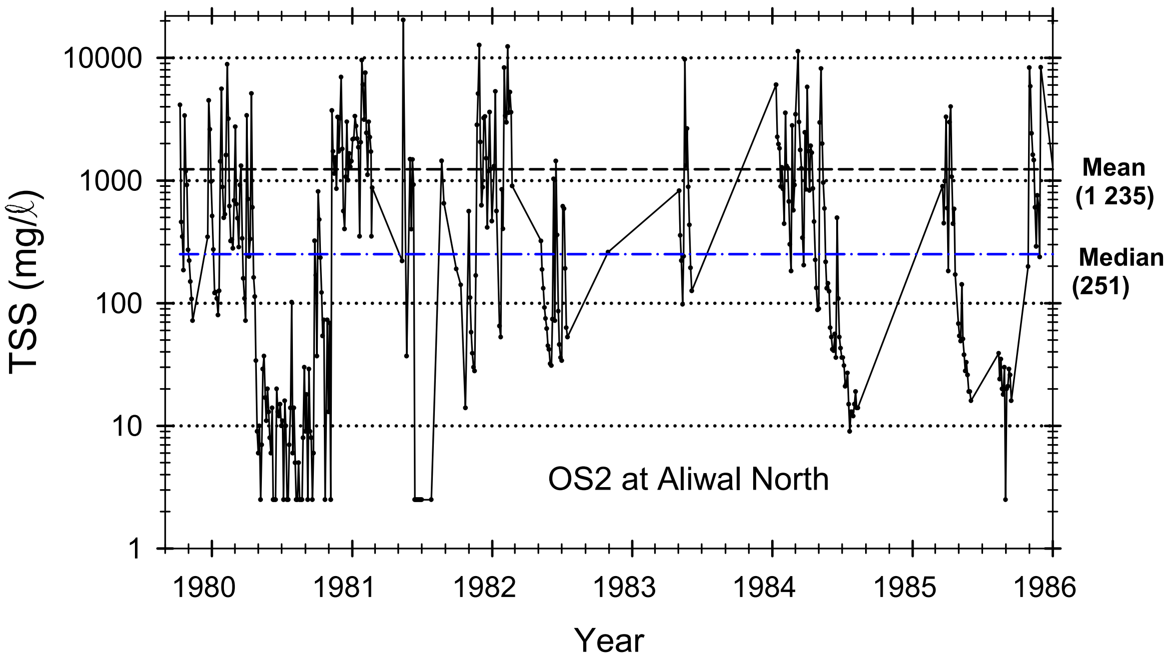


Figure 25: Temporal variation of total suspended solids (TSS) concentration (mg/ℓ) in the Orange River at Aliwal North (OS2) (1979 – 1986). Note the log scale on the y-axis.

6.3.3 Dissolved major salts (DMS)

The mean DMS at Aliwal North (140.8 mg/ℓ) was slightly higher than the mean at Oranjedraai (133 mg/ℓ) and also shows an increase with time (**Figure 26**). The higher salts could be associated with human activities (agriculture and sewage discharges) and lower flow.

The minimum DMS was 56 mg/ℓ and the maximum 471.1 mg/ℓ. DMS concentrations were inversely related to the river flow, *i.e.* low salt concentrations were observed during the rainy season (summer-autumn, November – May) and high concentrations observed during the drier winter-spring period (June to September) (**Figure 27**).

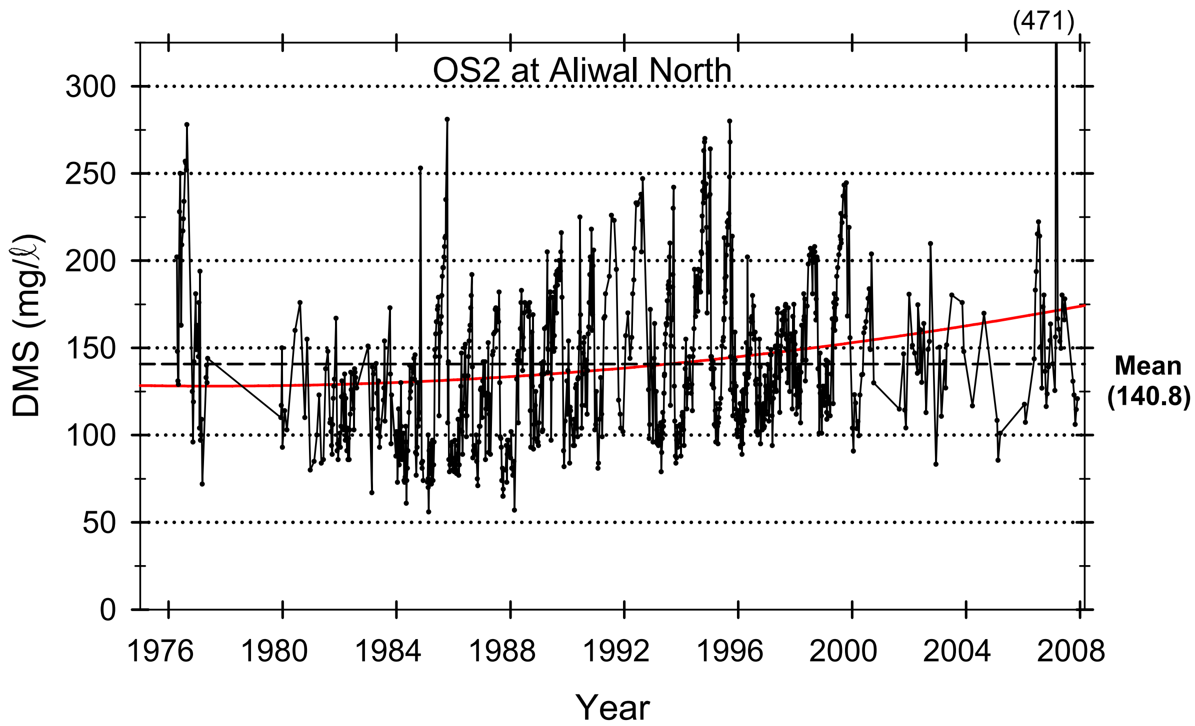


Figure 26: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Aliwal North (OS2) (1976 – 2007).

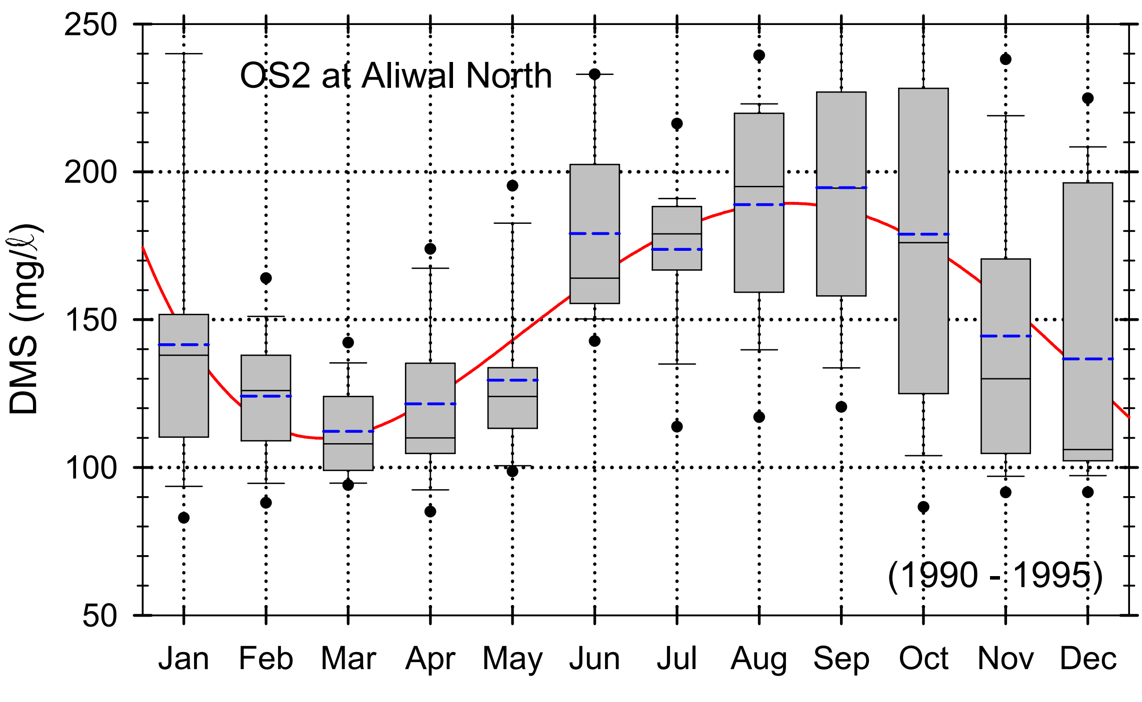


Figure 27: Box and whiskers plot of seasonal variation in dissolved major salts (DMS, mg/ℓ) in the Orange River at Aliwal North (1990 – 1995).

6.3.4 Total Phosphorus (TP)

Total phosphorus (TP) occurs in aquatic systems in three different components: (i) soluble reactive phosphorus or phosphate, (ii) soluble non-reactive P, largely organic, and (iii) particulate P, stored in living cells, present in organic detritus, and adsorbed to abiotic particulate surfaces.

The world river transport of TP has increased by no less than four times. This is the main reason for the progressing eutrophication of rivers, lakes, water reservoirs, and coastal marine waters (UNP, 2000). Within individual basins throughout the world, municipal wastewater treatment plant inputs often contribute 50 % to 90 % of annual nutrient inputs (Haggard *et al.*, 2004).

The TP concentrations in aquatic systems are usually strongly associated with trophic level and cyanobacteria (blue-green algae) increase with an increase in TP concentration.

TP values are limited in the Orange River monitoring data set. At Aliwal North the data are limited to the period 1982 to 1988 (**Figure 28**). TP is sometimes considered to be a better indicator of eutrophication than phosphates.

The mean TP at Oranjedraai of 0.392 mg/ℓ was surprisingly high because concentrations more than 0.100 mg/ℓ are usually considered to be unacceptably high for algal growth. According to the criteria used by DWAF's National Eutrophication Monitoring Programme (NEMP, 2000), a TP concentration >0.130 mg/ℓ is associated with hypertrophic systems with a serious potential for algal and plant productivity (DWAF, 2002). However, the NEMP values were developed for dams and probably not directly applicable to rivers because of their lotic nature.

The Orange River at Aliwal North can possibly be classified as mesotrophic because the oligotrophic-mesotrophic boundary for rivers in Africa is considered to be 0.21 mg TP/ℓ and the meso-eutrophic boundary is at 0.49 mg/ℓ (Dodds *et al.*, 1998). However, the mean phosphate concentration of 39 µg/ℓ at Aliwal North was lower than the upstream point, at Oranjedraai (46 µg/ℓ).

Unfortunately no chlorophyll-*a* data are available at this site, but the algal concentrations in Gariep Dam were low and classified as oligotrophic (**Figure 34**).

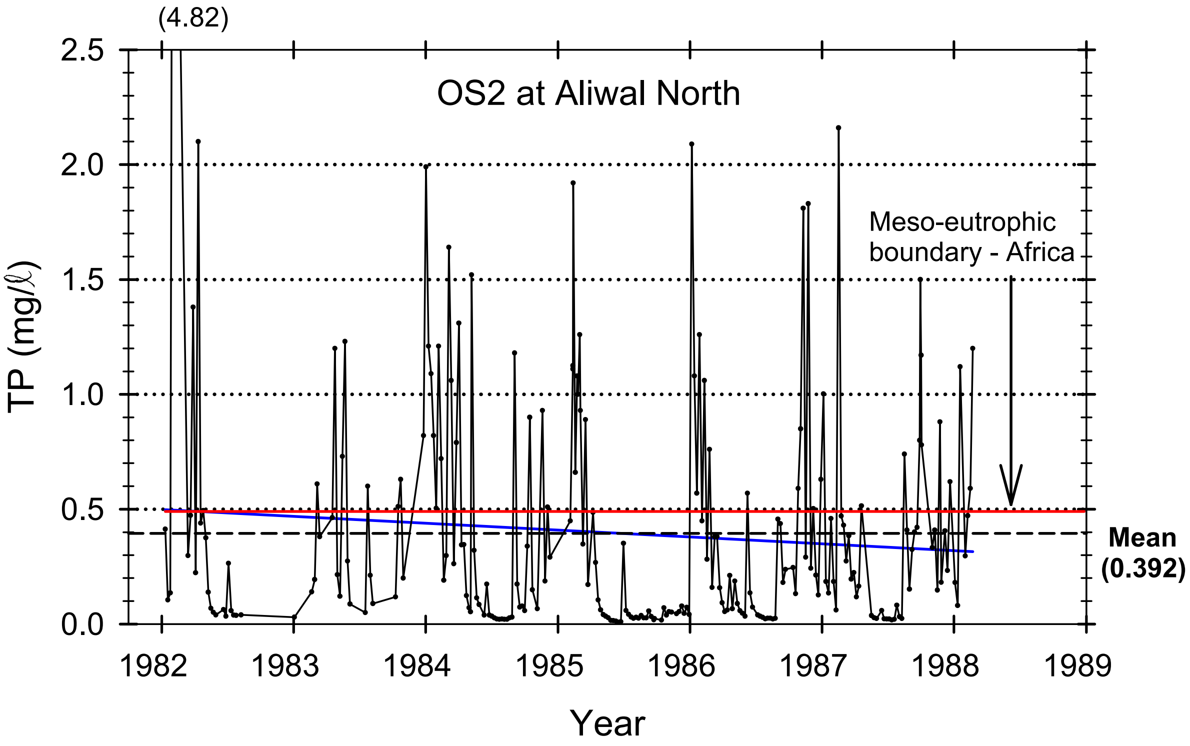


Figure 28: Temporal variation of Total phosphorus (TP) concentration (mg/ℓ) in the Orange River at Aliwal North (1982 – 1988). The blue line indicates the decreasing trend.

6.3.5 Other parameters

The general water chemistry at Aliwal North was very much the same as at Oranjedraai (the upstream monitoring point). For example the mean turbidity at Aliwal was 151 (mg/ℓ) compared to the 161 (mg/ℓ) at Oranjedraai (**Figure A4 B** in Appendix A).

Because the dissolved salts concentration was slightly higher, all the dissolved ions were slightly higher (approximately 10 %), *i.e.* Ca, Mg, Na, K, SO_4, Cl, F, and thus slightly higher EC and SAR (**Figure A4; Table C1-4**).

The pH was also high with a median value of 8.06 (**Figure A4 C**).

Slightly lower concentrations in Si, TSS, and DIN were recorded at Aliwal North (**Figure A4).**

6.4 OS3 – Saamwerk (S30.57622; E26.45638) – new site.

Proposed new site, thus no historical data **(Figure A5** in Appendix A) – see snapshot data – Chapter 7.

6.5 OSD1 – Gariep Dam – near dam wall D3R002 (S30.60794; E25.50465)

Gariep Dam (formerly known as H.F. (Hendrik) Verwoerd Dam) with a full level capacity of 5 343 Mm^3 and a surface area of more than 370 km^2, is the largest dam in South Africa (**Figure A6**). Gariep (Xhariep) is San (Bushmen) for "Great water".

The dam was commissioned in 1971 and is the central structure of the original Orange River Project which involves the supply of water to parts of the Vaal, Great Fish and Sundays catchments as well as to irrigation along the Orange River itself.

The dam wall is about 200 km downstream of Aliwal North (upstream monitoring site). A fairly good data base exists with weekly to biweekly measurements since 1972 ($n \approx 385$).

6.5.1 Dissolved major salts (DMS)

The salinity (DMS) in the dam was relatively low (overall mean, 130.4 mg/ℓ), which is lower than the upstream monitoring point at Aliwal North (140.8 mg/ℓ). It is assumed that the dam is filled during flood conditions that are associated with relatively low salt concentrations. However, the variation of salt concentrations was very low and generally ranged between 100 and 150 mg/ℓ (**Figure 29**).

The Lesotho Highlands Water Project has resulted in large volumes (770 Mm^3/a) of low salinity water being diverted from the Orange River into the Vaal River catchment. This has lead to an increase in salt levels in the Gariep and Vanderkloof dams.

Figure 29 shows that the mean salt concentration in Gariep Dam was 119 mg/ℓ for the 20 year period (1976 to 1996), and the salt concentration increased since 1996 (when Katse Dam was filling up) to a mean of 138 mg/ℓ.

In addition large volumes of water (650 Mm^3/a) have been transferred since 1975 from the Gariep Dam to the Great Fish drainage basin, mainly for irrigation purposes. The UNEP-GEMS (2006) report shows that the conductivity in the Orange River drainage basin increased significantly between 1980 and 2004 as a result of intensive irrigation practices and varying rainfall patterns. Concurrently, conductivity decreased significantly in the Great Fish drainage basin over the same time period as a result of inter-basin transfers of water from the Orange River basin.

Salinisation of the Orange River is a major concern, especially for the lower Orange (Earle *et al*., 2005). Therefore, the implementation of further phases of the Lesotho highlands water project, *i.e*. diverting water from the upper Orange-Senqu in Lesotho to the Vaal River system, will therefore aggravate the salinisation process in the whole Orange River.

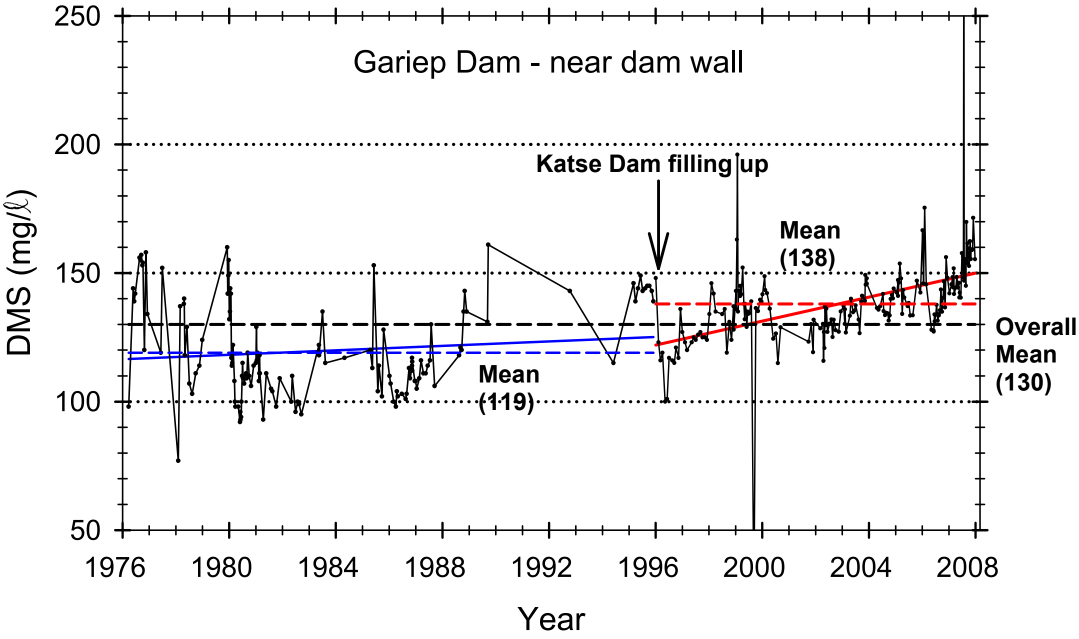


Figure 29: Temporal variation of dissolved major salts (DMS, mg/ℓ) in Gariep Dam. The blue line represents the conditions before the LHWP was implemented (1976 – 1996); the red line the conditions afterwards (1997 – 2007).

6.5.2 Nutrients (nitrogen, phosphorus and silica)

The DIN concentrations in Gariep Dam were relatively high and ranged between 0.04 and 6.02 mg/ℓ with the mean at 0.557 mg/ℓ (**Figure 30**). The DIN in Gariep Dam was on average 78 % higher than at Aliwal North (upstream point). The higher Nitrogen concentrations in Gariep Dam could partially be ascribed to the higher N concentrations from the Caledon River and Stormbergspruit.

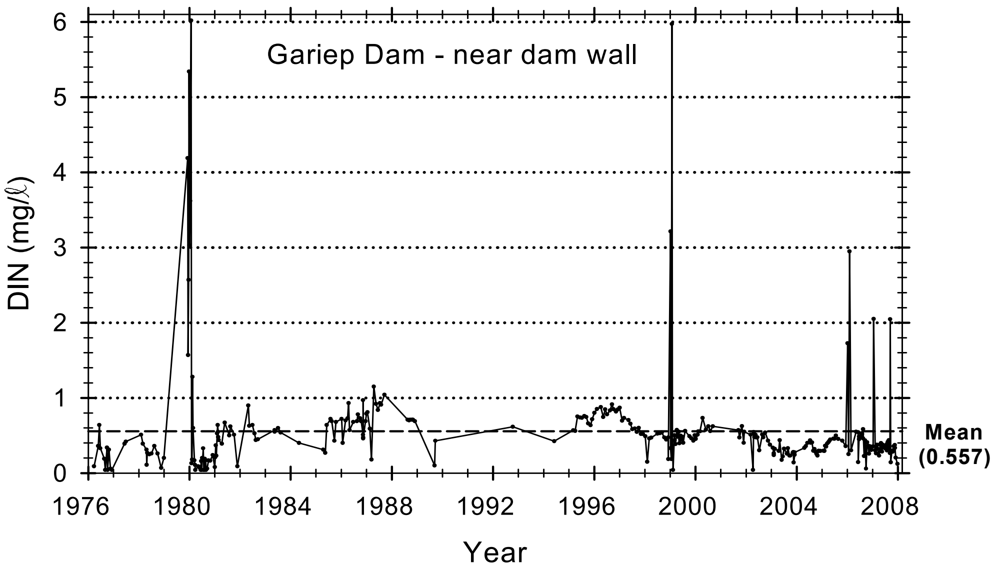


Figure 30: Temporal variation of dissolved inorganic nitrogen (DIN, mg/ℓ) in Gariep Dam (1976 – 2007).

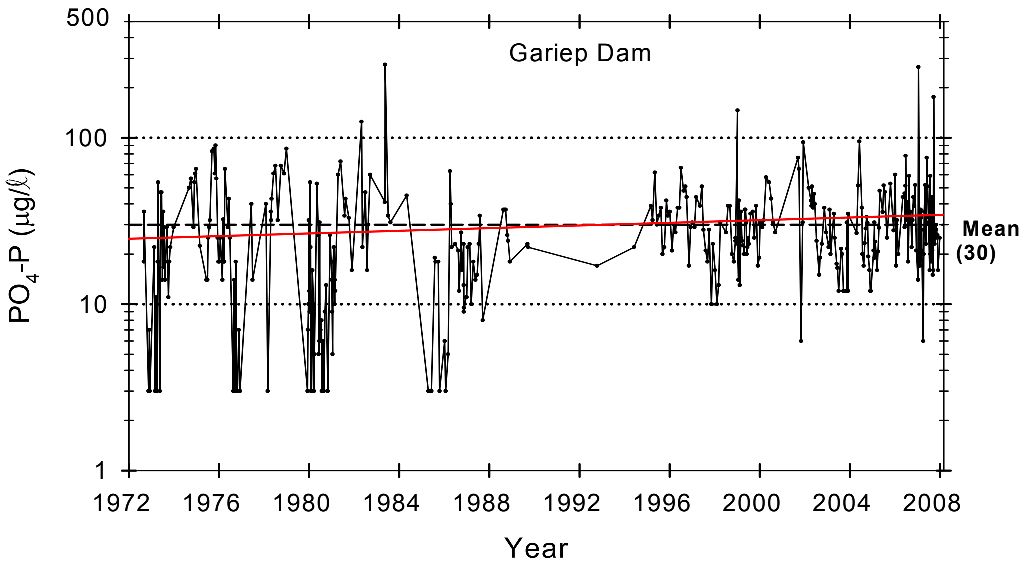


Figure 31: Temporal variation of the phosphate phosphorus (PO_4-P) concentration (µg/ℓ) in Gariep Dam (1972 – 2007). Note the log scale on the y-axis.

However, the phosphate concentrations were low, with the mean at 30 µg/ℓ (min. 3; max. 275 µg/ℓ) (**Figure 31**). Thus, the mean DIN:DIP ratio was very high at 28.5 that suggest a P limitation in the dam.

Silica or silicon dioxide (SiO_2) is a key micronutrient in diatom production, a very common algal group, and is taken up during the early growing season (usually Spring). Silica concentrations can limit diatom production if concentrations become depleted in surface waters. The depletion of silica tends to occur more often in lakes and reservoirs than in running waters (UNEP-GEMS, 2006). The mean silica concentration in Gariep Dam was slightly lower at 8.02 mg/ℓ (min. 5.48; max. 10.97 mg/ℓ). The silica concentration shows almost no significant seasonal variation (**Figure 32**).

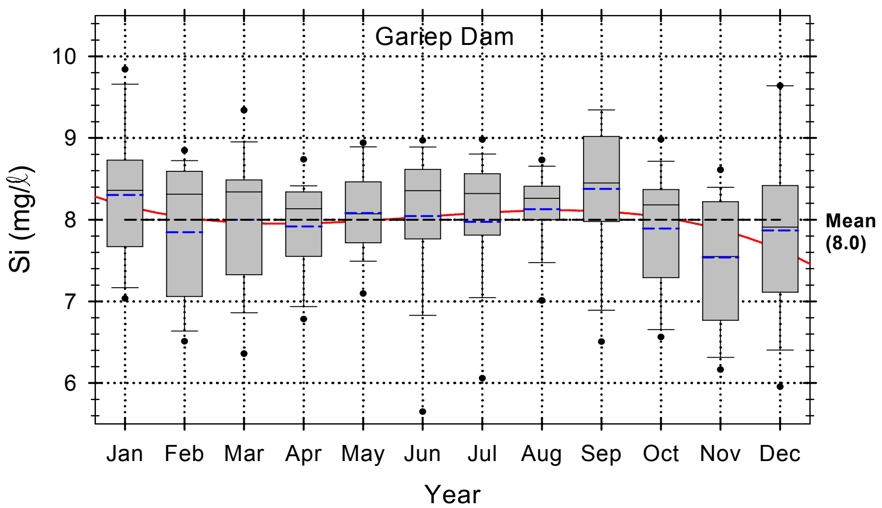


Figure 32: Box and whiskers plot of the seasonal variation of silica concentration (mg/ℓ) in Gariep Dam – near dam wall (1976 – 2007).

6.5.3 Total suspended solids (TSS)

Gariep Dam acts as a gigantic sediment trap, since a 1 % silt load in the water of the Orange River will add about 120 mm of sediment every year to the lake bottom, decreasing the reservoir's lifespan because of increased sediment storage. This is equivalent to topsoil from six 2 600 ha farms, or enough sediment to fill Midmar Dam in KwaZulu-Natal in 3 years (Davies & Day, 1998)

The mean TSS concentration (342 mg/ℓ) in Gariep Dam for the period 1972 to 1984 was significantly higher than for the period 1999 to 2007 (mean, 28.2 mg/ℓ; Δ = 92 %; **Figure 33**). Unfortunately, the TSS data set was not continuous and displays a vast gap between 1983 and 1999. Therefore, it is not possible to say if the change in TSS has happened gradual or suddenly for example after a flood. The reason for the lower TSS in Gariep Dam during the past 10 years is not clear. There are no indications that TSS transport from upstream has changed significantly during the past 30+ years (cf. **Figure 25**).

However, the recently low suspended solids (since 1999), would definitely have lead to clearer water conditions in the dam and hence a more favorable underwater light climate that can enhance algal growth. Algal blooms have been reported for Gariep Dam since 1998 (Venter, 2000).

By slowing the movement of water, dams prevent the natural downstream movement of sediments to deltas, estuaries, and wetlands, affecting species composition and productivity (WWF, 2004).

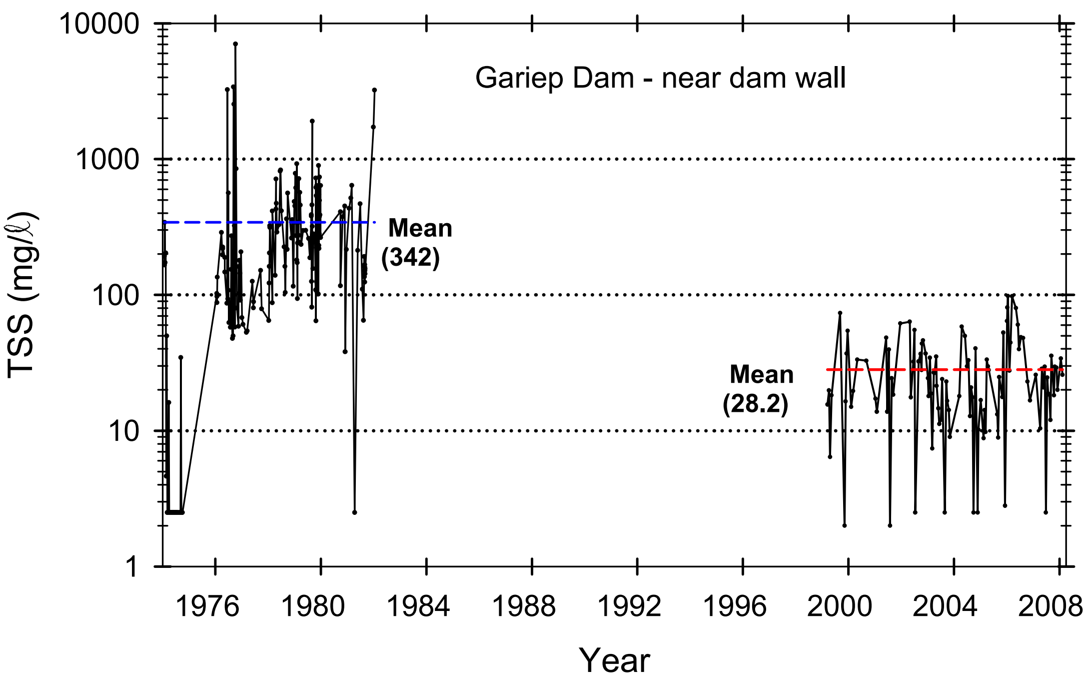


Figure 33: Temporal variation of total suspended solids (TSS, mg/ℓ) in the Orange River in Gariep Dam – near dam wall (1976 – 2007). Note the log scale on y-axis.

6.5.4 Algal biomass (Chlorophyll-*a*)

The growth of planktonic algae in a water body is related to the presence of nutrients, temperature, flow and availability of light (Young *et al.*, 1999). The green pigment chlorophyll (which exists in three forms: chlorophyll *a*, *b*, and *c*), is present in all photosynthetic organisms and provides an indirect measure of algal biomass and an indication of the trophic status of a water body. The Chl-*a* concentrations in Gariep Dam were low (ranged between 1 µg/ℓ and 69.2 µg/ℓ), but show an increasing trend (**Figure 34**).

The algal assemblage in Gariep Dam is usually dominated by diatoms (primarily *Cyclotella* and *Melosira* spp.), but the algal bloom during April 2006 was dominated by cyanobacteria (*Anabaena* sp., 50 % and *Microcystis* sp., 50 %). The genus *Microcystis* is a well-known toxin producing cyanobacteria and severe blooms were reported earlier (e.g. 1 084 µg/ℓ, February 1999) in the dam (Venter, 2000); not shown in the graph.

The increasing chlorophyll-*a* trend is probably associated with the increasing phosphate concentrations (**Figure 31**) because the low N:P ratios suggest a possible P limitation. Both TN and TP concentrations in Gariep Dam were very low (mean: TN, 1.08; TP, 0.069 mg/ℓ) compared to the upstream concentration in the river Aliwal North (mean: TN, 2.89; TP, 0.391 mg/ℓ). However, the very low mean Chl-*a* concentration of 3.8 µg/ℓ place the dam in an oligotrophic (clean, low nutrient water) category.

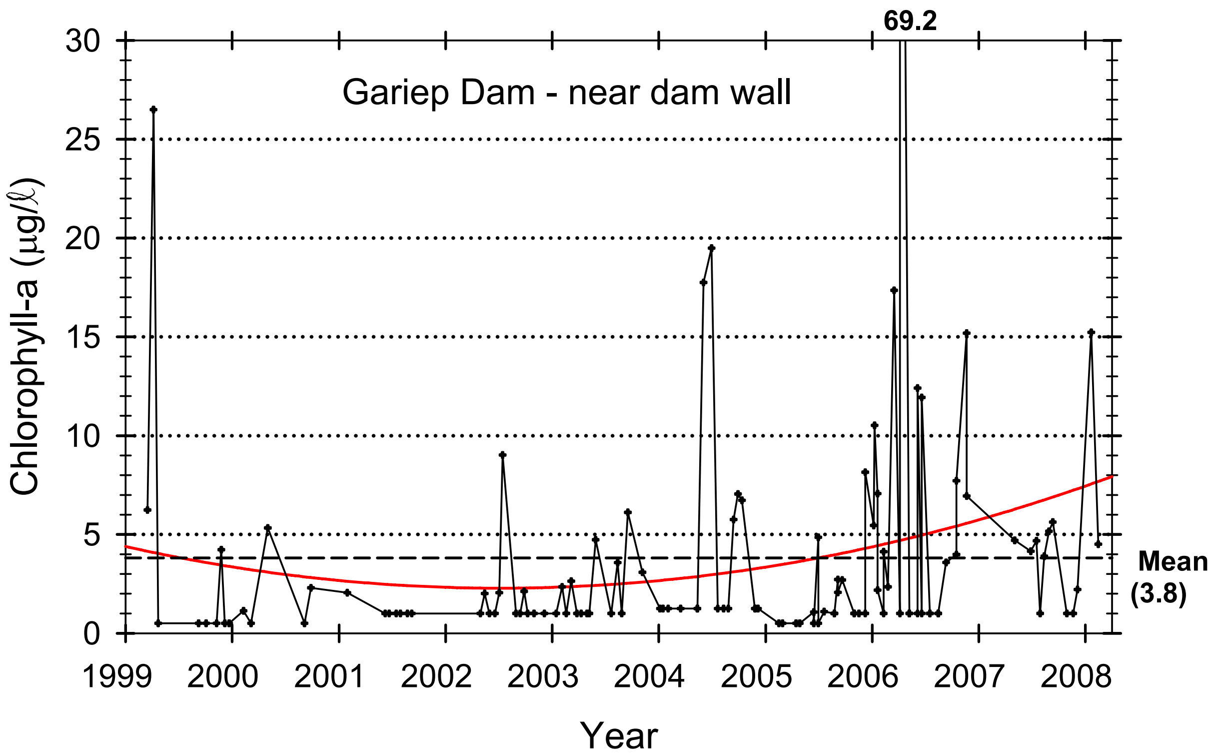


Figure 34: Temporal variation of Chlorophyll-*a* concentrations (µg/ℓ) in Gariep Dam – near dam wall (1976 – 2007).

6.5.5 Other parameters

Additional water quality graphs for Gariep Dam are shown in **Figure A7** in Appendix A.

The EC (mean 17.3 mS/m) and calcium (mean, 17.3 mg/ℓ) were relatively low but show slight increasing trends (**Figure A7 A & B**).

The pH was high, median 8.08 (**Figure A7 C**).

The sulphate concentrations (mean, 7.9 mg/ℓ) increased significantly with time, *i.e*. from about 5 mg/ℓ during 1970 to about 11 mg/ℓ during the last few years (**Figure A7 D**).

The turbidity was low (mean, 18.7 NTU) and shows a decreasing trend since 2001 associated with the lower TSS (**Figure A7 E**).

The fluoride concentrations were low (mean, 0.16 mg/ℓ) and stable over the study period (**Figure A7 F**).

The mean total alkalinity (TAL) was relatively low (68.9 mg/ℓ); lower than at Aliwal North, but showed an increasing trend associated with the higher dissolved salts (**Figure A7 G**).

The mean TP in Gariep Dam was very low at 0.069 mg/ℓ (**Figure A7 H**) compared to the 0.391 mg/ℓ at Aliwal North. The lower phosphorus could partially be ascribed to the lower suspended material because P transport is usually associated with the suspended silt particles (Horne & Goldman, 1994). The low TP concentrations also explain partly the low chlorophyll-*a* concentrations in the dam.

6.6 OS4 – Roodepoort (D3H013) – downstream Gariep Dam (S30.58487; E25.4208)

The Roodepoort gauging station is approximately 11.5 km downstream of Gariep Dam wall, at the N1 road cross with the Orange River. A very good chemical data set is available with almost weekly measurement since 1976 (n ≈ 954).

6.6.1 Stream flow (releases)

Water from the Gariep Dam is released downstream into the Vanderkloof Dam through four generators which are each capable of producing 90 MW of electricity at a flow rate of approximately 200 m^3/s. The hydro-power plant can therefore provide up to 360 MW of electricity at a flow rate of 800 m^3/s.

The mean stream flow measured at Roodepoort since 1974 ranged between 17.38 m^3/s and 2 301 m^3/s (mean, 210.2 m^3/s). However, the mean annual stream flow at Roodepoort has decreased notably since 1974, but was fairly stable since 1990 with an annual stream flow of about 6 000 Mm^3 – trend line (**Figure 35**).

Flow regulation by dams and diversions is a key component of virtually all large river development programs. Alteration of the natural timing of floods, magnitudes, frequencies, and duration of flows, disturb both terrestrial and aquatic communities. Dams are a principal threat to freshwater diversity and that threat is largely mediated through loss of habitat frequently involving modifications to the natural flow regime and to blockage of migrations (IUCN, 2001). See 9.1 for a more detailed discussion.

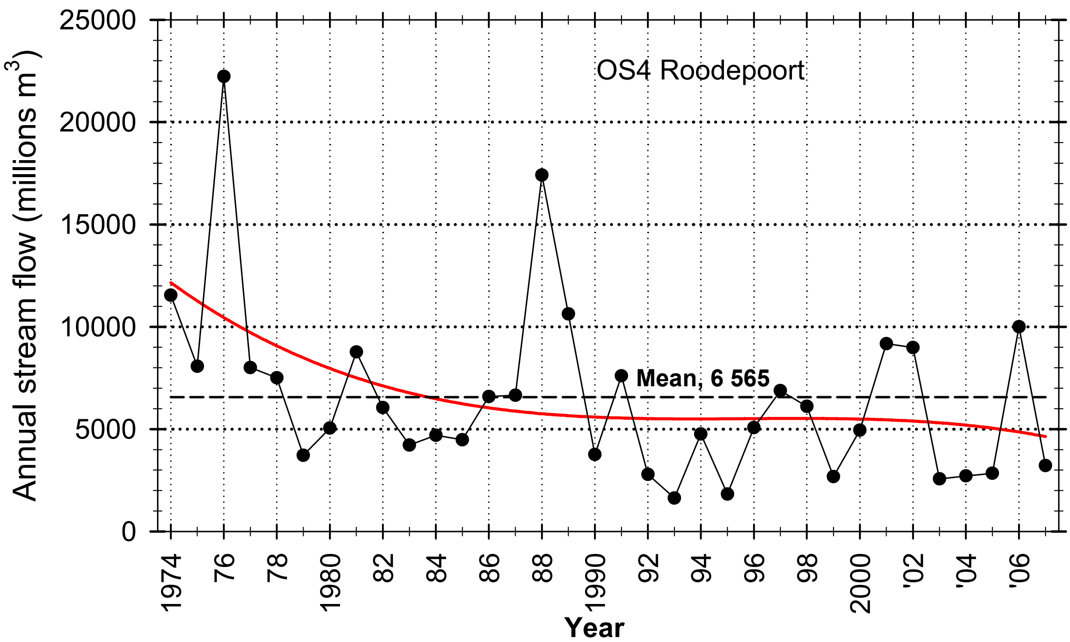


Figure 35: Annual variation of stream flow (millions m^3) in the Orange River at Roodepoort, downstream Gariep Dam (1974 – 2007).

6.6.2 Dissolved major salts (DMS)

The salt concentration in the water released from the dam was very constant (between 100 and 150 mg/ℓ) and displayed no seasonality (**Figure 36**). The impact of these uniform concentrations on the biota is uncertain but will probably be very negative. It is interesting to note that diatom samples were collected from stones on two occasions, but the laboratory report back as ‘no count possible’ that was ascribed to too little biomass.

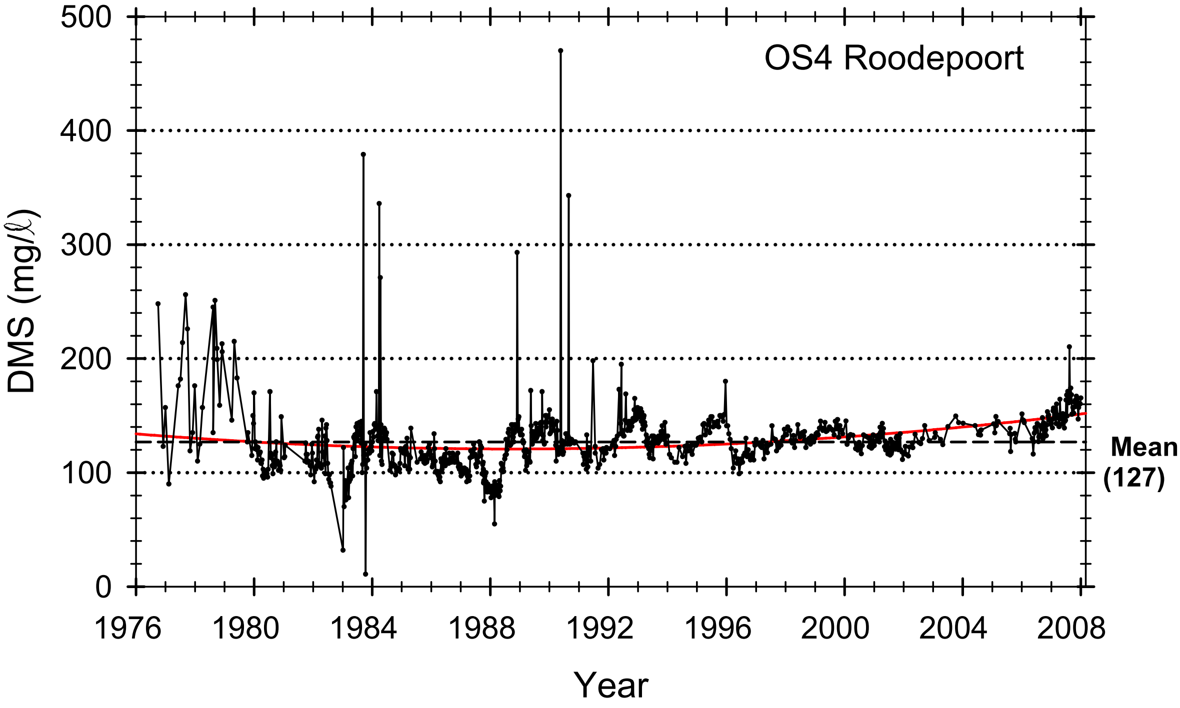


Figure 36: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Roodepoort (1976 – 2007).

6.6.3 Nutrients

The mean phosphate concentration at Roodepoort of 51 µg/ℓ (min. 3; max. 3 410 µg/ℓ; **Figure 37**) was significantly higher than the surface concentrations in the dam (30 µg/ℓ). The DIN concentration was also high with a mean of 0.722 mg/ℓ, however, the concentrations were generally lower during the past 10 years (**Figure 38**). Thus, the processes in the dam have affected the chemical composition of the water leaving the system to such an extent that its water quality upon release no longer resembles that of the inflows.

The reason for the exceptional high DIN concentrations (spikes), especially during 1988 and 1992, is unclear. A DIN concentration of 50.44 mg/ℓ (22/5/1999) was rejected as an outlier.

The nutrient concentrations in the water released from the dam was significantly higher than the surface concentrations in the dam. The higher nutrients concentrations could be ascribed to the release of nutrient-rich hypolimnetic water, *i.e*. water from lower levels in the dam with higher nutrient concentrations.

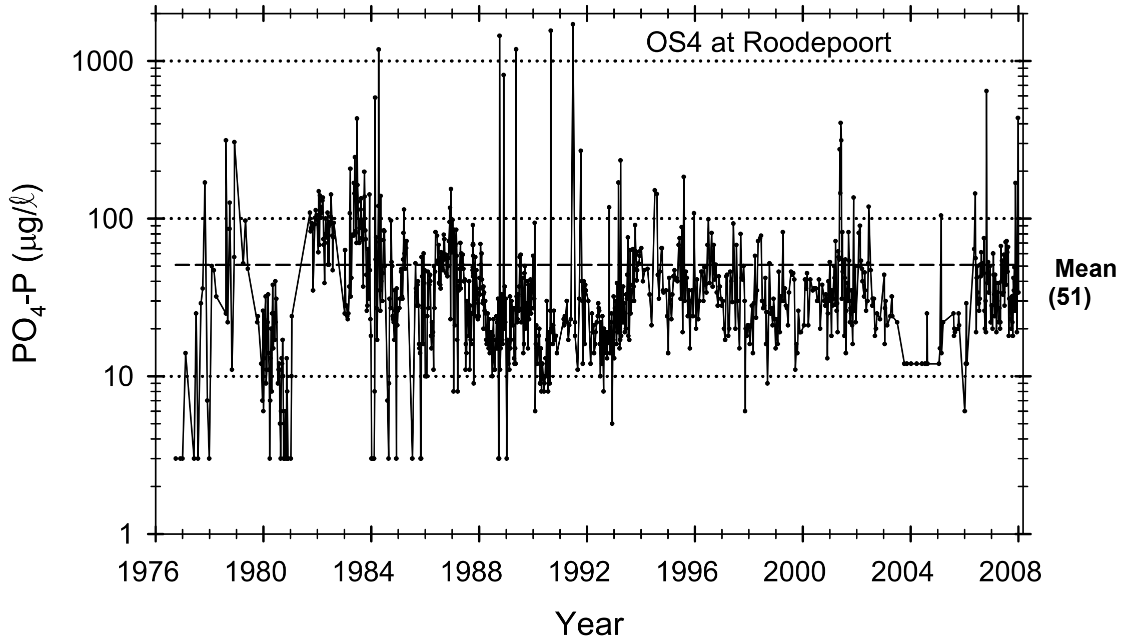


Figure 37: Temporal variation of phosphate phosphorus (PO_4-P) concentrations (µg/ℓ) in the Orange River at Roodepoort (1976 – 2007).

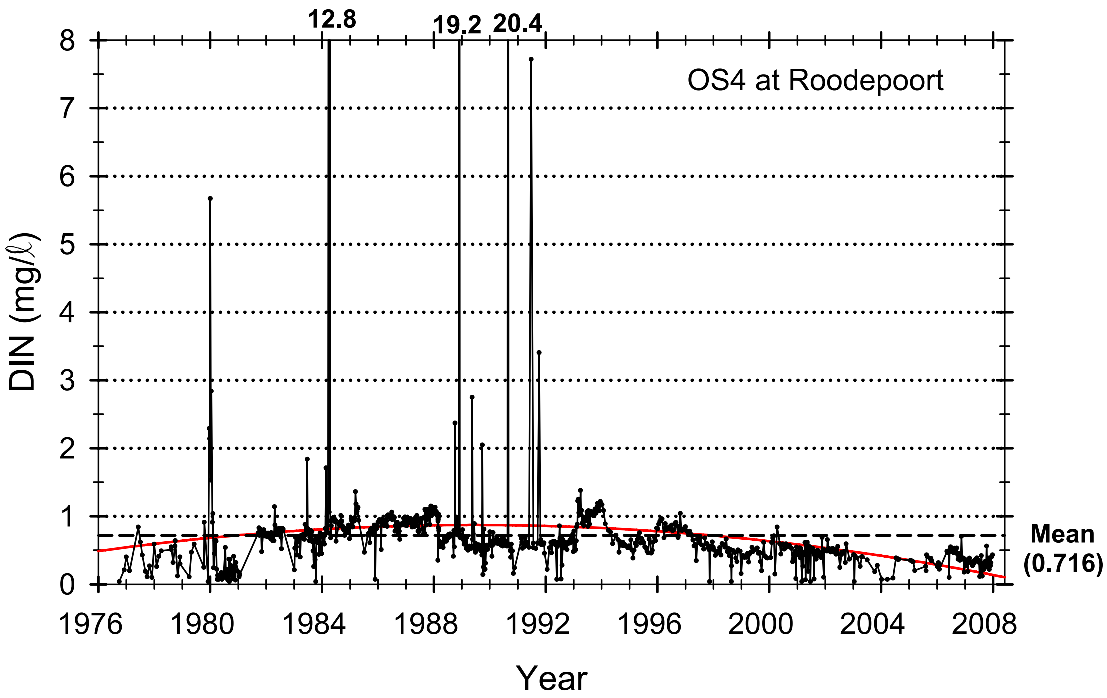


Figure 38: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Orange River at Roodepoort (1976 – 2007).

6.6.4 Other parameters

The EC and Ca values were constant over the study period and are almost identical to the dam's surface water; See **Figure A9** in Appendix A.

The ammonium concentration (mean, 0.125 mg/ℓ) was significantly higher than in the dam (mean, 0.088 mg/ℓ; **Figure A9 C**), which also indicates the release of hypolimnetic water from the dam.

The pH was slightly lower (median, 8.02), but the SAR, Si, SO_4 and TAL concentrations were similar to the concentrations in the dam and very stable over time (**Figure A9)**.

The alkalinity at Roodepoort was low (mean, 64.4 mg/ℓ) and show limited variation with time (**Figure A9 H).**

6.7 OSD2 – Vanderkloof Dam – near dam wall; D3R003 (S29.99447; E24.73524)

Vanderkloof Dam (originally named as P.K. Le Roux Dam) was commissioned during 1977 and is situated approximately 110 km downstream of Gariep Dam (**Figure A10**, Appendix A). With a capacity of 3 187 million m^3, it is the second largest dam in South Africa.

The flow reaching the lower reaches of the Orange River is controlled to a large degree by releases from Vanderkloof Dam, supported by water released from Gariep Dam. Water is released downstream through two hydro-power generators that can provide up to 240 MW of electricity at a flow rate of 400 m^3/s. Thus, it plays an important role in providing water for irrigation to more than 100 000 hectares of productive agricultural land. Hydro electricity generation costs at Vanderkloof Dam are in the order of R30/MWh, compared to R1 900/MWh for gas turbines (Palmer *et al*., 2007).

The water quality data base begins in 1976 but with limited data before 1992. Thereafter, biweekly measurements have been recorded (n ≈ 255). This is the first site with monthly measurements of metals from 2003 (n = 31).

6.7.1 Dissolved major salts (DMS)

The dissolved major salts in Vanderkloof Dam were slightly higher than upstream releases from Gariep Dam and ranged between 100 and 214 mg/ℓ (mean 139.5 mg/ℓ) (**Figure 39**). The salt concentrations show an increasing trend similar to the observation made in Gariep Dam.

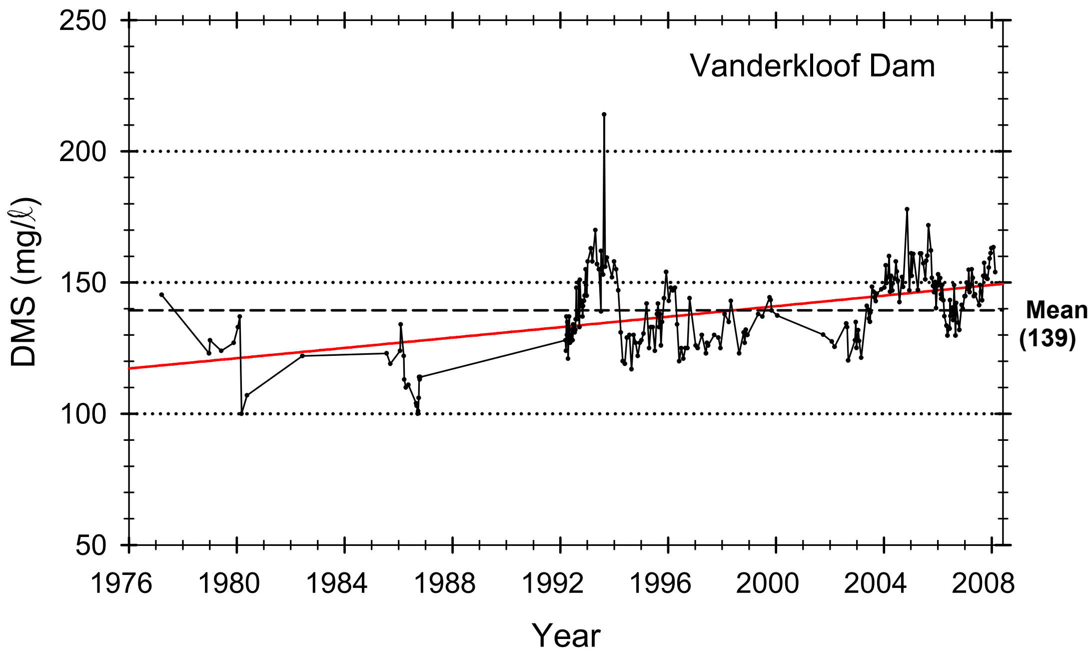


Figure 39: Temporal variation of dissolved major salts concentrations (DMS, mg/ℓ) in Vanderkloof Dam – near dam wall (1976 – 2007).

6.7.2 Nitrate nitrogen (NO_3-N)

The nitrate concentration ranged between 0.020 and 0.860 mg/ℓ (mean, 0.408 mg/ℓ), however, the concentrations show a significant decrease since 1992, *i.e.* from approximately 0.6 mg/ℓ to 0.2 mg/ℓ in 2007 (*i.e.* 67 % reduction, **Figure 40**).

This loss of nitrogen could be explained by either assimilation by algae and macrophytes, absorbed by the sediments, or by being converted to nitrogen gas through denitrification. Denitrification is believed to play the most important role in nitrogen removal.

Several studies indicate that bacterial denitrification in anaerobic sediments may play a major part in removing nitrogen from water during river transport (Hill, 1979; Billen *et al.*, 1991; Laursen & Seitzinger, 2002). Denitrification is the biological reduction of NO_3 or NO_2 to N_2 gas or gaseous nitrogen oxides. The process is performed by heterotrophic bacteria (such as *Pseudomonas fluorescens*) from all main proteolitic groups. Denitrification is the second step in the nitrification-denitrification process: the conventional way to remove nitrogen from sewage and municipal wastewater.

The initial increase (1972 to 1986) in DIN concentrations could be partly ascribed to a trophic upsurge. Relatively high levels of productivity are often observed in newly impounded reservoirs that are thought to be caused by the leaching of nutrients from flooded soils and through nutrients released by the decomposition of flooded vegetation and soil organic matter. However, these initial high nutrient releases were not observed in phosphorus concentrations, and unfortunately only a limited number of nitrate measurements were made between 1972 and 1992 (**Figure 40**).

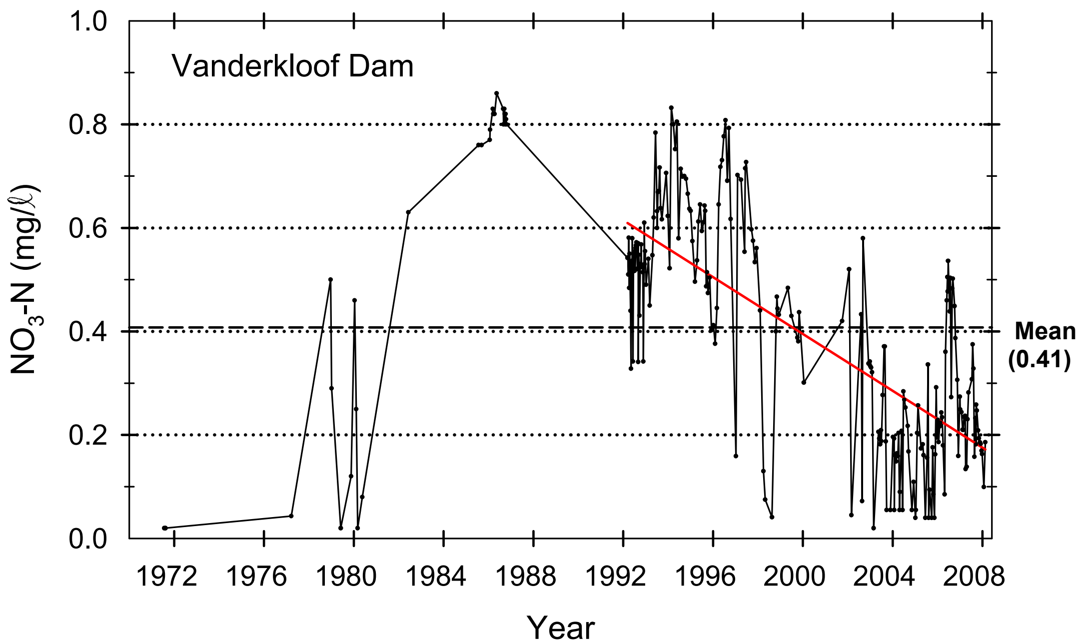


Figure 40: Temporal variation of nitrate nitrogen (NO_3-N) concentrations (mg/ℓ) in Vanderkloof Dam – near dam wall (1972 – 2007).

6.7.3 Phosphate phosphorus (PO_4-P)

The mean phosphate concentration in Vanderkloof Dam was low (31 µg/ℓ) and fairly stable with no significant increase with time (**Figure 41**).

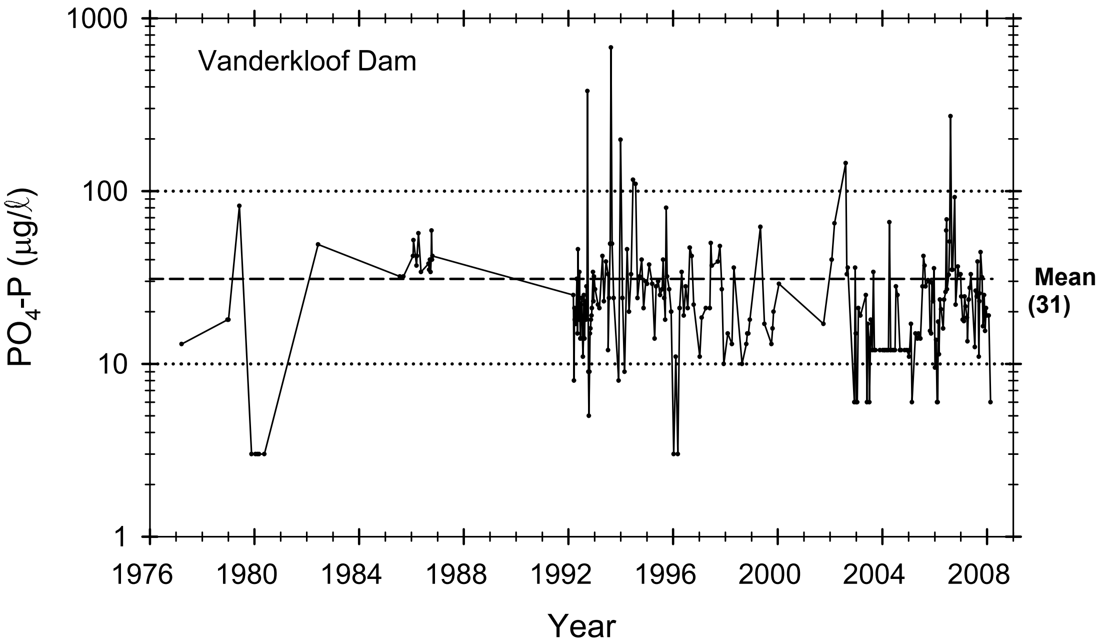


Figure 41: Temporal variations in phosphate concentrations (PO_4-P, µg/ℓ) in Vanderkloof Dam – near dam wall (1976 – 2007). Note the log scale on the y-axis.

6.7.4 Chlorophyll-*a* concentration

The chlorophyll-*a* data from Vanderkloof Dam are limited to the last two years, with a poor sampling frequency; only 2 measurements during 2000. However, the concentrations were very low (min. 0.5; max. 18.1 µg/ℓ), and with a mean of 2.3 µg/ℓ the dam could be classified as oligotrophic (**Figure 42**), but more data are required to substantiate this.

The significant drop in the nitrogen concentrations during the past 15 years could potentially limit the algal growth. The mean DIN concentration, from June 2006 – March 2008, was 0.360 mg/ℓ; the P concentration, 0.035 mg/ℓ and the median N:P was 13.3.

Interesting to note that the Total nitrogen (TN) and Total phosphorus (TP) concentrations in Vanderkloof Dam were the lowest recorded in the whole Orange River, which will probably prevent any significant algal growth in the dam. TN concentrations ranged between 0.18 mg/ℓ and 2.05 mg/ℓ with a mean of 0.61 mg/ℓ. For comparison, the mean TN at Aliwal North was 2.89 mg/ℓ; in Gariep Dam it was 1.08 mg/ℓ; and 1.57 mg/ℓ at Roodepoort (**Table C3**). The mean TP concentration was 0.052 mg/ℓ (ranged between 0.005 and 0.734 mg/ℓ). The mean TP at Aliwal North was 0.391 mg/ℓ; 0.069 mg/ℓ in Gariep Dam, and 0.130 mg/ℓ at Roodepoort (**Table C4**).

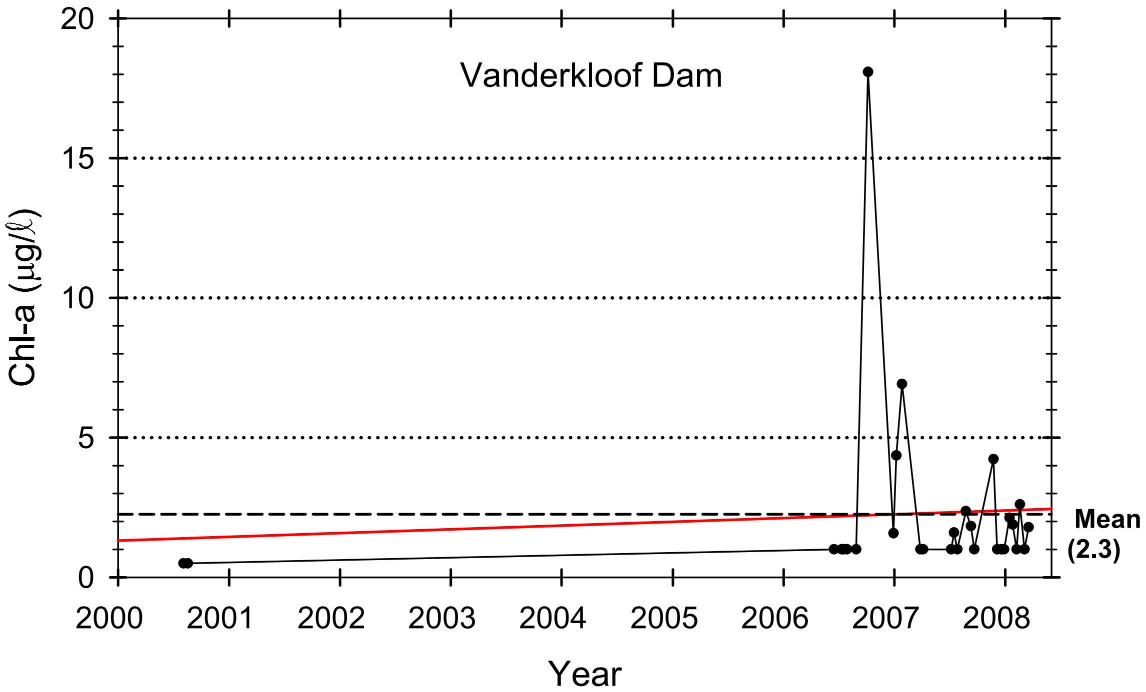


Figure 42: Temporal variation of chlorophyll-*a* concentrations (µg/ℓ) in Vanderkloof Dam – near dam wall (1976 – 2007).

6.7.5 Metals

Metals occur naturally and become integrated into aquatic organisms through food and water. Trace metals such as mercury, copper, selenium, and zinc are essential metabolic components in low concentrations. However, metals tend to bioaccumulate in tissues and prolonged exposure or exposure at higher concentrations can cause adverse effects. Elevated concentrations of trace metals can have negative consequences for both natural ecosystems and humans. Human activities such as mining and heavy industry can result in higher concentrations elevated above natural levels.

Metals tend to be strongly associated with sediments in rivers, lakes, and reservoirs and their release to the surrounding water is largely a function of pH, oxidation-reduction state, and organic matter content of the water (and the same is also true for nutrient and organic compounds) (UNEP-GEMS, 2006).

The metal concentrations in Vanderkloof Dam were relatively low (**Figure 43**). A comparison of the raw water concentrations with South African water quality guidelines for domestic use (DWAF, 1996), showed that all the concentrations (except for lead) were in the target water quality range (TWQR), *i.e.* ideal. The mean Pb concentration of 47 µg/ℓ is still acceptable for domestic water use, but should be carefully monitored. However, even low concentrations of certain metals could be harmful to aquatic biota – see Status Quo (section 8).

There is no domestic use water standard for Sr, but the mean of 102 µg/ℓ is comparable with concentrations found in unpolluted rivers – see below.

The world average concentrations (µg/ℓ) of trace elements carried in solution by major unpolluted rivers are: Al, 40; B, 30; Cd, 0.001; Cr, 0.1; Cu, 1.4; Fe, 50; Mn, 10; Mo, 0.8; Ni, 0.4; Pb, 0.04; Sr, 100; Zn, 0.2 µg/ℓ (Chapman, 1996).

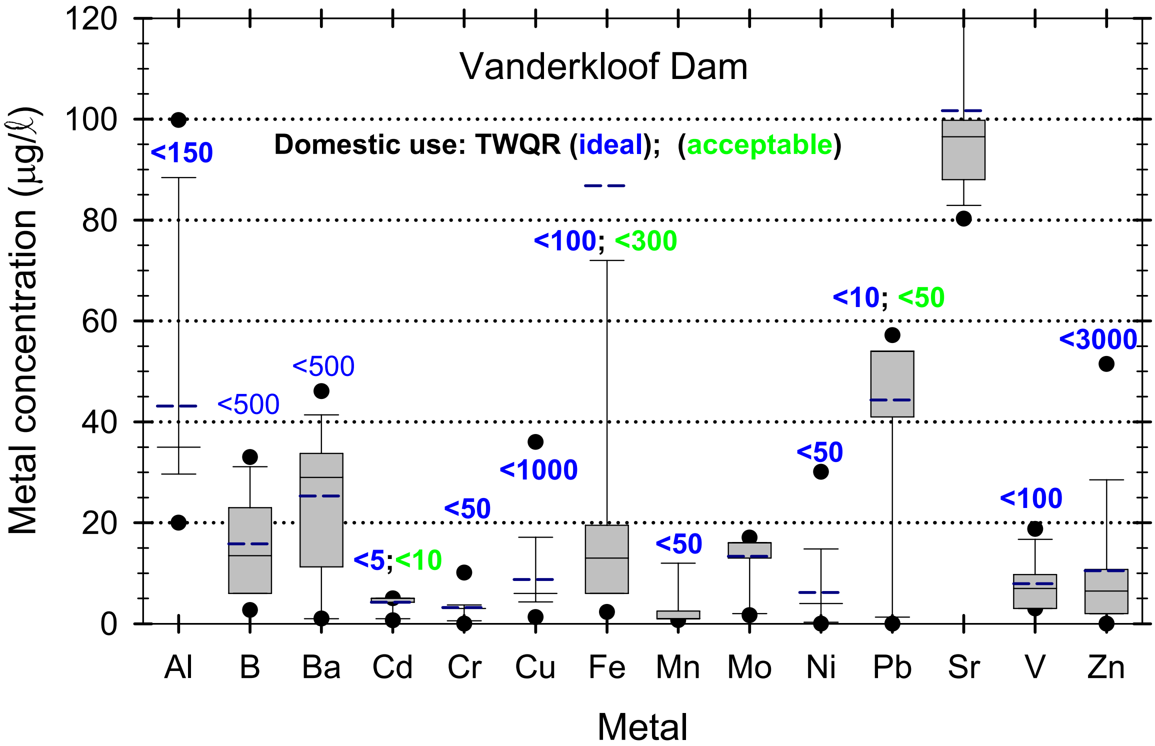


Figure 43: Box and whiskers plot of different metals concentrations (µg/ℓ) in Vanderkloof Dam – near dam wall (2003 – 2007; n ≈ 31). The ideal and acceptable concentrations for domestic use (DWAF, 1996) are indicated above the boxes.

6.7.6 Other parameters

The chemical composition of the water in Vanderkloof Dam is very similar to Gariep Dam. Concentrations for most of the parameters concentrations in Vanderkloof Dam were slightly higher (approximately 15 %) than in Gariep Dam, except for the suspended solids, turbidity and nitrogen concentrations that were lower (**Figure A11** in Appendix A).

The pH typically varied between 7.5 and 8.5 with the median at 8.0 (**Figure A11 E**).

The EC, Ca, SO_4 and alkalinity showed increasing trends with time, while DIN, F, and Silica show a decreasing trend in concentrations (**Figure A11**).

6.8 OS5 Dooren Kuilen, D3H012 (S29.99141; E24.72414)

The Dooren Kuilen monitoring and flow gauging station is 700 m downstream of the Vanderkloof Dam wall (**Figure A12**, Appendix A).

6.8.1 Stream flow (releases)

The developments in the lower reaches of the Orange River are mainly dependent on the releases made from Vanderkloof Dam. Releases from Vanderkloof Dam reach the last users 1 400 km downstream and take approximately one month to reach the estuary at the river mouth (DWAF, 2008b). Operational losses, estimated to be 270 Mm^3/a, and river evaporation losses of about 615 Mm^3/a, must be released in addition to the users requirements (DWAF, 2005; 2008b).

The monthly average water releases from Vanderkloof Dam were relatively low (min. 20.27; max. 2 445.0; mean, 153 m^3/s) but fairly constant with limited seasonal variation (**Figure 44**). The mean annual release of 4 835 Mm^3 was comparatively low to the releases from Gariep Dam (6 630 Mm^3).

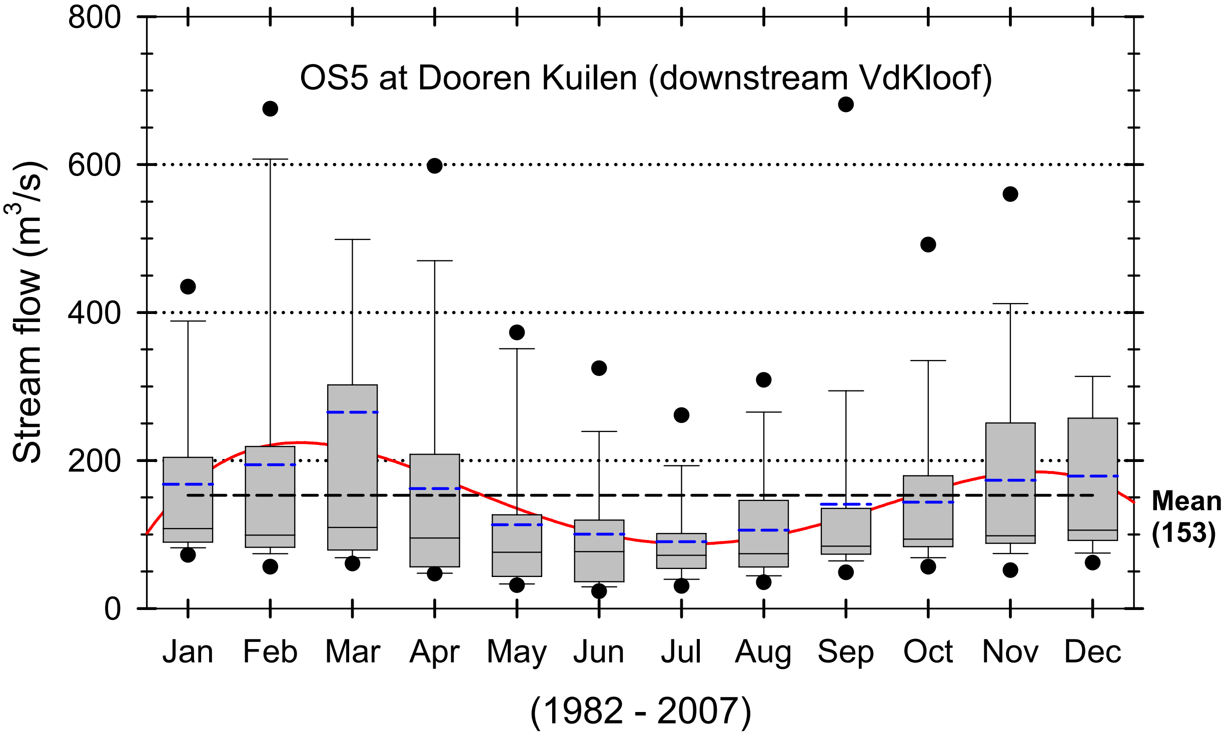


Figure 44: Box and whiskers plot of seasonal variation of stream flow (m^3/s) in the Orange River at Dooren Kuilen (OS5) – just downstream of Vanderkloof Dam (1982 – 2007).

6.8.2 Dissolved major salts (DMS)

The salt concentrations at Dooren Kuilen ranged in a narrow band between 98 and 227 mg/ℓ (mean, 133.8 mg/ℓ). Thus, the salt concentration in the water released from Vanderkloof Dam show limited variations (see small boxes in plot) and no seasonality, which is ascribed to the unnatural regulated releases (**Figure 45**).

The natural inverse relationship between stream flow and dissolved salts, for example at Oranjedraai (**Figure 16**), is not applicable to the unnatural releases from the storage dam. This means that all flows are not equal – the natural flow in the river after rain has a total different effect on the water quality and environment in comparison with just an unnatural controlled release of water from a dam.

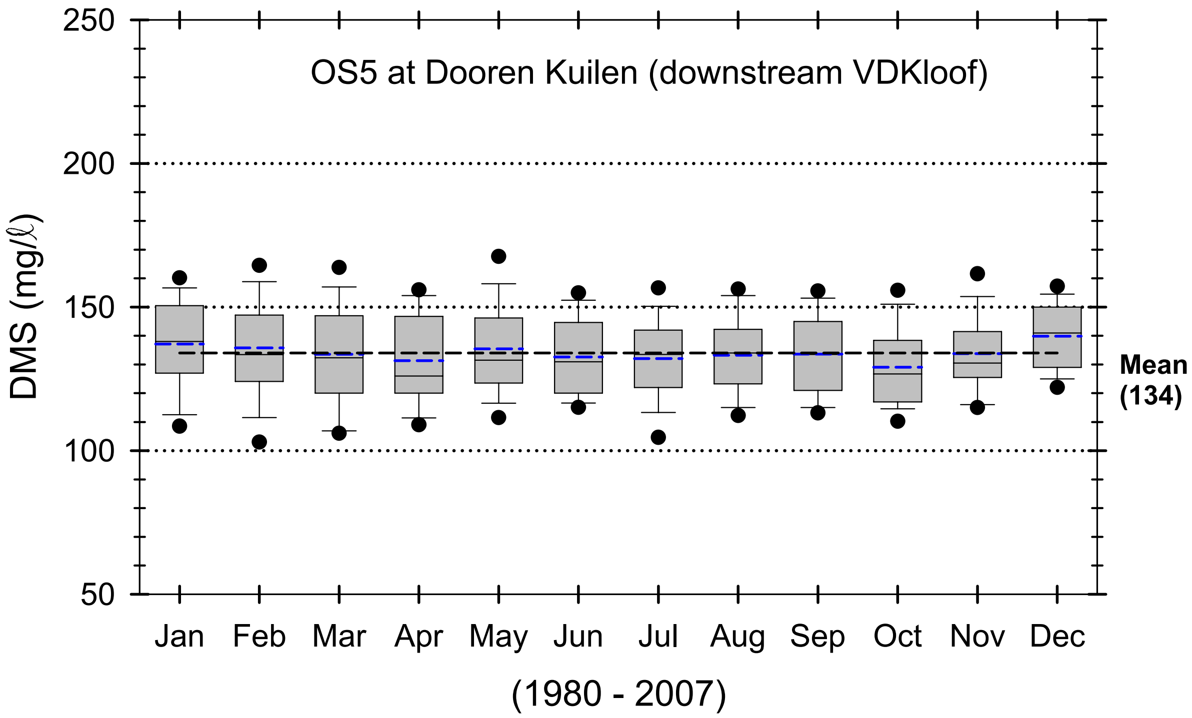


Figure 45: Box and whiskers plot of seasonal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Dooren Kuilen – downstream Vanderkloof Dam (1980 – 2007).

6.8.3 Turbidity

The turbidity of the water released from Vanderkloof Dam decreased significantly (by 75 %) from the period 1992 to 1998 (mean, 38.8 NTU) compared to the period 2002 to 2007 (mean, 9.5 NTU; **Figure 46**). The gap in the data (1999 - 2001) makes the interpretation of the data very difficult, thus the reason for this decrease is not clear. However, the low turbidity will result in favourable underwater light climate that could enhance algal growth in the presence of sufficient nutrients.

Higher stream flows are usually associated with higher suspended solids and turbidity, but the releases from Vanderkloof Dam and turbidity show almost no correlation.

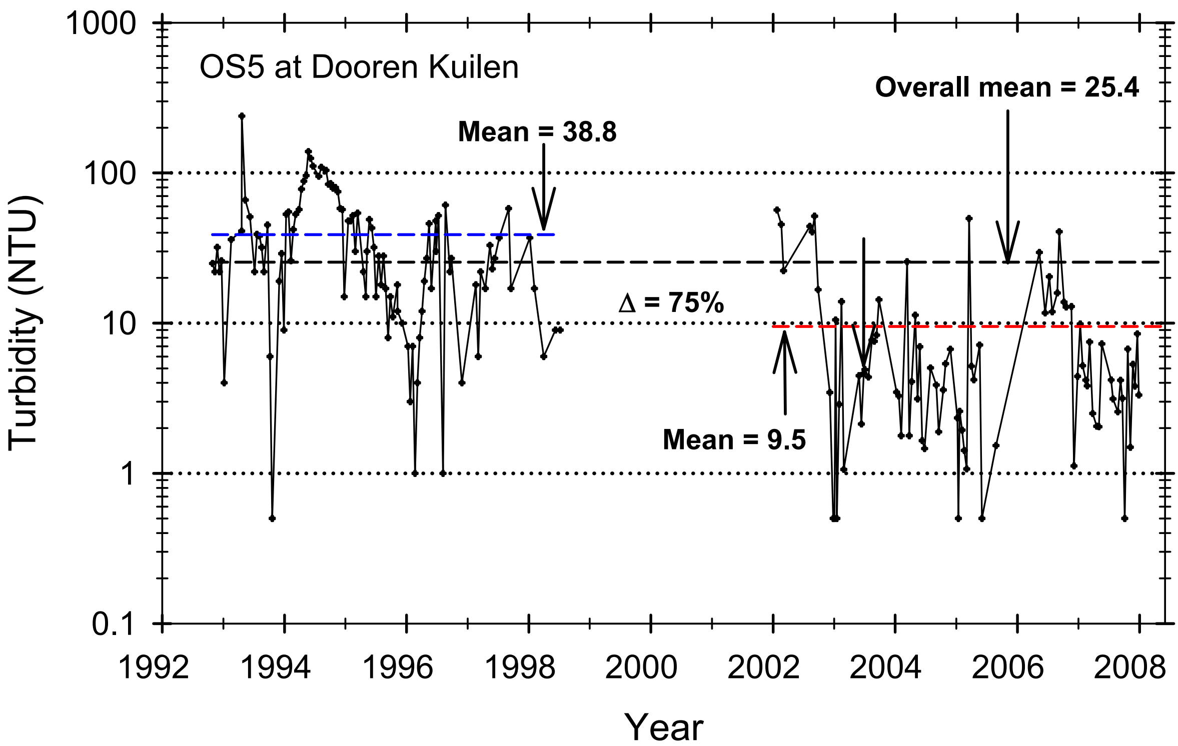


Figure 46: Temporal variation of turbidity (NTU) in the Orange River at Dooren Kuilen (1992 – 2007). Note the log scale on the y-axis.

6.8.4 Nutrients

The phosphate concentrations released from the dam were very similar to the sub-surface concentrations inside the dam with a mean of 31 µg/ℓ (min. 3; max. 281 µg/ℓ) (**Figure 47**).

The mean DIN concentration was higher (0.547 mg/ℓ) but follows the same decreasing pattern as the nitrate concentrations in the dam (**Figure 48**).

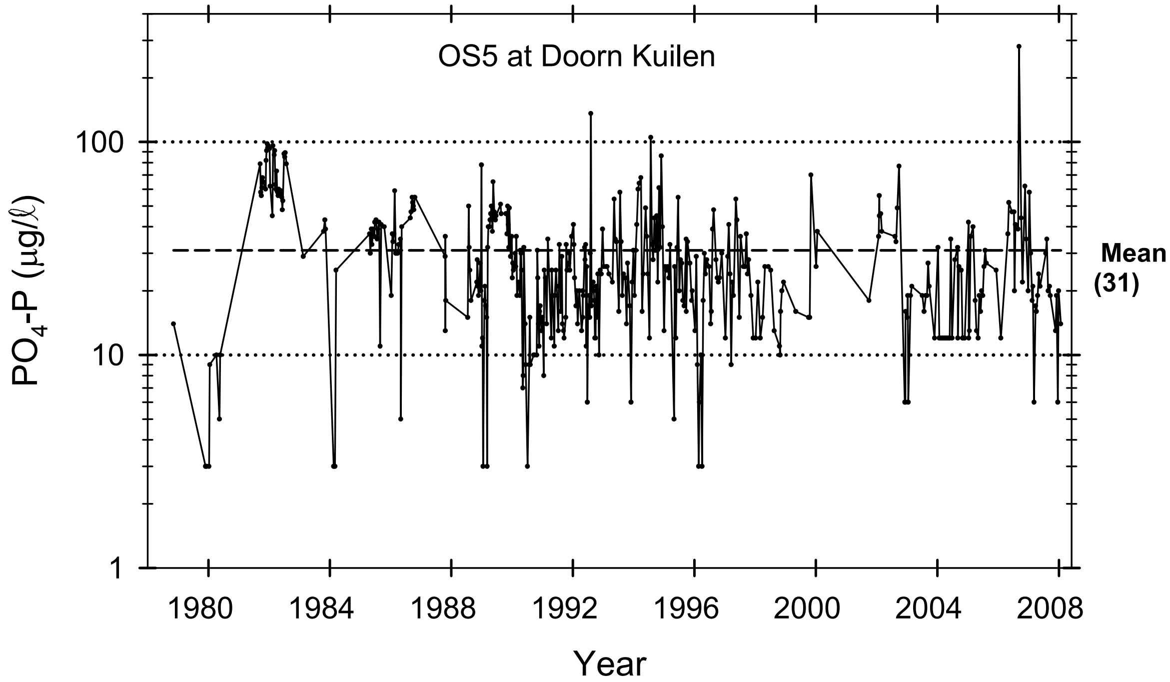


Figure 47: Temporal variation of phosphate (PO_4-P) concentrations (µg/ℓ) in the Orange River at Dooren Kuilen (1979 – 2007). Note the log scale on the y-axis.

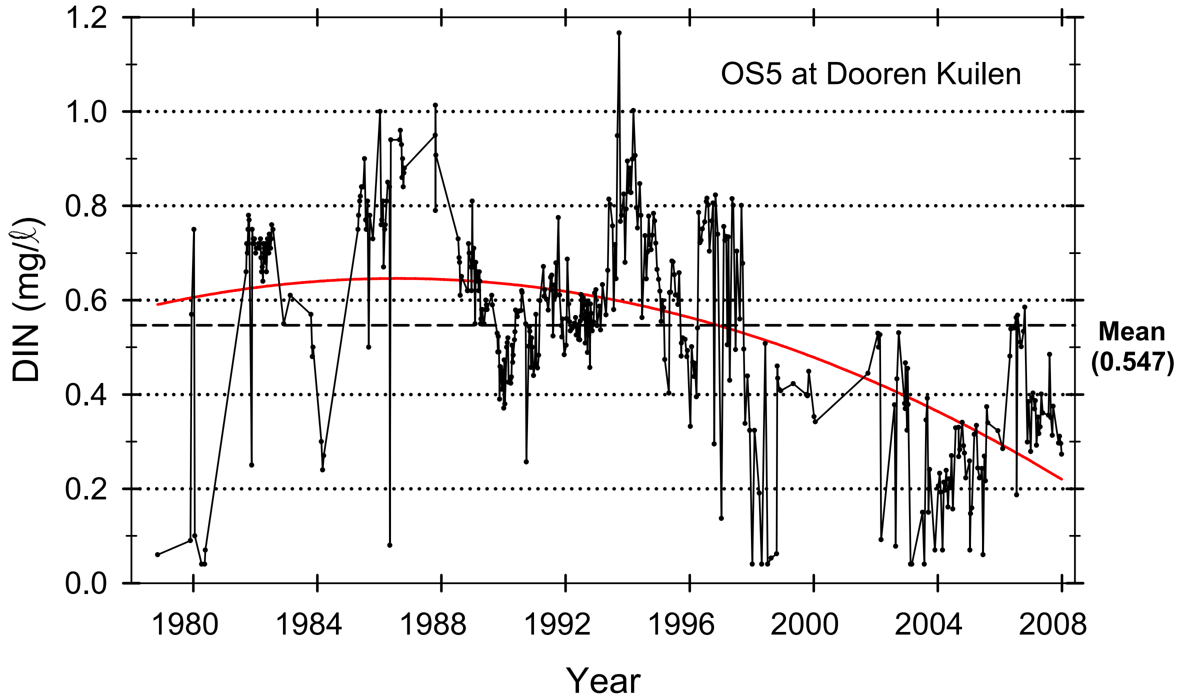


Figure 48: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Orange River at Dooren Kuilen (1979 – 2007).

6.9 OS6 – Marksdrift – D3H008 (S29.16201; E23.69447)

Marksdrift is 175 km downstream of Vanderkloof Dam, close to the town of Douglas and represents the last monitoring site of the Upper Orange River (**Figure A14** in Appendix A).

The Marksdrift monitoring site is included in the SA-Gems (Global Environment Monitoring System)/Water monitoring network to represent runoff from the Orange River catchment upstream of the Vaal River confluence. The data represents a mixture of water from the Caledon River, Kraai River and Orange River. The two large dams, namely the Gariep and Vanderkloof Dams are situated upstream of the site, below the confluences with the Caledon and Kraai Rivers (Van Niekerk, 2005).

6.9.1 Stream flow

The annual stream flow at Marksdrift ranged between 1 494 and 23 380 Mm^3 with a mean of 4 960 Mm^3 with no significant trend change over time (**Figure 49**). However, note the gap in the data (1988 – 1991) which excludes the extreme flood of 1988.

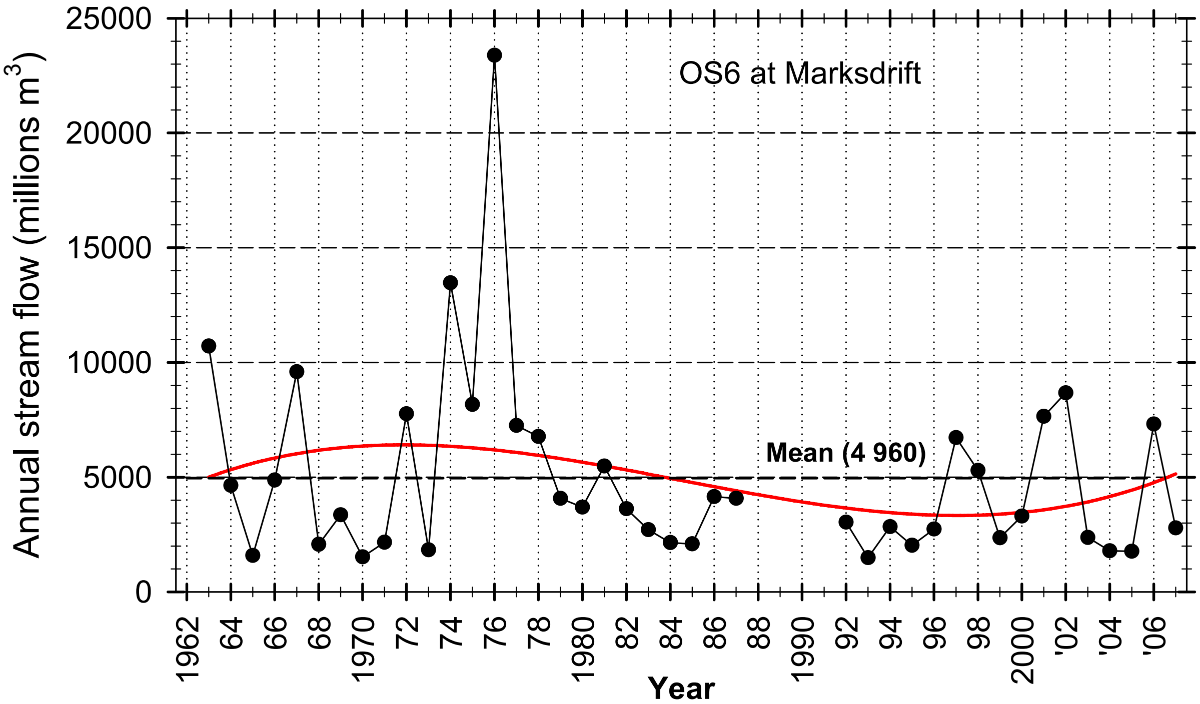


Figure 49: Temporal variation of annual stream flow (Mm^3/a) in the Orange River at Marksdrift (1962 – 2007).

6.9.2 Dissolved major salts (DMS)

The average salinity at Marksdrift was slightly higher than the upstream points at 156 mg/ℓ (min. 87; max. 683.9 mg/ℓ) and starts to show a natural seasonal pattern again (**Figure 50**). However, the dissolved salts show an increasing trend with time.

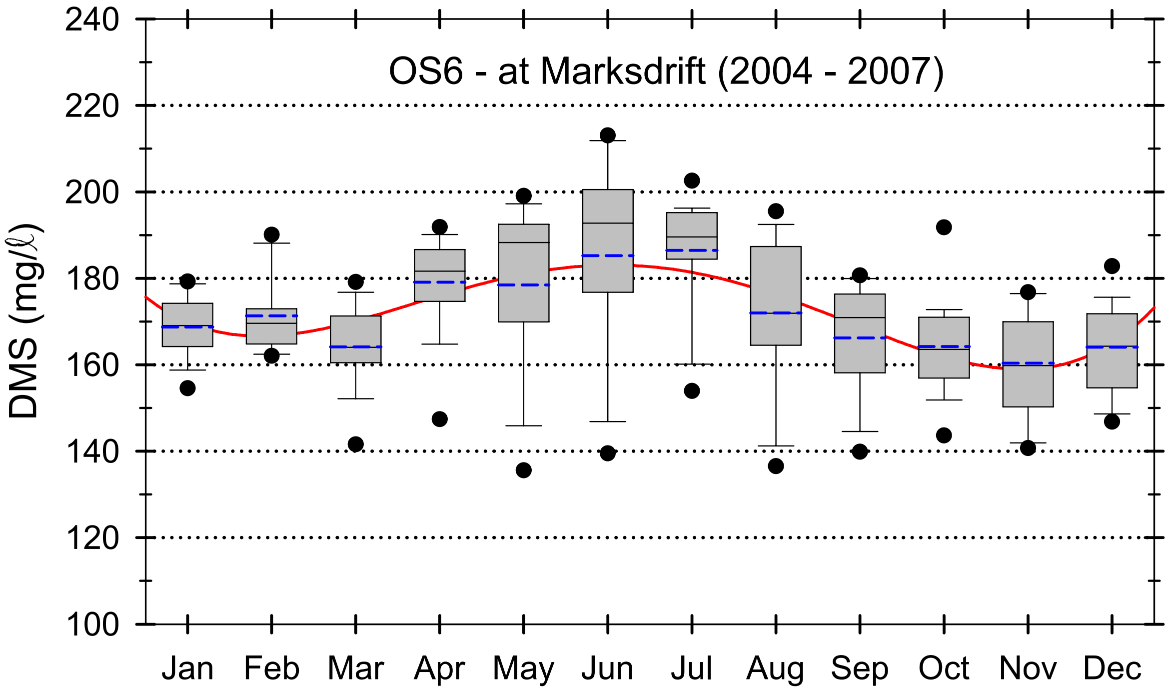


Figure 50: Box and whiskers plot of seasonal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Marksdrift (2004 – 2007).

6.9.3 Nutrients (PO_4-P and DIN)

The mean phosphate concentration at Marksdrift was relatively low at 28 µg/ℓ (min. 3; max. 816 µg/ℓ) and shows no significant trend with time (**Figure 51**). However, the phosphate concentrations show a great fluctuation with time and generally oscillate between 10 and 100 µg/ℓ (**Figure 51**).

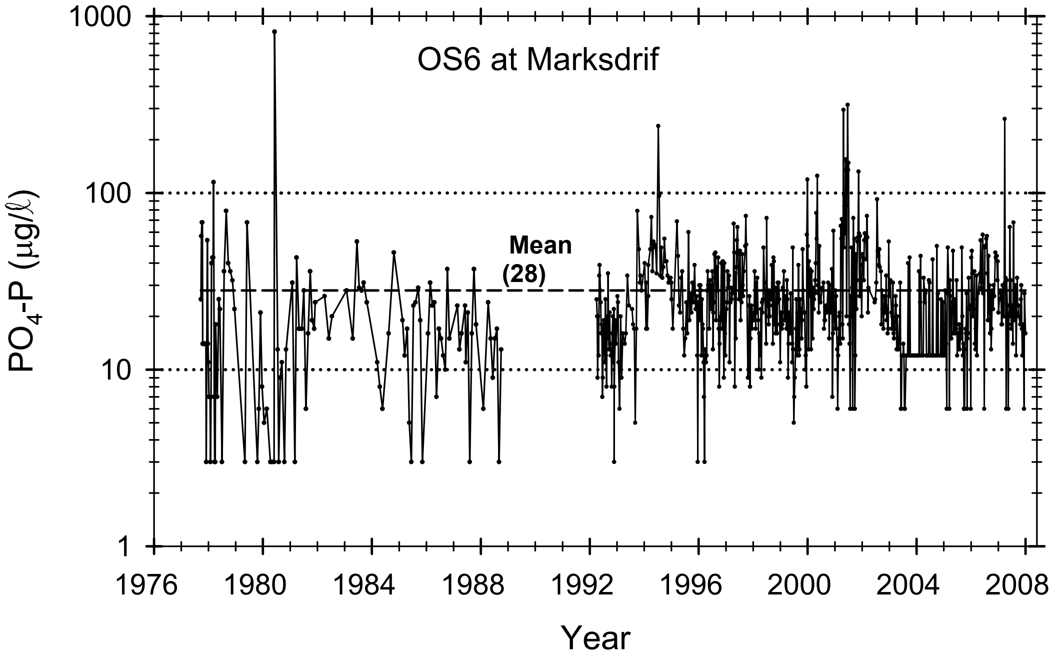


Figure 51: Temporal variation of phosphate (PO_4-P) concentration (µg/ℓ) in the Orange River at Marksdrift (1976 – 2007). Note log scale on y-axis.

The DIN concentrations at Marksdrift were lower than at Dooren Kuilen (upstream point) and ranged between 0.20 and 3.180 mg/ℓ (overall mean 0.469 mg/ℓ). However, the DIN concentration increased significantly from 1977 to 1988, *i.e.* from about 0.2 to 0.8 mg/ℓ (red line in **Figure 52**) and then showed a significant decrease from 1992 to 2007, *i.e*. from 0.7 to 0.3 mg/ℓ (blue line in **Figure 52**). The reason for this phenomenon is unclear.

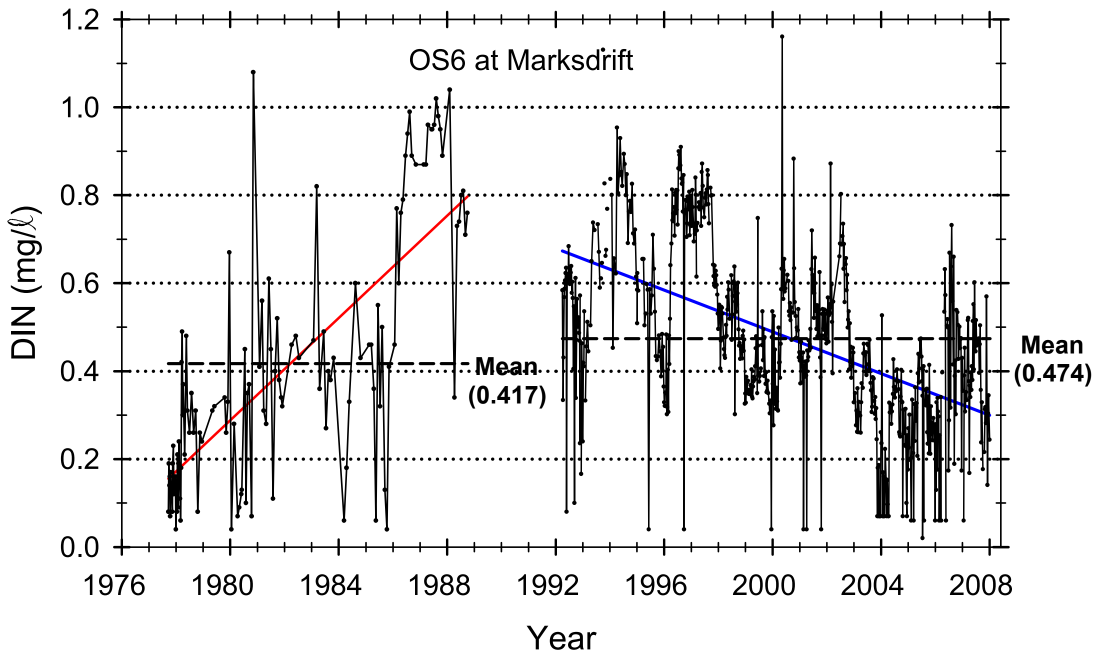


Figure 52: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Orange River at Marksdrift (1977 – 2007).

6.9.4 Other parameters

The EC values show little variation with a mean at 20.42 mS/m (**Figure A15 A** in Appendix A).

The pH usually varied between 7.5 and 8.5 with the median at 8.13, with a slight decreasing trend during the past 5 years (**Figure A15 B**).

The fluoride concentrations were generally low (mean, 0.19 mg/ℓ) with no significant change over time (**Figure A15 C**).

The silica concentrations were relatively low (mean 7.37 mg/ℓ) and showed a decreasing trend (**Figure A15 D**).

The sulphate concentrations were relatively high (11.7 mg/ℓ), and displayed large variations (min. 2; max. 28.4 mg/ℓ) and showed an increasing trend (**Figure A15 F**). Concentrations of 106.35 mg/ℓ (09/06/1999) and 139.37 mg/ℓ (04/04/2001) were rejected as outliers.

B) MONITORING SITES ON THE LOWER ORANGE RIVER: LEVEL 1 (Historical data)

6.10 OS7 – Irene (D7H012)

Historical data – only 21 samples were collected from 1989 – 1997. The limited data, low frequency and 'old' data made the data not usable. Samples were collected at De Hoek (new site) during the snapshot survey – see **Figure A16** in Appendix A.

6.11 OS8 – Prieska – D7H002 (S29.65700; E22.74415)

Prieska is situated on the south bank of the Orange River (**Figure A17**) about 166 km downstream of the Orange-Vaal Rivers' confluence and is renowned for its semi-precious stones and large array of succulents including the strange half-mens (*Pachypodium namaquanum)*.

Prieska has an interesting mining history. Copper and zinc was discovered in 1968 and the Prieska Copper Mines, owned by Anglovaal Mining Ltd, was established. It became one of the country's major base-metal mines, one of the first to have a decline from surface, using trackless mining methods. Copper was the more valuable product, but tonnage-wise more zinc was produced and even that became less and less profitable, resulting in the mines' closure in January 1996.

The chemical database (DWAF) was reasonably good until 1997, but was unfortunately discontinued since 2001 (except for the flow measurements).

6.11.1 Stream flow

The annual stream flow ranged between 1 224 and 29 738 Mm^3 (mean, 6 982 Mm^3) and shows a decreasing trend; red line in **Figure 53**. The lower stream flow could partially be ascribed to the lower inflow from the Vaal River.

6.11.2 Dissolved major salts (DMS)

The mean salt concentration (172.4 mg/ℓ) at Prieska was higher than at Marksdrift, but surprisingly shows a decreasing trend with time (**Figure 54**). The decreasing trend could be ascribed to the lower salt input from the Vaal River because the Vaal River is operated to minimise spills into the Orange River and it is therefore mainly during floods that significant volumes of water enter the Orange from the Vaal (DWAF, 2005).

However, almost no data were available since 1997 with only 1 reading in 2001. The TDS concentration during the snapshot survey was much higher at 238 mg/ℓ.

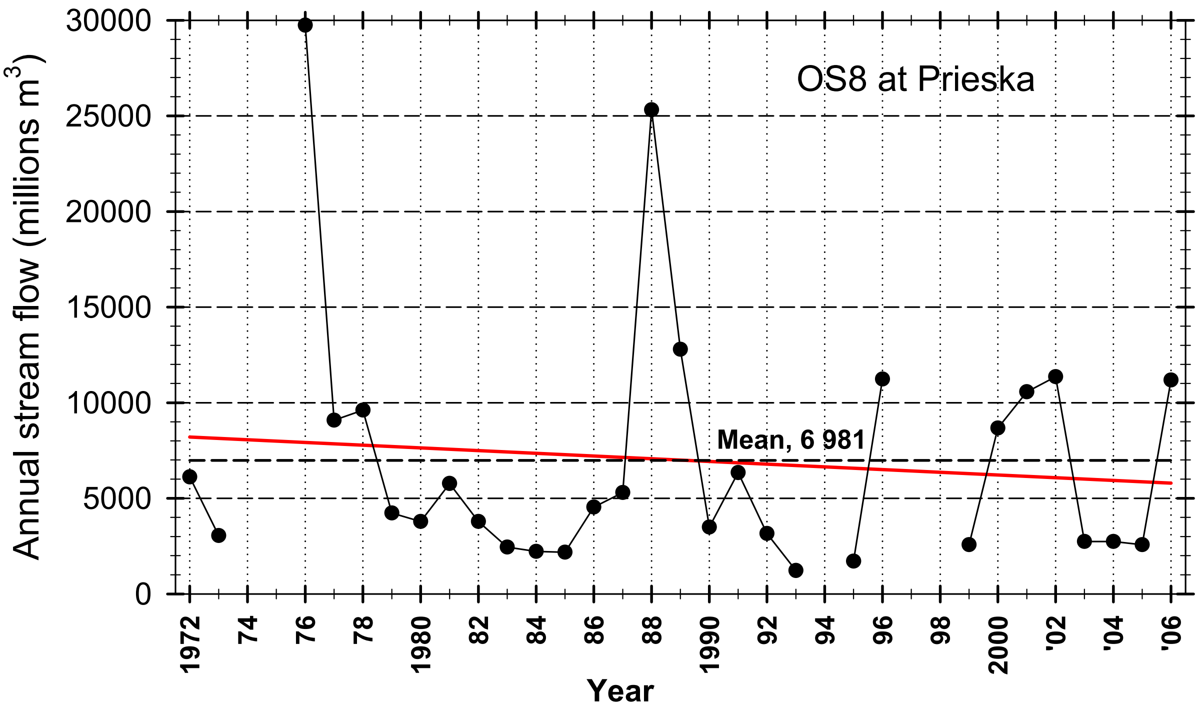


Figure 53: Temporal variation of annual stream flow (Mm^3/a) in the Orange River at Prieska (1972 – 2007). Stream flow trend is indicated by the solid line (red).

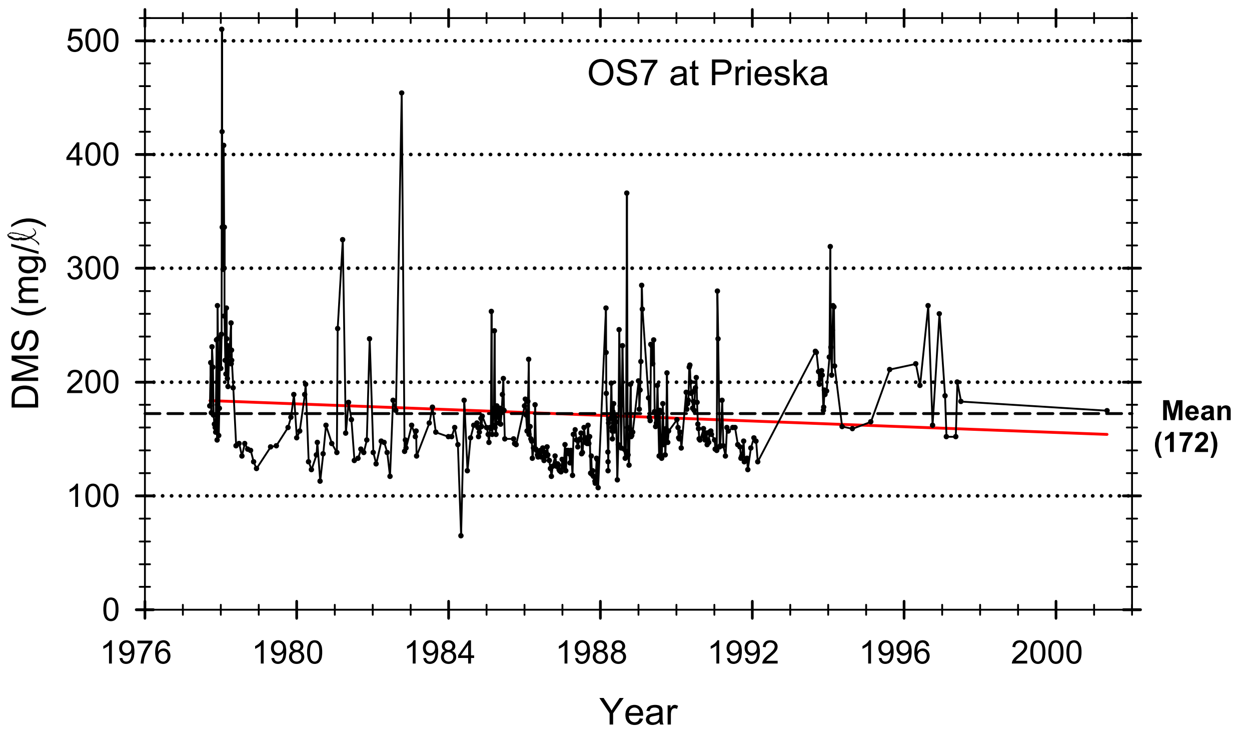


Figure 54: Temporal variation of dissolved major salts concentrations (DMS, mg/ℓ) in the Orange River at Prieska (1976 – 2000).

6.11.3 Phosphate (PO_4-P)

The mean phosphate concentration at Prieska for this period (1977 – 2001) was very low at 23 µg/ℓ (min. 3, max. 230 µg/ℓ) and shows no significant trend with time; red line in **Figure 55**).

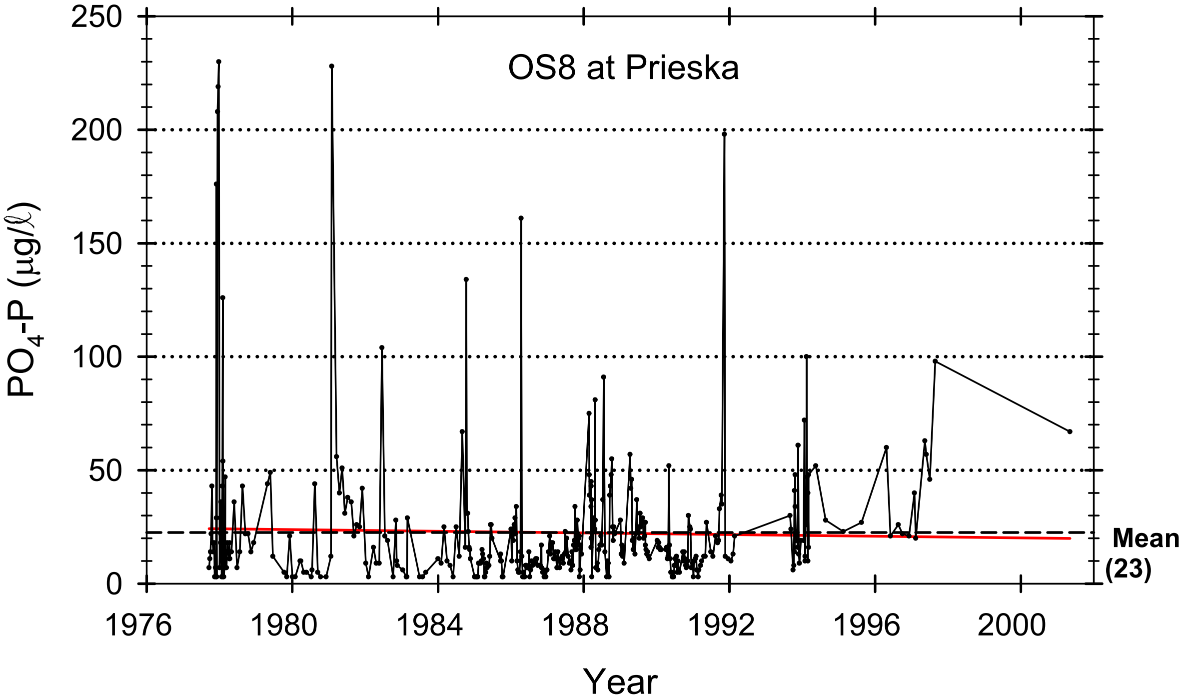


Figure 55: Temporal variation of phosphate concentration (PO_4-P, µg/ℓ) in the Orange River at Prieska (1976 – 2000).

The mean DIN concentration (0.486 mg/ℓ) was slightly higher than at Marksdrift but it does not include data from the past 10 years (**Figure A18 C**).

6.11.4 Total suspended solids (TSS)

The TSS concentrations at Prieska were very high (mean, 1 654 mg/ℓ) before the dams were built (1952 to 1955). After the dam construction, the mean TSS (1974 to 1985) was considerably lower at 192.5 mg/ℓ, *i.e.* a reduction of 88 % (**Figure 56**). The difference is ascribed to settling out of suspended material in the two major dams upstream that were built during 1971 and 1976. Unfortunately the TSS measurements were discontinued in 1986, because indications are that the TSS and turbidity have decreased even further in the Orange River during the past 10 years (cf. **Figures 33** and **39**).

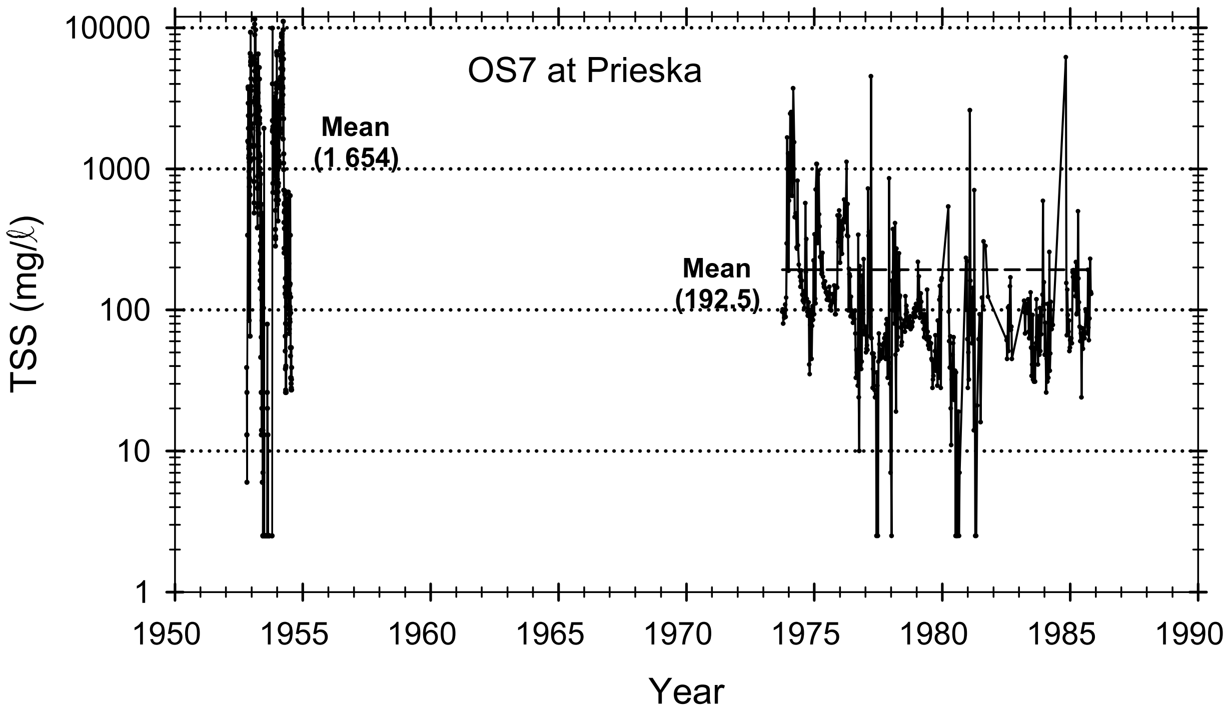


Figure 56: Temporal variation of Total suspended solids (TSS) concentrations (mg/ℓ) in the Orange River at Prieska (1952 – 1985). Note the log scale on the y-axis.

6.11.5 Other parameters

The EC was slightly higher than upstream points with a mean of 23.18 mS/m (**Figure A18** in Appendix A).

The pH was high (median, 8.03) and reached a maximum of 8.83 (**Figure A18 D**).

The silica concentration was relatively low (mean, 7.74 mg/ℓ) and continued the decreasing trend with time and space (**Figure A18 F**).

The sulphate concentrations (mean, 15.1 mg/ℓ) were significantly higher than upstream points and show extremely high spikes (max. 96.9 mg/ℓ) (**Figure A18 G**).

The alkalinity values at Prieska were moderate (mean, 80.4 mg/ℓ) with small variations (**Figure A18 H**).

6.12 OS9 – Boegoeberg Dam – D7H008 (S29.02625; E22.18608)

Boegoeberg Dam, located about 116 km downstream of Prieska and 32 km from Groblershoop, was constructed in the 1930's, primarily for irrigation supply (**Figure A19**). The original capacity of over 40 million m^3 has been reduced through sedimentation to the current capacity of approximately 20 million m^3 (DWAF, Website).

A gauging weir exists with poor chemical data from 1976 to 1987, but since 1988 the data frequency has improved noticeably to almost weekly measurements until today (n ≈ 725).

6.12.1 Stream flow (releases)

Figure 57 shows the monthly variation of stream flow at Boegoeberg Dam from 1933 to 2007, ranged between 0.39 and 4 432 m^3/s (mean, 250 m^3/s). However, the variability in stream flow before and after 1971 differs significantly. The variation before 1971 represents near natural flow conditions while the variability after 1971 indicates the impact of flow regulation because of the construction of the two major dams.

Thus, the Gariep and Vanderkloof Dams have altered the pattern of low flows, flood flows, as well as seasonal and daily flow variations significantly. Overall, the regulated regime results in a flattening of the annual hydrograph including a dampening of peak flows, particularly where the reservoir storage is large relative to runoff volume (**Figure 57**).

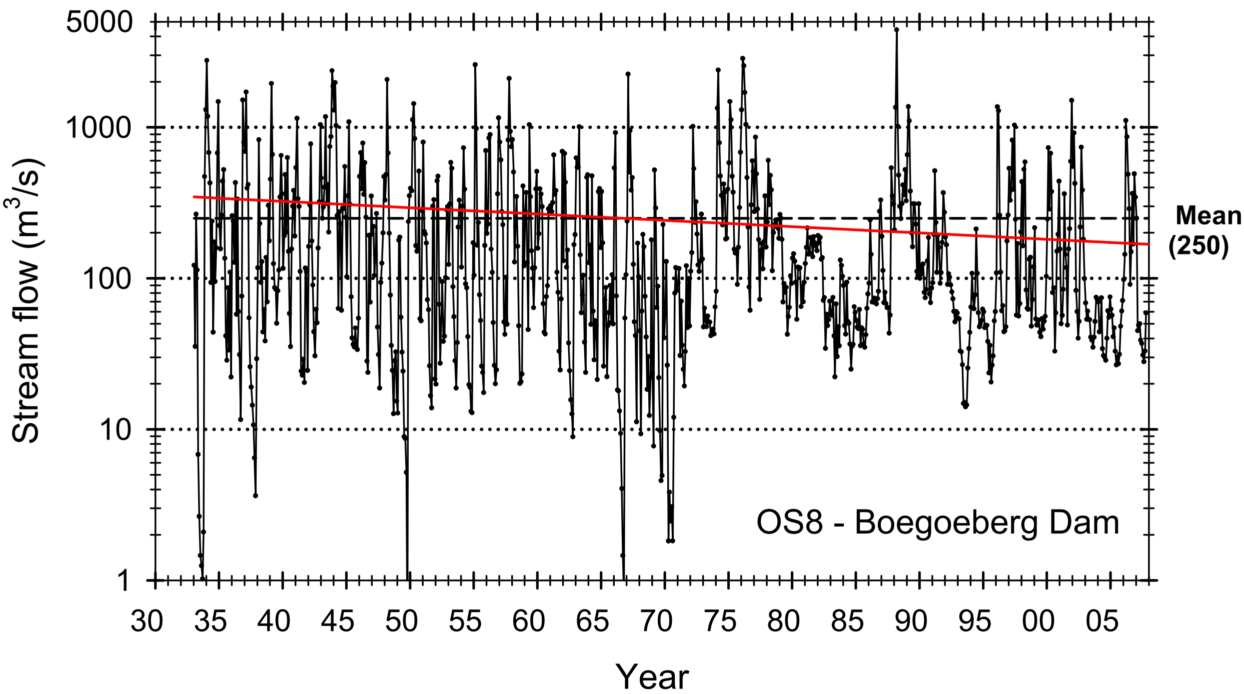


Figure 57: Temporal variation of stream flow (m^3/s) in the Orange River at Boegoeberg Dam (1933 – 2007). Note the log scale on the y-axis.

6.12.2 Dissolved major salts (DMS)

The dissolved salts at Boegoeberg Dam ranged between 98 and 632 mg/ℓ with 95 % of the time the concentrations were equal or less than 317 mg/ℓ. The higher mean salt concentration (210 mg/ℓ) at Boegoeberg Dam confirms the time (temporal) and downstream (spatial) salinisation in the Orange River (**Figure 58**).

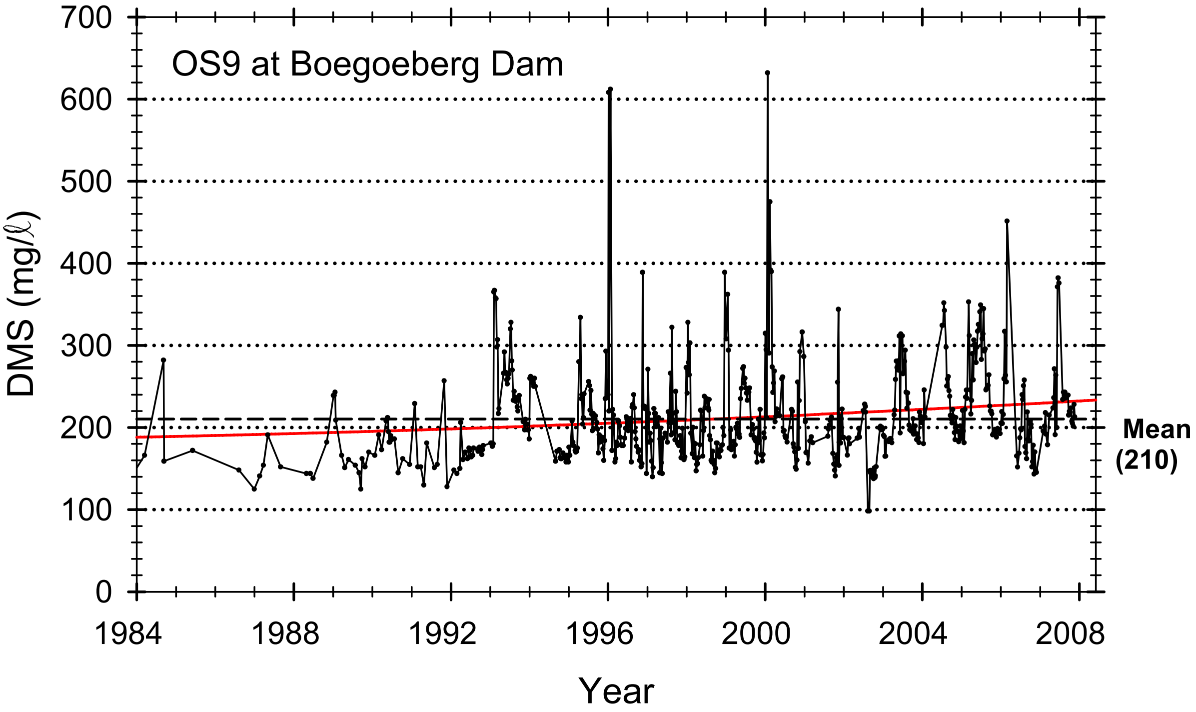


Figure 58: Temporal variation of the dissolved major salt (DMS) concentrations (mg/ℓ) in the Orange River at Boegoeberg Dam (1984 – 2007).

6.12.3 Turbidity

Turbidity values at Boegoeberg Dam were generally very low, with a mean of only 8.13 NTU (min. 0.5; max. 43.3 NTU; **Figure 59**), which was the lowest observed value for the Orange River and dramatically lower than at the upstream point Prieska (mean, 78.4 NTU). However, the measurements were only made from 2002 – 2007 (n = 92).

Stream flow (discharge) was shown to be the most important variable to influence the transparency of Vaal River water (Roos & Pieterse, 1994). Higher flow-rates resulted in higher turbidity and thus in a lower under water climate. However, the general low turbidity in Boegoeberg Dam is probably due to sedimentation in the upstream dams and weirs.

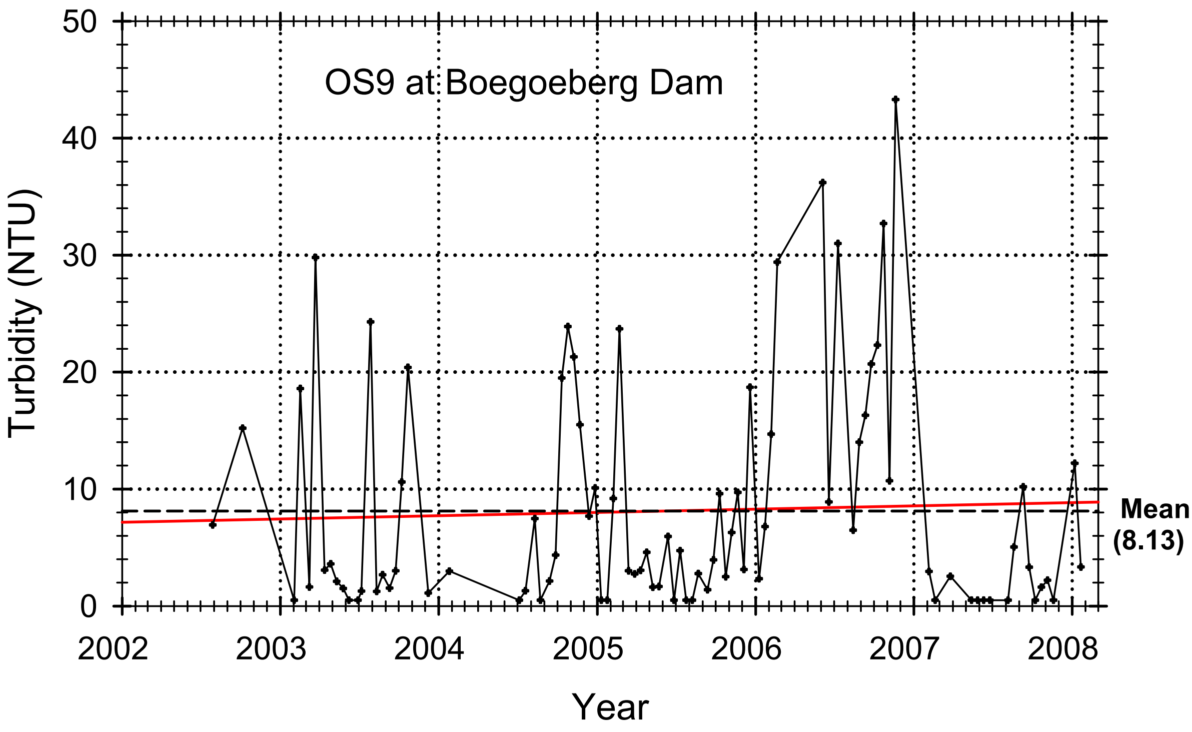


Figure 59: Temporal variation of turbidity (NTU) in the Orange River at Boegoeberg Dam (2002 – 2007).

6.12.4 Phosphate and Nitrogen

The phosphate concentrations in Boegoeberg Dam were low (mean, 27 µg/ℓ) but show a significant variation with time with the minimum at 3 µg/ℓ and the maximum at 456 µg/ℓ (**Figure 60**). A frequency histogram shows that most of the measurements (61 %) fall in the 10 – 30 µg/ℓ range and only 8 % of the observations were more than 50 µg/ℓ that could serve as a nutrient trigger to algal blooms.

The mean DIN concentration at Boegoeberg Dam of 0.336 mg/ℓ (min. 0.040, max. 1 228 mg/ℓ) was considerably lower than the upstream points (0.486 mg/ℓ at Prieska) and showed the same decreasing trend (since 1987) as observed in Vanderkloof Dam; blue line in **Figure 61**.

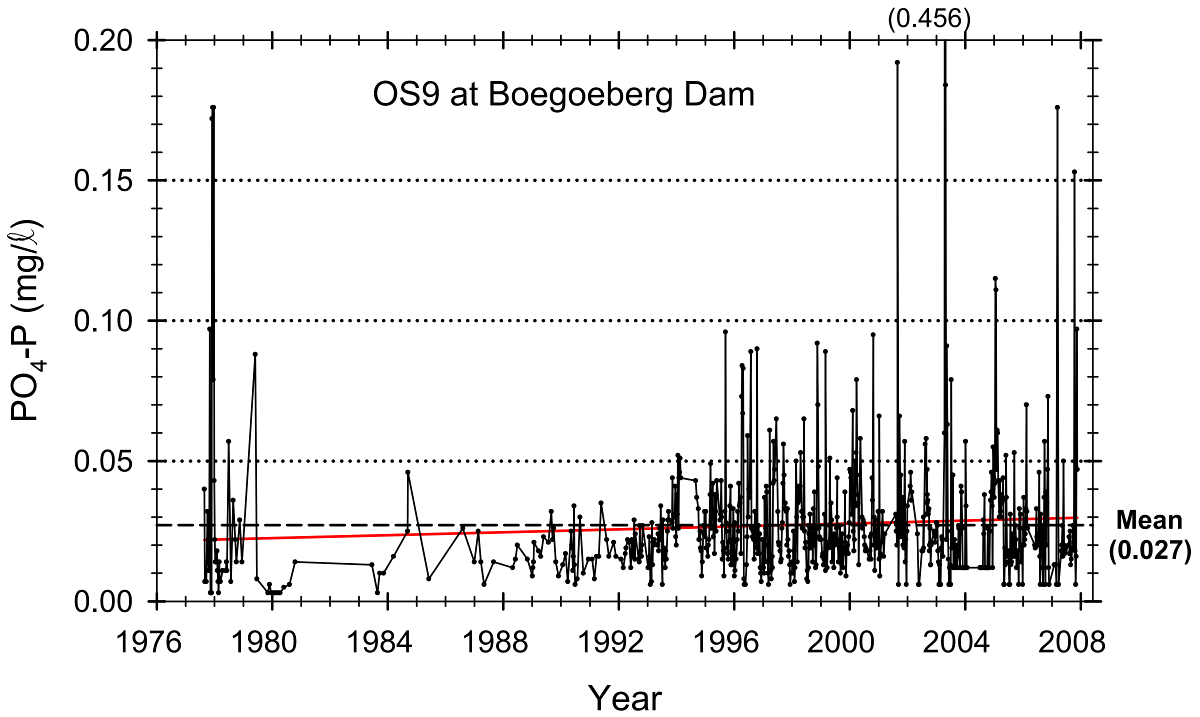


Figure 60: **Temporal variation of phosphate concentrations (PO_4-P, µg/ℓ) in the Orange River at Boegoeberg Dam (1976 – 2007).**

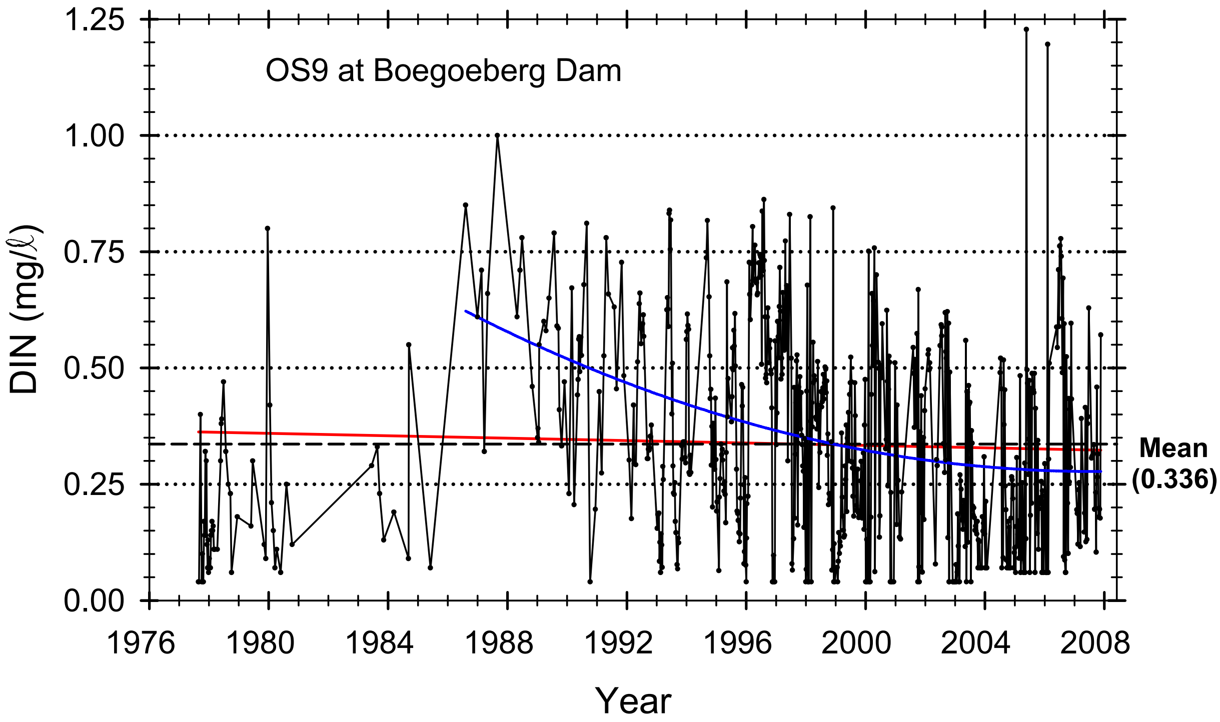


Figure 61: **Temporal variation of dissolved inorganic nitrogen (DIN) concentration (mg/ℓ) in the Orange River at Boegoeberg Dam (1976 – 2007).**

6.12.5 Chlorophyll-*a*

No Chl-a data were available at this monitoring site (D7H008), but at D7R001Q01 (WMS No. 101886; Boegoeberg Dam near dam wall). The chlorophyll-*a* concentrations were generally low (mean, 9.5 μg/ℓ), with only two blooms; one during 2002 and one during 2006 (**Figure 62**).

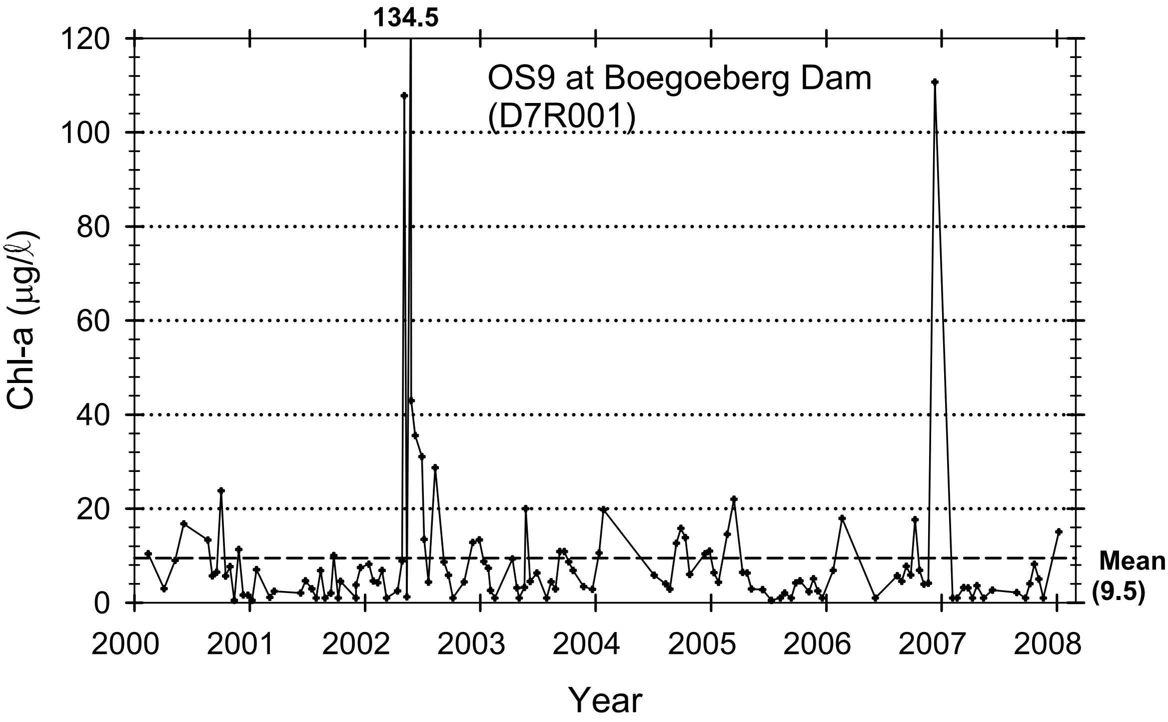


Figure 62: Temporal variation of chlorophyll-*a* concentration (μg/ℓ) in the Orange River at Boegoeberg Dam, near dam wall (2000 – 2007).

6.12.6 Other parameters

The EC ranged between 15.6 and 92.2 mS/m (mean, 28.13 mS/m) and showed an increasing trend (**Figure A20 A**). The median pH at Boegoeberg Dam (1989 – 2007) was high at 8.17 (min. 7.16; max. 9.33) and occasionally exceeds the upper limit for irrigation water of 8.4 (**Figure A20 B**).

The DIN:DIP ratio was relatively high (mean, 18.3), which suggest a P limitation for algal growth at Boegoeberg Dam. The mean total hardness (108.8 mg/ℓ) was higher than upstream values, but the SAR (mean, 0.68) was still very low and suitable for irrigation.

The silica concentration was low (mean, 6.44 mg/ℓ) and showed a decreasing trend with time (**Figure A20 E**). The sulphate concentrations (mean, 25.2 mg/ℓ) at Boegoeberg Dam were significantly higher than the upstream points. High sulphates are associated with irrigation return flows – see Chapter 7.

6.13 OS11 – Upington – D7H005 (S28.45259; E21.25994)

Upington is the main commercial, agricultural and educational center of the Green Kalahari and Gordonia regions in the Northern Cape Province and is bound by the Orange River and the Kalahari. Upington was founded in 1884 and as of 2007 the town had an estimated population of 100 920 (Wikipedia, Website). It was named after Sir Thomas Upington, the Attorney-General of the Cape. Upington originated as a mission station established by Reverend Schröder in 1873.

The wine grapes of Oranjerivier Wine Cellars originate from 930 producers all along the Orange River. These pockets of vineyard land stretch over a distance of more than 300 kilometers between Groblershoop and Blouputs. Five wineries have been established in Kakamas, Keimoes, Grootdrink and Groblershoop. The Oranjerivier Wine Cellars is one of the biggest wine cellars in South Africa, with a record harvest of 184 361 tons for 2004.

The monitoring site at Upington is a flow gauging station about 164 km downstream of Boegoeberg Dam, and has a good chemical data set with about 390 measurements from 1975 to 2007. Including almost daily measurements of TSS from 1952 to 1973 (n = 3 505), but unfortunately a TSS data gap occurred between 1975 and 1999 with only limited measurements from 2000 to 2007 (n = 60). The chlorophyll-*a* data are also weak with variable frequencies (sometimes weekly, sometimes monthly or longer gaps) that make the interpretation of the data almost impossible – see **Figure A21** in Appendix A.

Upington is also a monitoring site in the National Microbial Monitoring Programme (NMMP). Water temperature data and *E. coli* counts from this data set were used.

6.13.1 Temperature

Upington was the only monitoring station in the Orange River with water temperatures and therefore shortly discussed here. Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic residents (UNEP-GEMS, 2006). Temperature is important in aquatic systems because it can cause mortality and it can influence the solubility of dissolved oxygen (DO) and other materials in the water-column (e.g. ammonia).

Water temperatures fluctuates naturally both daily and seasonally. The maximum daily temperature is usually several hours after noon and the minimum is around daybreak. Under natural conditions the temperature of running water varies between 0 ºC and 30 ºC. Water temperatures recorded in the Orange River at Upington were relatively high and varied between 11.2 ºC and 33.8 ºC (mean, 20.5 ºC) because of the very hot summers (summer air temperatures varying between 30 and 40°C; record high, 46°C). The water temperature displayed a seasonality that follows the normal climatic fluctuations (**Figure 63**).

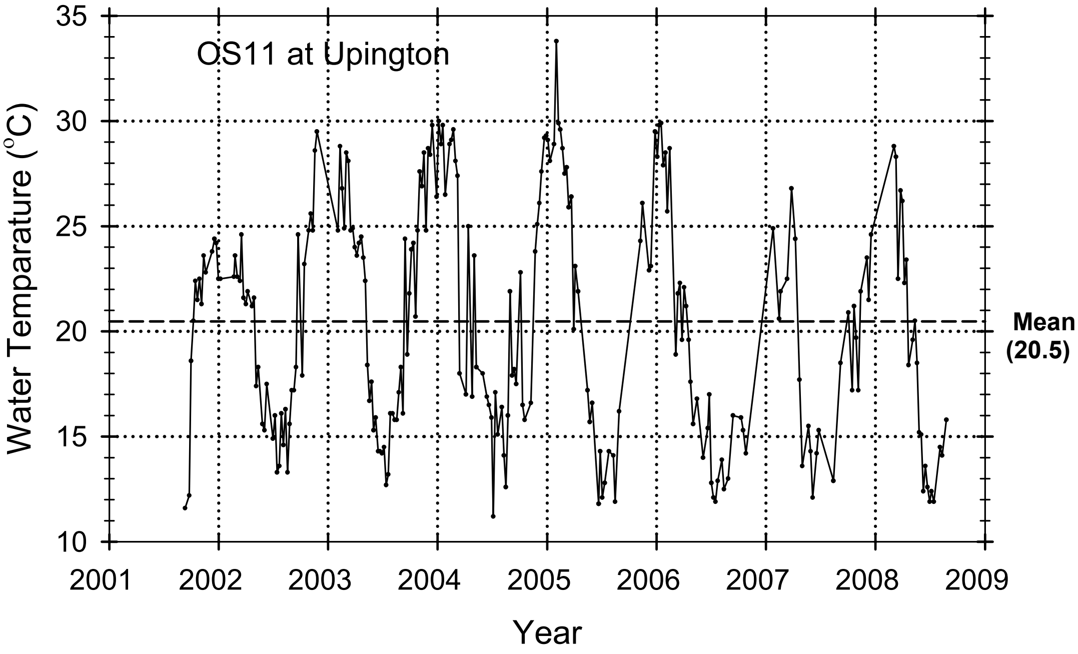


Figure 63: Temporal variation of water temperature (ºC) in the Orange River at Upington (2001 – 2008).

6.13.2 Stream flow

The mean annual stream flow at Upington was fairly high (8 635 Mm^3), but decreased significantly from approximately 11 000 Mm^3 to 6 000 Mm^3 (Δ = 45 %) during the past 63 years; see third order trend line (red) in **Figure 64**.

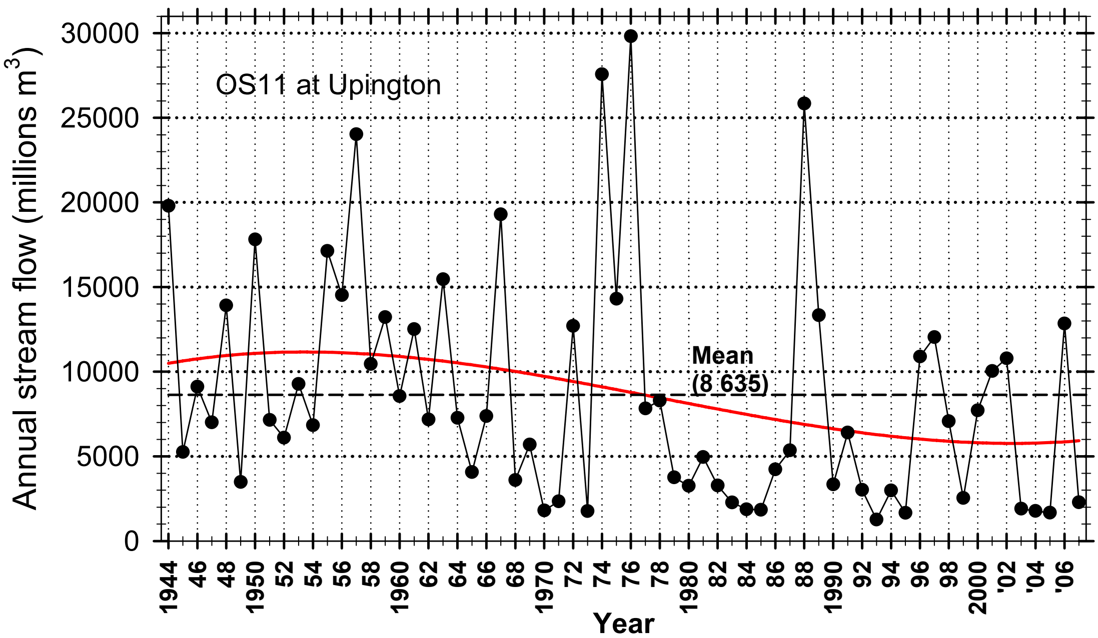


Figure 64: Temporal variation of annual stream flow (Mm^3/a) in the Orange River at Upington (1944 – 2007). The solid (red) line represents a third order trend line.

6.13.3 Total suspended solids (TSS)

The TSS concentration in the Orange River at Upington was high (mean, 1 105 mg/ℓ) and highly variable before the dams were built (1952 – 1969) but recently (2000 – 2008) values lowered dramatically (mean, 35 mg/ℓ), *i.e.* a 97 % reduction (**Figure 65**). Unfortunately, a huge gap in the TSS data set makes any trend analysis impossible. Similar observation was made at Prieska (**Figure 56**).

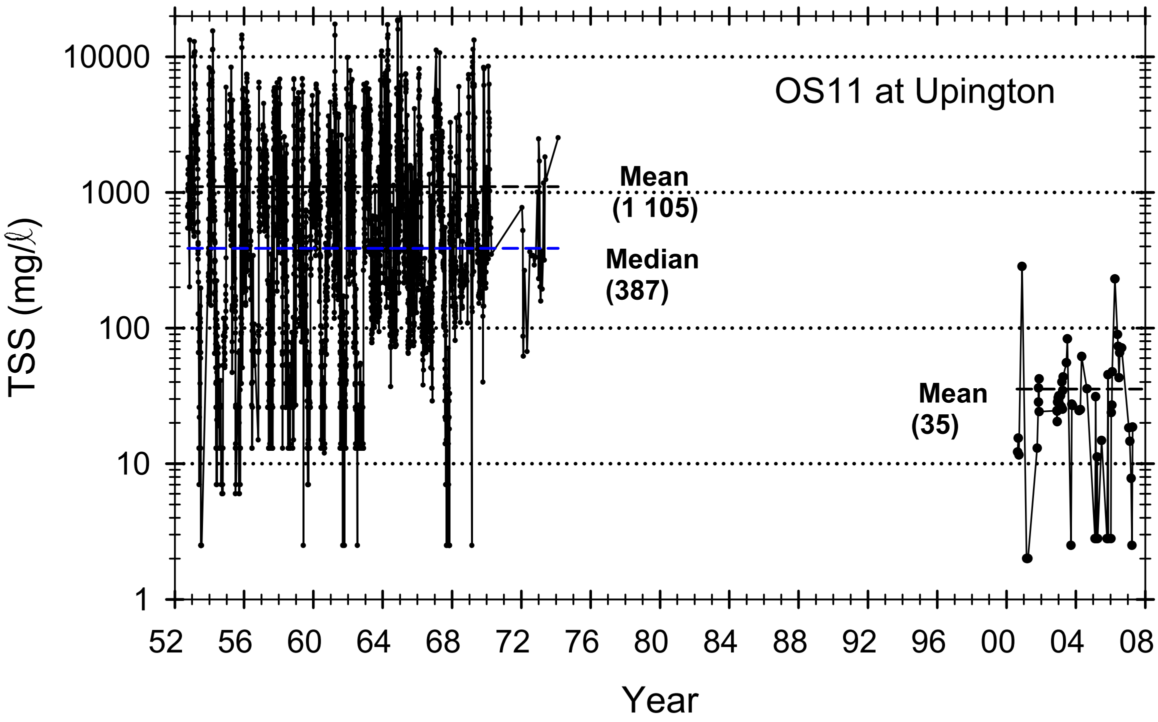


Figure 65: Temporal variation of total suspended solid (TSS) concentrations (mg/ℓ) in the Orange River at Upington (1952 – 2007). Note the log scale on the y-axis.

Suspended solids in rivers are often the result of sediments carried by the water, as depicted by the relationship between stream flow and suspended solids in the Orange River (**Figure 66**). The concentration of TSS in rivers increases as a function of flow. The source of these sediments includes natural and anthropogenic (human) activities in the catchment, primarily excessive soil erosion.

The amount of TSS can vary substantially in rivers as a function of stream flow. However, the sediment transport is not always proportional to the amount of water discharged, e.g. a three-month study during the Orange River floods of 1988 (Bremner *et al.*, 1990), it was noted that some 24.3 km^3 of water was discharged, which was more than twice the mean annual runoff from the river (11.3 km^3). Although sediment transport was large, it was not proportional to the amount of water discharged through the mouth, with a steady decline through time: 64.2 $x10^6$ t in March, 9.4 $x10^6$ t in April, and 7.3 x 10^6 t in May of 1988.

Total sediment discharge exceeded the mean annual value of 60.4 x 10^6 t by only 40 % (that is, it reached 80.9 x 10^6 t).

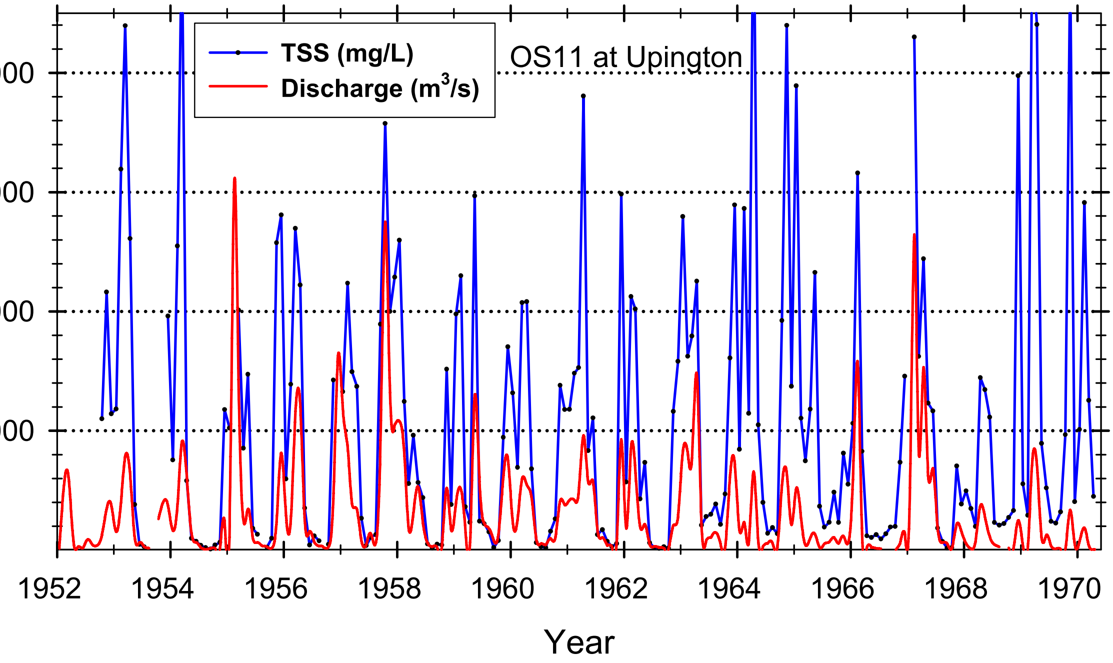


Figure 66: Temporal variation of total suspended solids (TSS) concentration (mg/ℓ) and stream flow (discharge, m^3/s) in the Orange River at Upington (1952 – 1970).

6.13.4 Dissolved major salts (DMS)

The dissolved major salt concentrations at Upington were relatively high (mean, 241.5 mg/ℓ; min. 128; max 674.8 mg/ℓ) and show a clear increasing trend, but seem to lower off during the past seven years; see red trend line in **Figure 67**. The higher salt concentrations are primarily ascribed to the intense irrigation activities along the river.

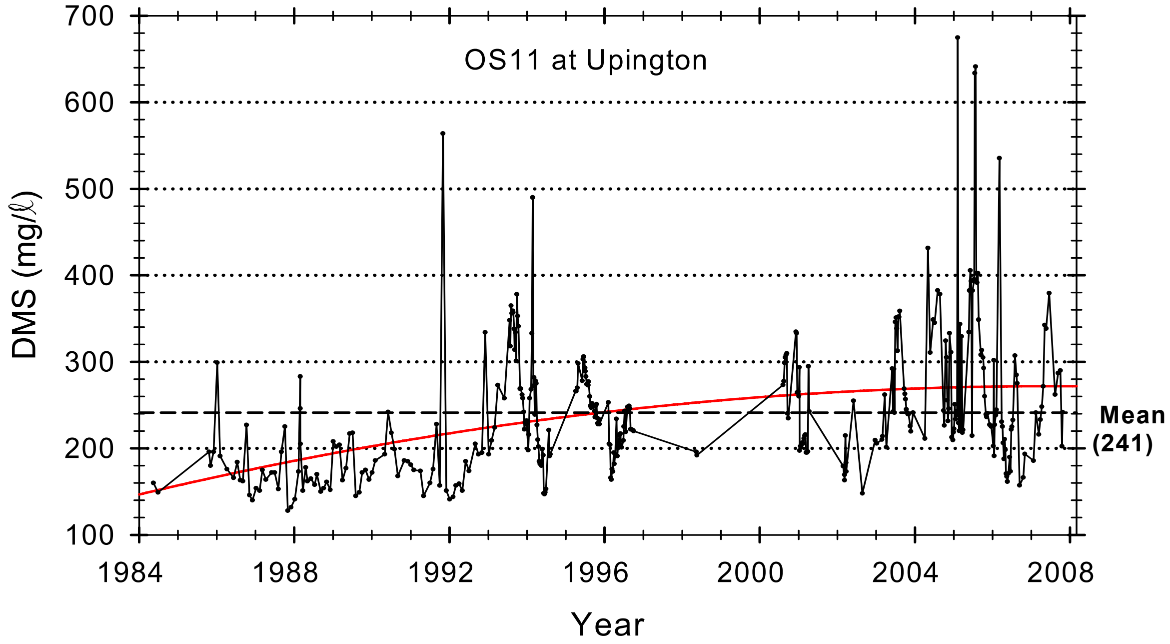


Figure 67: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Upington (1984 – 2007).

The mean dissolved ionic composition of the Orange River water at Upington is illustrated as a pie chart in **Figure 68**. The order of ionic prominence in the Orange River was:

$HCO_3^- > SO_4^{2-} > Ca^{2+} > Na^+ > Cl^- > Mg^{2+} > K^+$.

The concentration of major anions showed proportions of HCO_3^- >SO_4^{2-} >Cl^- and the cations of Ca^{2+} >Na^+ >Mg^{2+} > K^+. The cation and anion proportions at Upington were different from the upstream point at Oranjedraai with proportionally higher sulphates, sodium and chlorides (cf. **Figure 17**).

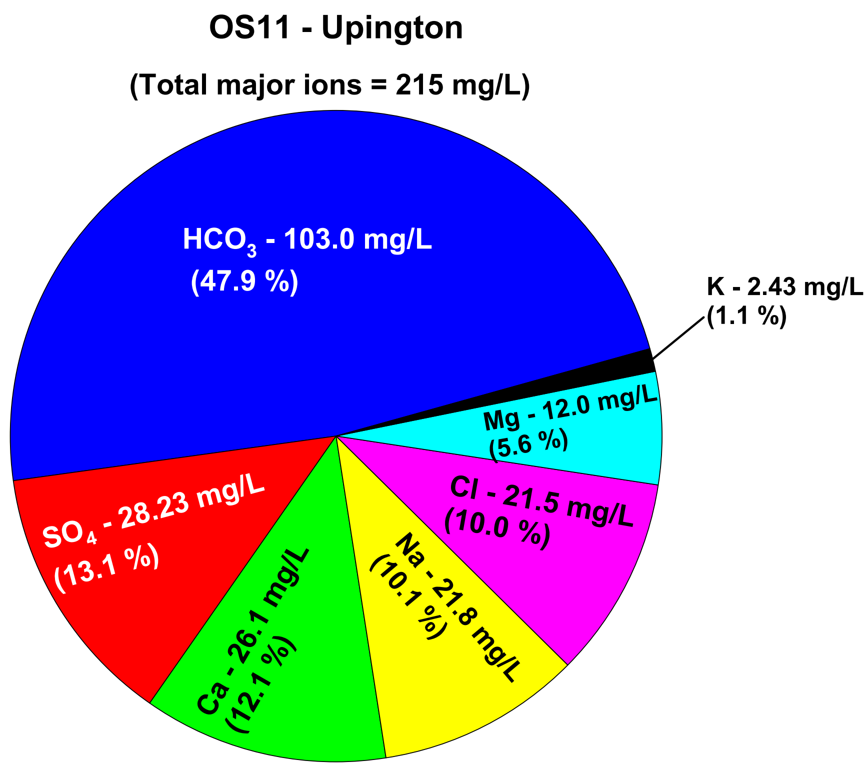


Figure 68: Pie chart of the ionic composition (averages) in the Orange River at Upington (1984 – 2007).

Return flow water from irrigations systems is usually of poorer quality – see snapshot results – Chapter 7.

Because the return flow consists of relatively high sulphate concentrations, it changes the ionic dominance to SO_4 in the composition.

In the irrigation area, the salts are apparently from the same origin (fertilisers), therefore the close correlation between certain ions, e.g. Mg^{2+} and SO_4^{2-} (**Figure 69**).

Under more natural conditions (at Oranjedraai) there was no significant correlation between Mg and SO_4 – see **Figure 18**.

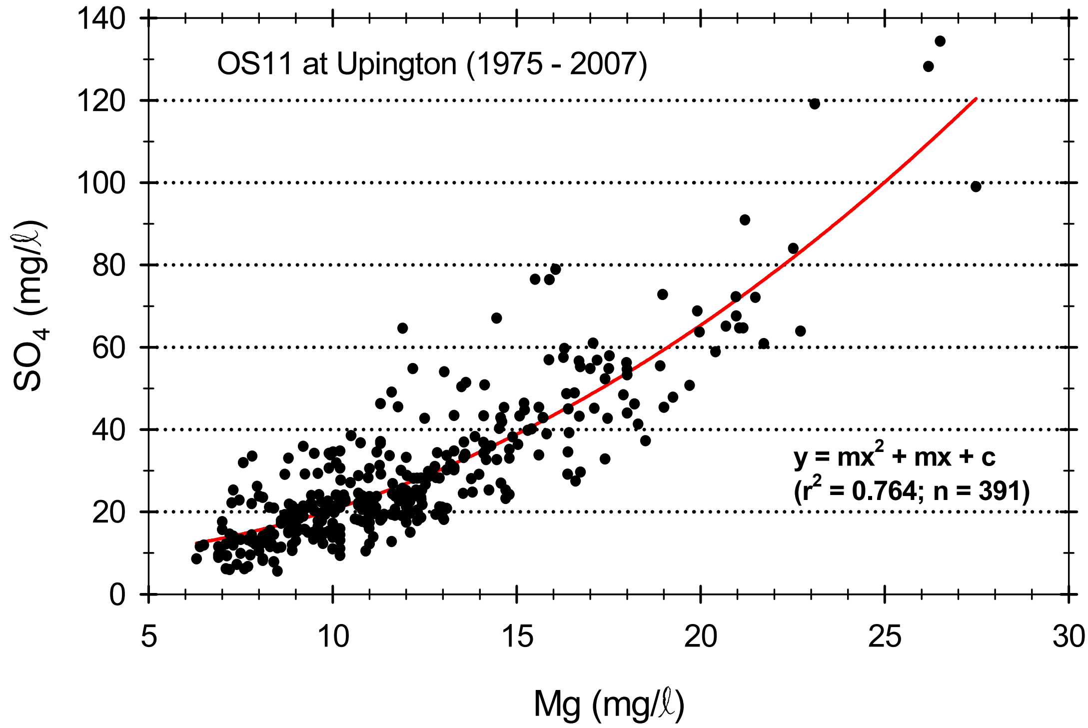


Figure 69: Scatter graph of magnesium vs. sulphate concentrations (mg/ℓ) in the Orange River at Upington (1975 – 2007).

6.13.5 Total hardness

The total hardness of the river has also shifted now from moderately soft (<100) in the upper catchment area (Aliwal North, **Figure 20**) to slightly hard (>100 mg $CaCO_3$/ℓ) (**Figure 70**).

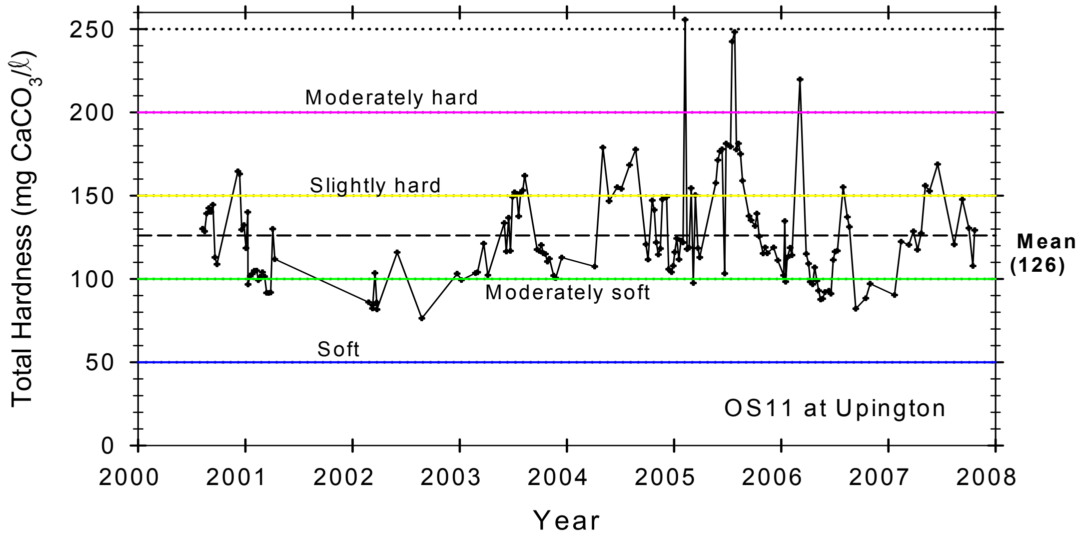


Figure 70: Temporal variation of total hardness concentrations (mg/ℓ) in the Orange River at Upington (2000 – 2007).

6.13.6 Nutrients (DIN and DIP)

The mean DIP (phosphorous) concentration at Upington (30 µg/ℓ) was slightly higher than at Boegoeberg Dam (27 µg/ℓ). Seventy percent of the samples contain less than 30 µg/ℓ phosphate, and 12 % were more than 50 µg/ℓ (**Figure 71**).

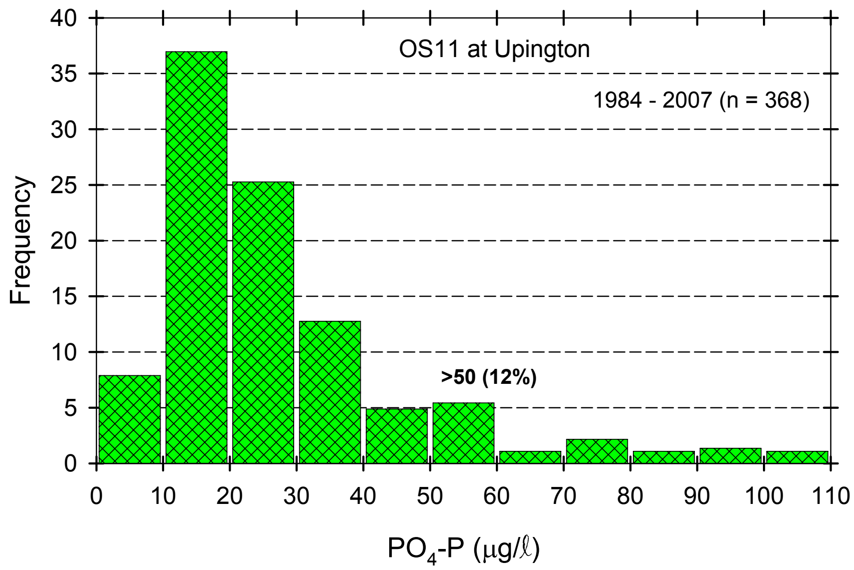


Figure 71: Frequency distribution (%) of phosphate concentrations (µg/ℓ) in the Orange River at Upington (1984 – 2007).

The DIN (nitrogen) concentrations were slightly higher than at Boegoeberg Dam (mean, 0.345 mg/ℓ), showed a decreasing trend since 1988, but levelled off since 2000 (**Figure 72**).

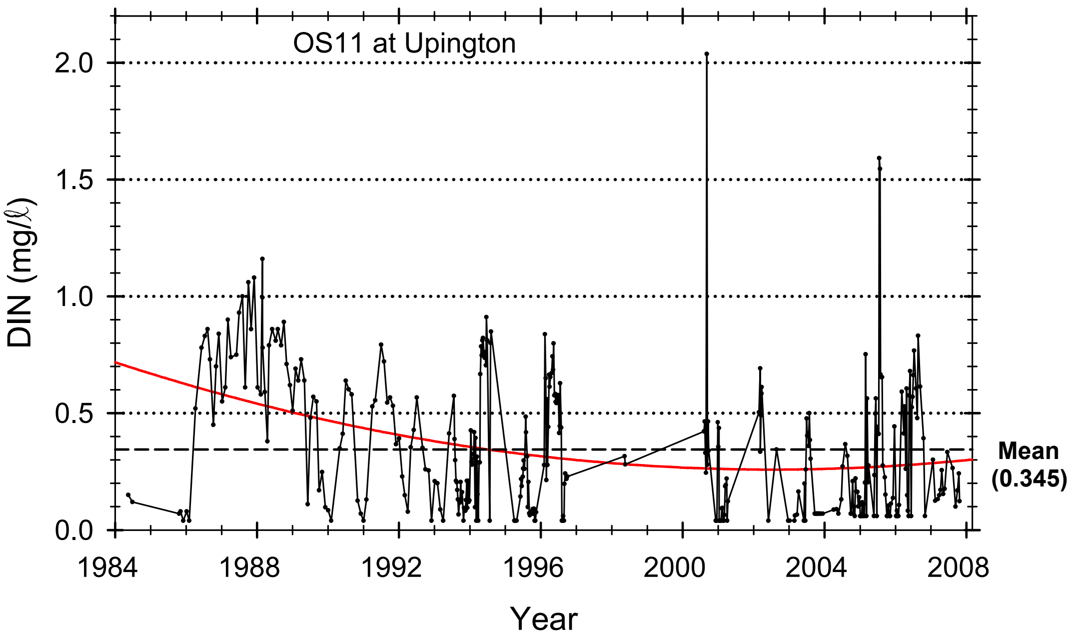


Figure 72: Temporal variation of dissolved inorganic nitrogen (DIN) concentration (mg/ℓ) in the Orange River at Upington (1984 – 2007).

6.13.7 Metals

The metal concentrations in the Orange River at Upington were also fairly low and comparable with the concentrations at Vanderkloof Dam and Marksdrift, and within the ideal range of domestic use (**Figure 73**). However, the concentrations were not always suitable for the aquatic environment – see section 8 (Status Quo).

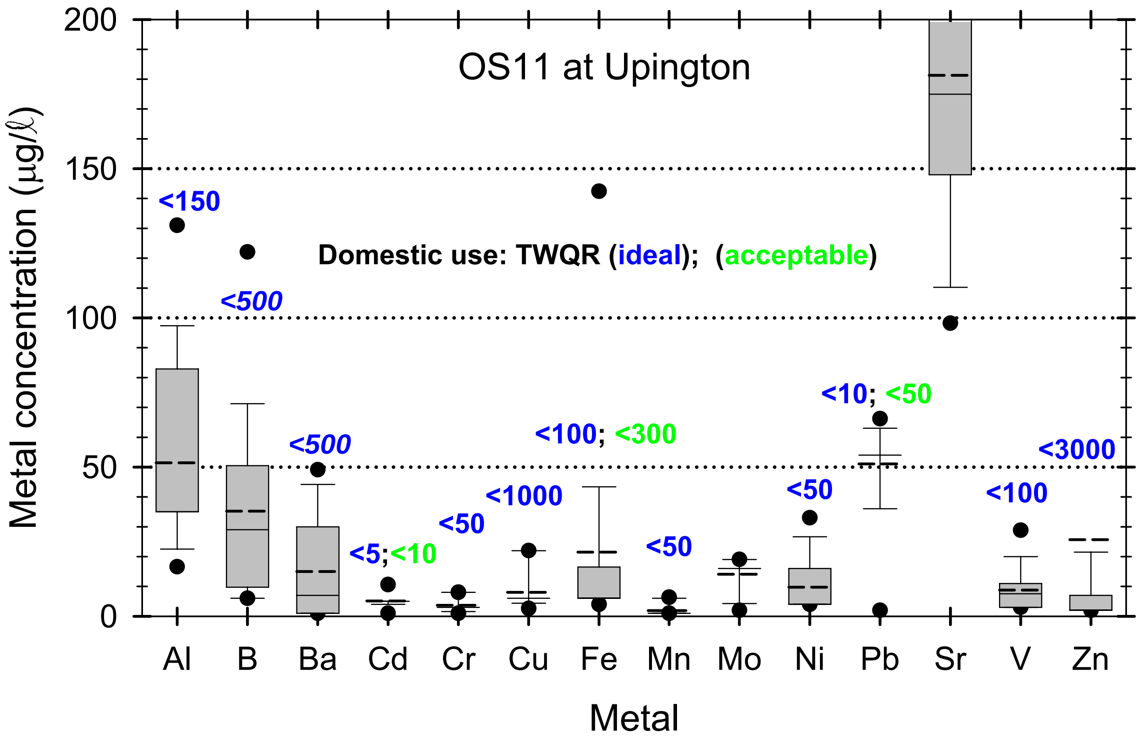


Figure 73: Box and whiskers plot of dissolved metal concentration (µg/ℓ) in the Orange River at Upington (1976 – 2007). The maximum concentration levels for the target water quality range (ideal) and acceptable for domestic use (DWAF, 1996) are indicated above the boxes.

6.13.8 Phytoplankton – Chlorophyll-*a*

The chlorophyll-*a* concentrations at Upington ranged between 1 and 346 µg/ℓ (2000 – 2007), but showed a decreasing trend (**Figure 74**). The maximum concentration (346 µg/ℓ) was observed during July of 2003. This value is indicative of a severe algal bloom, but unfortunately the dominate species is unknown. It is suspected that it was diatoms because they usually dominate the algal assemblages during winter periods. The mean Chl-*a* concentration was 16.8 µg/ℓ, which is in the range of mesotrophic systems.

However, the data monitoring frequency was poor with, for example, only 5 measurements recorded during 2004, so that algal biomass could easily be under estimated because an algal bloom can develop and crash (die out) in three weeks without being noticed.

Under favorable conditions algal growth rates can be very high. For example, cyanobacterial populations in natural water bodies, especially in hot climates, may double in size in approximately two days (growth rate, μ, 0.3/d). Based on these conditions, it would take about 5.5 days for an initial algal population to increase by a factor of five, for example from 1 000 to 5 000 cell/mℓ or 20 000 to 100 000 cells/mℓ. Therefore, an algal bloom (from 1 000 to 100 000 cells/mℓ) can develop within 15 days.

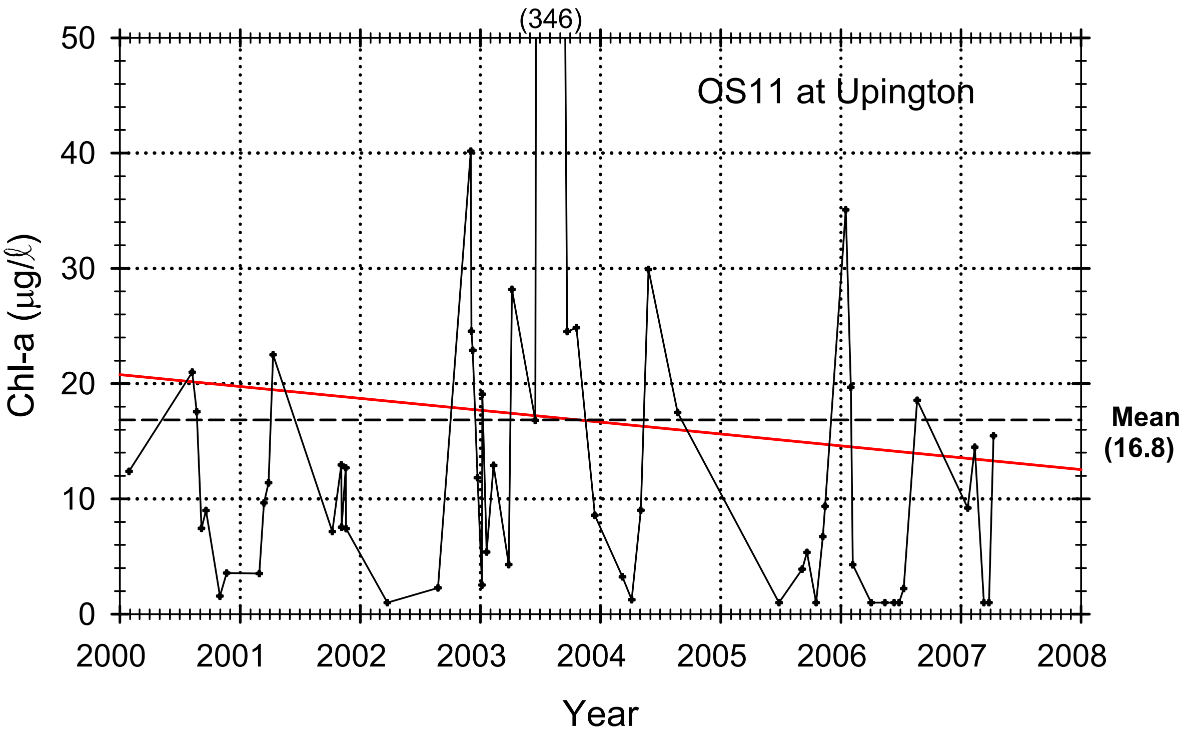


Figure 74: Temporal variation of chlorophyll-*a* concentrations (µg/ℓ) in the Orange River at Upington (2000 – 2007).

6.13.9 Bacteriological (*E. coli*)

The most common risk to human health associated with water stems from the presence of pathogens (disease-causing microorganisms). Many of these microorganisms originate from water polluted with human excrement. *Escherichia coli (E. coli)* is a highly specific indicator of faecal pollution which originates from humans and warm-blooded animals, which is used to evaluate the quality of the water.

The *E. coli* concentrations at Upington ranged between 2 and 1 986 cfu/100mℓ, with the mean at 132 cfu/100mℓ which is at the limit for safe full contact recreational use (**Figure 75**). The decreasing trend is significant because it indicates better water quality (*E. coli* concentrations <100 cfu/100mℓ) during the past few years.

The snapshot surveys also showed that the *E. coli* concentrations in the Orange River were relatively low – see Chapter 7.

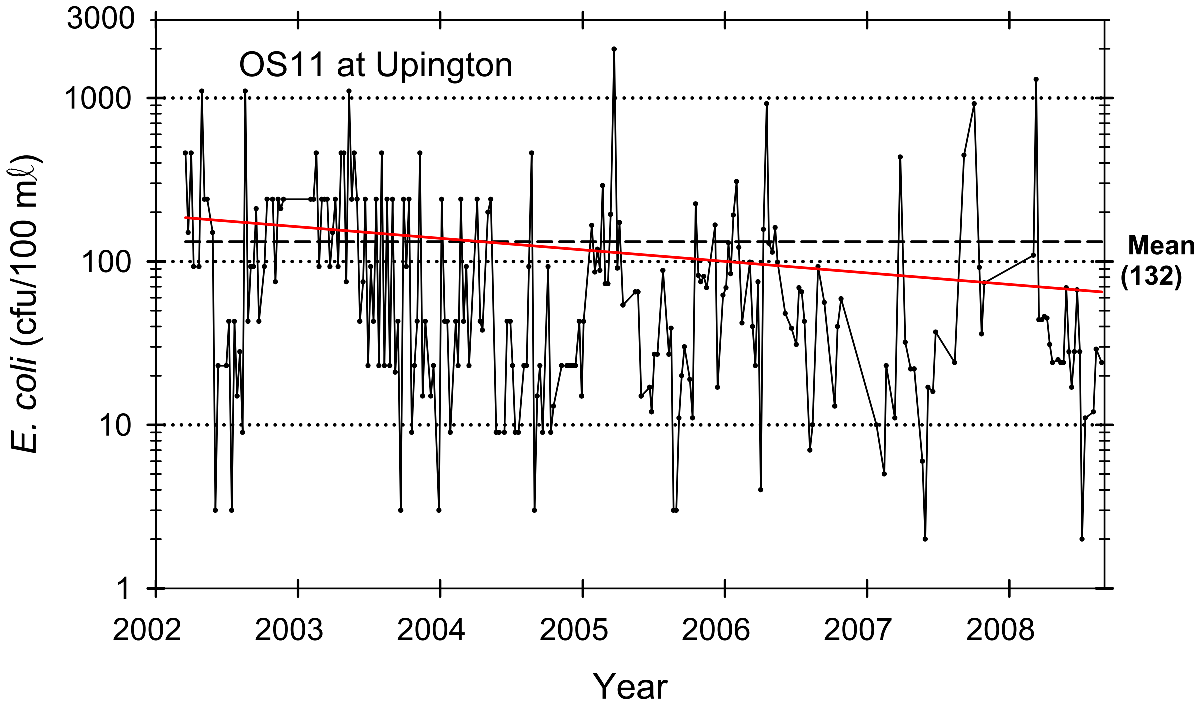


Figure 75: Temporal variation of *E. coli* concentrations (cfu/100mℓ) in the Orange River at Upington (1984 – 2007).

6.13.10 Other parameters

The mean lead (Pb) concentration of 0.051 mg/ℓ is in the tolerable range for domestic use (**Figure A22 A**), but could cause problems for aquatic organisms – see Chapter 8. However, the Pb concentrations were <0.010 mg/ℓ during the snapshot surveys.

The pH was relatively high (median, 8.20), but show a slight decreasing trend during the last five years (**Figure A22 B**).

The mean DIN:DIP ratio was relatively high at 16.7, indicating P limitation, but show a decreasing trend (**Figure A22 D**). Low N:P ratios are usually favourable for the growth of cyanobacteria.

The sulphate concentrations were high (mean, 28.4 mg/ℓ) and increased with time (**Figure A22 E**), probably because of irrigation return flows.

The TN concentrations at Upington were relatively high (mean, 0.88 mg/ℓ), but show a decreasing trend (**Figure A22 H**).

6.14 OS13 – Neusberg weir – D7H016 (S28.77392; E20.74297)

The Neusberg Weir, planned as far back as 1897 by the British Colonial Officers of the time, was finally completed in 1993. The weir is 995 m long with an average height of 5 m and was both designed and constructed by DWAF. The weir is located approximately 70 km downstream of Upington and 12 km upstream of Kakamas and forms a small reservoir in the Orange River with a storage of almost 2 million m^3 (DWAF, Website).

The weir diverts water into two canals (north and south), one on each bank of the Orange River which supplies water to the Kakamas Irrigation Scheme. The Kakamas Irrigation Scheme produces high value table grapes for both local and international consumption – it is one of the most valuable and productive irrigation schemes in South Africa (DWAF, Website).

The chemical data set for the weir (D7H014) is poor with only about 86 observations from 1995 to 2005, and most of the parameters were terminated in 2002, but the stream flow data, since 1994, are good. However, the chemical data set from the North Canal (D7H016) is good and used as representative of the weir. Statistical analyses have shown that the water quality data in the weir and from the canal is very similar and the canal can be used as a substitute.

6.14.1 Stream flow (releases)

The average stream flow at Neusberg weir (231 m^3/s) was lower than the stream flow at Upington (274 m^3/s) and showed a slight decreasing trend with time; red line in **Figure 76.**

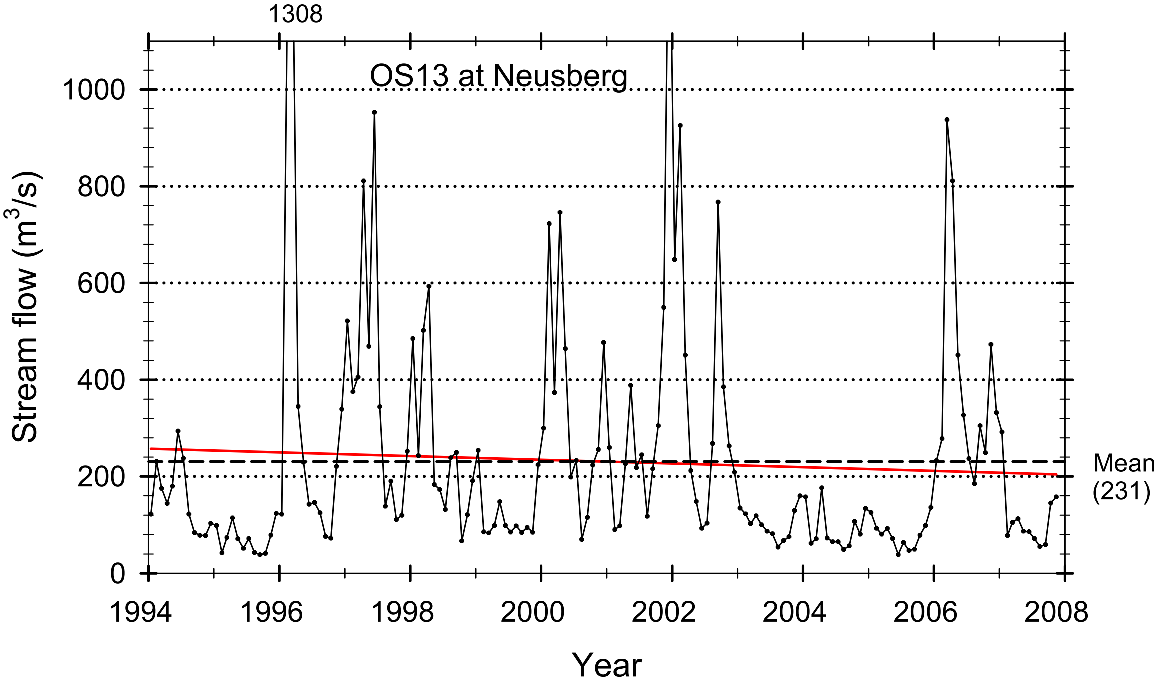


Figure 76: Temporal variation of stream flow (m^3/s) in the Orange River at Neusberg weir (1994 – 2007).

6.14.2 Salinity

The mean dissolved salts concentration at Neusberg (254 mg/ℓ) was slightly higher than at Upington (241 mg/ℓ) and showed a seasonal pattern with an increasing trend (**Figure 77**).

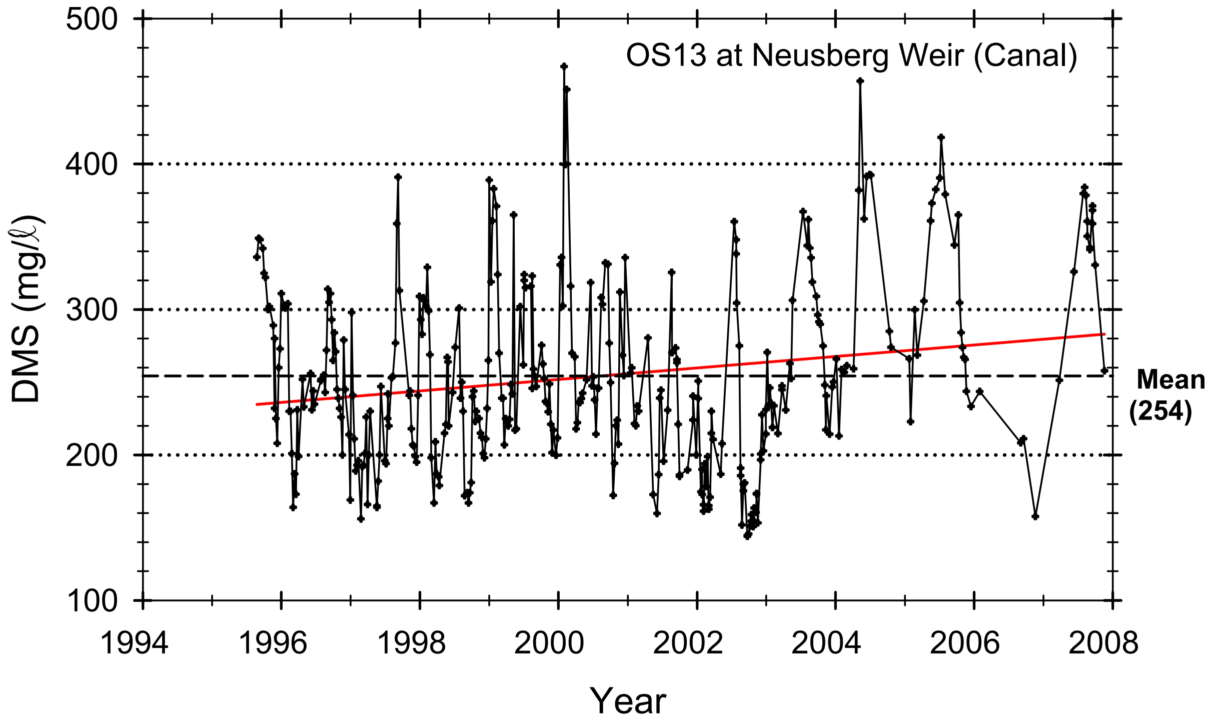


Figure 77: Temporal variation of dissolved major salts concentrations (mg/ℓ) in the Orange River at Neusberg weir (1995 – 2007).

6.14.3 Phosphate and Nitrogen

The mean phosphate concentration of 0.030 mg/ℓ was the same as the upstream point and showed a decreasing trend (**Figure 78**). The phosphate concentrations during the snapshots were also relatively low at 0.035 mg/ℓ.

The mean DIN concentration in Neusberg weir (0.198 mg/ℓ) was significantly lower than at Upington (mean, 0.345 mg/ℓ), and also showed a decreasing trend (**Figure 79**).

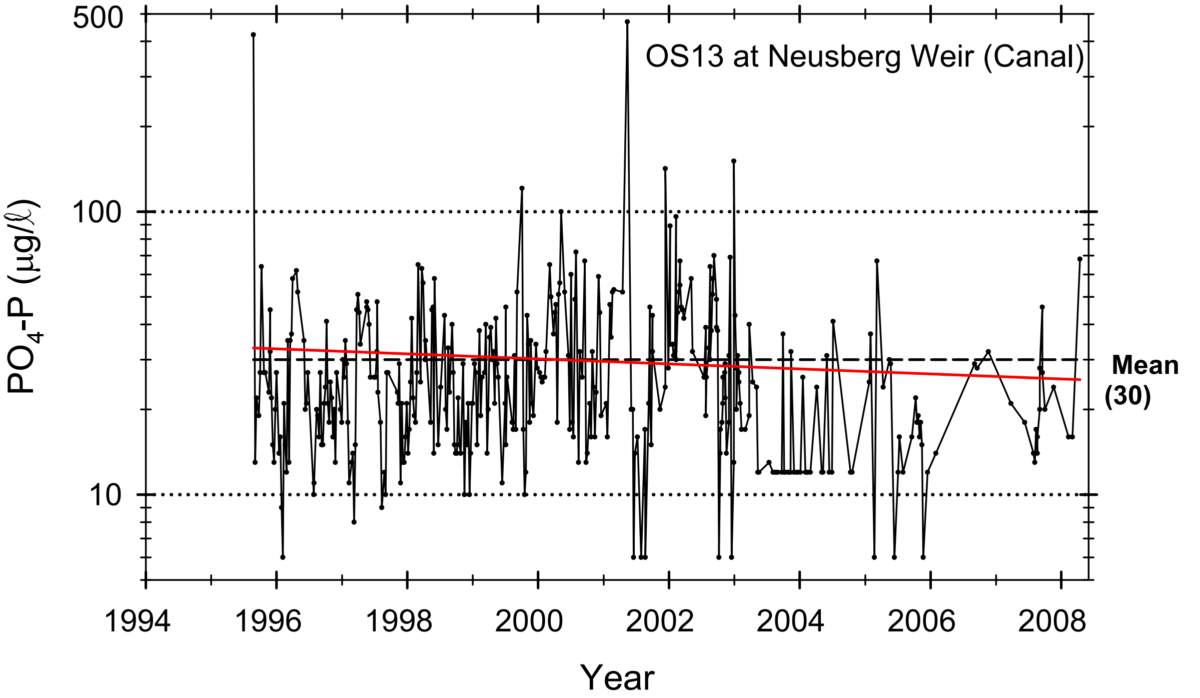


Figure 78: Temporal variation of the phosphate concentrations (mg/ℓ) in the Orange River at Neusberg weir (1995 – 2007). Note the log scale on the y-axis.

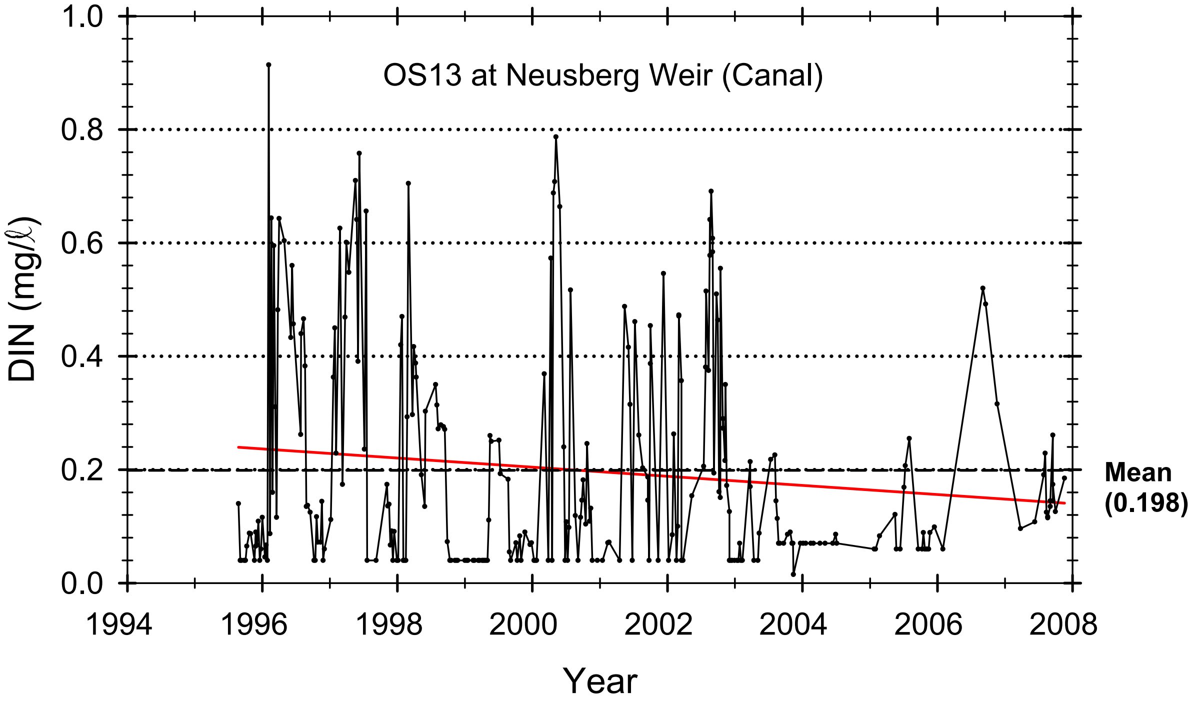


Figure 79: Temporal variation of dissolved inorganic nitrogen (DIN) concentration (mg/ℓ) in the Orange River at Neusberg weir (1995 – 2007).

6.14.4 Phytoplankton – Chlorophyll-*a*

The chlorophyll-*a* concentrations at Neusberg weir (canal) ranged between 1 and 211 µg/ℓ with the mean at 14.3 µg/ℓ (oligo-mesotrophic range), but shows a decreasing trend (**Figure 80**). The annual maximum concentrations usually occurred during January to March, but no significant algal bloom was recorded since 2004. The decreasing Chl-*a* trend was associated with a decreasing trend in the N and P concentrations. However, the sampling frequency is poor and probably underestimates the Chl-*a* concentration. The sampling frequency should be increased to biweekly measurements.

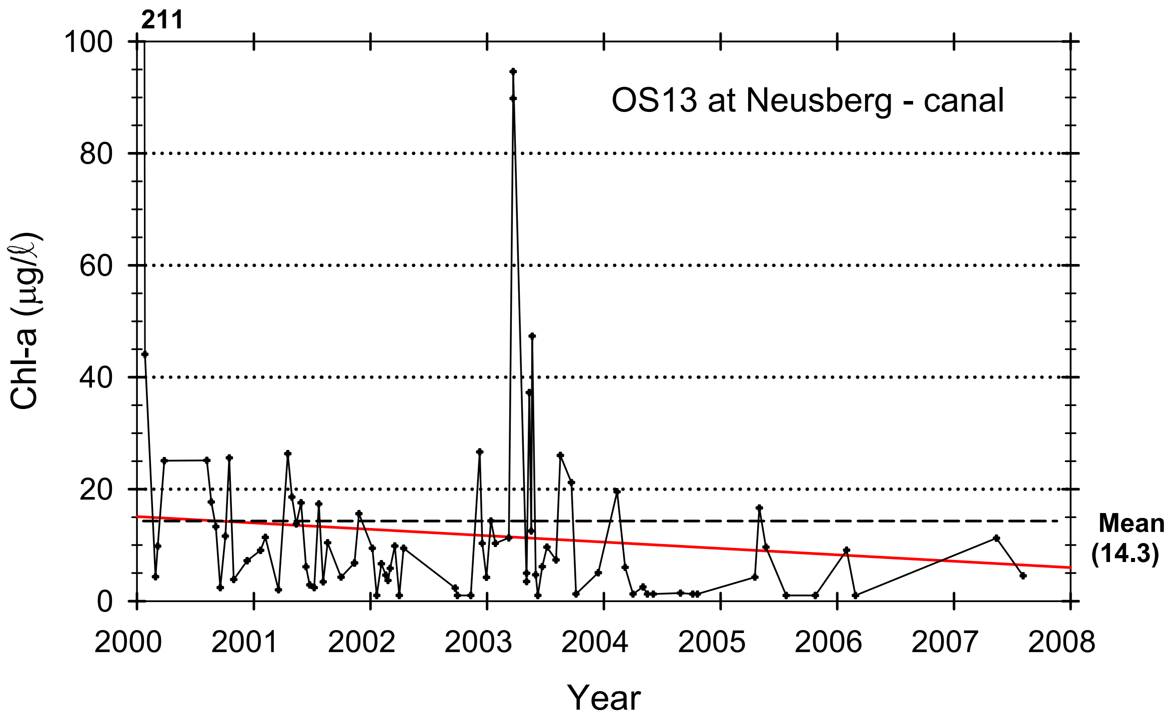


Figure 80: Temporal variation of chlorophyll-*a* concentrations (µg/ℓ) in the Orange River at Neusberg (2000 – 2007).

6.14.5 Other parameters

The EC was relatively high (mean, 35.7 mS/m) and show an increasing trend (**Figure A24**). The pH was high (median, 8.24) but fairly stable (**Figure A24 D**). The TP concentration was low (mean, 0.070 mg/ℓ) and show a decreasing trend (**Figure A24 E**). The sulphate concentration was relatively high (mean, 33.2 mg/ℓ), but stable during the past 12 years (**Figure A24 G**). The alkalinity was also fairly high (mean, 111.2 mg/ℓ), and show an increasing trend (**Figure A24 H**).

6.15 OS14 – Blouputs – new site (S28.51409; E20.18518)

Proposed new site – see **Figure A25**. No historical data – see snapshot results (Chapter 7).

6.16 OS15 – Pella Mission – D8H008 (S28.96443; E19.15276)

Pella, a Catholic mission Church was built in 1878 and the area is also well-known for date plantations at Klein Pella. (**Figure A26**). The Lower Orange, especially below Augrabies falls, is sparsely populated (rural densities about 0.2 people per km^2), with dispersed settlements almost entirely concentrated along the banks of the river (ARTP JMB, 2008).

A number of relatively pristine stretches of shoreline and island vegetation have been observed in the mountainous and less accessible areas; however, these areas are under threat. The exotic tree, *Prosopis* species has invaded large areas of the riparian vegetation, including Pella (ARTP JMB, 2008).

Pella Mission is an important monitoring station about 225 km downstream of Neusberg weir with a very good data set with almost weekly measurements since 1995 (n ≈ 600). Chl-*a* concentrations were measured biweekly.

6.16.1 Stream flow

The mean flow rate at Pella (143 m^3/s) was significant lower (about 38 %) compared to the releases from Neusberg weir (231 m^3/s) and showed a decreasing trend (**Figure 81**). The low stream flow is ascribed to large irrigation extractions, limited inflows from tributaries, and high evaporation losses. The evaporation in the Lower Orange was estimated to range between 575 and 989 Mm^3/a, depending on the flow rates (McKenzie & Craig, 2001).

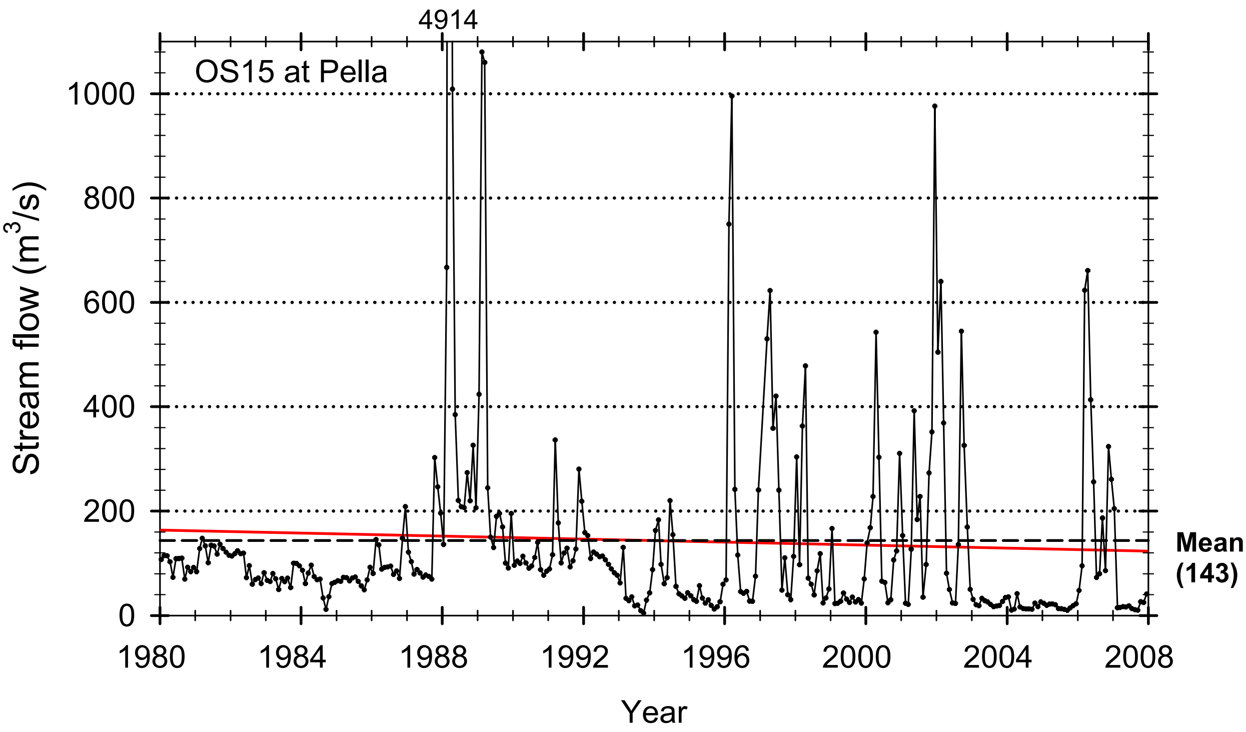


Figure 81: Temporal variation of monthly flow rates (m^3/s) in the Orange River at Pella (1980 – 2007).

The Orange River Pilot Study documents the colonisation by reeds (*Phragmites australis*) of 41 000 ha of riverbed has occurred as a result of stabilised flows on the Orange River (WCD, 2000).

6.16.2 Dissolved major salts (DMS)

Because of the lower flow rates and high evaporation, the salts concentrations in the river were relatively high with the mean concentration at 286 mg/ℓ (min. 147; max. 513.2 mg/ℓ) and the condition is worsening as indicated by the increasing salt trend; solid line (red) in **Figure 82**.

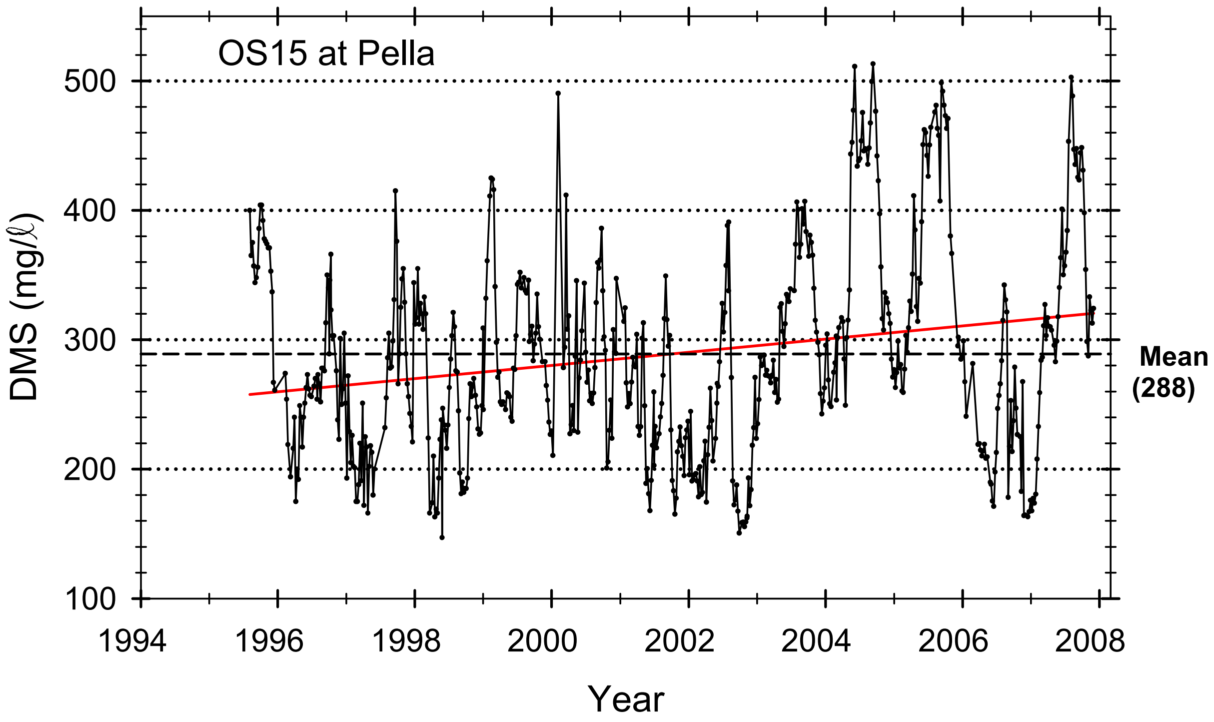


Figure 82: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Pella (1995 – 2007).

6.16.3 Dissolved inorganic nitrogen (DIN)

The DIN concentrations at Pella were significantly lower than the upstream points and ranged between 0.040 and 3.266 mg/ℓ (mean, 0.179 mg/ℓ) (**Figure 83**).

The lower end of the river evidently serves as a major sink of nitrogen because nitrogen is naturally consumed (absorbed and converted), but with only limited transport of 'new' nitrogen into the river (allochtonous sources) because of limited inflows from tributaries.

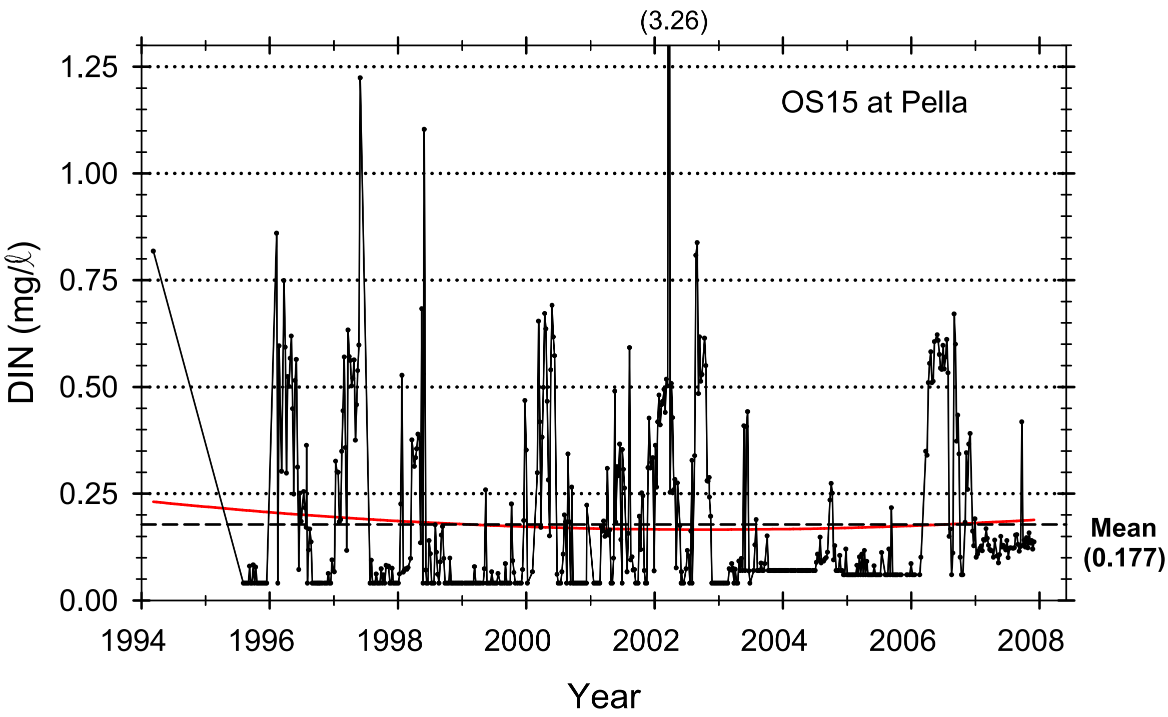


Figure 83: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Orange River at Pella Mission (1994 – 2007).

6.16.4 Phosphate

The mean phosphate concentration was fairly low at 29 µg/ℓ (min. 3; max. 237 µg/ℓ) and showed a slight decrease with time (**Figure 84**).

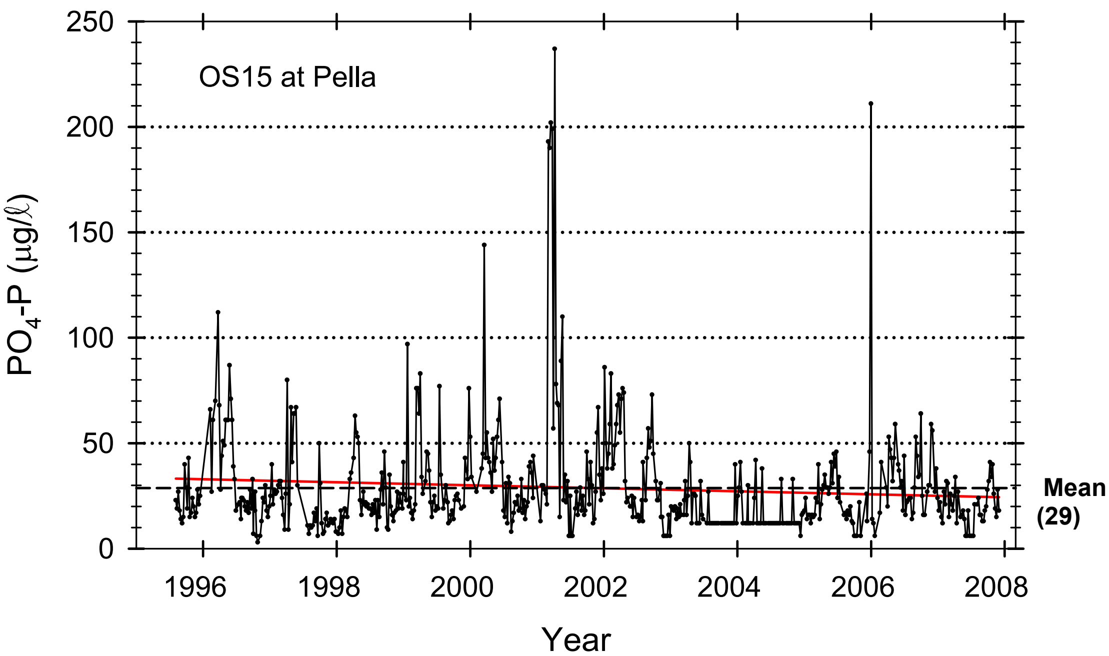


Figure 84: Temporal variation of phosphate (PO_4-P) concentrations (µg/ℓ) in the Orange River at Pella Mission (1995 – 2002).

6.16.5 Chlorophyll-*a*

Filamentous algae are fairly abundant in the side streams of the lower Orange and blue-green algae occur in the lower stretches of the river (ARTP JMB, 2008).

The phytoplankton Chl-*a* concentration at Pella ranged between 1 µg/ℓ and a high (bloom) of 157 µg/ℓ (**Figure 85**). The dominant algal species were mainly diatoms (*Cyclotella*, *Nitzschia*, and *Fragilaria* sp.). Cyanobacteria were recorded occasionally. The mean Chl-*a* concentration of 17 µg/ℓ is almost the same as at Upington and place the lower Orange River in the mesotrophic category.

High Chl-*a* concentrations were usually associated with low flow conditions with peak concentrations usually reached during April or May (**Figure 85**). The exception was during 2006 when high flow rates during March and April prevented and an algal bloom. The algal bloom was shifted and develops only during August 2006 (low flow conditions).

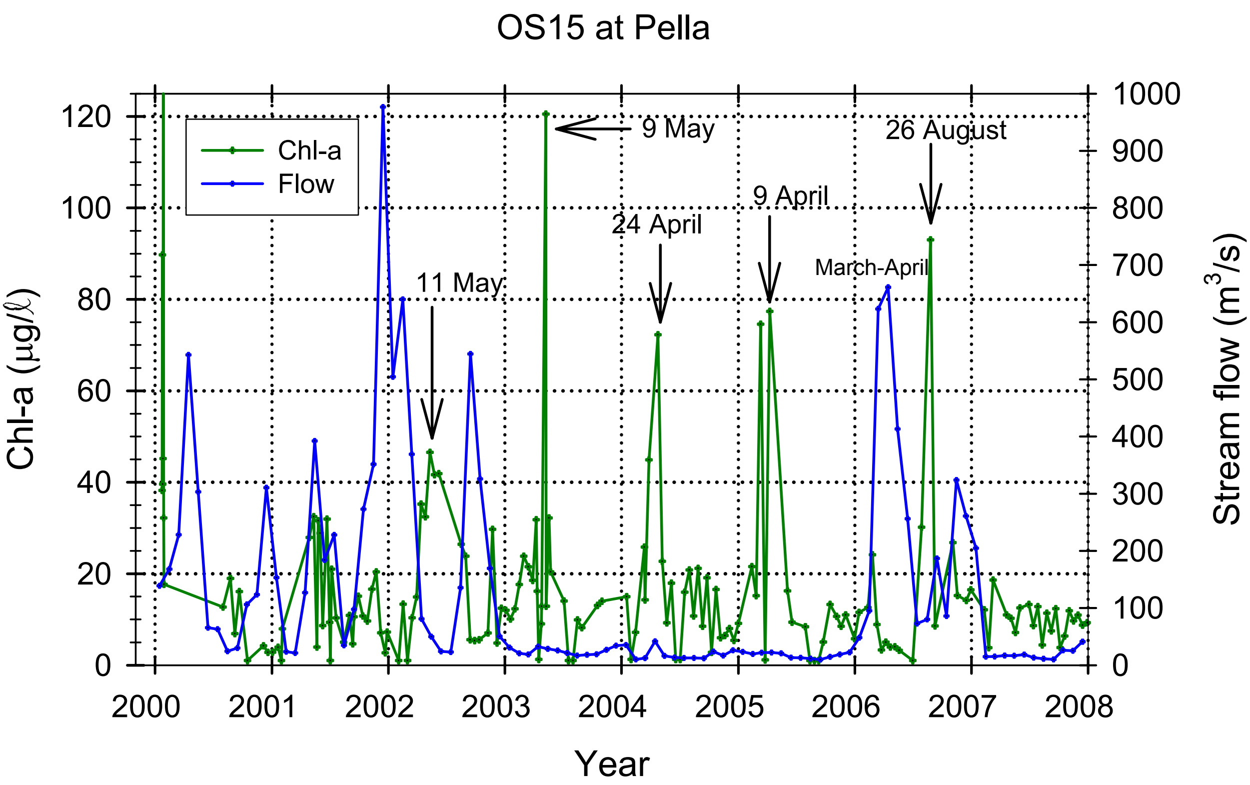


Figure 85: Temporal variation of chlorophyll-*a* concentration (µg/ℓ) and stream flow (m^3/s) in the Orange River at Pella (2000 – 2007). Specific dates of algal blooms are also indicated.

6.16.6 Metals

The database on the metals is poor with irregular measurements about every second month from 2003 (n = 20). The metal concentrations were generally low and comparable with the levels at Upington. However, the mean lead concentration of 98 µg/ℓ in the river water is a matter of concern because concentrations >100 µg/ℓ is unacceptable for domestic use (DWAF, 1996) and the concentrations showed an increasing trend (**Figure 86**). The normal water treatment process for drinking water would probably not change the lead concentration significantly from the river to the tap.

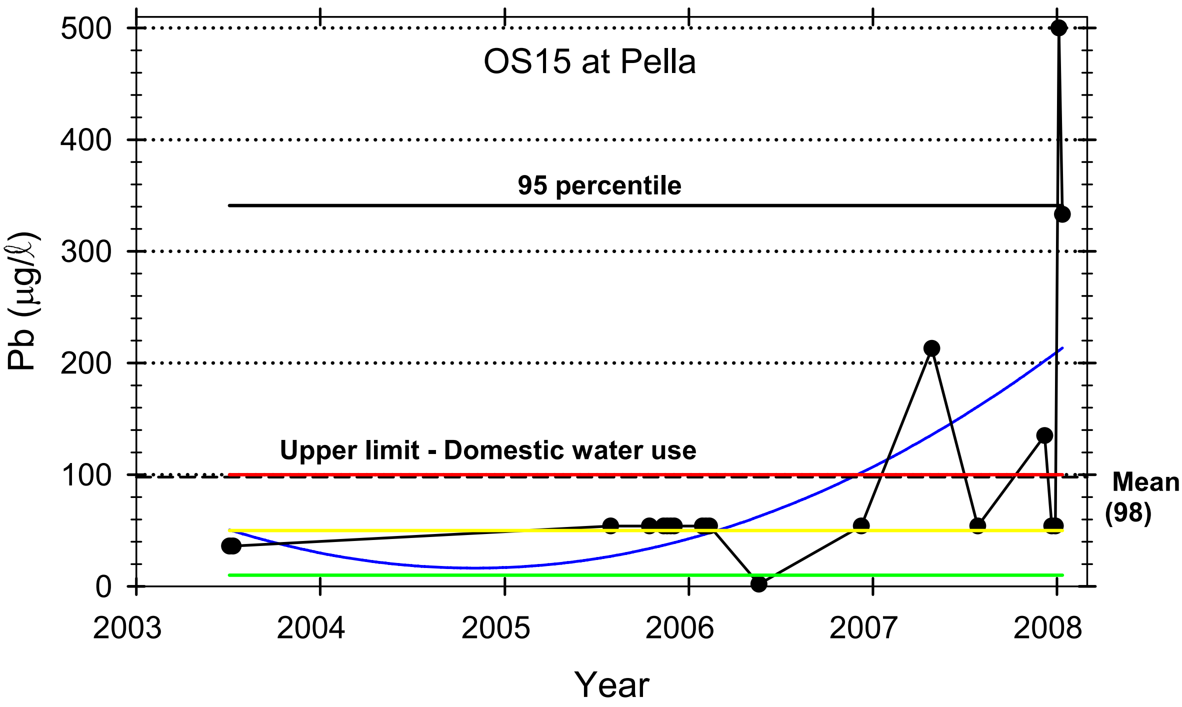


Figure 86: Temporal variation of lead (Pb) concentrations (µg/ℓ) in the Orange River at Pella Mission (2003 – 2007). The green, yellow, and red lines indicate the limits for acceptable, tolerable and unacceptable range for domestic use respectively (DWAF, 1996).

6.16.7 Other parameters

The TSS was low (mean, 48.7 mg/ℓ) and show a decreasing trend (**Figure A27 A**). The low TSS concentrations contribute to favorable light conditions for algal growth.

The TN (mean, 0.728 mg/ℓ) and TP (mean, 0.078 mg/ℓ) concentrations were relatively low and show a slight decreasing trend during the past 7 years (**Figure A27 B & C**).

6.17 OS16 – Vioolsdrift – D8H003 (S28.76208; E17.72631)

Vioolsdrift and Noordoewer are small towns on opposite banks of the Lower Orange River (LOR), some 350 km from the river mouth. Vioolsdrift is in South Africa and Noordoewer is in Namibia. The South African Government constructed a canal system serving the two settlements in 1933. The Joint Irrigation Authority (JIA) was established to manage this scheme (Turton, 2008). The canal fed from a weir (the monitoring site) upstream of the river crossing (**Figure A28**). The canal infrastructure has supported agriculture on the southern and northern banks of the LOR for some 70 years (DWAF, 2004).

Vioolsdrift is an important monitoring site because it is included in the SA-GEMS/Water monitoring network and is also used as a GEMS/Water site that is used in the Global River Flux monitoring network and Global Water Quality Trends (Van Niekerk, 2005). The hydrometric station at Vioolsdrift receives runoff from 87 % (850 530 km^2) of the Orange River Catchment. The remaining 13 % drains a dry area between Vioolsdrift and the Orange River mouth. Vioolsdrift gauging station is the closest SADC Hydrological Cycle Observing System (SADC-HYCOS) station to the ocean.

6.17.1 Stream flow (releases)

Flow regulation by dams and diversions is a key component of virtually all large river development programs. Alteration of flood timing, magnitude, frequency, and duration disturb both terrestrial and aquatic communities.

The mean monthly stream flow at Vioolsdrift before the major dams were built (1940 – 1970) was 346 m^3/s and only 201 m^3/s after the dams were built (1971 – 2007), *i.e*. a 42 % reduction in stream flow (**Figure 87**). However, a second order fit to the mean annual stream flow data at Vioolsdrift indicates a reduction of 63 % during the past 67 years (**Figure A29 A**).

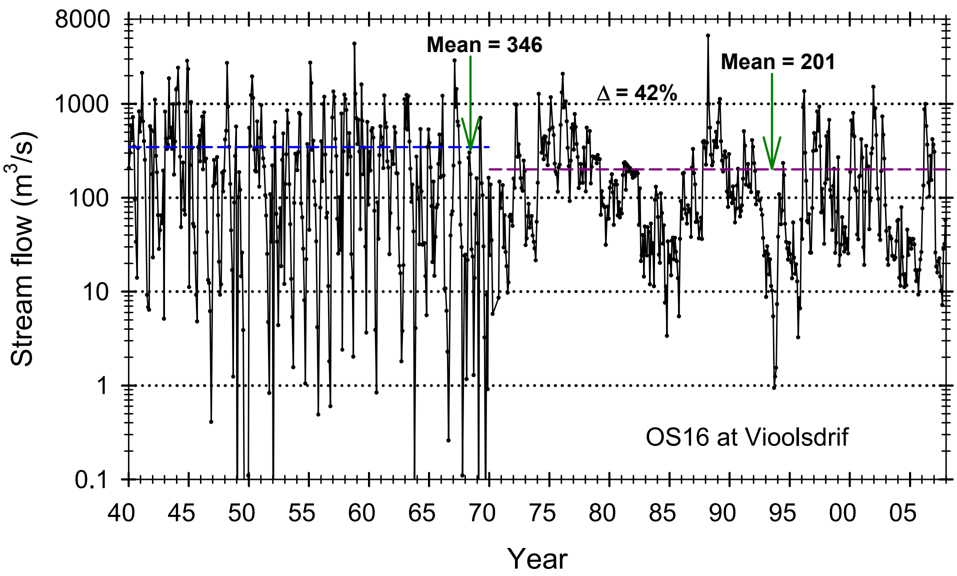


Figure 87: Temporal variation of stream flow (monthly averages) in the Orange River at Vioolsdrift (1940 – 2007). Note the log scale on the y-axis.

Figure 88 shows the natural seasonal variation of stream flow before the big dams were built (1940 – 1969; **Figure 88 A**) and the unnatural homogenised flow after the dams were built (1970 – 2007; **Figure 88 B**) in the Orange River at Vioolsdrift. The frequency, duration and magnitude of all but the largest floods have been reduced. (**Figures 87 & 88**).

A) **B)**

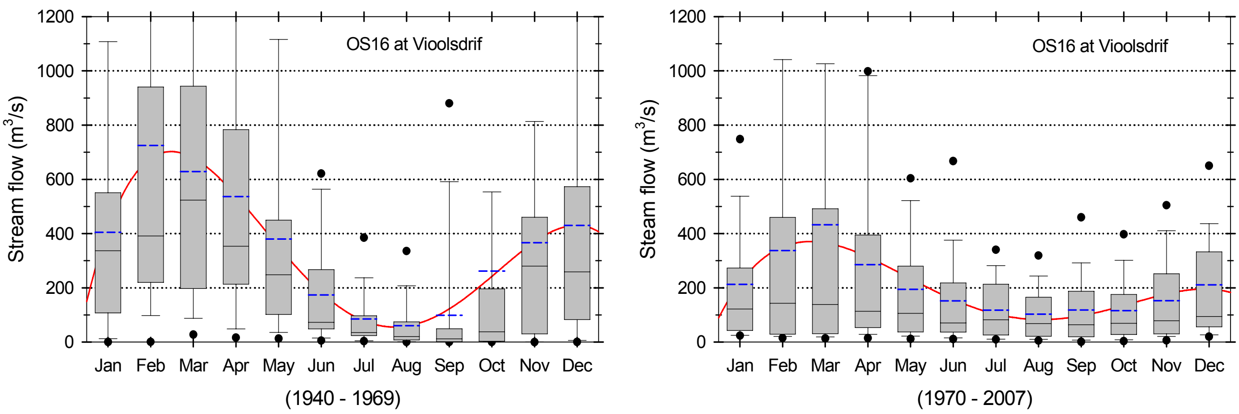


Figure 88: Box and whiskers plot of seasonal variation of stream flow (m^3/s). A) before dam building (1940 – 1969) and B) after dam building (1970 – 2007) in the Orange River at Vioolsdrift.

6.17.2 Dissolved major salts (DMS)

The salt concentration at Vioolsdrift increased significantly during the past 30 years, *i.e.* from about 200 mg/ℓ in 1977 to 310 mg/ℓ currently, *i.e.* about 55 % increase (**Figure 89**). The salt concentrations during the study period ranged between 132 and 597 mg/ℓ (mean, 279 mg/ℓ).

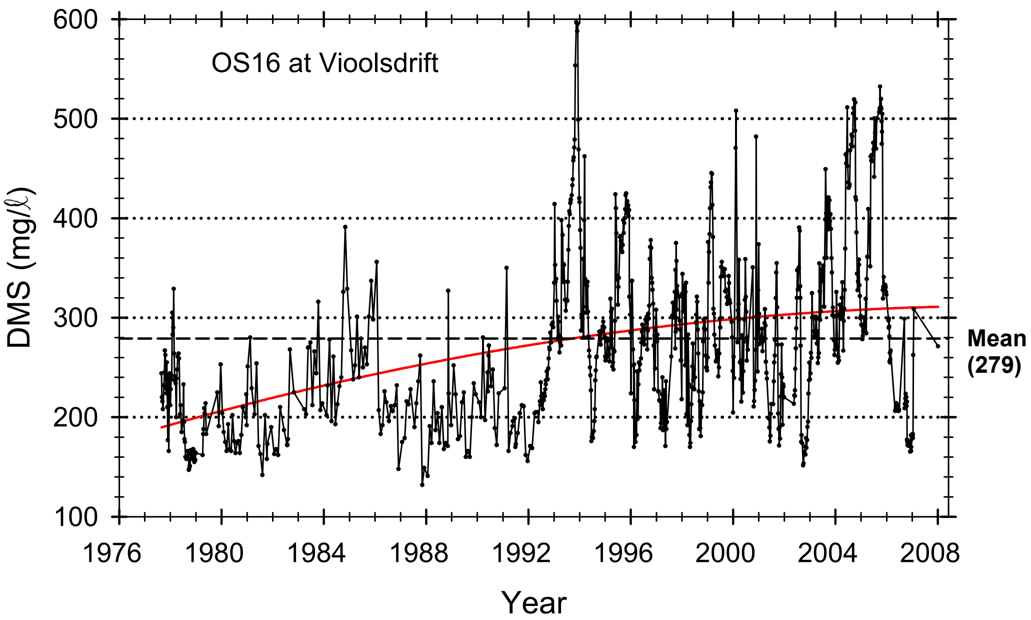


Figure 89: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Vioolsdrift (1977 – 2007).

6.17.3 Nutrients

The mean DIN concentration at Vioolsdrift of 0.161 mg/ℓ was the lowest in the Orange River, but a few spikes occurred that was apparently associated with low flow conditions (min. 0.040; max. 3.130 mg/ℓ). The DIN concentration also showed a slight decreasing trend (**Figure 93**).

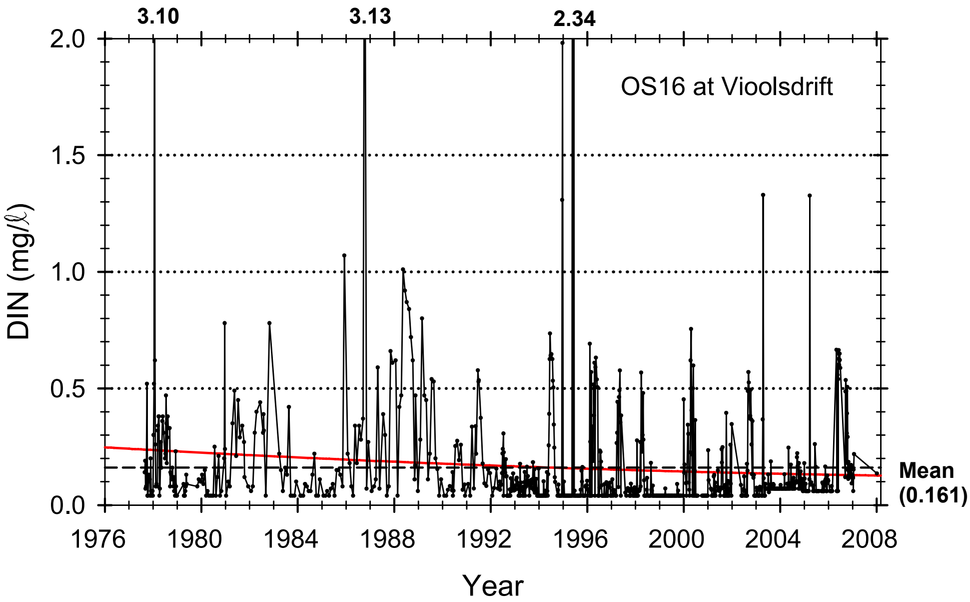


Figure 90: Temporal variation of dissolved inorganic nitrogen (DIN) concentration (mg/ℓ) in the Orange River at Vioolsdrift (2000 – 2007).

The phosphate concentrations at Vioolsdrift were also the lowest in the system with a mean of only 25 µg/ℓ (min. 3; max. 215 µg/ℓ) (**Figure 91**).

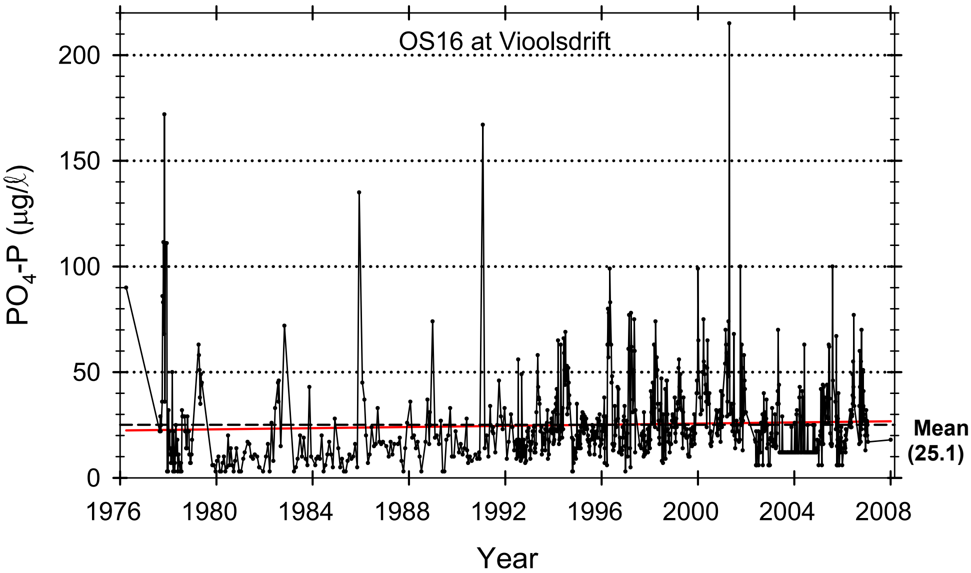


Figure 91: Temporal variation of phosphate concentration (PO_4-P, µg/ℓ) in the Orange River at Vioolsdrift (1976 – 2007).

6.17.4 Other parameters

The mean chlorophyll-*a* concentration was 63 μg/ℓ, but the limited number of measurements (n = 4) makes the data almost useless (**Figure A29 B**). However, Chlorophyll-*a* concentrations are available for Henkries (Namaqua Water Board abstraction point), which is about 40 km upstream of Vioolsdrift that can serve as a substitute. The mean chl-*a* concentration of 10.6 μg/ℓ is in the range of oligo-mesotrophic systems and annual blooms usually occur (**Figure 95**).

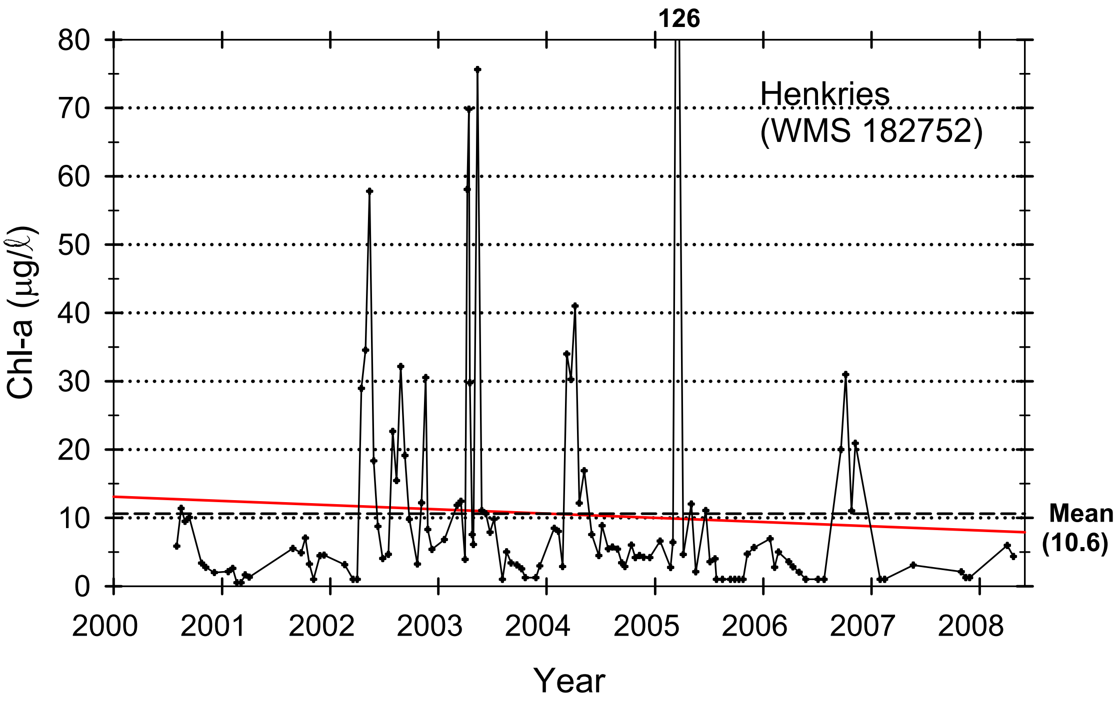


Figure 92: Temporal variation of Chlorophyll-*a* concentrations (μg/ℓ) in the Orange River at Henkries (2000 – 2007).

The pH at Vioolsdrift since 1991 was very high (median, 8.33), but show a slight decreasing trend since 2002 (**Figure A29 C** in Appendix A.

The mean TN (0.737 mg/ℓ) and TP (0.078 μg/ℓ) concentrations were low (**Figure A29**). The silica concentrations were low (mean, 6.25 mg/ℓ) with a huge variation (min. 0.2; max. 13.14 mg/ℓ) and are decreasing (**Figure A30 A**).

The ammonium concentrations were low (mean, 0.046 mg/ℓ) and stay fairly constant with an occasional spike in the concentration (**Figure A30 B**). SAR values were relatively high (mean, 1.01) and regularly above the TWQR of 1.5 and is increasing (**Figure A30 C**).

The alkalinity was high (mean, 120 mg/ℓ) but the concentration seems to lower off during the past 10 years (**Figure A30 D**). The fluoride concentrations were relatively high at 0.31 mg/ℓ (**Figure A30 E**).

6.18 OS17 – Sendelingsdrift – new site (S28.12288; E16.89032)

Proposed new site about 168 km downstream of Vioolsdrift – see **Figure A31**.

No historical data available – see snapshot surveys.

6.19 OS18 – Brand Kaross – D8H007 (S28.48570; E16.69444)

The chemical database at Brand Kaross is poor with only significant data between 1980 and 1988 and the monitoring was ended in 2002, which make the data of limited value – see **Figure A32,** Appendix A.

6.19.1 Electrical conductivity (EC)

The EC was relatively high (mean, 34.56 mS/m) (**Figure 96**), associated with high salt concentrations (min, 126; max. 616 mg/ℓ, mean, 242 mg/ℓ). The EC during snapshot 1 was significantly higher at 44 mS/m, with a TDS of 386 mg/ℓ.

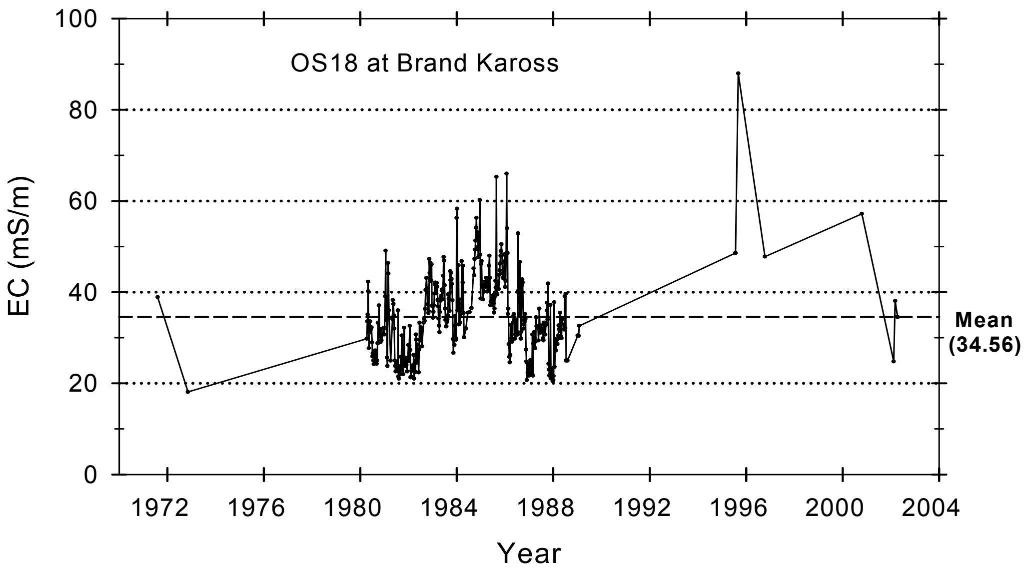


Figure 93: Temporal variation of electrical conductivity (EC, mS/m) in the Orange River at Brand Kaross (1972 – 2002).

6.19.2 Phosphate (PO_4-P)

The mean phosphate concentration was only 0.017 mg/ℓ, but the data show a significant increasing trend (**Figure 97**). However, it is difficult to conclude anything from these limited data. The phosphate concentration during the snapshot survey was 0.033 mg/ℓ.

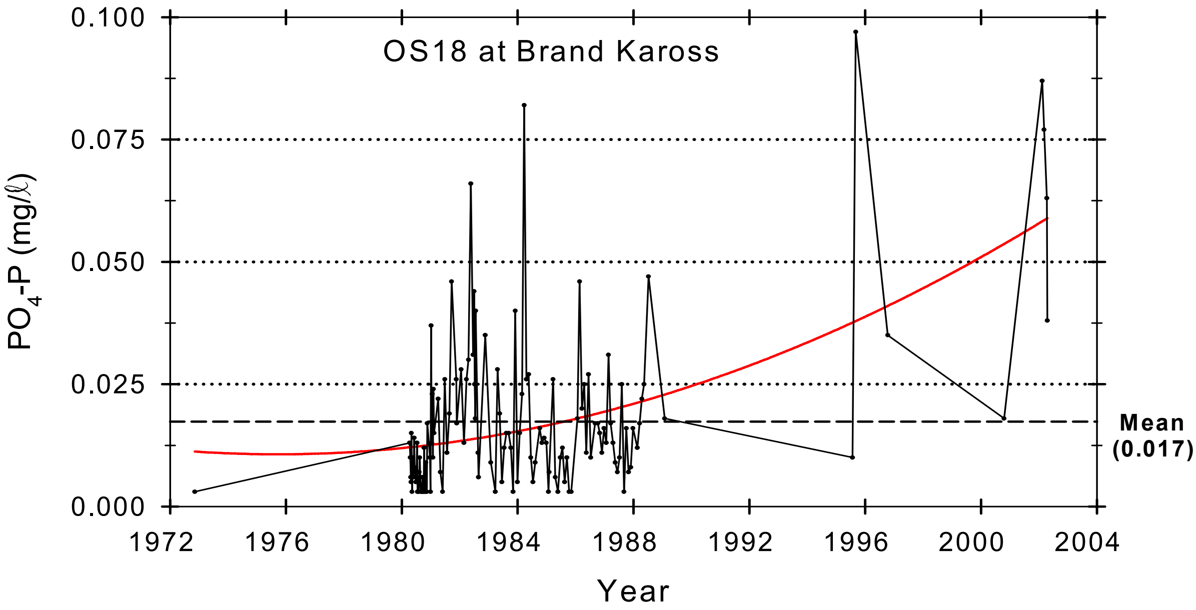


Figure 94: Temporal variation of phosphate concentration (PO_4-P, mg/ℓ) in the Orange River at Brand Kaross (1972 – 2003).

6.19.3 Other parameters

The mean nitrate concentration of 0.17 mg/ℓ was higher than at Vioolsdrift, but the limited data make comparison with other sites difficult and unreliable (**Figure A33** in Appendix A).

The mean silica concentration of 7.62 mg/ℓ was also higher than at Vioolsdrift and also show a decreasing trend.

The mean sulphate concentration was relatively low at 24.5 mg/ℓ, but this is based on concentrations measured 20 years ago (**Figure A33 C**). The concentration during the snapshot survey was 64 mg/ℓ.

6.20 OS19 – Alexander Bay – D8H012 (S28.56689; E16.50728)

The monitoring site is at the bridge (Sir Ernest Oppenheimer, border between South Africa and Namibia) approximately 10 km upstream of the river mouth (**Figure A34** in Appendix A). The data capturing was very good (weekly to biweekly) from 1995 until 2002 when the data collection was unfortunately terminated. Water quality data at this point are crucial for the management of the river mouth which is a Ramsar wetland area.

6.20.1 Dissolved major salts (DMS)

The mean salt concentration was high at 342 mg/ℓ (min. 163, max. 626 mg/ℓ), but shows a decreasing trend, however, the data already ended in 2002 (**Figure 98**).

The average DMS concentration recorded during snapshot 1 and 2 was much higher at 456 mg/ℓ.

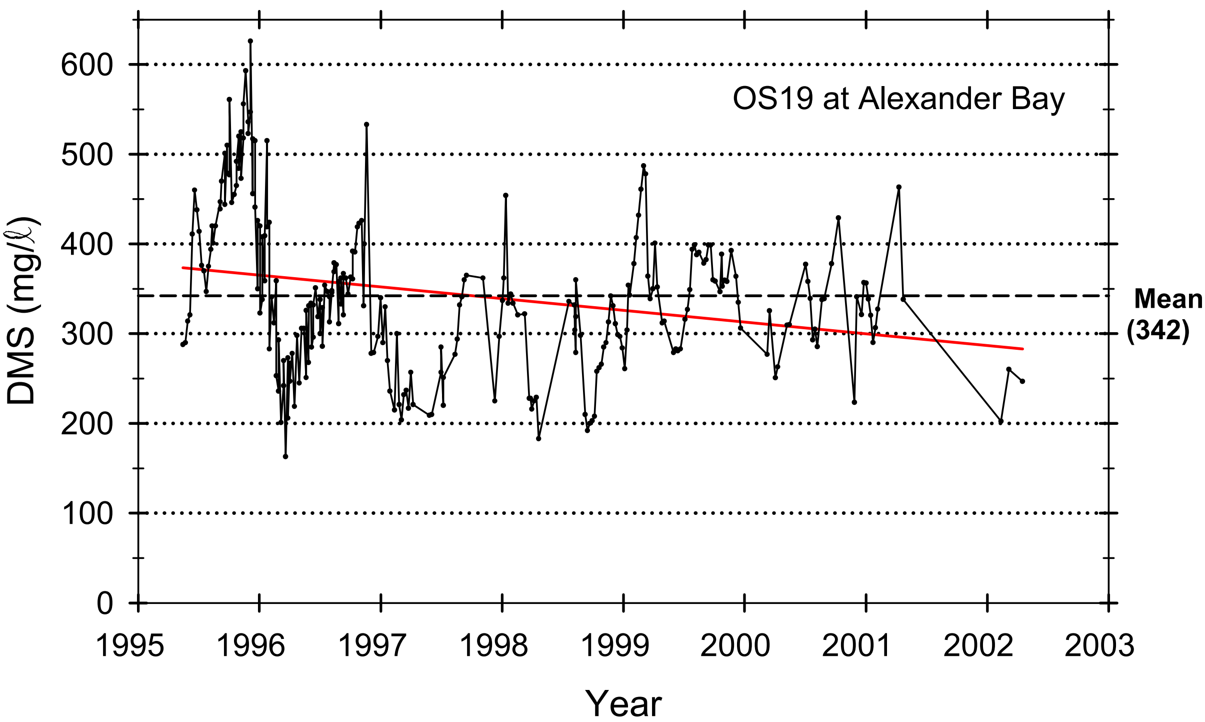


Figure 95: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Orange River at Alexander Bay (1995 – 2002).

6.20.2 Other parameters

The Chl-*a* and TSS data are not useful at all (**Figure A35 A & B** – Appendix A).

The mean silica concentration was very low at only 4.85 mg/ℓ and is decreasing (**Figure A35 C**). The average Si concentration during snapshot 1 and 2 was also very low at 2.7 mg/ℓ.

The sulphate concentrations were very high with a mean of 48.8 mg/ℓ (**Figure A35 D**).

The mean SAR was high at 1.31, but still acceptable for irrigation (**Figure A35 E**).

The mean alkalinity was high at 135 mg/ℓ, but showed a decreasing trend (**Figure A35 F**). However, the TAL during the snapshot was fairly high at 151 mg/ℓ.

The TN concentration (mean, 0.872 mg/ℓ) was relatively low compared to the TP concentration (mean, 0.162 mg/ℓ), which results in low TN:TP ratio (~5) that indicates possible N limitation for algal growth (**Figure A35 G & H**). The DIN:DIP during the snapshot surveys was also low at 7.0.

C) MONITORING SITES ON THE TRIBUTARIES OF THE ORANGE RIVER: LEVEL 2 (Historical Data)

6.21 OSL2/1 – Kornetspruit at Maghaleen, D1H006 (S30.16003; E27.40145)

Kornetspruit, known as the Makhaleng River in Lesotho, is near the town of Zastron and is for a short stretch the International border between South Africa and Lesotho. The catchment area of the Kornetspruit is mainly in Lesotho.

The Makhaleng River is a river of western Lesotho. The river flows southwest from the Maluti Mountains past the towns and villages of Molimo-Nthuse, Makhaleng, Ramabanta and Qaba before entering South Africa and joining the Orange River (Wikipedia, Website).

The monitoring station is close to the border post (Makhaleen Bridge) between South Africa and Lesotho (**Figure A36**). The historical data base is good with biweekly measurements beginning in 1975 and is still active (n ≈ 612).

6.21.1 Stream flow

The stream flow measurements at Kornetspruit are very good and started already in 1950. The monthly mean stream flow at Kornetspruit displays a natural variation with no significant change over time. The mean stream flow was 18.5 m^3/s (min. 0.06; max. 152.0 m^3/s), thus a mean annual stream flow of approximately 583 Mm^3 (**Figure 96**). The constant flow in the spruit is probably the reason for the old watermill that is at this site, however, is not operational any more (**Figure A36 B**).

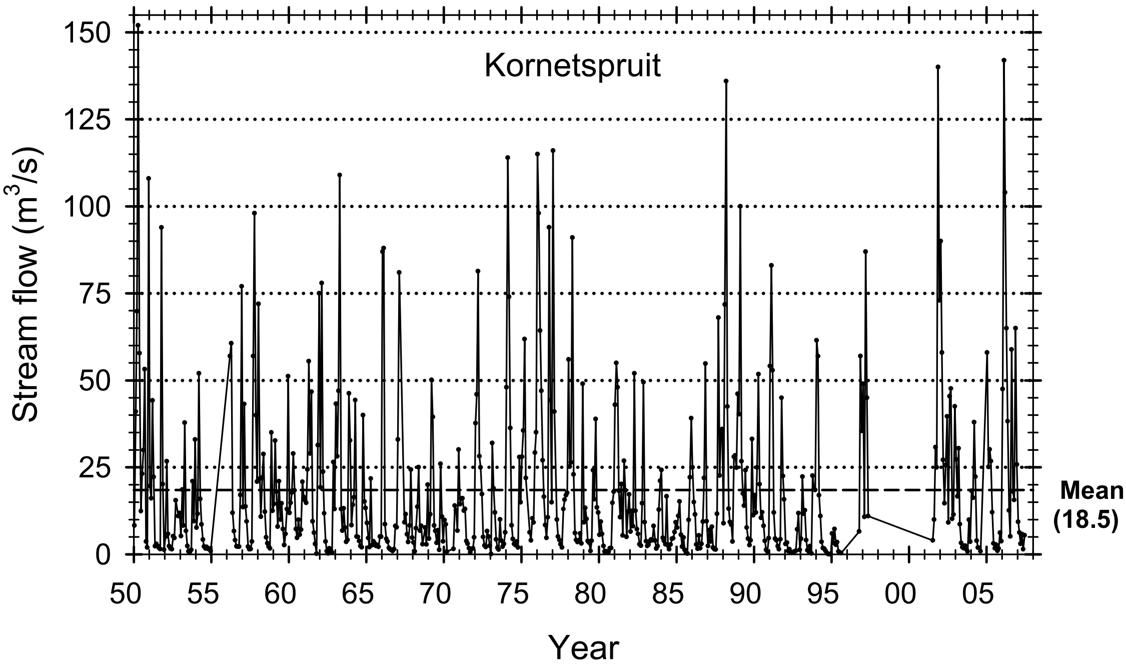


Figure 96: Temporal variation of stream flow (m^3/s) in Kornetspruit at Makhaleen (1950 – 2007).

6.21.2 Dissolved major salts (DMS)

The mean salts concentration was relatively high at 155 mg/ℓ (min. 60; max. 625 mg/ℓ) compared to the mean of 133 mg/ℓ in the Orange River at Oranjedraai - close to this site. However, we assume that the concentration is fairly natural with only a slight increase over time (**Figure 97**). The reason for the very high salt concentrations recorded during 1992 and 1993 (mean, 185 mg/ℓ) is unclear.

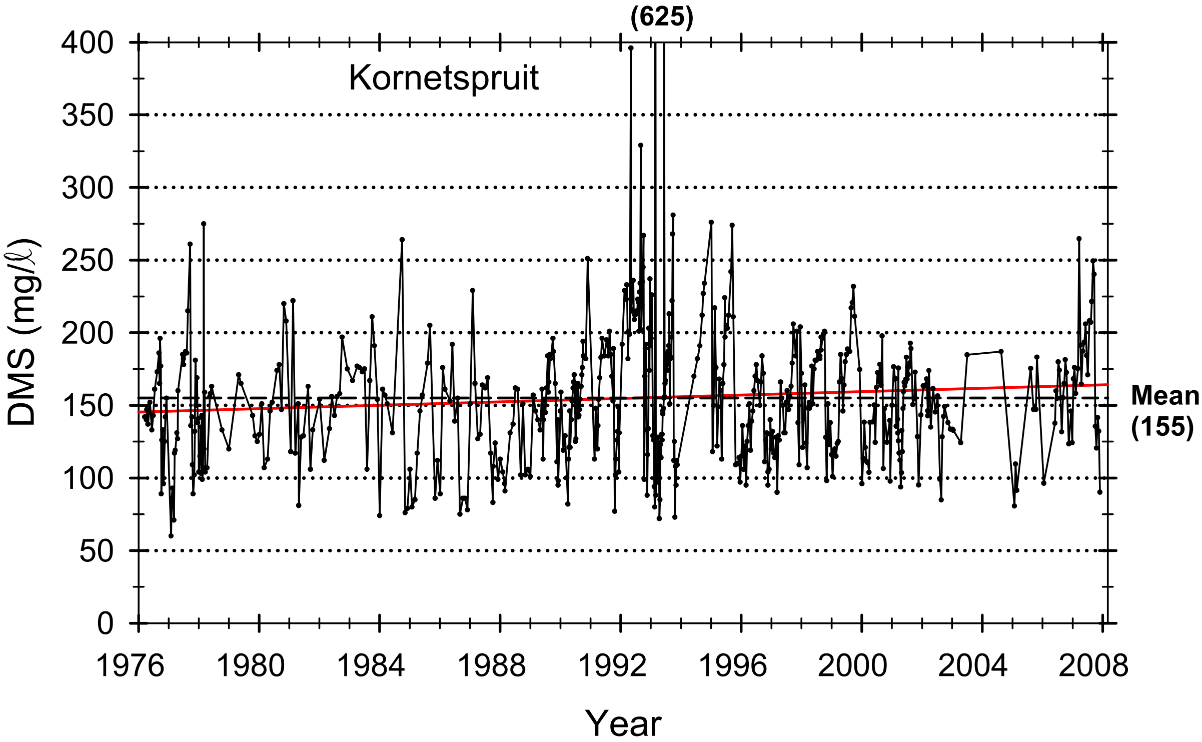


Figure 97: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in Kornetspruit at Makhaleen (1976 – 2007).

6.21.3 Nutrients (N&P)

The phosphate concentrations were somewhat high and range between 3 and 5 493 μg/ℓ (mean, 58 μg/ℓ) and display a slight increase with time (**Figure 98**). However, the median concentration was only 26 μg/ℓ. The reason for the unusual high concentration in 1993 and 2001 is unclear. The Kornetspruit water generally carries a large amount of suspended solids and phosphates are usually associated with suspended material, which could partially explain the high P concentrations.

The dissolved inorganic nitrogen (DIN) concentration in Kornetspruit was also high with a mean of 0.428 mg/ℓ (min. 0.015; max. 10.346 mg/ℓ), but show no significant change with time (**Figure 99**).

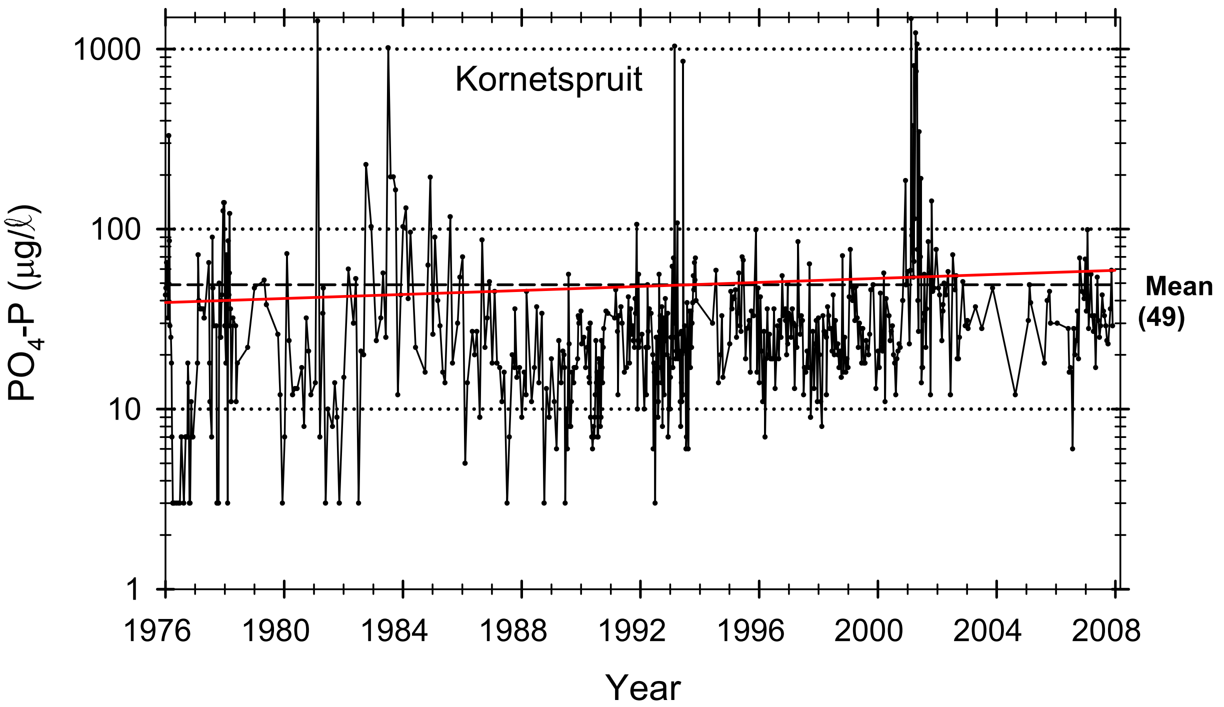


Figure 98: Temporal variation of phosphate phosphorus (PO_4-P) concentrations (µg/ℓ) in Kornetspruit at Makhaleen (1976 – 2007). Note the log scale on y-axis.

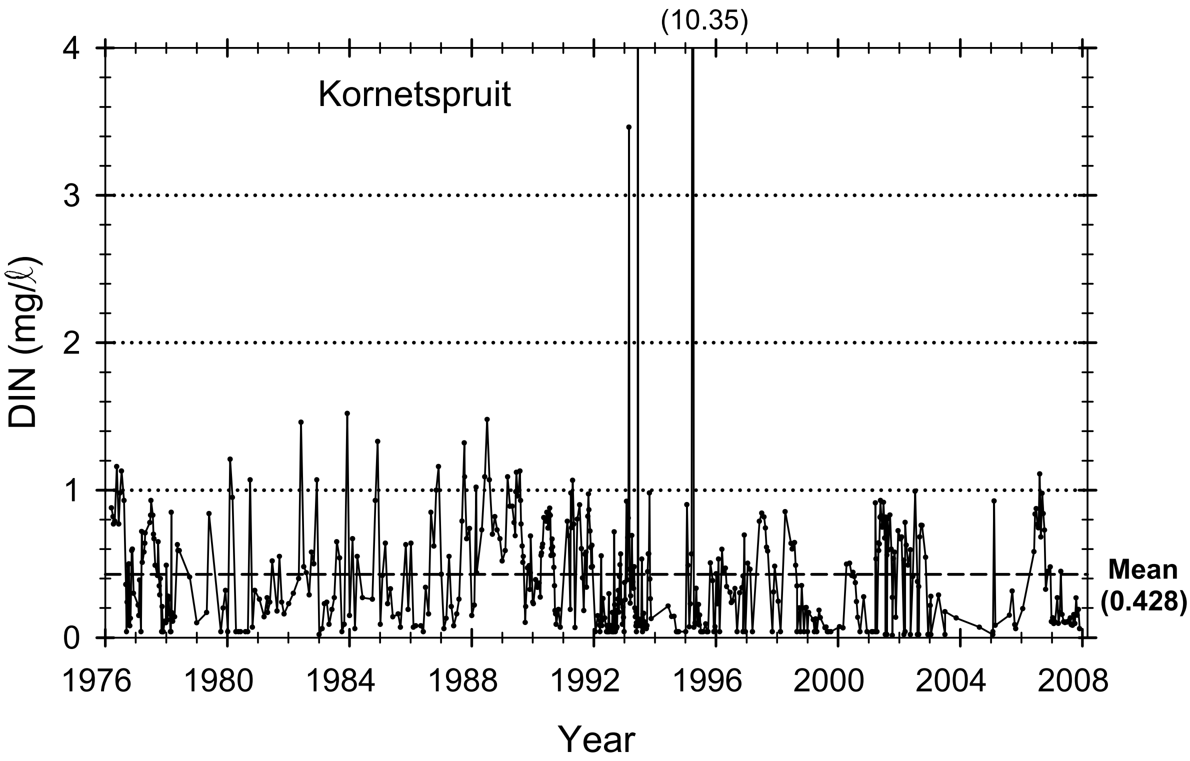


Figure 99: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in Kornetspruit at Makhaleen (1976 – 2007).

6.21.4 Other parameters

The EC values in Kornetspruit were relatively low with a mean of 19.8 mS/m (**Figure A37 A** – Appendix A).

The salt concentrations were generally low, e.g. Ca mean, 21 mg/ℓ and sulphate mean, 10.0 mg/ℓ (**Figure A37 B & C**).

The turbidity in Kornetspruit was generally high (mean 170 NTU) and shows a large variation with time (**Figure A37 D**).

Silica concentrations were high (mean, 9.32 mg/ℓ) and stable over time (**Figure A37 E**).

The water hardness was low (mean, 83.6 mg/ℓ) and fell in the range of moderately soft systems (**Figure A37 F**).

The SAR was low (mean, 0.304) and stable over time (**Figure A37 G**).

The alkalinity in Kornetspruit was moderate low (mean, 82.7 mg/ℓ) and showed no change with time (**Figure A37 H**).

6.22 OSL2/2 – Sterkspruit – new site (S30.52694; E27.37484)

Proposed new site; no historical data available – see **Figure A38** in Appendix A and snapshot surveys data.

6.23 OSL2/3 – Kraai River at Roodewal (D1H011) (S30.68612; E26.70600)

The Kraai River drains the Drakensberg D13 catchment (Barkly East area, Eastern Cape) towards the Orange River. It is a relatively clear and unimpacted river (**Figure A39**, Appendix A). The river is an important tributary to the Orange River. A reasonable historical data set with monthly recordings that were started in 1976 until today (n ≈ 505) – see **Tables C13 – C16** Appendix C.

6.23.1 Stream flow

The mean monthly stream flow of 20.7 m^3/s was fairly constant since 1965 (no significant change over time), which implies limited impact by water abstractions or influences by dams or weirs upstream (**Figure 100**). The monthly stream flow ranged between 0.0 and 215 m^3/s (median, 7.97 m^3/s) with a mean annual stream flow of 652 Mm^3.

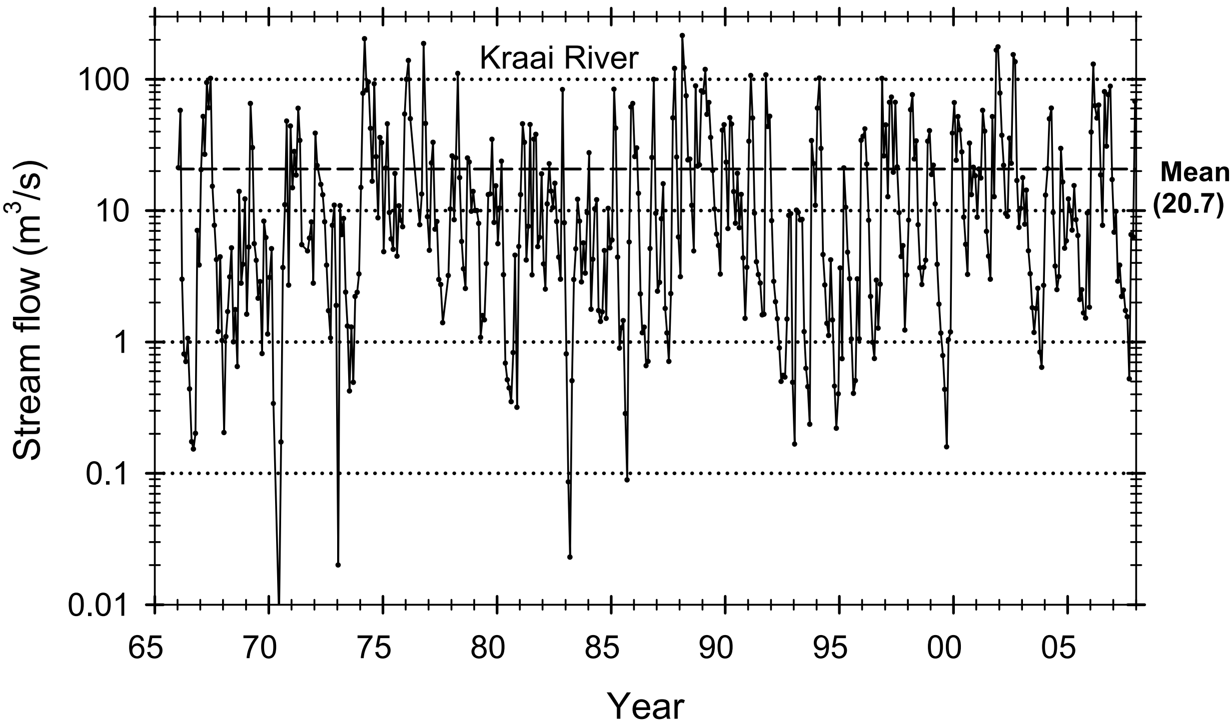


Figure 100: Temporal variation of monthly stream flow (m^3/s) in Kraai River at Roodewal (1965 – 2007).

6.23.2 Dissolved major salts (DMS)

The concentration of dissolved salts were relatively high and ranged between 80 mg/ℓ and 654 mg/ℓ (mean 185.3 mg/ℓ) but is considered to be natural because it shows no significant change (increase) during the past 32 years (**Figure 101**).

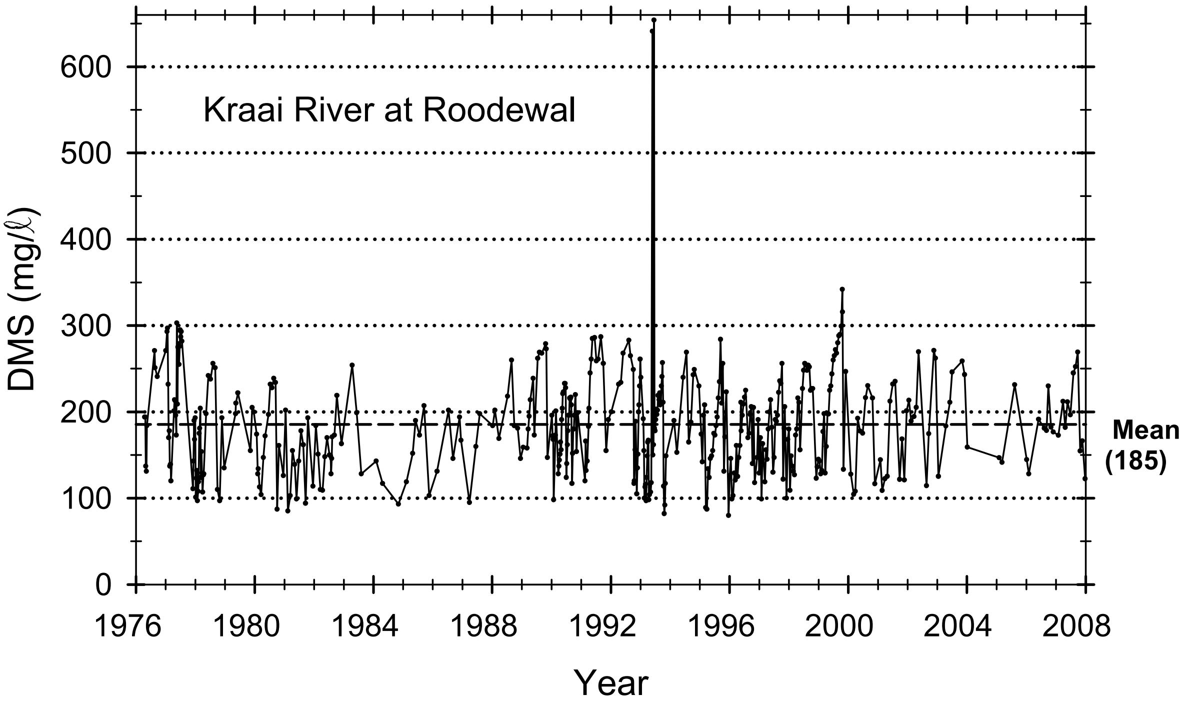


Figure 101: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in Kraai River at Roodewal (1976 – 2007).

6.23.3 Nutrients (N&P)

The mean phosphate concentration was relatively high at 39 μg/ℓ (min. 3; max. 2 097 μg/ℓ), but fairly constant with time and comparable to the other rivers in the same area (**Figure 102**).

The mean DIN concentration was low (0.136 mg/ℓ) and shows no significant change over time which suggests limited pollution (**Figure 103**). The low DIN concentrations result in low DIN:DIP ratios (mean 3.5), which indicate that the river is nitrogen limited.

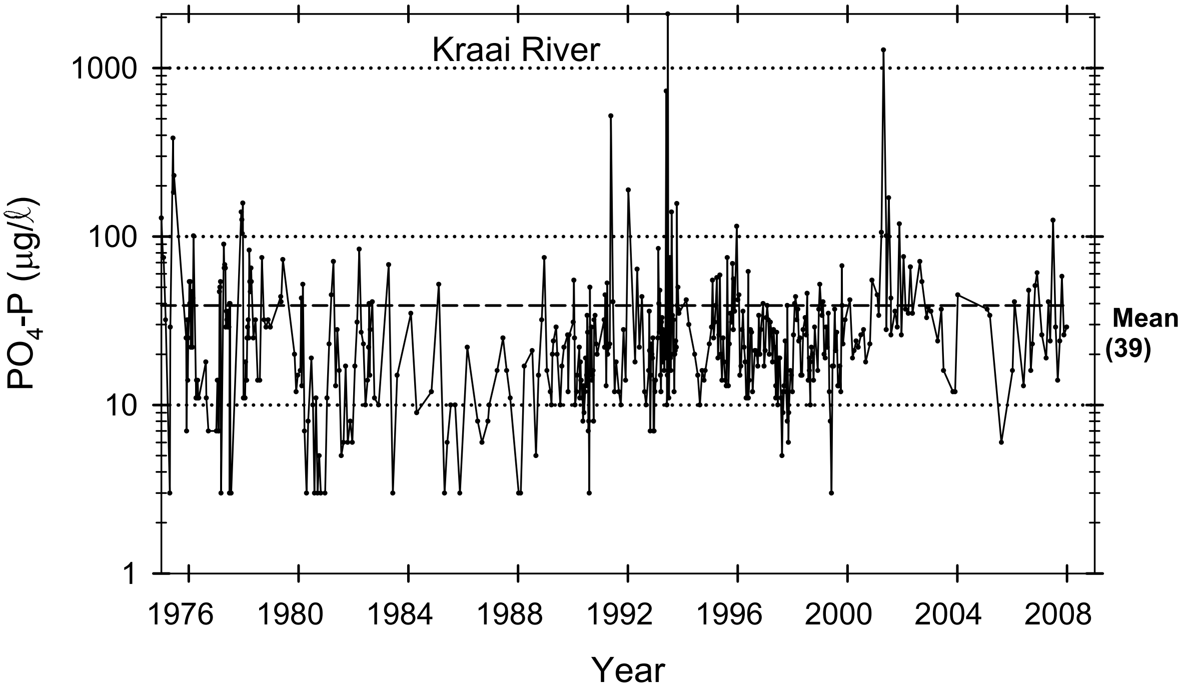


Figure 102: Temporal variation of phosphate (PO_4-P) concentrations (µg/ℓ) in Kraai River at Roodewal (1976 – 2007). Note the log scale on y-axis.

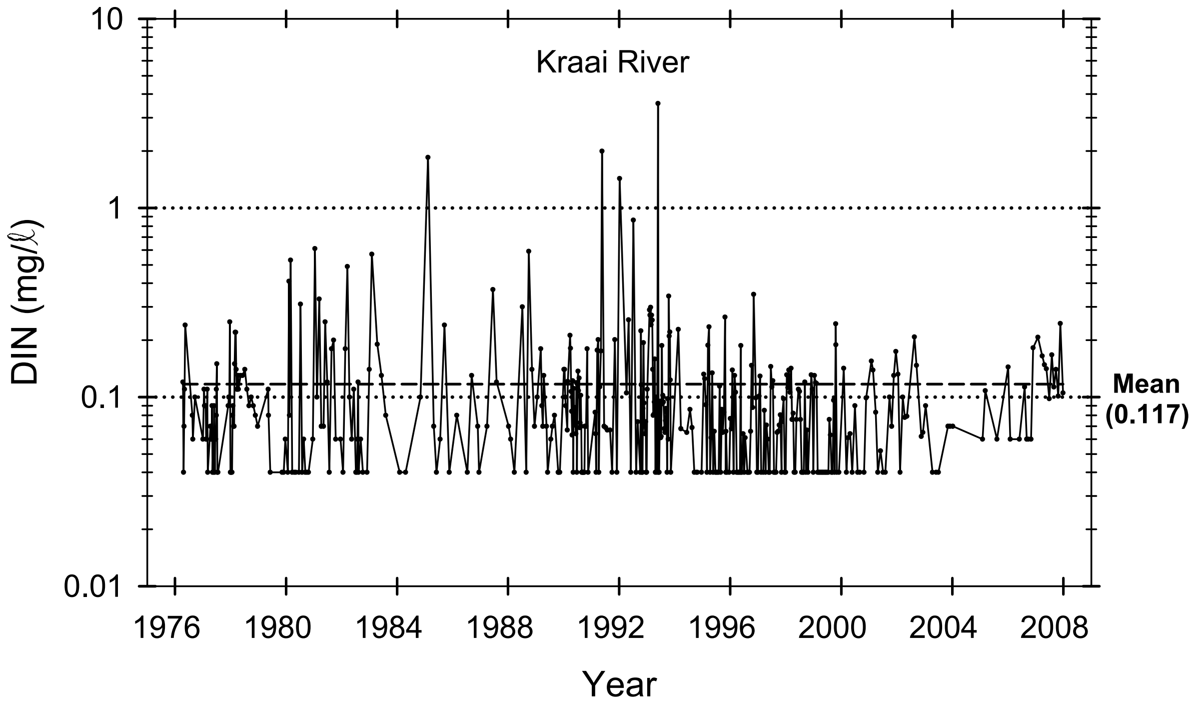


Figure 103: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in Kraai River at Roodewal (1976 – 2007).

6.23.4 Turbidity

The Kraai River is known as a clear water river with low suspended solids. The low mean turbidity of 47.6 NTU and very low median value of 7.0 NTU confirm this perception (**Figure 104**). The turbidity shows a significant decrease over time – the reason for this is not clear because the stream flow, that usually influences the turbidity, was fairly constant (**Figure 100**). However, the frequency of measurement was low (monthly or bimonthly), especially from 2000, which could underestimate the actual turbidity values. The turbidity in a river can change rapidly and weekly measurements are necessary to get a realistic picture of the suspended solids and turbidity.

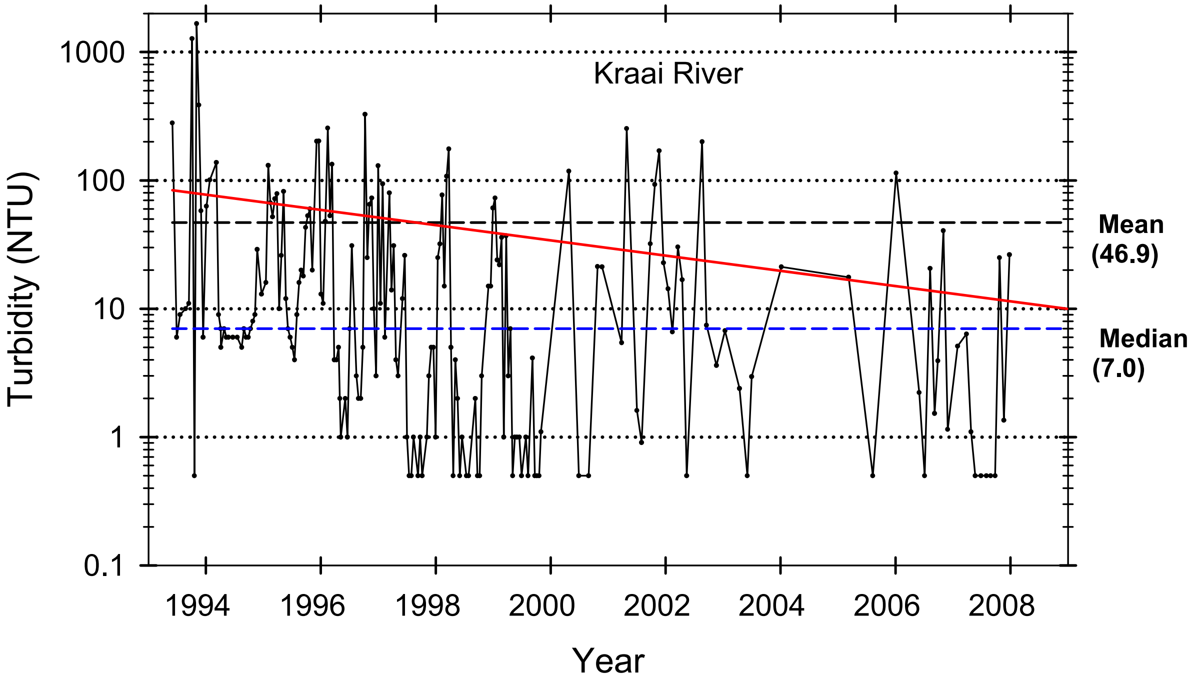


Figure 104: Temporal variation of turbidity values (NTU) in the Kraai River at Roodewal (1993 – 2007). Note the log scale on y-axis.

6.23.5 Other parameters

The majority EC values ranged between 10 and 40 mS/m with a mean of 23.25 mS/m. The pH was very high (median, 8.50) with a maximum of 9.16 (**Figure A40 B** – Appendix A).

The sulphate concentrations were low (mean, 8.8 mg/ℓ), but show a slight increasing trend. Silica concentrations were high (min. 0.64, max. 14.79, mean, 9.11 mg/ℓ) and stable over time (**Figure A40 E**).

The alkalinity was moderate (mean, 103 mg/ℓ) and the SAR was very low at 0.30 and showed no change with time (**Figure A40 G & H**).

6.24 OSL2/4 – Stormbergspruit at Burgersdorp (S31.00109; E26.35314)

The Stormbergspruit (also known as Wonderboomspruit) is a relative small spruit close to the town of Burgersdorp (**Figure A41**). A reasonably good historical data set exits from 1976 – 2007 (n ≈ 729); see **Tables C13 – C16** Appendix C.

6.24.1 Stream flow

The monthly average stream flow (since 1913) in the Stormbergspruit was relatively low at only 1.22 m^3/s (min. 0.00; max. 55.8 m^3/s) and showed no significant change with time (**Figure 105**). The mean annual stream flow was approximately 38 Mm^3.

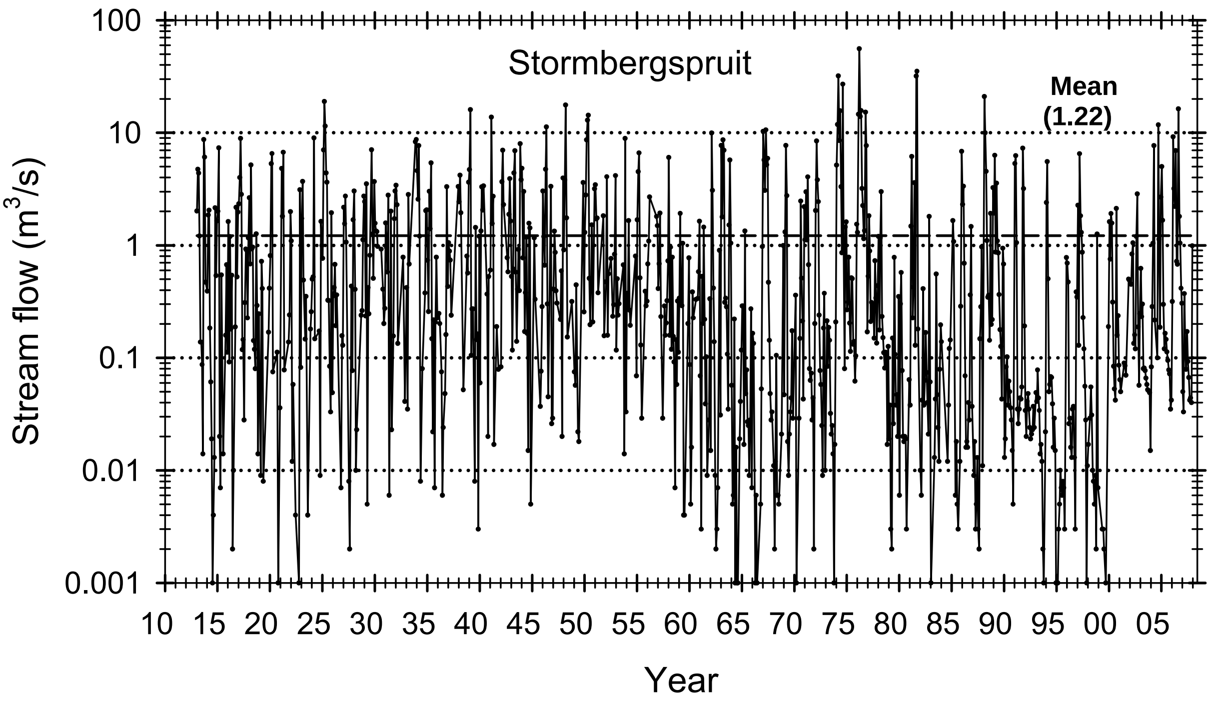


Figure 105: Temporal variation of monthly stream flow (m^3/s) in the Stormbergspruit at Burgersdorp (1913 – 2007). Note the log scale on y-axis.

6.24.2 Dissolved Major Salts (DMS)

The DMS in the Stormbergspruit were very high and ranged between 100 and 1 012 mg/ℓ (mean, 540 mg/ℓ), which is comparable with polluted systems like the Vaal River. The increasing trend indicates continuous pollution (**Figure 106**). Indications are that poorly treated sewage is the main source of the dissolved salts.

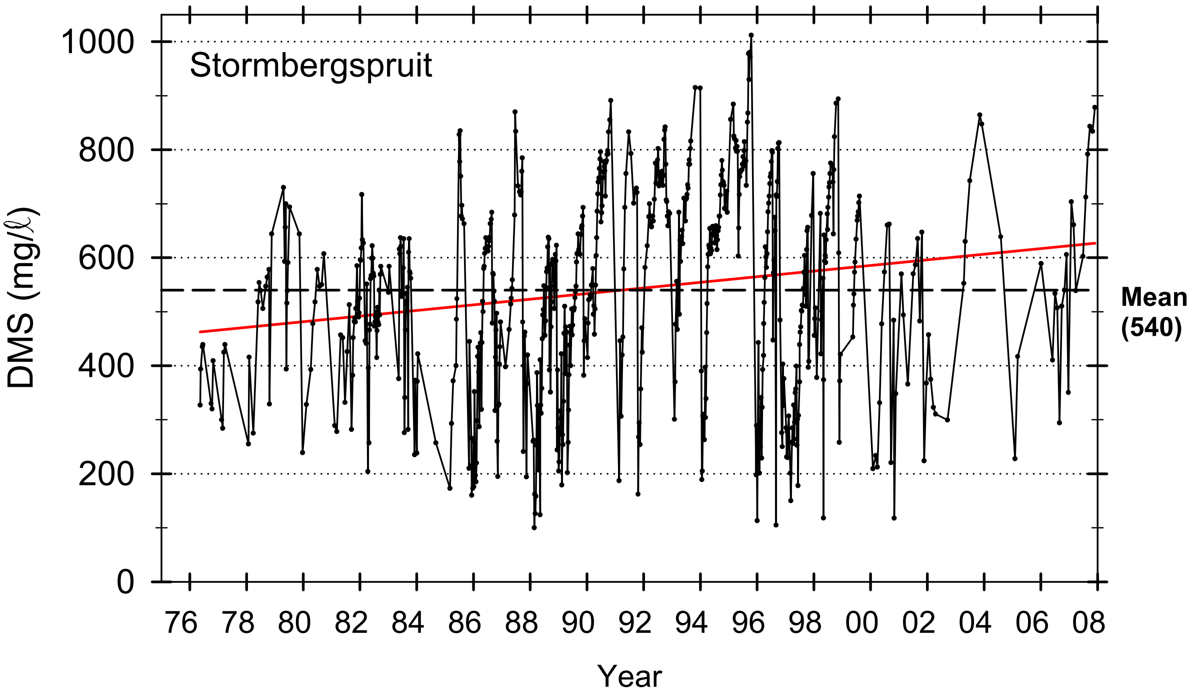


Figure 106: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in Stormbergspruit at Burgersdorp (1975 – 2007).

6.24.3 Nutrients

The phosphate concentrations in the Stormbergspruit were relatively low (mean, 0.04 mg/ℓ) from 1976 to 1991. It then shows a sudden increase from 1992 to an unacceptable mean concentration of 0.754 mg/ℓ (**Figure 107**). Problems with a sewage treatment plant that releasing poorly treated effluent into the spruit, is in all probability, the reason for this sudden change in water quality.

The same trend was illustrated for the DIN concentrations. Low DIN from 1976 – 1991, mean 0.372 mg/ℓ with an increase since 1992 to a mean concentration of 4.54 mg/ℓ (**Figure 108**).

It is recommended that serious attention is given by the municipality to upgrade the sewage treatment infrastructure and to minimise operational spillages of untreated sewage or sludges.

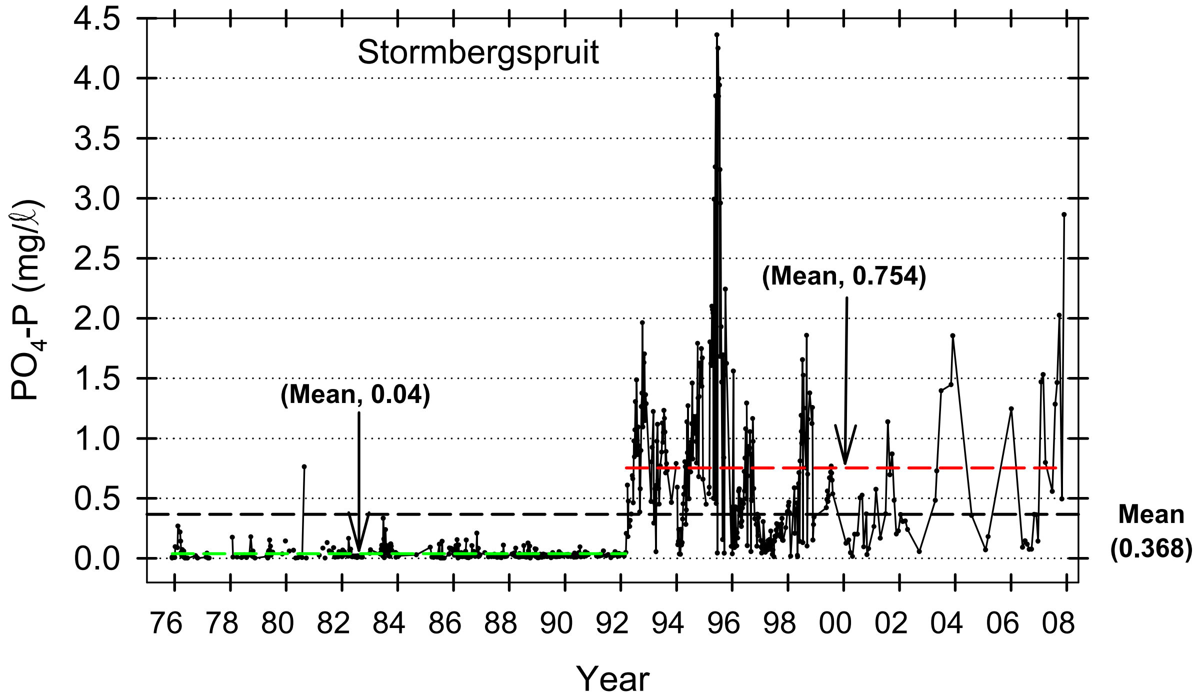


Figure 107: Temporal variation of phosphate (PO_4-P) concentrations (mg/ℓ) in Stormbergspruit at Burgersdorp (1976 – 2007).

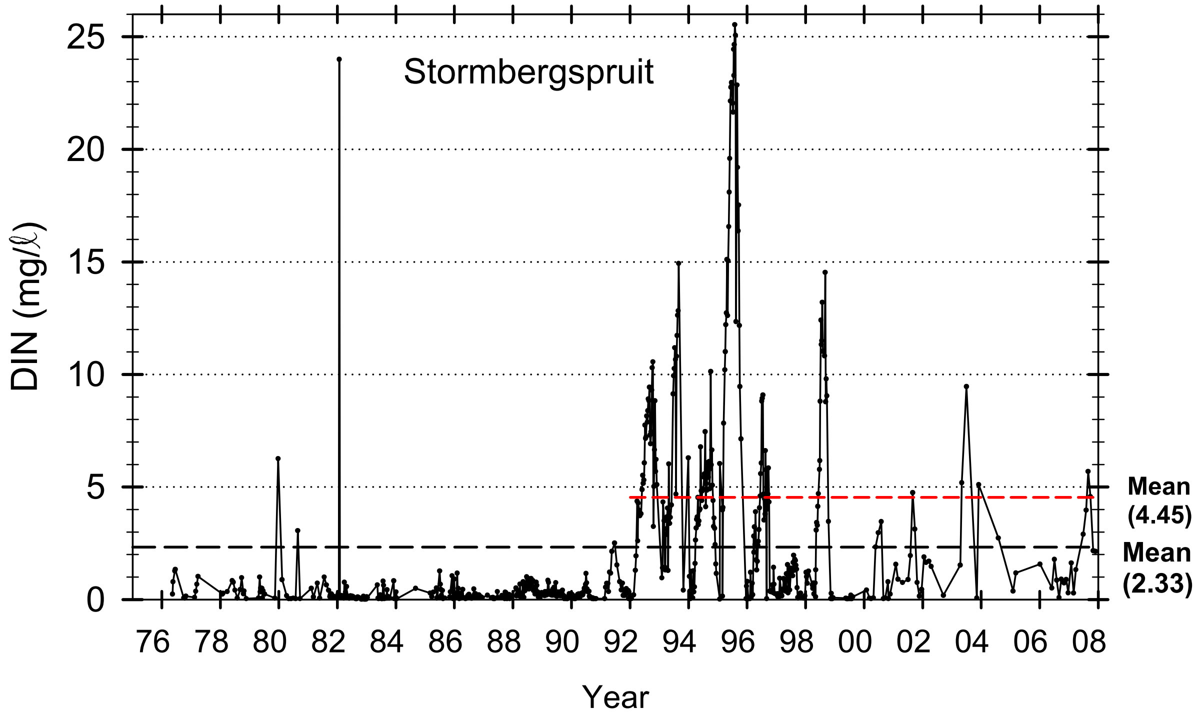


Figure 108: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Stormbergspruit at Burgersdorp (1976 – 2007).

6.24.4 Other parameters

The EC was very high (mean, 67 mS/m) and increasing (**Figure A42 A** in Appendix A).

The pH was very high (median, 8.50), with an exceptional maximum of 10.03, probably associated with an algal bloom (**Figure A42 B**).

The calcium (mean, 44 mg/ℓ) and sulphate (mean, 55 mg/ℓ) concentrations were very high and increasing (**Figure A42 C & E**).

The fluoride concentrations was not influenced by the pollution and stay fairly constant (mean, 0.41 mg/ℓ) since 1975 (**Figure A42 D**)

The silica concentrations were very low (mean, 4.15 mg/ℓ) and highly variable (**Figure A42 F**).

The alkalinity was very high (mean, 235 mg/ℓ) and increasing (**Figure A42 G**).

The SAR (mean, 1.5) is at the ideal limit for irrigation (**Figure A42 H**).

6.25 OSL2/5 – Seekoei River at De Eerste Poort – D3H015 (S30.53480; E24.96250)

The Seekoei River drains a relatively unpolluted area in the Karoo (**Figure A43**). However, the water quality results show relatively high concentrations of almost all the parameters. Data set is good from 1981 to 1993 (biweekly measurements) but thereafter relatively poor data with large gaps (n ≈ 341); see **Tables C13 – C16** in Appendix C.

6.25.1 Stream flow

The monthly average stream flow in the Seekoei River was relatively low (mean, 0.507 m^3/s) but showed a serious decreasing trend from about 1 m^3/s in 1980 to 0.1 m^3/s from 2000 (**Figure 109**). The lower stream flow could be ascribed to impoundment (weirs) and/or indicate an over-abstraction of water for irrigation.

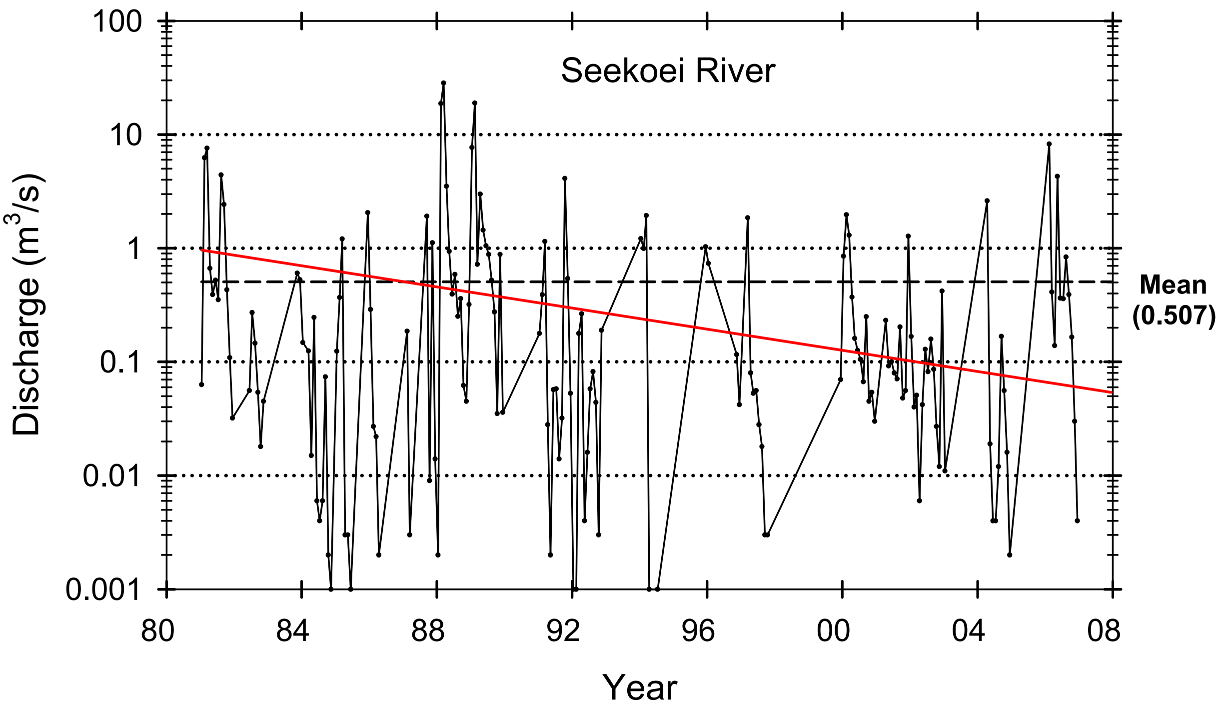


Figure 109: Temporal variation of monthly stream flow (m^3/s) in the Seekoei River at De Eerste Poort (1913 – 2007). Note the log scale on y-axis.

6.25.2 Dissolved major salts (DMS)

The dissolved salts in the Seekoei River were high (min. 89; max. 1 856; mean, 622 mg/ℓ), however, it is considered to be largely natural because it is fairly stable and showed no significant change over the past 27 years (**Figure 110**).

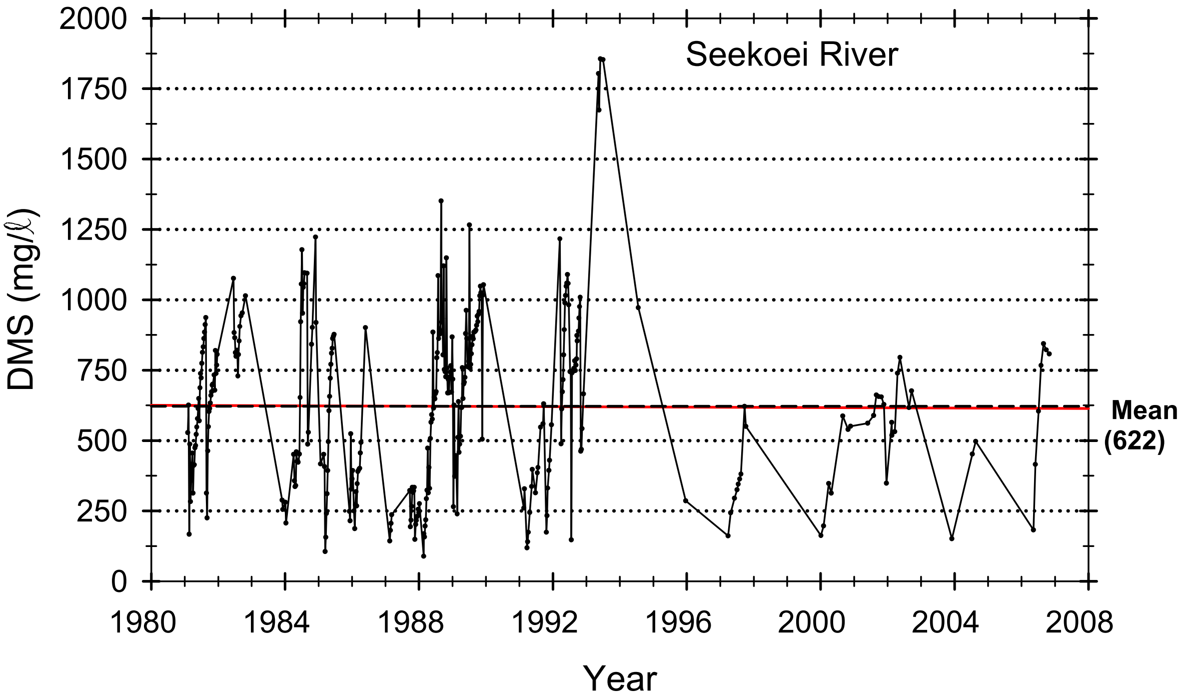


Figure 110: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in Seekoei at De Eerste Poort (1976 – 2007).

6.25.3 Nutrients

The phosphate concentrations in the Seekoei River were very high and ranged between 3 and 6 531 µg/ℓ with the mean at 160 µg/ℓ (**Figure 111**). However, the mean during the last 10 years was 57 µg/ℓ. The reason for the very high PO_4-P concentrations during 1988 – 1989 is unclear, but could be associated with the flood conditions that prevailed during 1988 and 1989 (cf. **Figure 109**) and associated washout of fertilisers from agricultural soils.

The nitrogen concentrations were also very high with the mean at 0.718 mg/ℓ (**Figure 112**). However, the mean from 1991 – 2007 was only 0.113 mg/ℓ. The reason for the very high DIN concentrations during 1988 – 1989 is probably the same as for the phosphates – possibly associated with the flood conditions that prevailed during 1988 and 1989 (cf. **Figure 109**). Heavy rain falling on exposed soil can cause substantial leaching of nitrates, some of which goes directly into rivers, but most of which percolates into the groundwater from where it may eventually reach the rivers if no natural denitrification occurs (Chapman, 1996).

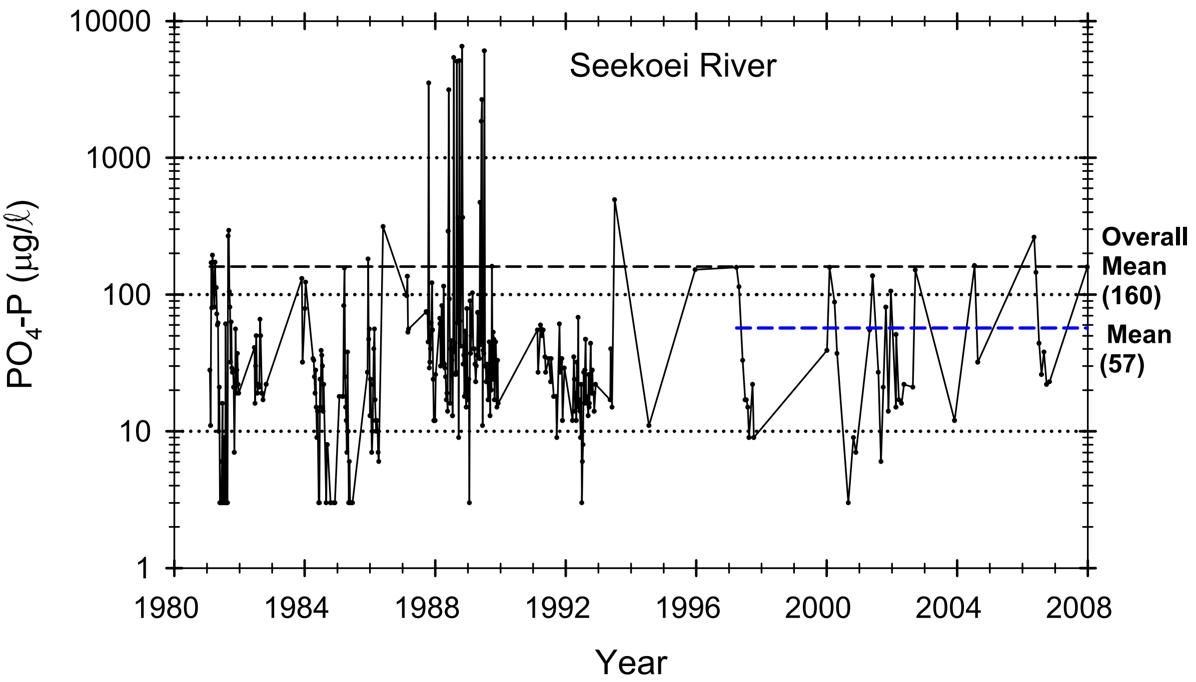


Figure 111: Temporal variation of phosphate (PO_4-P) concentrations (µg/ℓ) in the Seekoei River at De Eerste Poort (1976 – 2007).

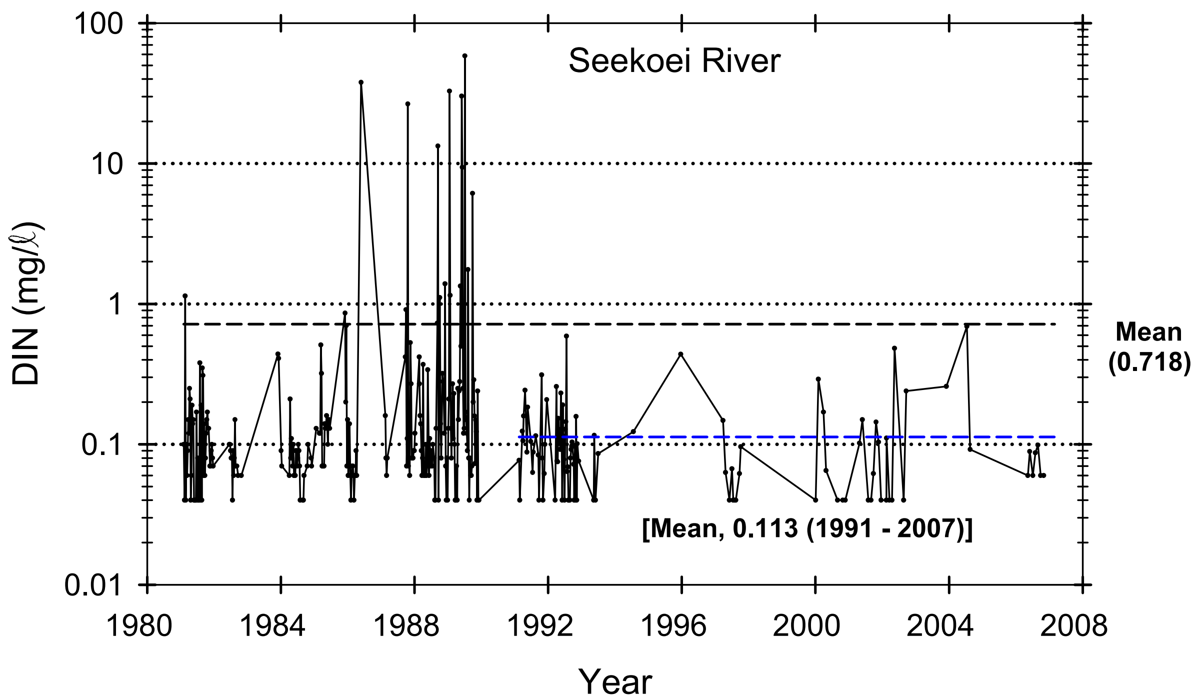


Figure 112: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Seekoei River at De Eerste Poort (1976 – 2007).

6.25.4 Other parameters

The EC was high (mean 82.4 mS/m) (**Figure A44 A** in Appendix A).

The pH was very high (median, 8.50) (**Figure A44 B**).

The fluoride concentrations were high (mean, 0.58 mg/ℓ); probably associated the Karoo geology; highest in the Orange system (**Figure A44 D**).

Silica was very low (mean, 3.71 mg/ℓ) – lowest in the Orange system (**Figure A44 F**).

The alkalinity (TAL) was very high at 249.3 mg/ℓ; associated with the high dissolved salts – highest in the system (**Figure A44 G**).

The high SAR (mean, 2.31) is above the TWQR for irrigation (**Figure A44 H**).

D) MONITORING SITES: CALEDON RIVER – LEVEL 1
(Historical Data)

6.26 CS2 – Caledon River at Ficksburg Bridge, D2H035 (S28.69363; E28.23445)

The Caledon River, which is known as the "Mohokare" in Lesotho, originates from the Mount-Aux-Sources in the north-east, along the Drakensberg and forms the International boundary between South Africa and Lesotho. This transboundary river, provides water for *inter alia* the capital city of Lesotho, Maseru, and, as it flows further down to South Africa, it leads to the Welbedacht Dam, which supplies water for the city of Bloemfontein in South Africa. It then flows west before meeting the Orange River at the Gariep Dam near Bethulie in southern Free State.

The historical data set at Ficksburg Bridge (D2H035) started in 1994 and is still active with a monthly monitoring frequency (n ≈ 295); see **Tables C17 – C20** in Appendix C. Monitoring site C1 (Caledon River at Caledonpoort, **Figure B1**) is a new proposed site with no historical data. See snapshot survey, Chapter 7.

6.26.1 Stream flow

The monthly average stream flow at Ficksburg was 17.7 m^3/s (min. 0.0; max. 130.5 m^3/s) and shows no significant change over time (**Figure 113**). The Caledon River is one of the major tributaries of the Orange River (**Figure B2**). With an annual stream flow of about 558 Mm^3, it contributes approximately 13 % to the Upper Orange River water yield. Interesting to note that the annual stream flows in the three major tributaries to the upper Orange River, namely, Caledon River, Kornetspruit and Kraai River are very similar, *i.e*. 558, 583, and 652 Mm^3 respectively.

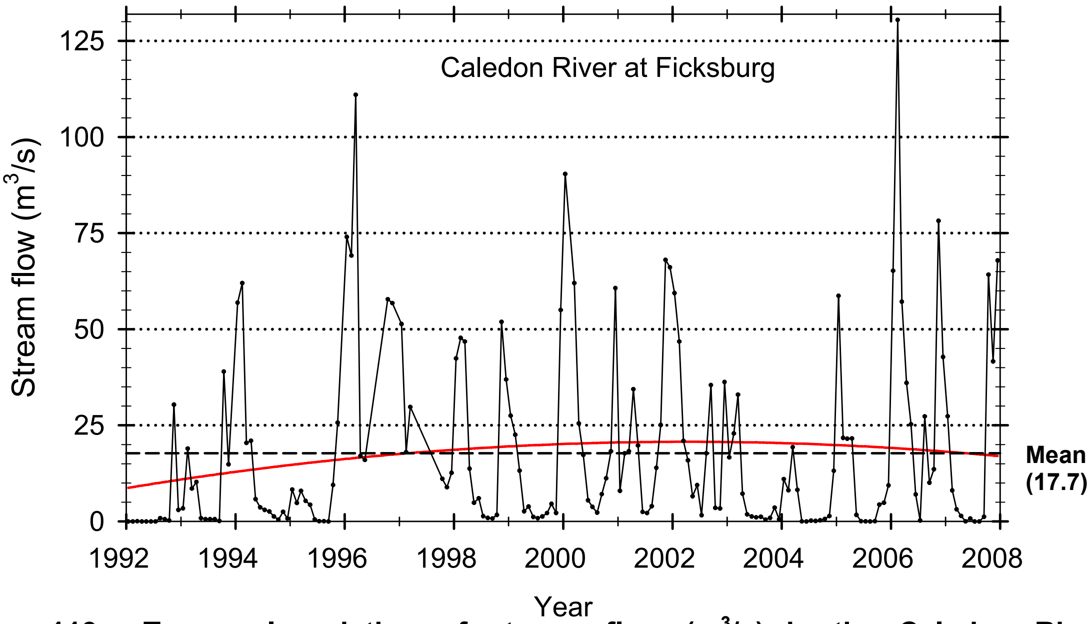


Figure 113: Temporal variation of stream flow (m^3/s) in the Caledon River at Ficksburg (1992 – 2007).

6.26.2 Dissolved major salts (DMS)

The dissolved salts concentrations at Ficksburg were relatively high (mean, 165 mg/ℓ) and show a slight increasing trend with time (**Figure 114**). Unfortunately, the data frequency of monitoring was very poor between 2003 and 2005 (n = 8).

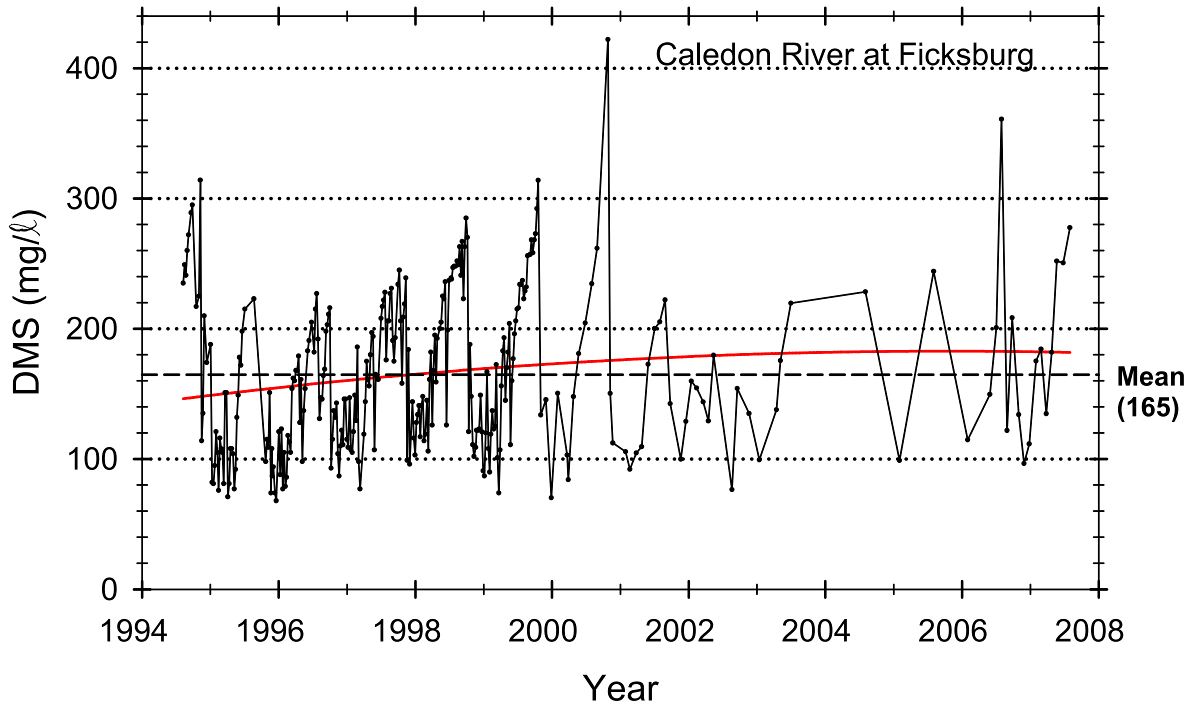


Figure 114: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Caledon River at Ficksburg (1994 – 2007).

6.26.3 Nutrients (N & P)

The mean phosphate concentration was relatively low at 0.033 mg/ℓ (min. 0.003; max. 0.253 mg/ℓ) and seemed to be fairly stable during the past 14 years (**Figure 115**).

The mean DIN concentration was high at 0.323 mg/ℓ, but showed a decreasing trend with time (**Figure 116**). Therefore, the mean DIN concentration during the past 5 years was only 0.224 mg/ℓ.

The ammonium concentrations were low and ranged between 0.015 and 0.198 mg/ℓ (mean, 0.028 mg/ℓ). However, the DWAF monitoring point is above the sewage treatment plant of Ficksburg and does not reflect the impact of the sewage effluent on the river. In fact, the snapshot results taken downstream of the town indicate nutrient enrichment – see Chapter 7.

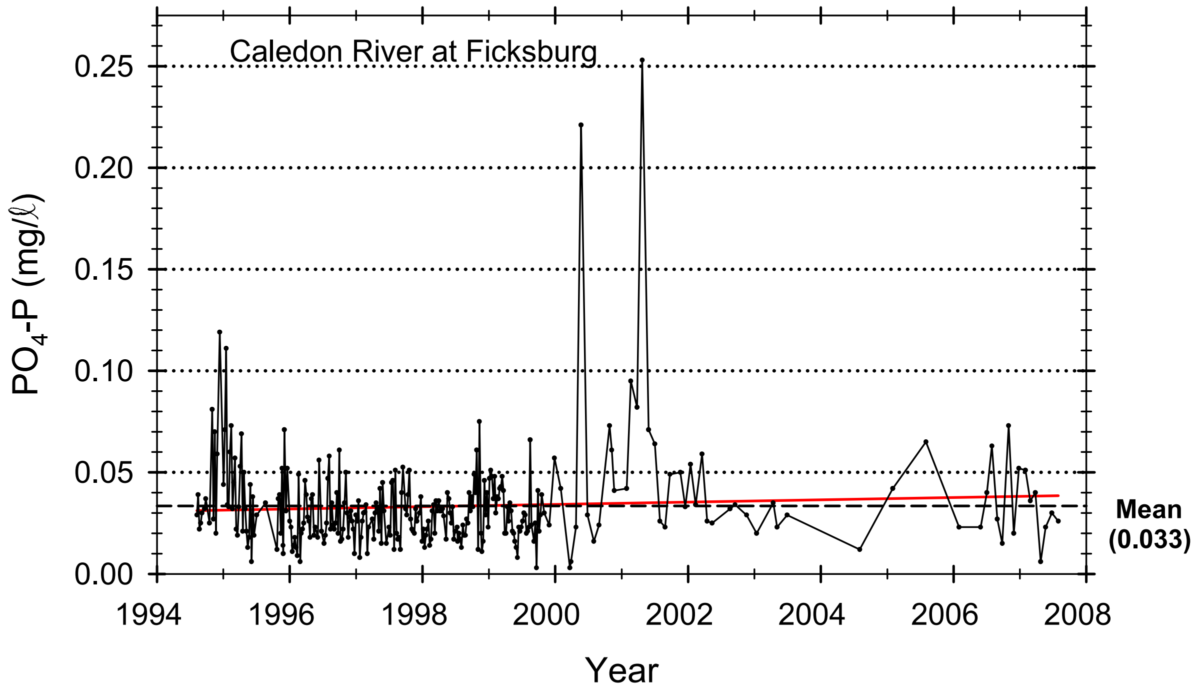


Figure 115: Temporal variation of phosphate phosphorus (PO_4-P) concentrations (mg/ℓ) in the Caledon River at Ficksburg (1994 – 2007).

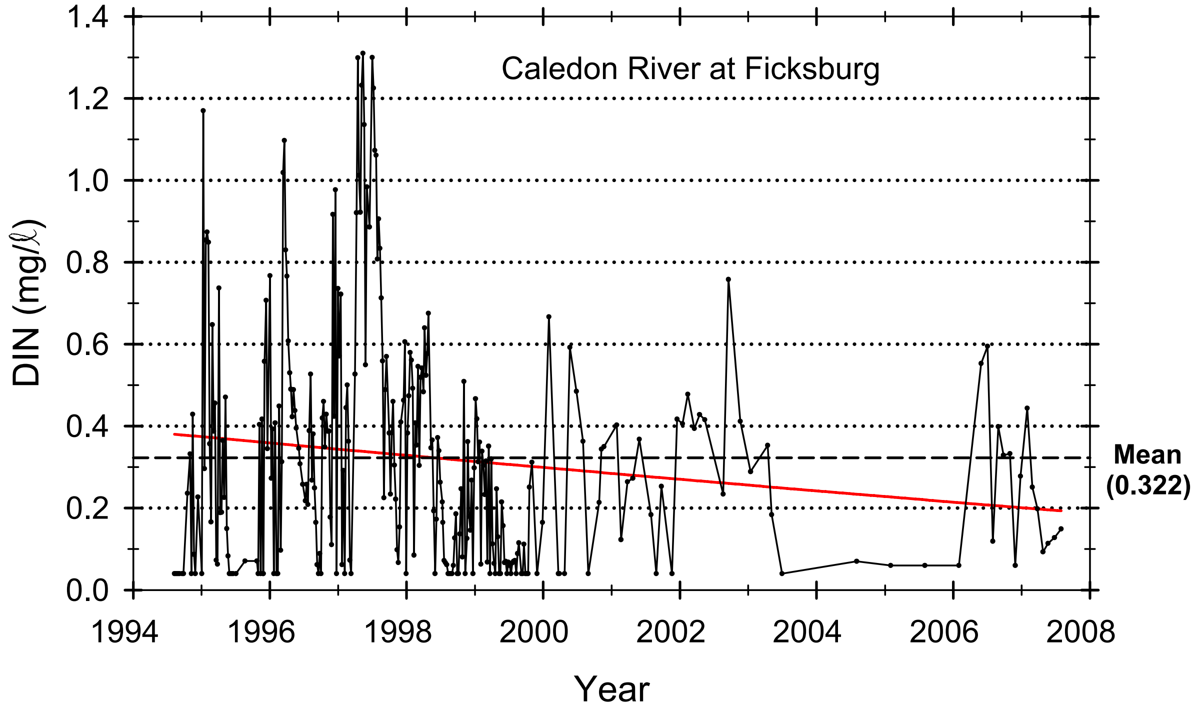


Figure 116: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Caledon River at Ficksburg (1994 – 2007).

6.26.4 Other parameters

The EC values at Ficksburg ranged between 8.4 and 56.1 mS/m with a moderate mean of 20.6 mS/m, but increasing (**Figure B3 A** in Appendix B).

The pH was high (mean, 8.03) but fairly stable (**Figure B3 B**).

The sulphate concentrations were low (mean, 11.85 mg/ℓ) and showed no significant change over time. The ammonium concentrations were also low (mean, 0.028 mg/ℓ) (**Figure B3 D**).

The silica concentration was moderate at 7.53 mg/ℓ and fairly constant from 1994 (**Figure B3 E**).

The mean turbidity at Ficksburg was only 78.17 NTU, but is considered to be unreliable and a total underestimate of turbidity because of the low frequency of monitoring (**Figure B3 F**).

The SAR was low (mean, 0.33) and suitable for irrigation (**Figure B3 G**).

The alkalinity was moderate (mean 89.4 mg/ℓ) and comparable to levels found in Kornetspruit and Kraai River (**Figure B3 H**).

6.27 CS3 – Caledon River at Maseru – new site (S29.38042; E27.41203)

Proposed new site downstream of Maseru, see **Figure B4**, - no historical data.

The chemical data collection at Maseru, Lesotho (D2H011) unfortunately ended in 1994 and is not reported here. See snapshot results – Chapter 7.

6.28 CS4 – Caledon River at Tienfontein pump station (S29.78357; E26.90998)

This is a new proposed monitoring site upstream of the Welbedacht Dam, **Figure B5** – no historical data.

See snapshot survey, Chapter 7.

6.29 CS5 – Caledon River at Kommissiedrift, D2H036 (S28.69363; E28.23445)

Kommissiedrift is below Welbedacht Dam and the last monitoring point before the Caledon River enters Gariep Dam (**Figure B6**). A good historical data set exists with biweekly recordings from 1993 (n ≈ 212), except for the period 2003 – 2005 with only 5 recordings; see **Tables C17 – C20** for a summary of the statistical data (Appendix C). The accessibility to the river at this site is difficult.

6.29.1 Dissolved major salts (DMS)

The mean DMS concentration of 186 mg/ℓ (min. 86.0; max. 490.7 mg/ℓ) was significantly higher than the upstream points (e.g. Ficksburg, mean 165 mg/ℓ), but was fairly stable over time with a slight increasing trend (**Figure 117**). Typically salts would accumulate downstream in a river because of salt inputs upstream.

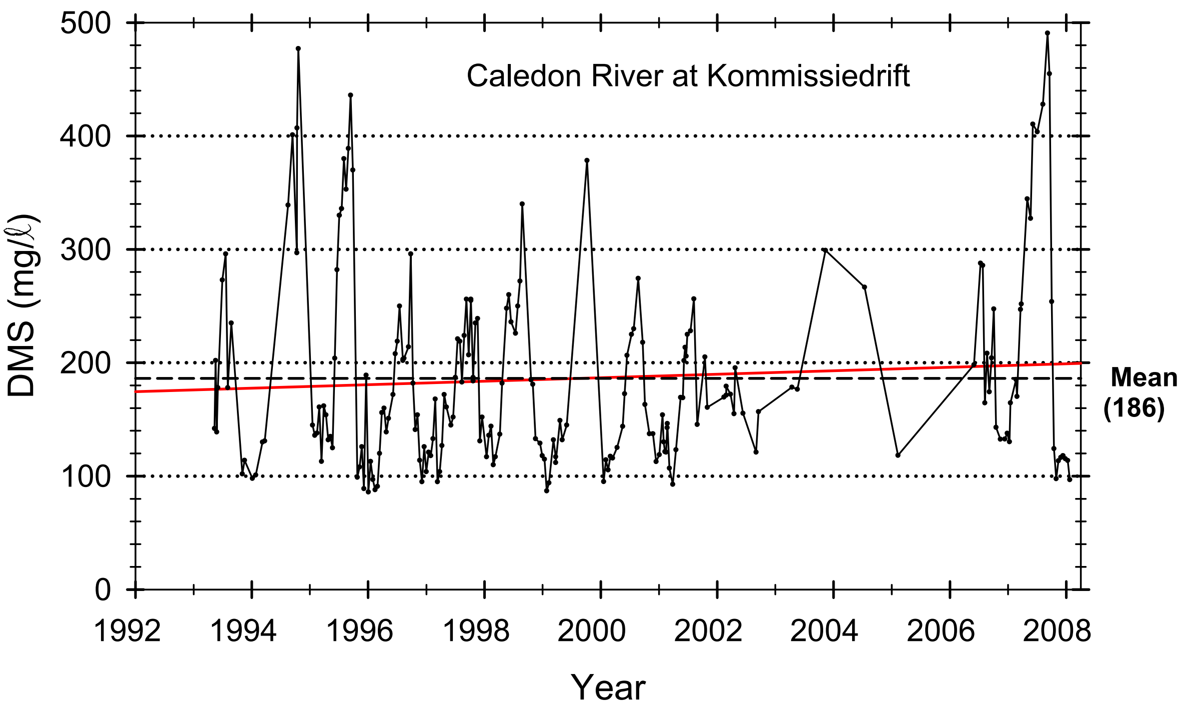


Figure 117: Temporal variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Caledon River at Kommissiedrift (1993 – 2007).

6.29.2 Nutrients (N & P)

The phosphate concentrations at Kommissiedrift were significantly higher than the upstream point (mean 42 µg/ℓ; min. 6, max. 557 µg/ℓ) (**Figure 118**).

The mean DIN concentration (0.438 mg/ℓ) was also considerably higher than at Ficksburg, but also showed a decreasing trend with time (**Figure 119**).

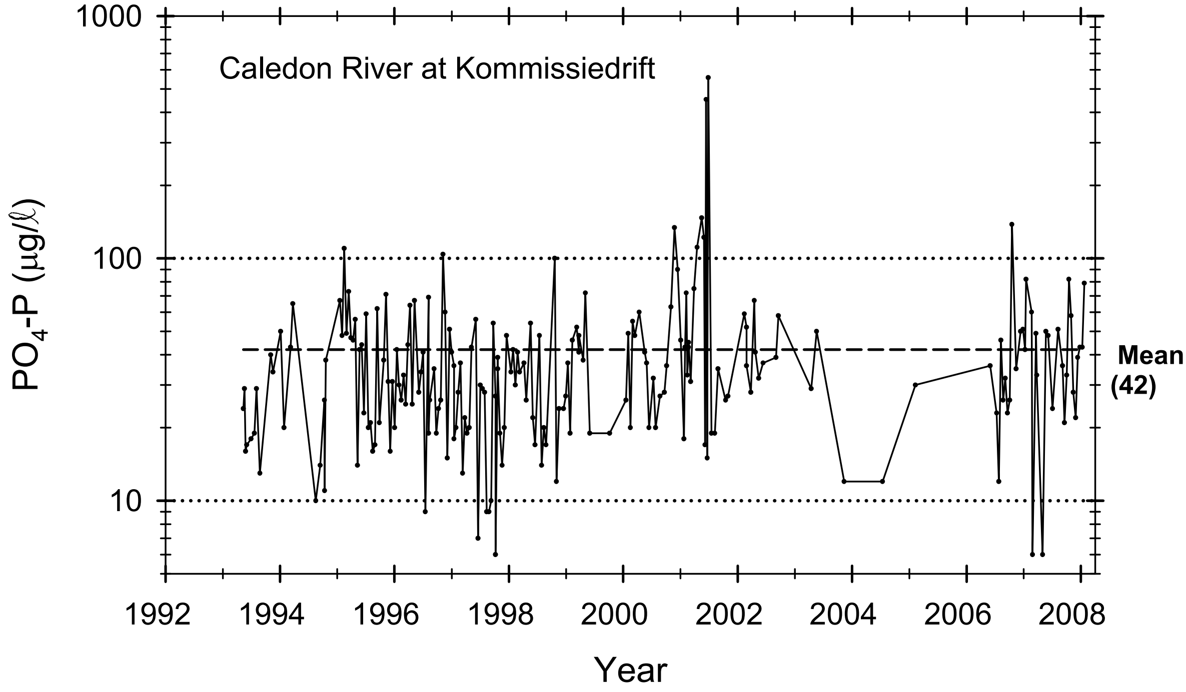


Figure 118: Temporal variation of phosphate phosphorus (PO_4-P) concentrations (µg/ℓ) in the Caledon River at Kommissiedrift (1993 – 2007). Note the log scale on the y-axis.

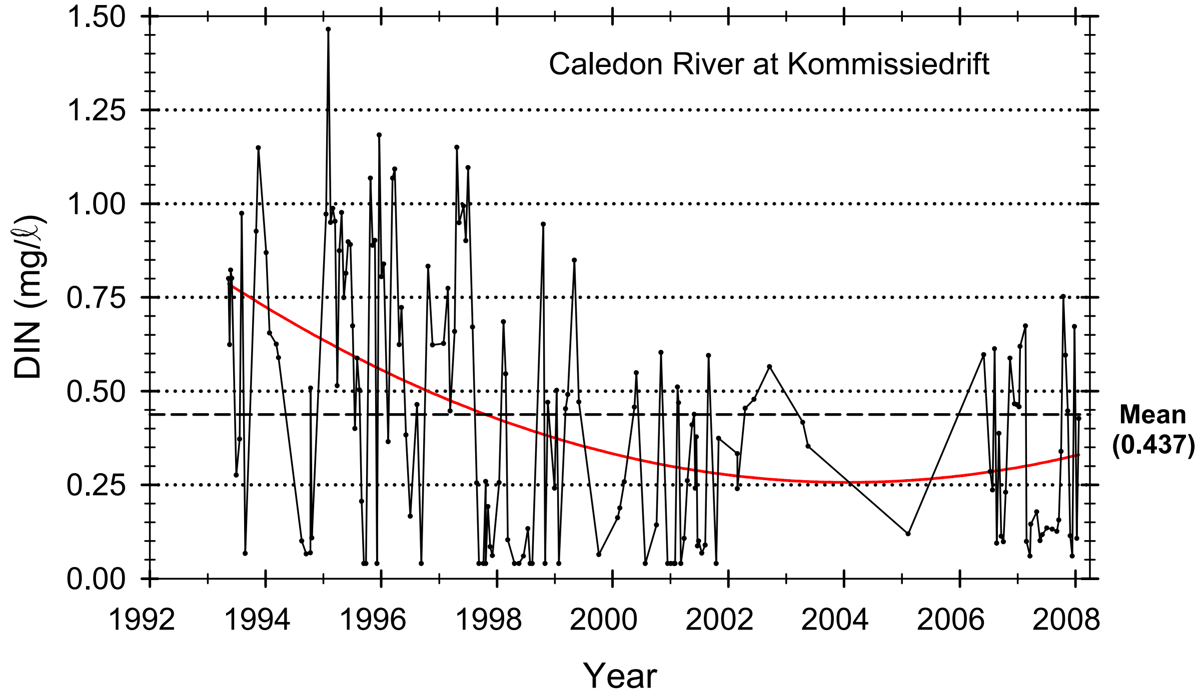


Figure 119: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Caledon River at Kommissiedrift (1993 – 2007).

6.29.3 Turbidity

The Caledon River delivers most of the fine mud suspended load of the Orange River and much of the suspended load of the Caledon River is derived from the erosion of topsoil (Compton & Maake, 2007). The River Health Programme (2003), of South Africa states that, "The Caledon catchment has almost 100 % grassland cover but poor management practices resulting in high sediment yields. The slope as well as the erodability of the soils in the upper Caledon catchment leads to increased sediment deposition".

Due to siltation, the storage capacity of the Welbedacht Dam reduced rapidly from the original 115 million m^3 to approximately 16 million m^3, *i.e.* by 86 %, during the twenty years since completion (DWAF, 2004). Unfortunately, no suspended solids data is available for the whole Caledon River.

The mean turbidity in the Caledon River was very high (400 NTU) and reached occasionally extremely high values with a maximum of 10 000 NTU (**Figure 120**). The mean turbidity in the Caledon River was more than double the mean value reported for the Orange River at Oranjedraai (160 NTU) and is probably the most turbid river in South Africa. However, the water in the Caledon River becomes very clear during the winter months and can reach values of <1 NTU (see **Figure 157**).

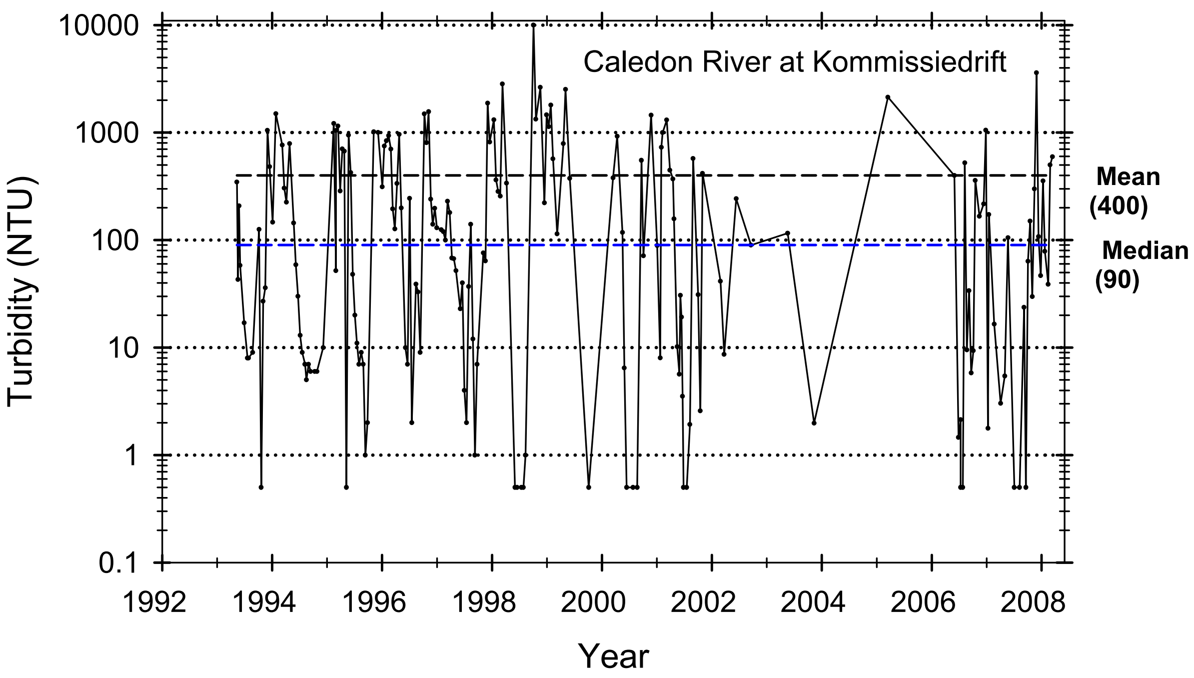


Figure 120: Temporal variation of turbidity (NTU) in the Caledon River at Kommissiedrift (1993 – 2007).

6.29.4 Other parameters

The EC ranged between 10.8 and 59 mS/m (mean, 23.6 mS/m) with a slight increasing trend (**Figure B7 A**) – Appendix B.

The pH values ranged usually between 7.5 and 8.5 with the median at 8.10 (**Figure B7 B**).

The Ca, Cl, and SO_4 concentrations were very similar but slightly higher than the concentrations at the upstream point (**Figure B7 C, D & E**).

The silica concentrations were relatively low with a mean of 5.65 mg/ℓ (**Figure B7 F**).

The hardness of the water (mean, 94.9 mg/ℓ) fell in the range of moderately soft systems (**Figure B7 G**).

The alkalinity was fairly stable with a moderate mean of 99 mg/ℓ (**Figure B7 H**).

E) MONITORING SITES ON THE TRIBUTARIES OF THE CALEDON RIVER – LEVEL 2 (Historical Data)

6.30 CS2/1 – Little Caledon River – downstream of Golden Gate (S28.49980; E28.58196)

Proposed new site – see **Figure B8**. No historical data. See snapshot results – Chapter 7.

6.31 The LittlCS2/2 – Little Caledon River at the Poplars – confluence, D2H012 (S28.69363; E28.23445)

The Little Caledon River is a relative small river, but is known as a clear water stream with low levels of pollution. With an annual stream flow of about 30.6 Mm^3 it contributes only about 5 % to the Caledon River's flow. The water quality at the upstream sampling point near Golden Gate was very good – see snapshot results, Chapter 7.

The flow gauging and monitoring site is at the confluence with the Caledon River (**Figure B9**). The historical data set is good with almost weekly measurements (n ≈ 347). See **Tables C17 – C20** in Appendix C for a statistical summary of data.

6.31.1 Stream flow

The monthly average stream flow at The Poplars was only 0.96 m^3/s and shows no significant change with time (**Figure 121**). The river displays a clear seasonal flow that follows a natural pattern with high flows during summer and low flows during winter (**Figure 122**).

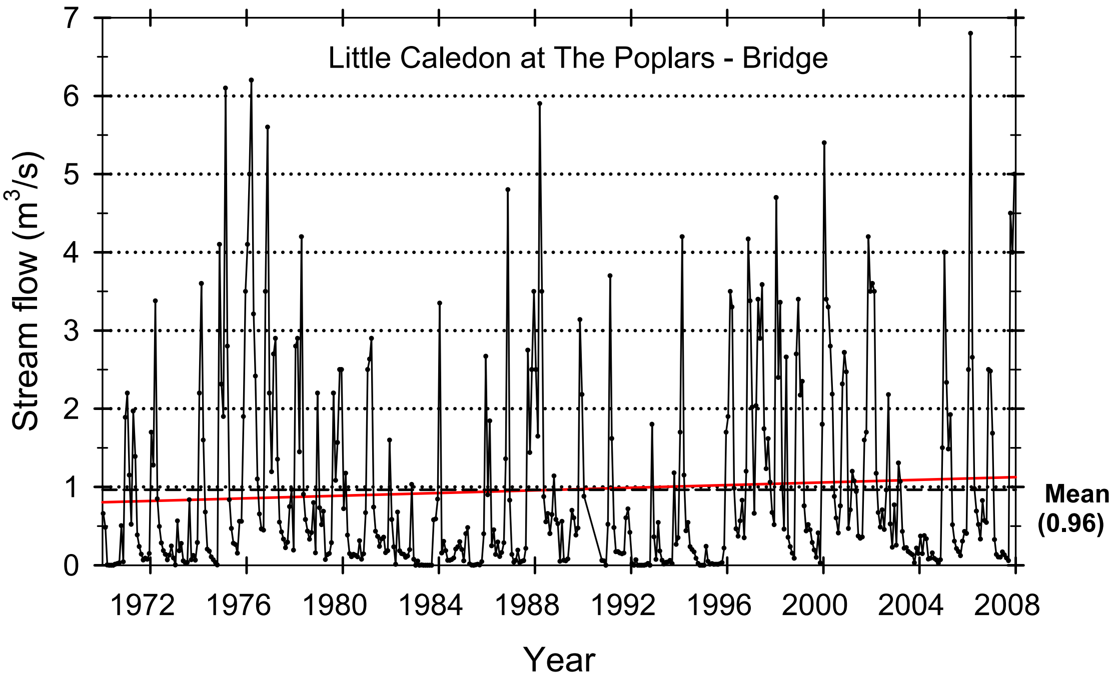


Figure 121: Temporal variation of stream flow (m^3/s) in the Little Caledon River at The Poplars (1971 – 2007).

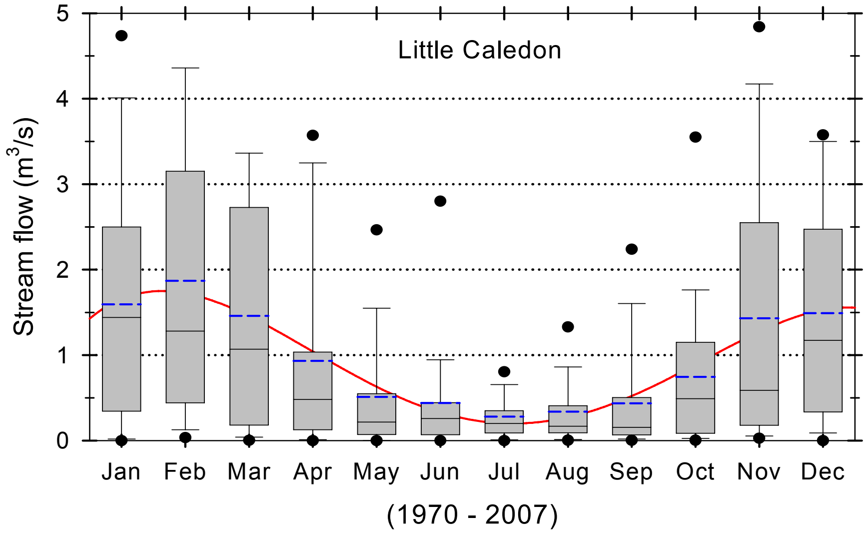


Figure 122: Seasonal variation of stream flow (m^3/s) in the Little Caledon River at The Poplars (1970 – 2007).

6.31.2 Dissolved major salts (DMS)

The concentration of the DMS in the Little Caledon River (at the confluence with Caledon) was relatively high with a mean of 258 mg/ℓ (min. 79; max. 415 mg/ℓ), but showed a slight decreasing trend (**Figure 123**). During the snapshot survey, the salts concentration at the upstream point (at Golden Gate) was only 186.3 mg/ℓ compared to a reading at this site with a DMS of 283.7 mg/ℓ - see Chapter 7.

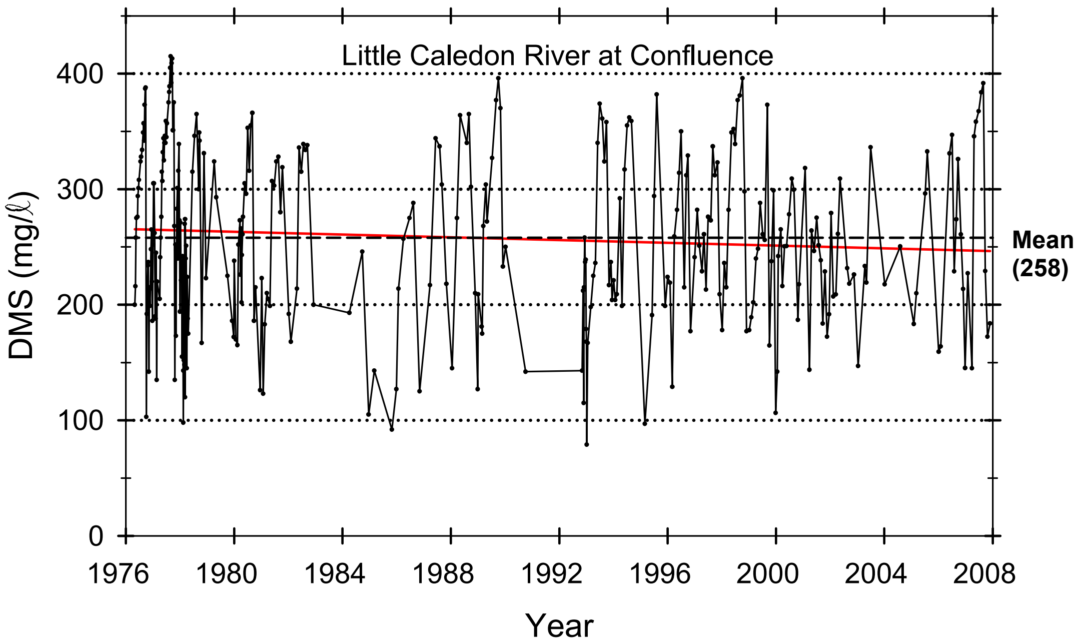


Figure 123: Temporal variation of dissolved major salts (DMS) concentration (mg/ℓ) in the Little Caledon River at The Poplars (1976 – 2007).

6.31.3 Nutrients (N & P)

The phosphate concentration in the Little Caledon River was relatively low (mean, 35 µg/ℓ) low but showed an increasing trend that possibly indicates nutrient enrichment of the system (**Figure 124**).

The DIN concentrations were very low and ranged between 0.040 and 1.490 mg/ℓ (mean 0.144 mg/ℓ), but also show an increasing trend (**Figure 125**).

Significant benthic filamentous algal growth was observed at the monitoring point that is an indication of nutrient enrichment (eutrophication). However, the bacterial counts during the snapshots were relatively low 59 – 179 cfu/100 mℓ.

The low N:P ratio (mean, 8.0; median 3.5) indicates a potential nitrogen limitation to phytoplankton growth in the Little Caledon River.

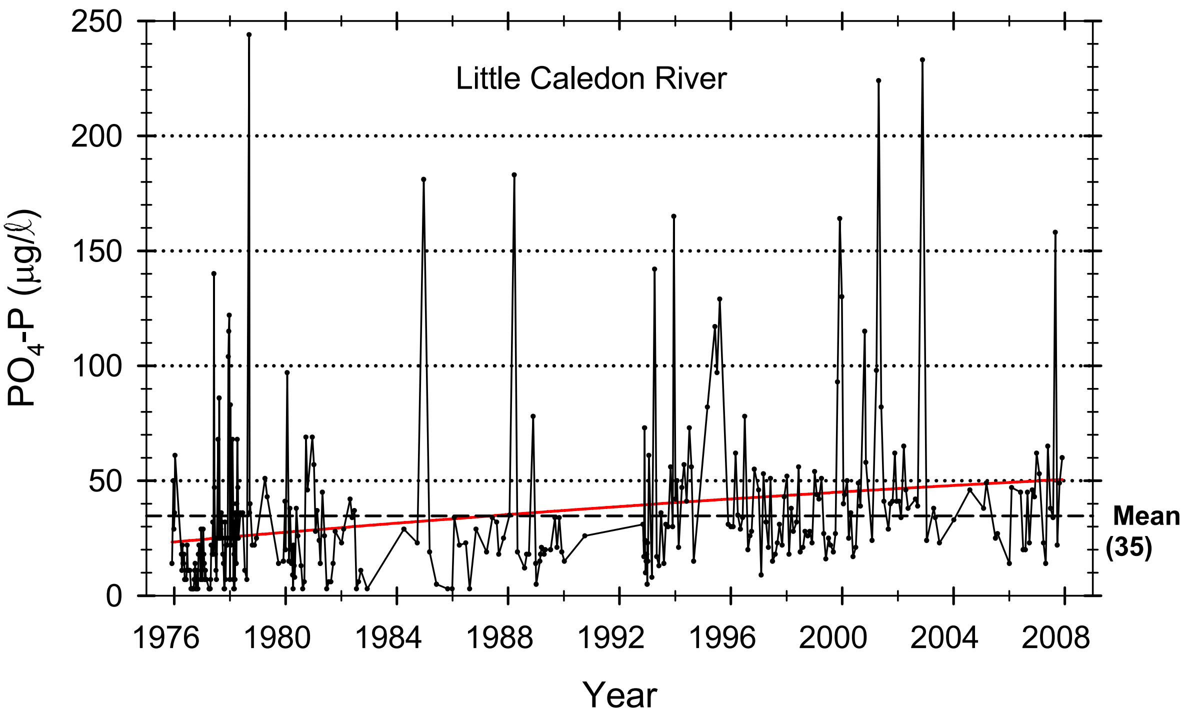


Figure 124: Temporal variation of phosphate phosphorus (PO_4-P) concentrations (µg/ℓ) in the Little Caledon River at The Poplars (1975 – 2007).

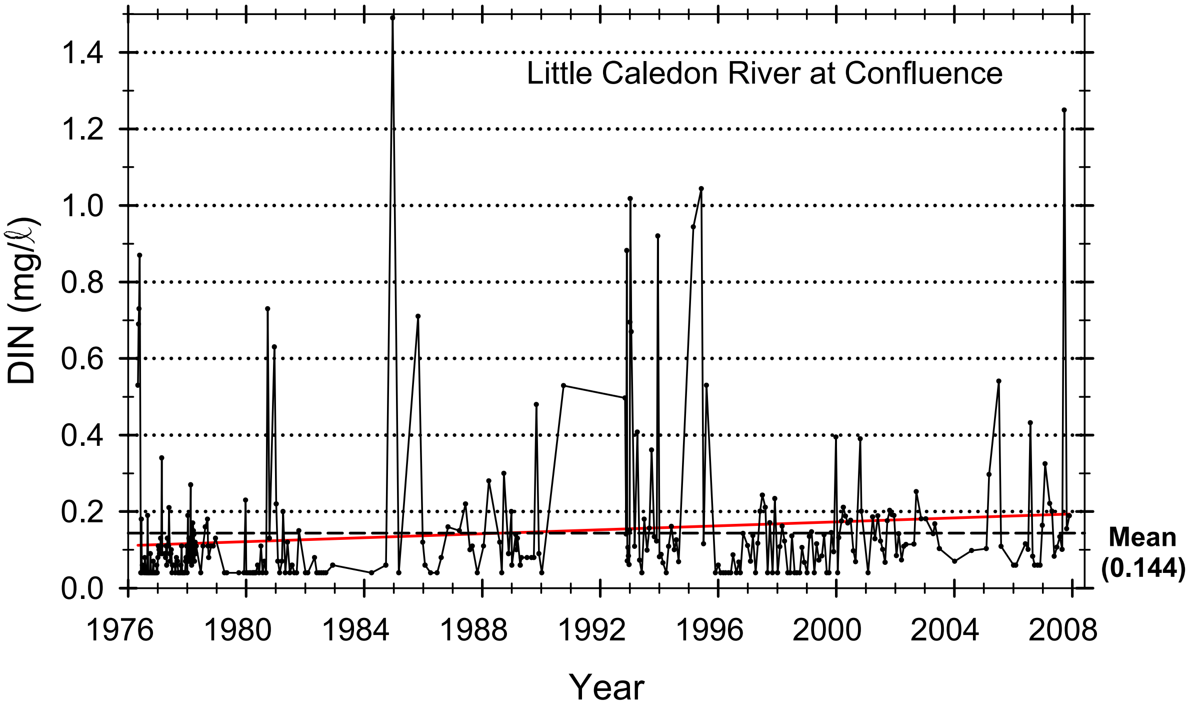


Figure 125: Temporal variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Little Caledon River at The Poplars (1976 – 2007).

6.31.4 Other parameters

The EC was relatively high, mean of 32.3 (mS/m), but was fairly constant since 1976 (**Figure B10 A**) – Appendix B.

The median pH of 8.26 is relatively high but comparable with values in the Caledon River (**Figure B10 B**).

The sulphate concentrations were relatively low (mean, 12.8 mg/ℓ) but show a considerable increase over time probably associated with irrigation activities upstream (**Figure B10 B**).

The mean silica concentration of 10.15 mg/ℓ in the Little Caledon was the highest in the whole Upper WMA, but show a decreasing trend (**Figure B10 E**).

The turbidity in the Little Caledon River was very low with the mean at 14.96 NTU (median, 3.22 NTU) (**Figure B10 F**).

The SAR was low (mean, 0.42) and ideal for irrigation. The mean alkalinity was fairly high at 144.6 mg/ℓ (**Figure B10 G & H**).

7 RESULTS AND DISCUSSION OF SNAPSHOT SURVEY DATA

Two snapshot surveys were conducted during 2008. The first snapshot was conducted during 3 separated weeks, stretching from middle April to the beginning of June and the second snapshot from middle August to the beginning of September 2008. The monitoring sites assessed are indicated **in Table 2, 3** and **4** and in **Figures 4, 5 and 6**. See Appendix A and B for images (Satellite and on site) of sampling sites.

The snapshot surveys provide water quality information on sites in rivers and streams that were not previously monitored (new sites) and on parameters, like dissolved oxygen and diatom scores, at all sites that are not part of the routine measurements made in DWAF's monitoring programme. Thus, the present state at the new sites and some parameters are based only on the results of 2 snapshot surveys, therefore, low confidence values – see also Report 5 on RWQOs.

7.1 Level 1 monitoring sites on the Orange River

Abbreviations for the sites used in the graphs following sections are listed in **Table 5** below:

Table 5: Abbreviations for site names used in the graphs

Site Name	Abbreviation
Oranjedraai	OD
Aliwal North	AN
Saamwerk	Sw
Gariep Dam	GD
Site downstream of Gariep Dam	G-B
Vanderkloof Dam	VK
Downstream of Vanderkloof Dam	V-B
Marksdrift	MD
De Hoek	De-H
Katlani	Kat
Prieska	Pr
Boegoeberg Dam	B-W
Upington	Up
Kanon Island	Kan
Neusberg Weir	Neu
Blouputs	Bl
Pella	Pel
Vioolsdrift	Vio
Sendelingsdrift	Sen
Brand Kaross	Bk
Alexander Bay	Ale

7.1.1 Dissolved major salts (DMS)

The DMS concentrations in the Orange River show a clear downstream increase, *i.e.* by 573 % during snapshot survey 1 (*i.e.* from 60 to 404 mg/ℓ) and a 266 % increase (from 139 to 508 mg/ℓ) during snapshot survey 2 (**Figure 126**).

The reason for the high increase during snapshot survey 1, was the effect of rain and dilution of salts at Oranjedraai during the first fieldtrip, thus starting at a low salt concentration level, in the upper Orange (especially at Oranjedraai and Aliwal North) and the significant input of salts from the Vaal River during April 2008 – see arrow in **Figure 126 A**).

A) **B)**

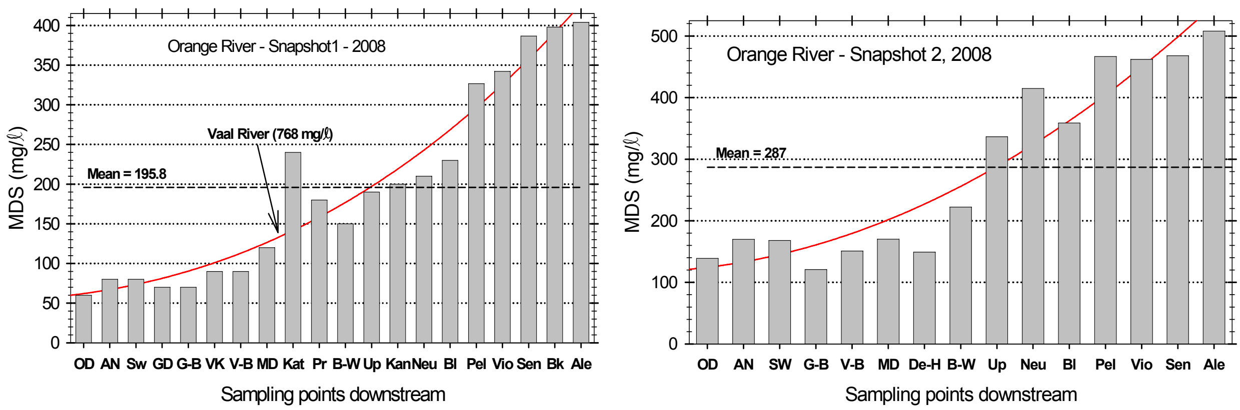


Figure 126: Spatial variation of dissolved major salts (DMS, mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B) during 2008.

7.1.2 Return flows

A once-off sample of water from the return flow canals at Louisvale (near Upington) was collected during snapshot 2 (15 September 2008). The water quality of the return flow water was compared with water from the river at Upington to determine the impact, if any of the return flows on the river– see **Figure 127**.

The return flow water contains significantly higher salt concentrations (1 065 mg/ℓ) compared to the 332 mg/ℓ in the river water, *i.e.* an increase of 220 %. The smallest increase was in phosphate (PO_4-P) that increased only by 22 %, while the nitrates increased by 800 % (**Figure 127**).

Nutrient enrichment (eutrophication) of the water, especially with N & P, can lead to higher productivity and algal blooms with associated problems.

The return flows do probably result in the change in ionic composition of the river water, *i.e*. from a calcium to a sulphate dominated system (cf. **Figure 68** and **Figure 68**).

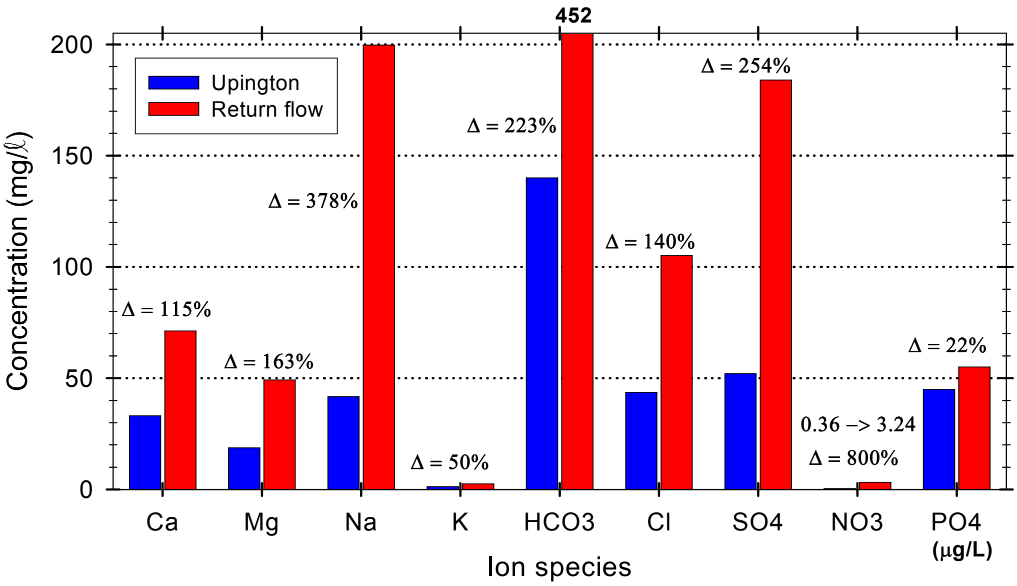


Figure 127: Comparison of dissolved ions in the Orange River water at Upington (TDS, 332 mg/ℓ) with irrigation return flow at Louisvale (1 065 mg/ℓ) during snapshot survey 2 (15 September, 2008).

7.1.3 Major ions – Sulphates

The sulphate concentrations in the Upper Orange River were low (mean <10 mg/ℓ) but increase significantly below Marksdrift (**Figure 128 A**). The impact of the high sulphate concentration in the Vaal River (150 mg/ℓ) during relative high flow (~20 m^3/s) on the sampling point downstream in the Orange River was clear during snapshot 1. This was especially noted at Katlani that peaked at 70 mg/ℓ followed by a dilution of salts from a high rainfall (**Figure 128 A**). During snapshot 2, the sulphate concentrations increased significantly from Upington and downstream that is probably associated with the intensive irrigation in this area (**Figure 128 B**).

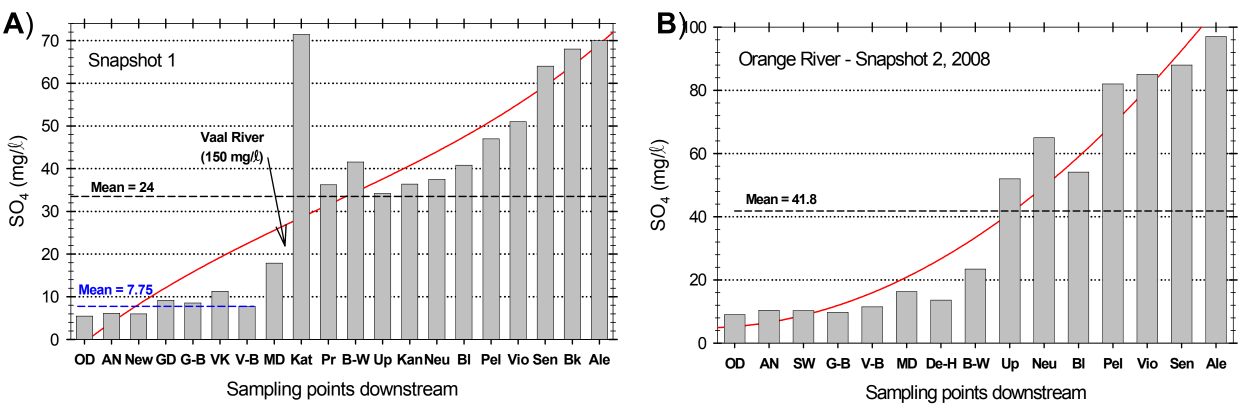


Figure 128: Spatial variation of sulphate concentration (SO_4, mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.4 Other ions

The potassium concentrations were very conservative with minor changes downstream. Magnesium showed a slight increase downstream, but the sodium concentrations increase significantly downstream (**Figure 129**). The exceptional increase in sodium concentration could be ascribed to the irrigation activities and return flows.

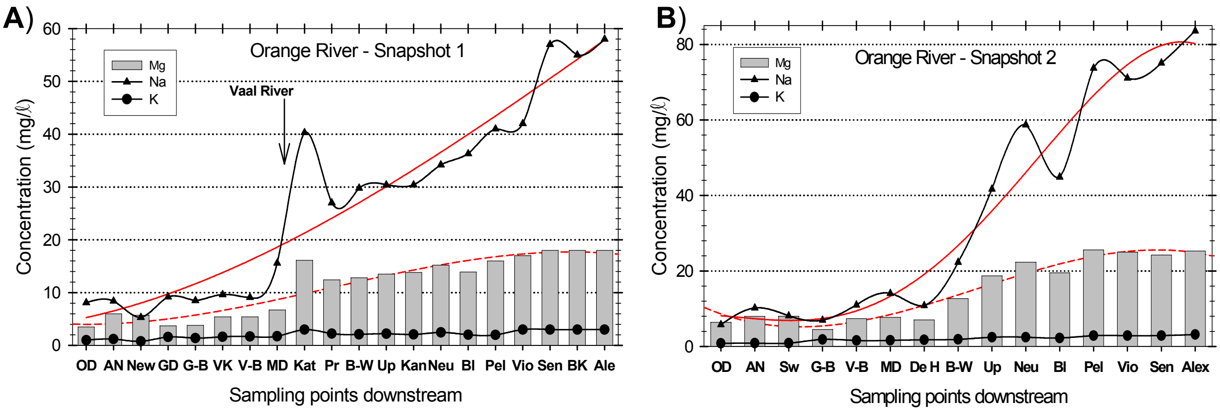


Figure 129: Spatial variation of potassium, sodium, and magnesium concentrations (mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B) (2008).

7.1.5 pH

The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. Dissolved inorganic carbon exists mostly in the form of bicarbonate (HCO_3^-) in rivers where the pH range is commonly between 6 and 8.4.

The pH values in the Orange River ranged between 7.8 and 8.7 (median, 8.3) and also showed an increasing trend downstream (**Figure 130**). The higher pH values in the lower Orange River are ascribed to higher algal biomass and thus higher photosynthetic rates that tend to increase the pH of the water. The water released from Gariep Dam (G-B) has the lowest pH values indicating the presence of deep layer water.

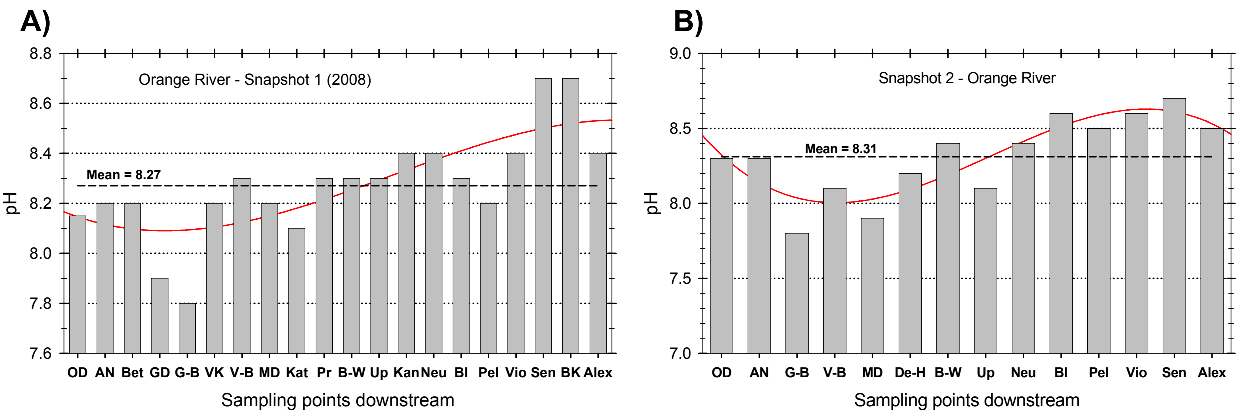


Figure 130: Spatial variation of pH in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.6 DIN

One would expect higher nitrate concentrations downstream in the Orange River, because of the intensive irrigation in the downstream areas. However, the DIN (nitrate and ammonium) concentrations showed a decreasing trend downstream. The same trends were observed for the historical data (**Figure 131**) and during both snapshot surveys (**Figure 132**). The downstream decrease was from approximately 0.6 mg/ℓ to 0.2 mg/ℓ, *i.e.* a 67 % reduction. Billen and co-authors (1991) work suggests that river retention, due to denitrification and net burial, is generally near 30 % of N loading.

The high DIN concentrations at G-B (below Gariep Dam, **Figure 131**) are ascribed to the high nitrates and ammonium concentrations in the low level layers (hypolimnetic) waters that are released from the dam.

Possible reasons for the lower DIN concentrations downstream are effective denitrification of NO_3, assimilation by riparian vegetation, absorption by sediments, and limited inflows and thus replenishment of nutrients downstream of Douglas. Local inflows from the catchment downstream of the Orange/Vaal confluence are sporadic and contribute less than 7 % of the total runoff under natural conditions (DWAF, 2005).

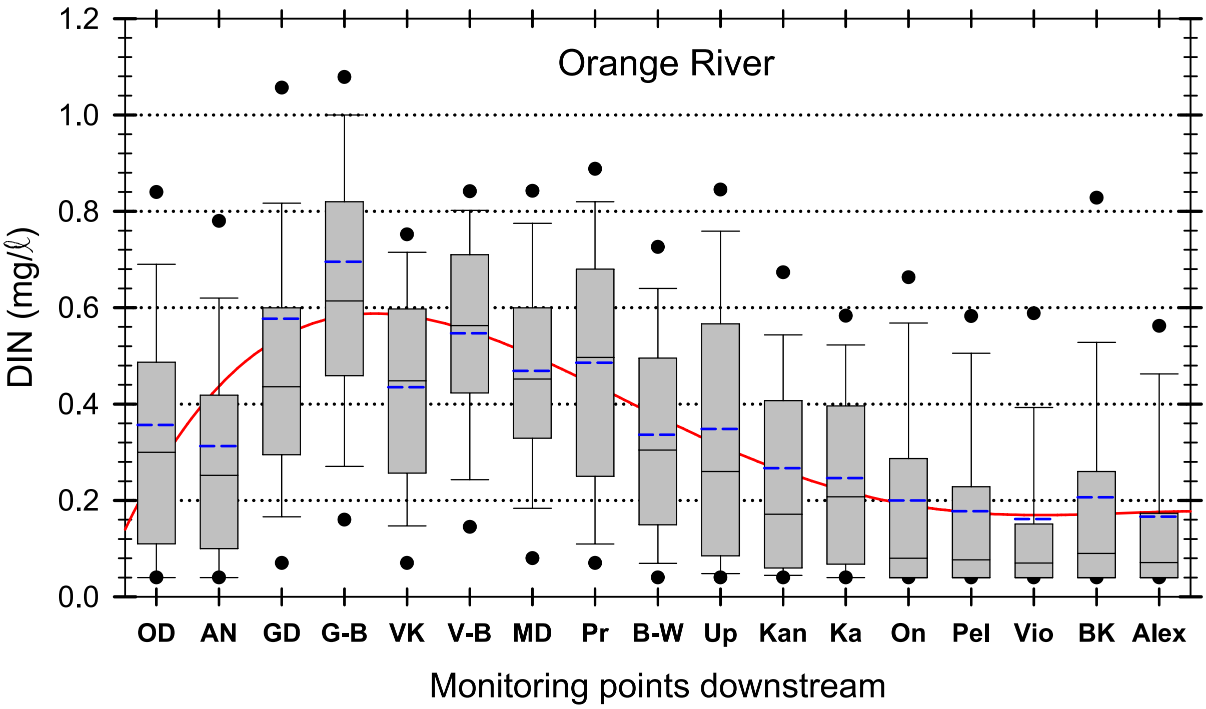


Figure 131: Box and whiskers plot of the spatial variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Orange River for all the historical data available – various time periods, typically 1972 – 2007.

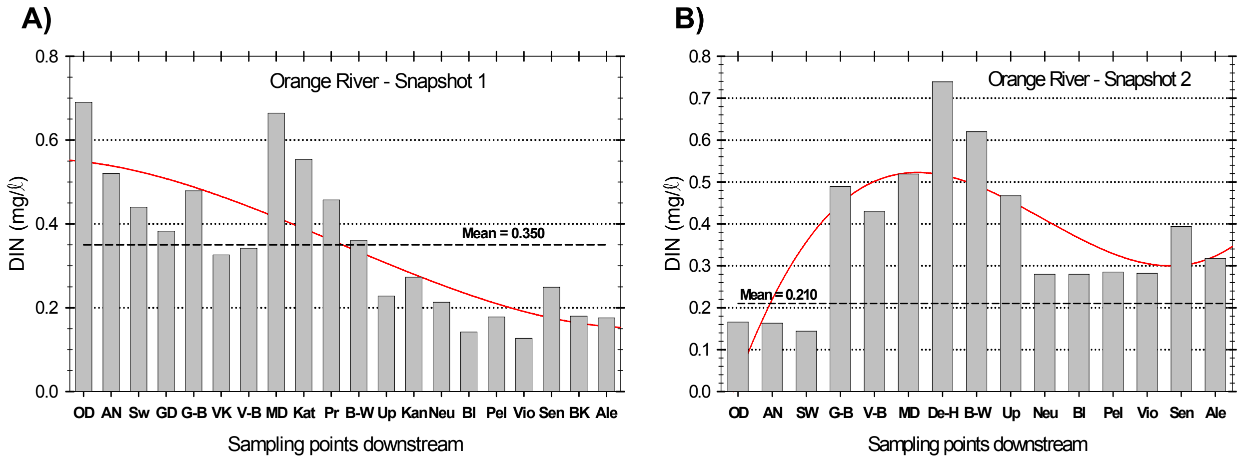


Figure 132: Spatial variation of dissolved inorganic nitrogen concentrations (DIN, mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.7 Phosphates

During snapshot survey 1, the phosphate concentrations were fairly constant from upstream to downstream (except for Oranjedraai) with a mean of 37 µg/ℓ (**Figure 133 A**). Slightly higher phosphate concentrations were recorded downstream during snapshot survey 2 (**Figure 133 B**), but generally no clear trends. The historical phosphate data also showed no significant changes downstream with an average concentration of 0.031 mg/ℓ (**Figure 134**).

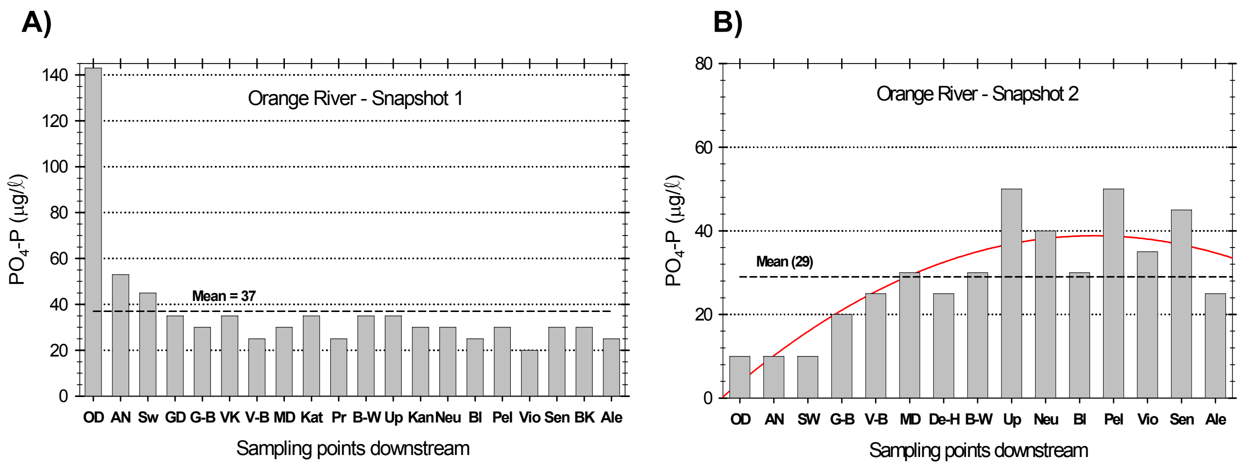


Figure 133: Spatial variation of phosphate concentrations (PO_4-P, µg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

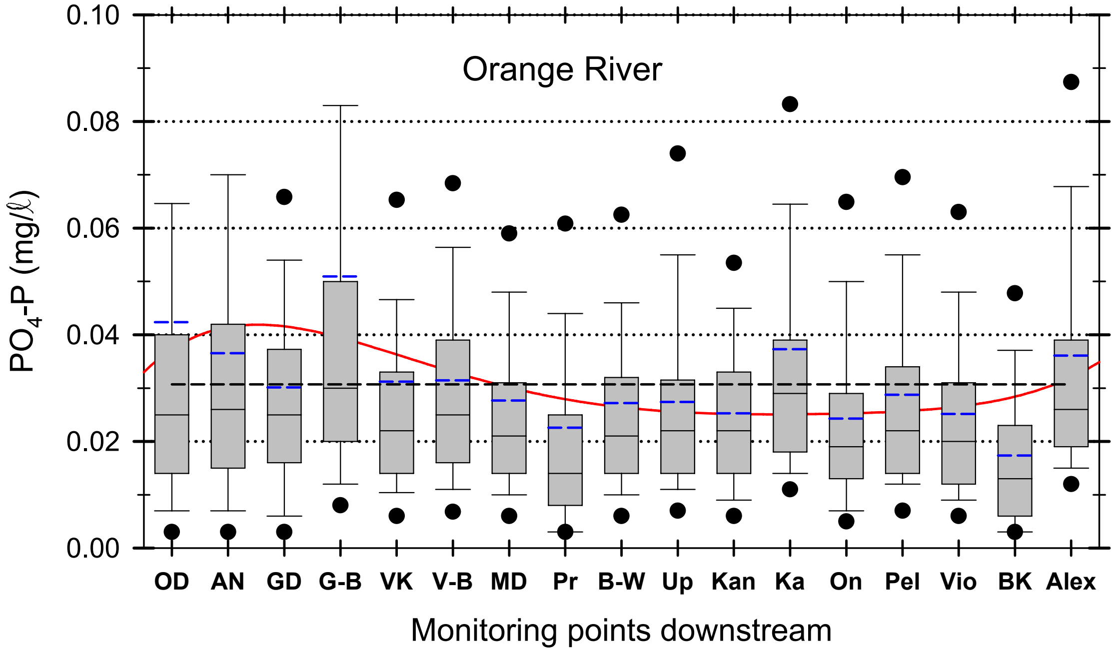


Figure 134: Box and whiskers plot of the spatial variation of phosphate concentrations (PO_4-P, mg/ℓ) in the Orange River for historical data – various time periods (1972 – 2007).

7.1.8 Turbidity

During snapshot 1, the turbidity values were significantly higher in the upper Orange River because of rainfall during the day before sampling; however, this rain had no influence on the turbidity below Gariep Dam (**Figure 135 A**). During the late winter, early spring (snapshot 2) the turbidity was low at al the sampling points (**Figure 135 B**). The general clear water conditions in the Orange River create favourable conditions for algal growth.

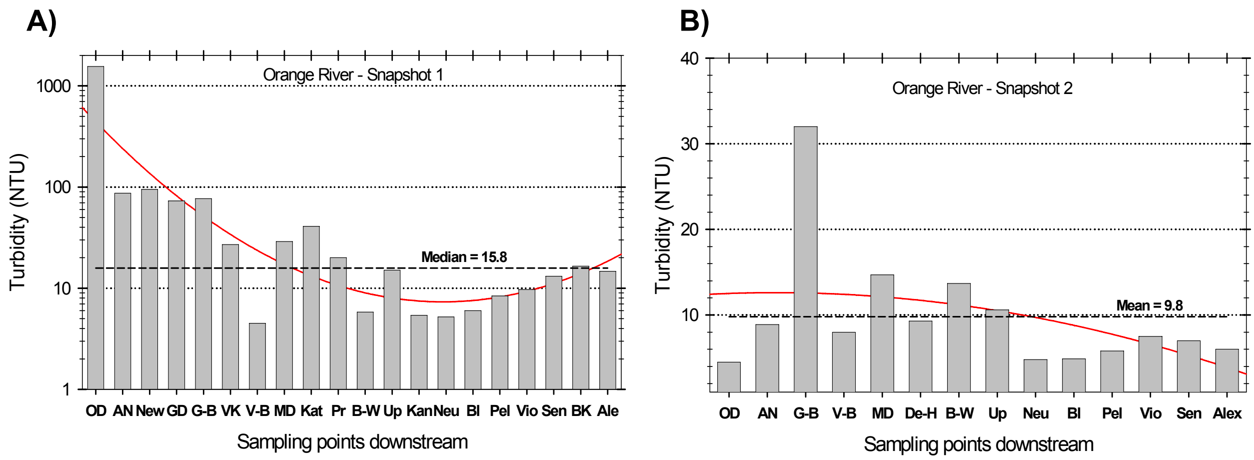


Figure 135: Spatial variation of turbidity (NTU) in the Orange River during snapshot 1 (A; note log scale on y-axis) and 2 (B), 2008.

7.1.9 Silica

The silica concentrations were generally low (mean, 6.2 and 5.0 mg/ℓ) and show a decreasing trend downstream (**Figure 136**). The historical data have also shown a temporal (time) decrease of silica at most of the sites.

A) **B)**

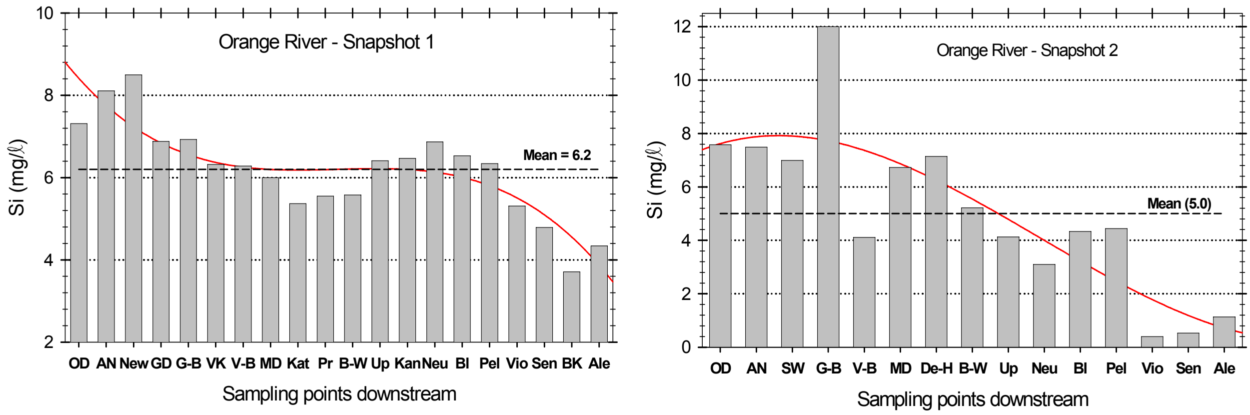


Figure 136: Spatial variation of Silica concentrations (SiO_2, mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.10 Alkalinity

The alkalinity increased significantly downstream, this is especially clear during snapshot survey 1 (**Figure 137 A**). The higher alkalinity was expected because of the positive correlation between TAL and salts.

A) **B)**

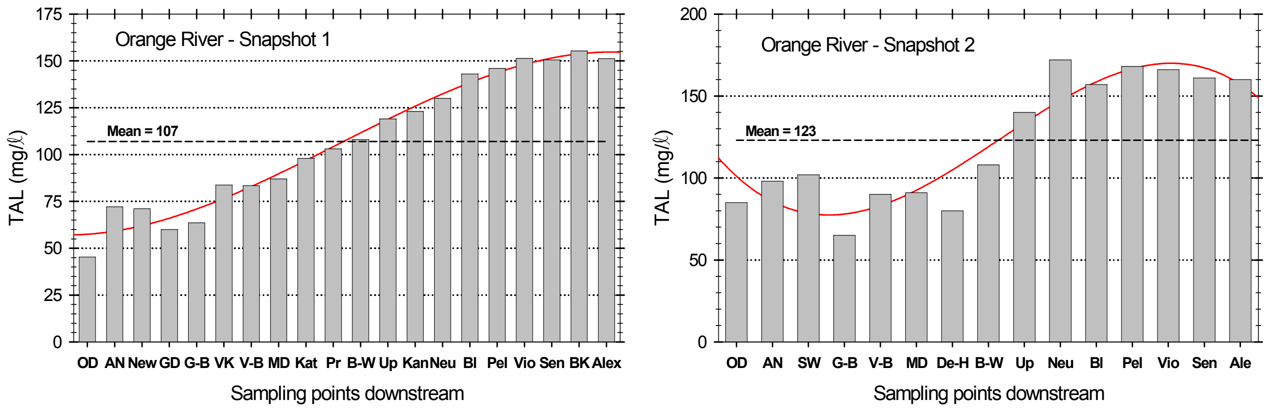


Figure 137: Spatial variation of total alkalinity (TAL, mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.11 *E. coli*

The *E. coli* concentrations in the Orange River (main stem) were high in the turbid water after rain at the upper 3 sampling points during snapshot 1, however, the median concentration was relatively low (**Figure 138 A**). The mean *E. coli* concentrations during snapshot 2 were also low (12 cfu/100 mℓ) and within the target water quality range of 130 cfu/100 mℓ for full contact recreational use (**Figure 138 B**).

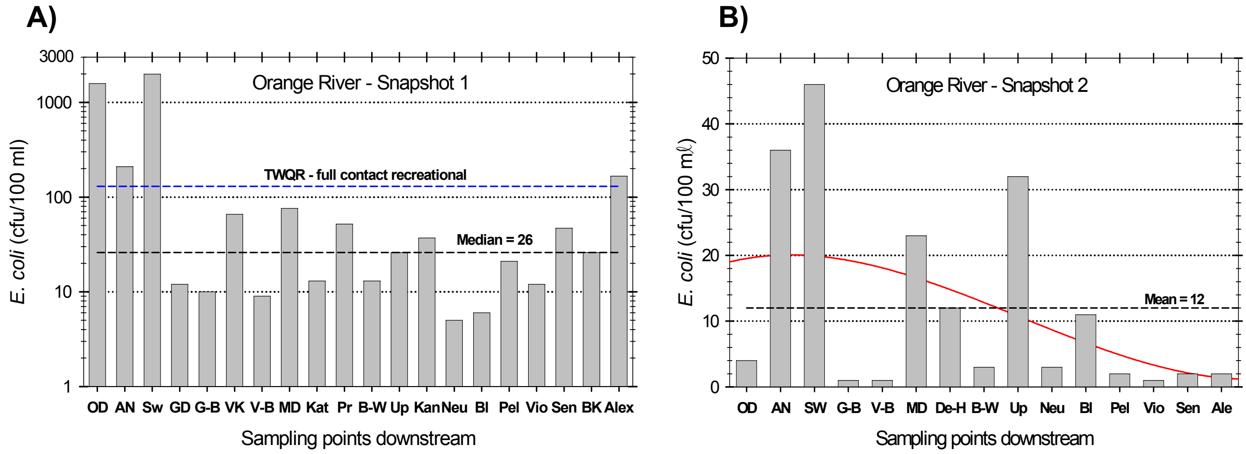


Figure 138: Spatial variation of *E. coli* concentration (cfu/100 mℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008. Note the log scale on y-axis in Fig. A.

7.1.12 Phytoplankton (Chlorophyll-*a*)

During snapshot survey 1 the chlorophyll-*a* concentrations increase significantly downstream and reach high concentrations in the lower section of the river, especially from Pella and downstream (**Figure 139**). The higher concentrations are mainly ascribed to relatively low flow rates, longer residence times and clear water conditions.

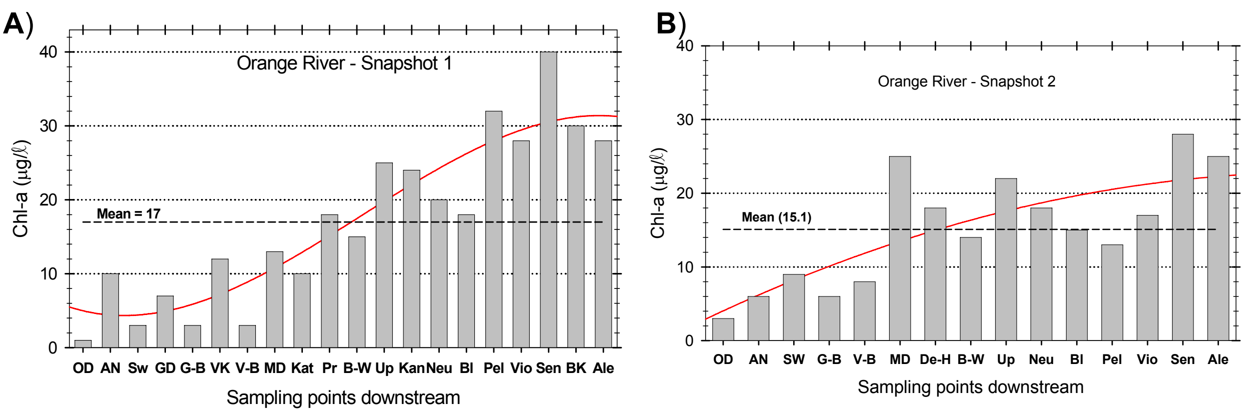


Figure 139: Spatial variation of chlorophyll-*a* concentration (Chl-*a*, µg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.13 Dissolved Oxygen

Oxygen is one of the most important factors for water quality and the associated aquatic life. Oxygen deficiency, even if it occurs only occasionally and for short periods, leads to a rapid decrease in the number of aquatic animals present, particularly clean water species, most fish, and aquatic invertebrates adapted to living in fast flowing aquatic environments – all of which depend on high levels of dissolved oxygen (Chapman, 1996).

During both snapshots, the dissolved oxygen concentrations (daytime) in the surface water of the Orange River were high (mean, >90 %) in the whole river (**Figure 140**). The increasing trend downstream is ascribed to the higher chlorophyll-*a* downstream (cf. **Figure 139**). However, because of diurnal variations in water quality, the DO concentrations can be significantly lower during night time when respiration rates are high.

The high oxygen concentrations were corroborated by the diatom index which showed that for the most part of the river the diatom oxygen requirements were continuously high, *i.e.* ~100 % saturation.

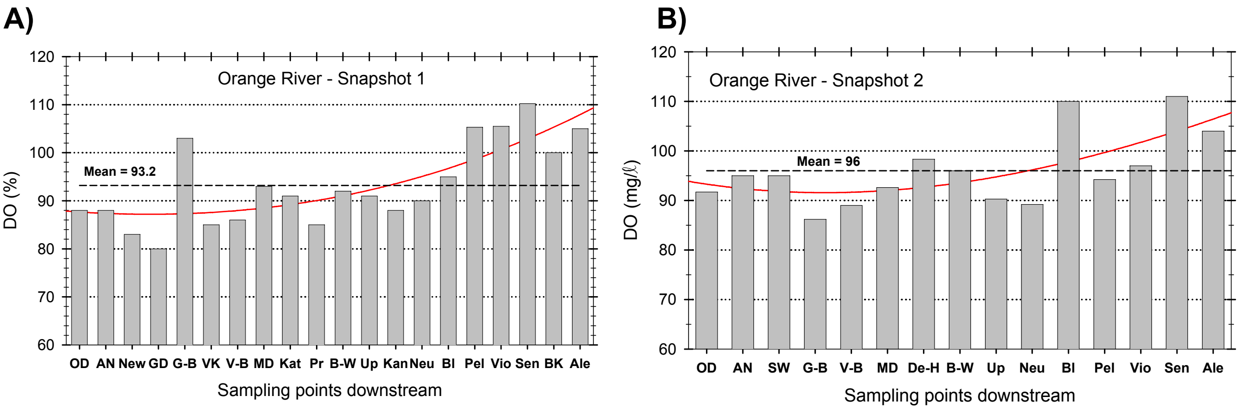


Figure 140: Spatial variation of dissolved oxygen concentrations (DO, %) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.14 Dissolved Organic Carbon (DOC)

Natural concentrations of dissolved organic carbon (DOC) are mainly dependent on environmental conditions; DOC varies from 1 mg/ℓ in the mountainous alpine environments to 20 mg/ℓ in some taiga rivers. The world DOC average is 5.75 mg/ℓ (Meybeck, 1982).

The DOC concentrations in the Orange River were relatively low and varied between 0.08 and 5.94 mg/ℓ with an overall mean of 3.0 mg/ℓ (**Figure 141**). The increasing trend downstream is ascribed to increasing algal biomass and thus higher organic load in the water. One by-product of dense algal blooms is high concentrations of dissolved organic carbon. When water with high DOC is disinfected by chlorination (during water purification), potential carcinogenic and mutagenic trihalomethanes are formed (UNP, 2000).

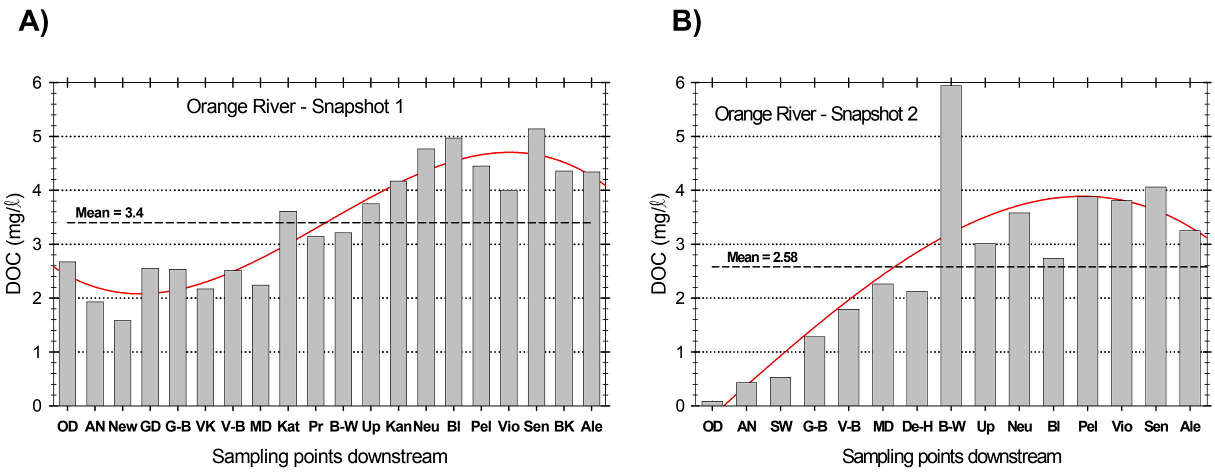


Figure 141: Spatial variation of dissolved organic carbon (DOC, mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.15 Diatom Index

Various indices are used in the River Health Programme (RHP), e.g. SASS, etc. Diatoms, although not a formal part of the RHP, are recognised as an important measuring index.

Overview:

Algae (including diatoms) and other microorganisms attached to submerged surfaces occur in most shallow aquatic habitats where there is penetration of sufficient light. In most wetlands, these aggregations of algae known as periphyton, grow attached to submerged substrata such as sediment, woody and herbaceous plants and rocky substrata. Because of their high dispersal rates, rapid growth rate and their direct response to environmental changes, algae provide the first indication of changes and are thus one of the most widely used indicators of biological integrity and physico-chemical conditions in aquatic ecosystems.

Diatoms, which constitute approximately 40% of any algal community, are unicellular, occasionally filamentous algae belonging to the group *Bacillariophyceae.* The diatoms are characterized by having a cell wall composed of silica. These microscopic organisms are found throughout most aquatic, sub-aerial and terrestrial habitats. Their communities react rapidly and specifically to changes in environmental conditions such as eutrophication, organic enrichment, salinisation and changes in pH.

Diatom community structures can be used to study current water quality as well as historical conditions. These organisms are very easy to sample and permanent records can be made from each sample collected. They differ from fish and macro-invertebrates in that, in general, they do not need any specialised food, habitat, depth or velocity of water and they occur anywhere where there is water. For these reasons, the use of diatoms for bioassessment in wetlands may provide a valuable tool for inferring water quality.

As microorganisms they lack dispersal barriers and may be transported by wind, aerosols, wading birds and may even survive passage through insect's digestive tracts. Many hundreds of thousands of cells may be produced within a few square centimetres of an aquatic environment and this adds to the ease with which they are dispersed.

As diatoms cell walls are composed mostly of silica they can remain preserved for thousands of years. These preserved cell walls or frustules when removed in a core from the sediment may be used to trace the history of a wetland. The persistence of diatoms in sediments, even when wetlands are dry, may provide a year round approach for assessing the ecological integrity of wetlands when other organisms are not present. Furthermore, their rapid growth rates enable experimental manipulation of environmental conditions to determine cause-effect relationships between diatomic response and specific environmental stressors. The cumulative response of the diatoms to environmental stressors is reflected as an index score (Taylor *et al*., 2005).

Interpretation of the Specific Pollution sensitivity Index (SPI) scores is as follows:

>17, high quality (blue line in graph);
>13 to 17, good quality (green line in graph);
>9 to 13, moderate quality (yellow line);
5 to 9, poor quality (red line) and
<5 bad quality.

The low scores at Oranjedraai and Gariep Dam (snapshot 1) were probably associated with the high turbidity and the significant organic impact after rain. For the rest of the river, the scores ranged between moderate and good quality with a decreasing trend downstream. However, during snapshot 2, the scores fell mainly in the range of good quality, with the highest score observed at Alexander Bay (**Figure 142 B**).

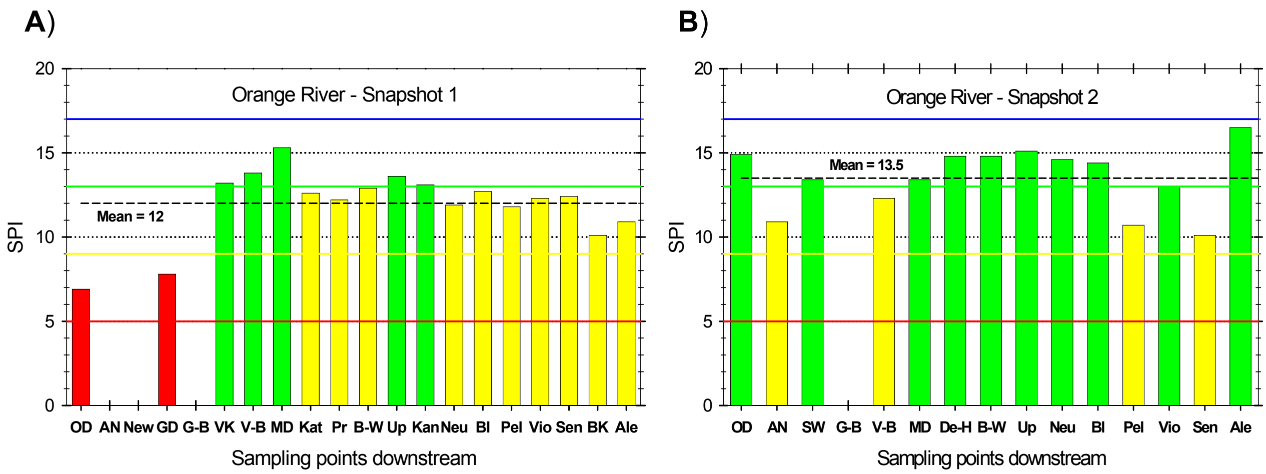


Figure 142: Spatial variation of the Specific Pollution Index (SPI) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.1.16 Metals

The aluminium concentrations were relatively high (mean, 0.069 and 0.119 mg/ℓ) with a decreasing trend downstream (**Figure 143**). The overall mean concentration for aluminium in the historical data set was 0.076 mg/ℓ.

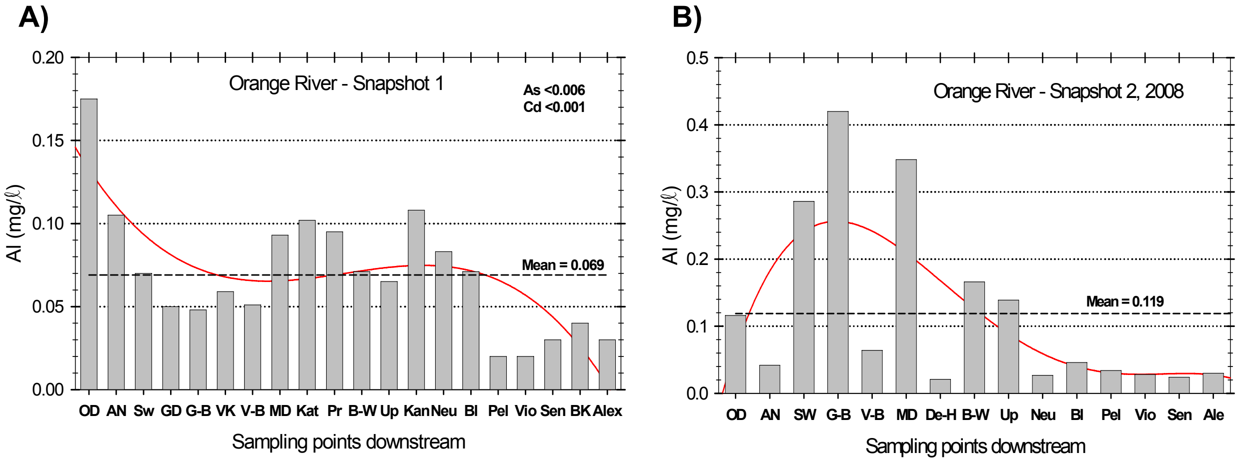


Figure 143: Spatial variation of Aluminium (Al) concentrations (mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), 2008.

The iron concentrations were fairly high and ranged between 0.01 and 0.226 mg/ℓ (mean, 0.071 mg/ℓ) which is higher than the historical data; overall mean of 0.037 mg/ℓ. The Fe concentrations were generally low (<0.05 mg/ℓ) from Blouputs (Bl) and downstream. The zinc concentrations were low (mean, 0.008 mg/ℓ) in the whole river and show no significant trend. The lead and vanadium concentrations were undetectable low in the Orange River (**Figure 144**).

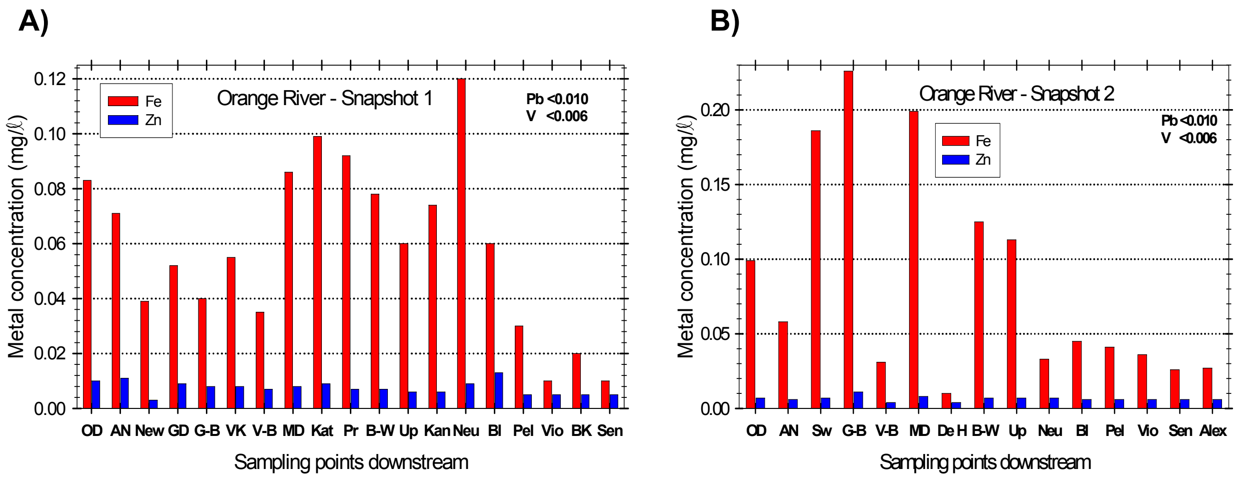


Figure 144: Spatial variation of iron (Fe) and zinc (Zn) concentrations (mg/ℓ) in the Orange River during snapshot 1 (A) and 2 (B), (2008).

7.2 Level 2 monitoring sites on the tributaries of Orange River

The major tributaries of the Orange River include the Kornetspruit, Sterkspruit, Kraai River, Stormbergspruit, Seekoei River, Riet, and Vaal River. The Caledon River is also an important tributary, but is dealt with separately in section 8.

7.2.1 Dissolved major salts (DMS)

The dissolved salts in the Kornetspruit, Sterkspruit, and Kraai River were low (<200 mg/ℓ) and within the TWQR for irrigation and drinking water. However, the salts in Stormbergspruit, Seekoei, Riet and Vaal River were usually >400 mg/ℓ and above the TWQR for irrigation and domestic use (**Figure 145**).

The high salts in the Stormbergspruit were associated with sewage pollution, with irrigation return flows in the Riet River, and with industrial and irrigation return flows in the Vaal River. However, the high salts in the Seekoei River appear to be natural.

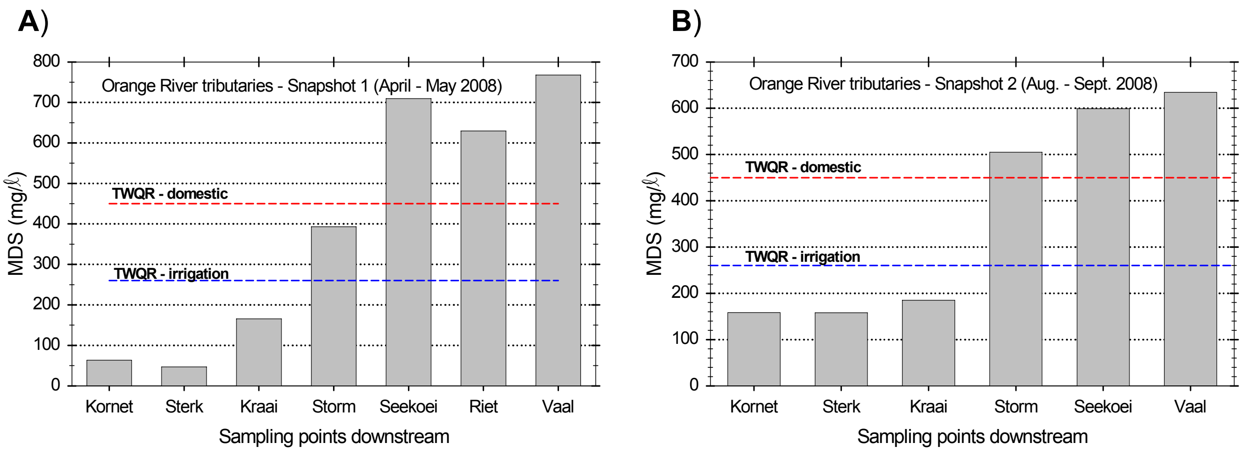


Figure 145: Spatial variation of dissolved major salts (DMS, mg/ℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), 2008. The upper level of the target water quality range for irrigation and domestic water are indicated in the graph as dashed lines.

It is well-known that salinisation is big problem in the Vaal and Riet Rivers. The Water Users Association (WUA) chairperson at Douglas (Mr. Willie Bruwer) provided us with salinity data (TDS) at various sites in their irrigation area. The TDS concentrations in the Vaal River (upstream in weir) and Riet River before confluence with the Vaal River are shown in **Figure 146**.

The high TDS concentrations in both rivers (Vaal: mean, 502 mg/ℓ; Riet: mean, 857 mg/ℓ) and the increasing trend is evident from **Figure 146**.

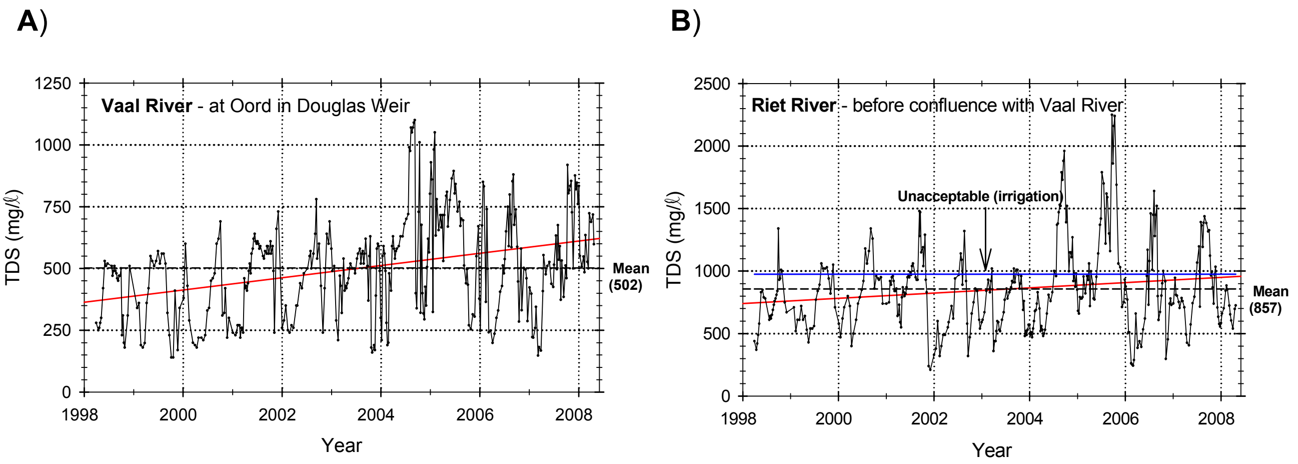


Figure 146: Temporal variation of total dissolved salts (TDS) concentrations (in mg/ℓ) for the period 1998 – 2008 in A) the Vaal River (in Douglas weir) and B) in the Riet River (before its confluence with the Vaal River). Data: WUA, Douglas.

The sodium (Na) ions dominate in the more polluted sites, *i.e.* Strombergspruit, Seekoei, Riet and Vaal Rivers. Calcium (Ca) usually dominates in the 'unpolluted' sites, *i.e.* Kornetspruit, Sterkspruit and Kraai River (**Figure 147**).

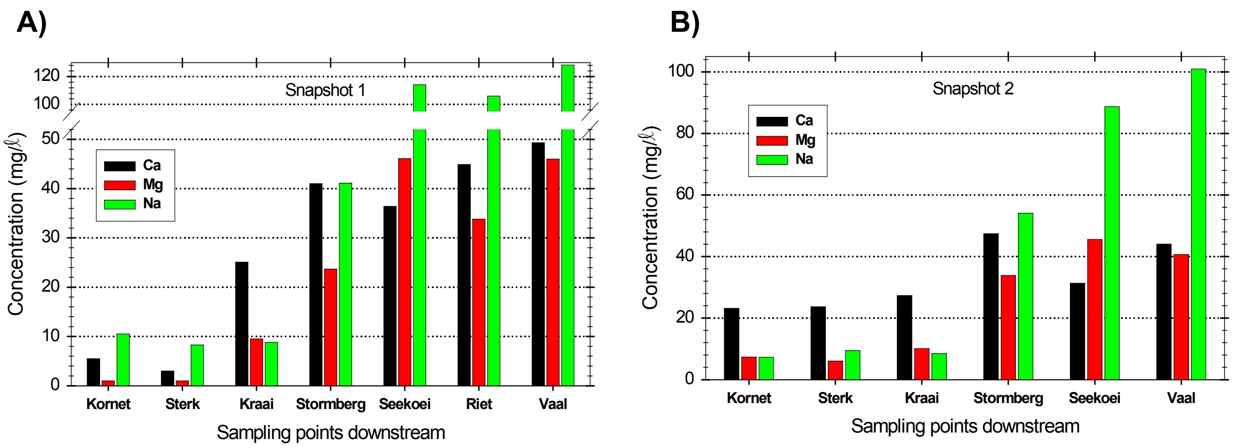


Figure 147: Spatial variation of sodium, magnesium and calcium concentrations (mg/ℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B) (2008).

7.2.2 Anions

The chloride and sulphate ions were low in the Kornetspruit, Sterkspruit, and Kraai River and high in the Stormbergspruit, Seekoei, Riet and Vaal Rivers (**Figure 148**).

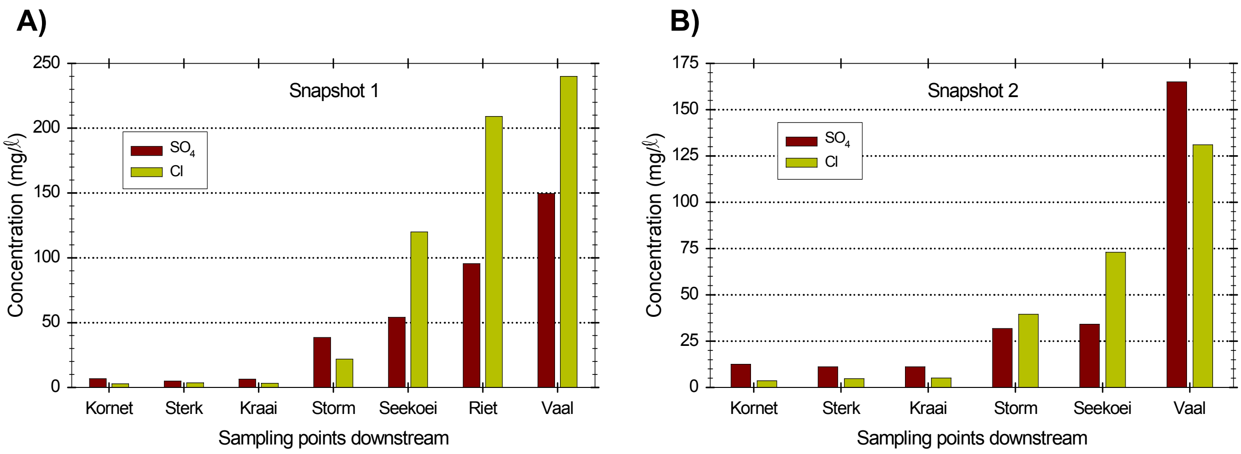


Figure 148: Spatial variation of sulphate and chloride concentrations (mg/ℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), 2008.

The dissolved organic carbon (DOC) concentrations were always high in the more polluted sites (Stormbergspruit, Seekoei, Riet and Vaal Rivers) (**Figure 149**). During low flow conditions (snapshot 2), the DOC concentrations were very low in the 'unpolluted' sites (Kornetspruit, Sterkspruit, and Kraai River), while the Si concentrations were high.

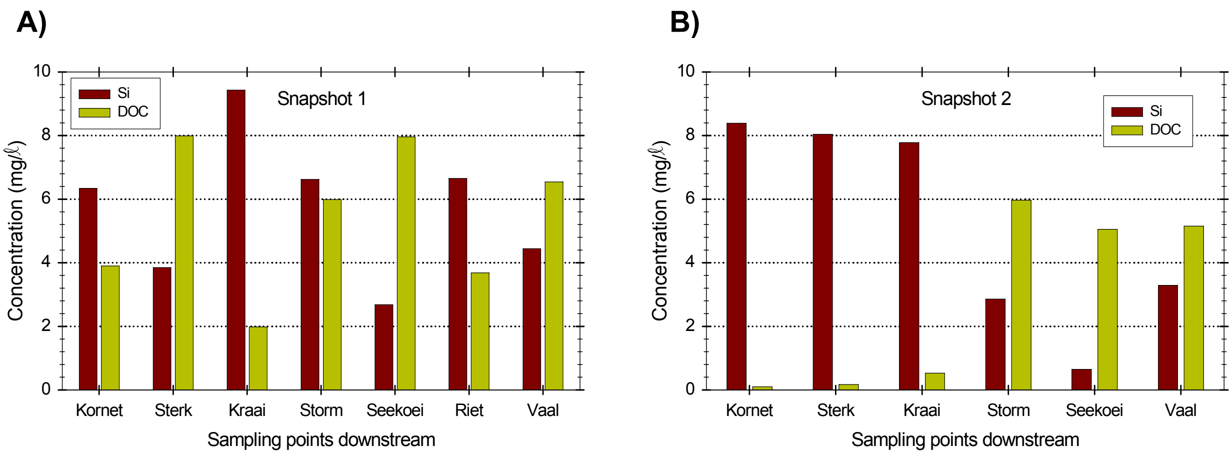


Figure 149: Spatial variation of silica and dissolved organic carbon (DOC) concentrations (mg/ℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), (2008).

7.2.3 Nutrients (Dissolved inorganic nitrogen, DIN and Phosphorus, DIP)

The sources of ammonium may be organic matter including fertilisers using ammonia salts, sewage or organic industrial effluents. The Stormbergspruit was over-enriched with nitrogen which indicates sewage pollution. The phosphates were generally low (<0.10 mg/ℓ), but exceptionally high (1.15 mg/ℓ) in Stormbergspruit during snapshot 2 (**Figure 150**).

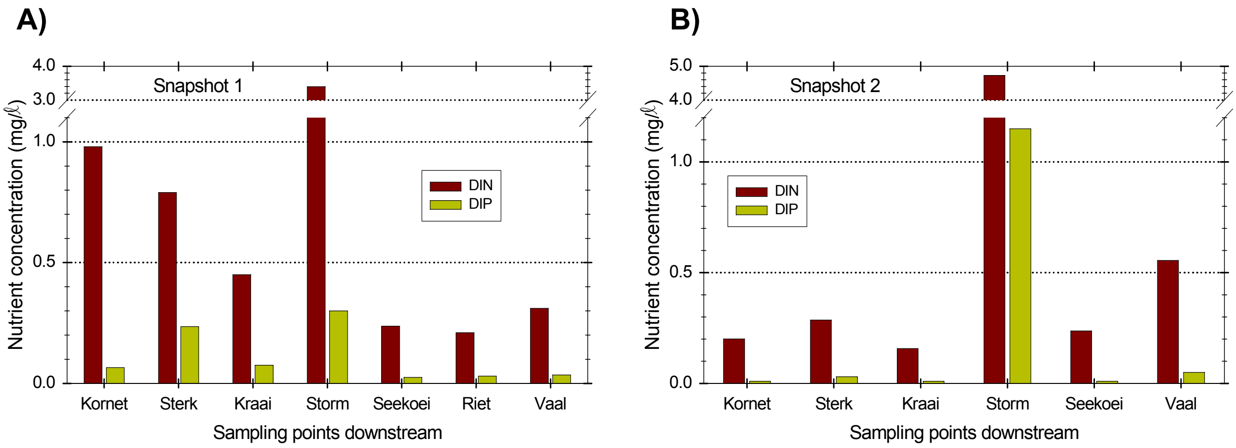


Figure 150: Spatial variation of dissolved inorganic nitrogen (DIN) and phosphorus (DIP) concentrations (mg/ℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.2.4 Phytoplankton (Chlorophyll-*a*)

The algal biomass was very low in Kornetspruit and Sterkspruit because of the relatively high flow and very high turbidity during sampling (Snapshot 1, **Figure 151 A**). The Chl-*a* concentrations in the fast flowing Kraai River were low (<5 µg/ℓ) during both snapshot surveys. The chlorophyll-*a* concentrations in the Stormbergspruit were moderately high but the Vaal River reach high levels (bloom condition) during snapshot 2 (**Figure 151 B**).

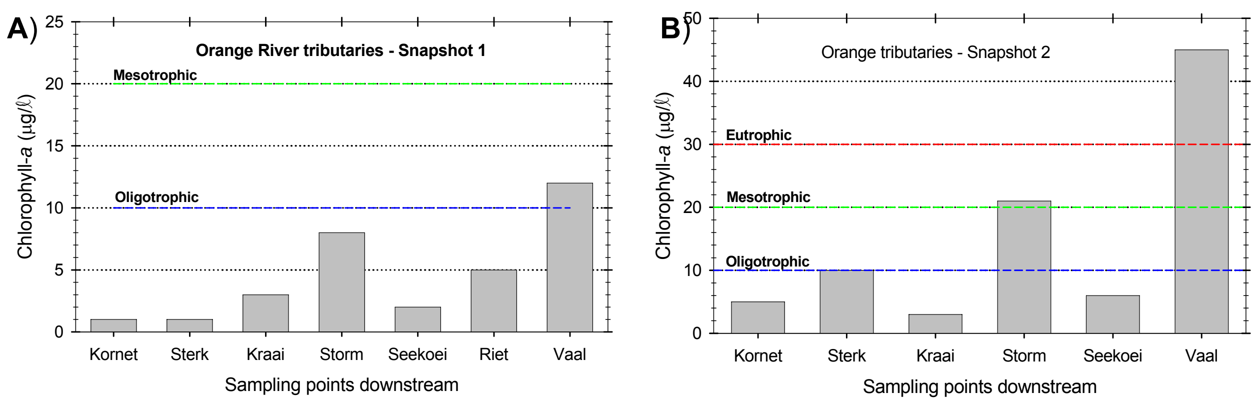


Figure 151: Spatial variation of chlorophyll-*a* concentrations (µg/ℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), 2008.

7.2.5 Diatom index

During snapshot 1, the diatom SPI scores were generally low (<13) indicating moderate quality but poor quality in the Riet River. During snapshot 2, the SPI scores were good in the Kornetspruit, Sterkspruit, Kraai and Seekoei Rivers, but poor in the Stormbergspruit associated with the sewage pollution occurring upstream of this site. The Vaal River scores were associated with moderate quality during both snapshots (**Figure 152**).

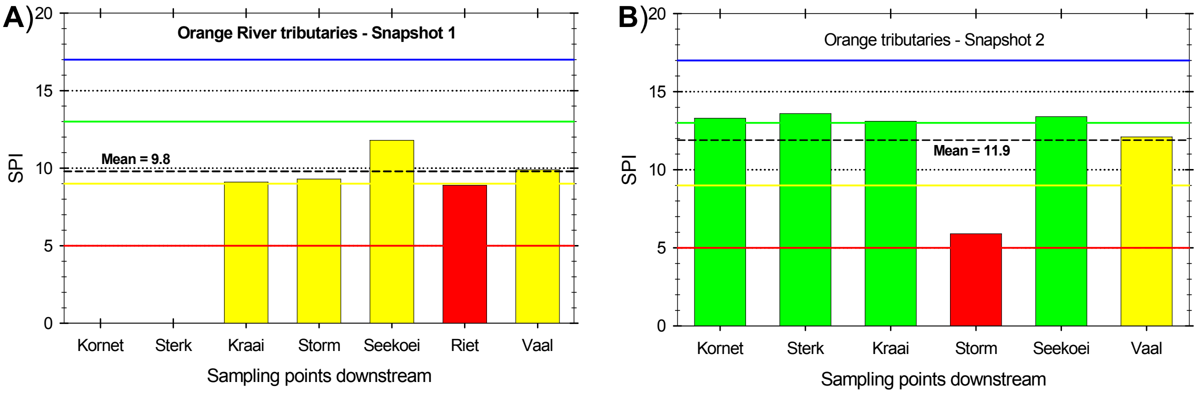


Figure 152: Spatial variation of the Specific Pollution Index (SPI) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), 2008. Red = Poor quality; Yellow = Moderate; Green = Good quality.

7.2.6 Bacteriological (*E. coli*)

The high *E. coli* in Sterkspruit and Kornetspruit was associated with higher flow conditions and turbid conditions after rain (impurities washed in). The high concentration in Stormbergspruit was associated with the poorly treated sewage upstream of this site. During snapshot 2, Stormbergspruit and the Vaal River *E. coli* concentrations were higher than the ideal for full contact recreation (130 cfu/100 mℓ). The *E. coli* concentrations in the Kraai and Seekoei Rivers were acceptable during both snapshot surveys (**Figure 153**).

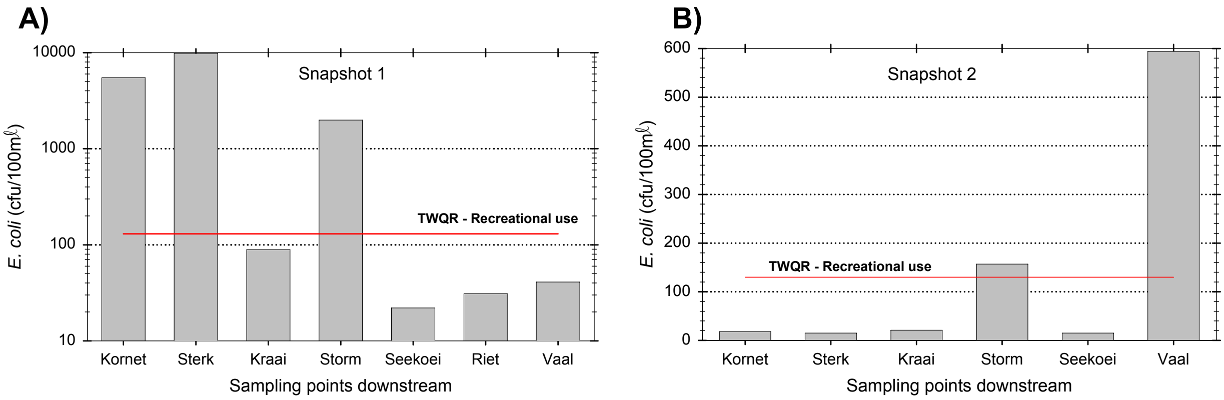


Figure 153: Spatial variation of *E. coli* concentrations (cfu/100 mℓ) in selected tributaries of the Orange River during snapshot 1 (A) and 2 (B), 2008. Note log scale on y-axis for graph A.

7.3 Monitoring sites on Caledon River system – level 1 & 2

Reults for the Caledon River and its tributaries are discussed in the sections below, where shaded bars in the graphs represent the main stem of the Caledon River and tributaries are represented by a solid bar. Abbreviations for the sites used in the graphs following sections are listed in **Table 6** below:

Table 6: Abbreviations for site names used in the graphs

Site Name	Abbreviation
Little Caledon River near Golden Gate	**LC-G**
Little Caledon River at the confluence with the Caledon	**LC-C**
Caledon River at the confluence with the Little Caledon	**Cal-C**
Grootspruit	**Gro**
Caledon River at Ficksburg	**C-Fic**
Meulspruit	**Meul**
Moperispruit	**Mop**
Caledon at Maseru	**C-Mas**
Leeu River	**Leeu**
Caledon River at 10 Fontein pump station	**C-10**
Skulpspruit	**Skulp**
Caledon River at N6 road crossing (= Kommissiedrift).	**C-N6**

7.3.1 Dissolved major salts (DMS)

The dissolved salts in the Caledon River (shaded bars) were moderate and within the ideal range for irrigation (260 mg/ℓ), however, the salts in the tributaries were generally higher than the TWQR for irrigation (**Figure 154**).

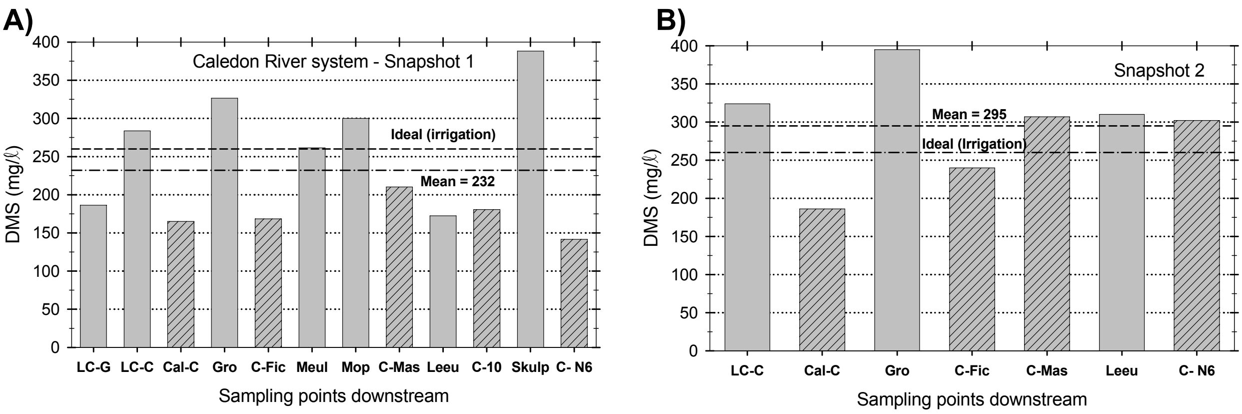


Figure 154: Spatial variation of dissolved major salts (DMS) concentrations (mg/ℓ) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), 2008.

7.3.2 Bacteriological (*E. coli*)

The *E. coli* in the Caledon River were generally high (>1 000 cfu/100 mℓ), especially at Ficksburg and Maseru, which indicates sewage pollution contamination from the towns (**Figure 155**). Grootspruit and Leeu River also show faecal contamination.

Little Caledon at Golden Gate (LC-G) and Meulspruit were the less contaminated sites.

A) B)

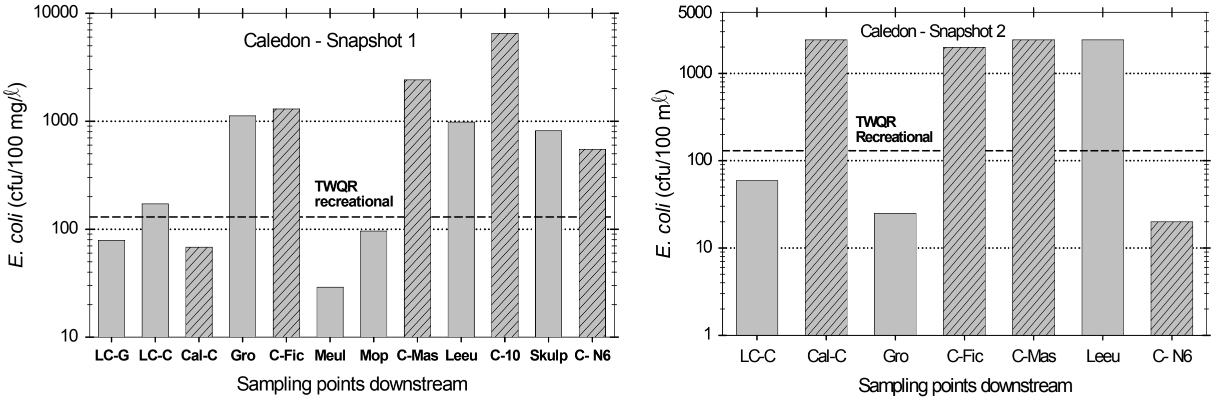


Figure 155: Spatial variation of *E. coli* concentration (cfu/100 mℓ) in the Caledon River and tributaries during snapshot 1 (A) and 2 (B), (2008). Note log scale on y-axes.

7.3.3 Turbidity

The turbidity values in the Little Caledon River were very low (<4 NTU), indicating low suspended material and clear water conditions during snapshot 1 and 2 (**Figure 156**). The Caledon River is known for a high sediment load in the river, but high turbidity (>100 NTU) were only observed in the lower end of the river (snapshot 1). However, the turbidity in the Caledon River during snapshot 2 (August) was very low (except at Maseru) and typical of the winter clear water conditions **(Figure 156**). See also picture below (**Figure 157**).

A) B)

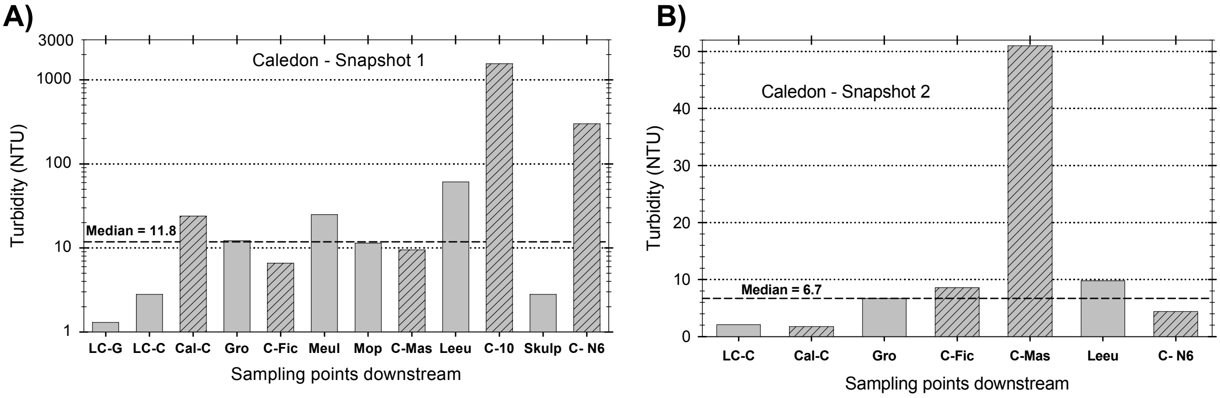


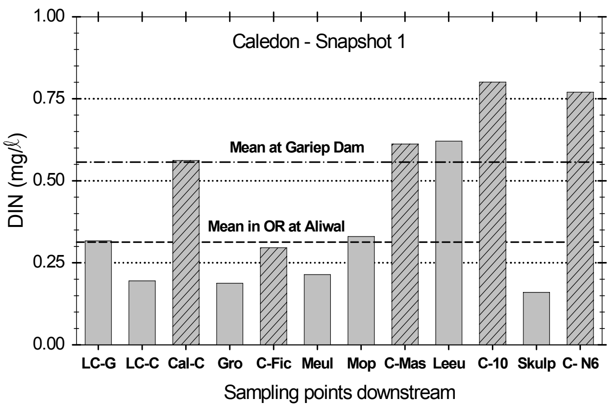
Figure 156: Spatial variation of Turbidity (NTU) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), 2008. Note log scale on y-axis for graph A.

Figure 157: Clear water (low turbidity, 1.8 NTU) of the Caledon River at the confluence with the Little Caledon River during snapshot 2 (28 August, 2008).

7.3.4 Dissolved inorganic nitrogen (DIN)

The DIN concentrations in the Caledon River were generally high (>0.5 mg/ℓ) especially at Ficksburg and Maseru (snapshot 2) (**Figure 158**). Most of the tributaries have DIN concentrations less than 0.5 mg/ℓ.

A)



B)

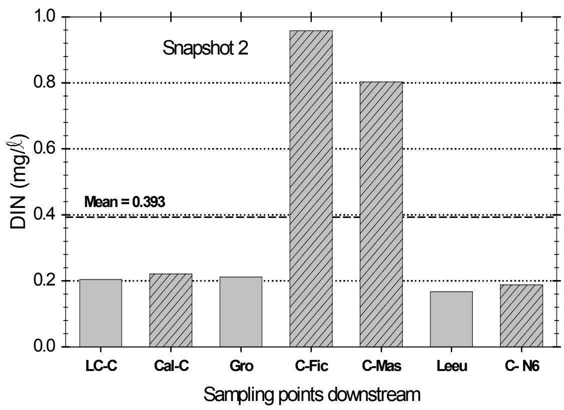


Figure 158: Spatial variation of dissolved inorganic nitrogen (DIN) concentrations (mg/ℓ) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), 2008.

7.3.5 Phosphates

The phosphate concentrations in the Caledon River showed an increasing trend downstream during snapshot 1 and were high (>50 µg/ℓ) from Maseru and downstream (**Figure 159 A**). During snapshot 2, high phosphate concentrations were recorded in Grootspruit, and Caledon River at Ficksburg and Maseru (**Figure 159 B**).

A) **B**)

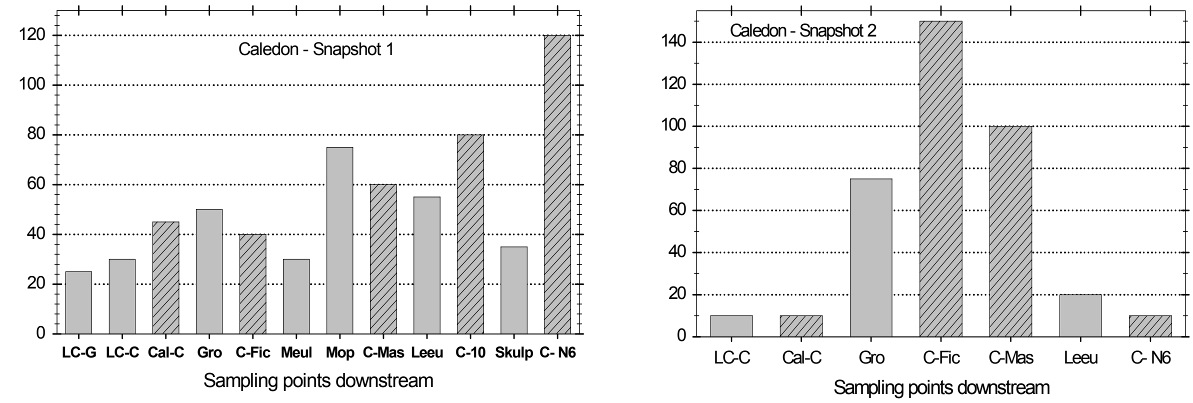


Figure 159: Spatial variation of phosphate concentrations (PO_4-P, µg/ℓ) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), 2008.

7.3.6 Phytoplankton (Chlorophyll-*a*)

The algal biomass in the Caledon and tributaries were generally low during both snapshot surveys, except for Moperispruit with a high Chl-*a* of 30 µg/ℓ (**Figure 160**).

A) **B)**

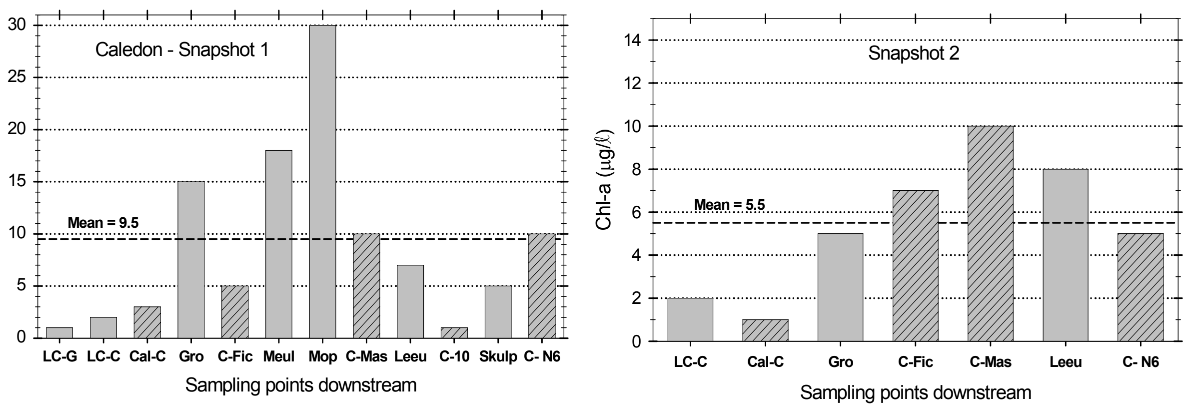


Figure 160: Spatial variation of chlorophyll-*a* concentrations (µg/ℓ) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), 2008.

7.3.7 Periphyton (Diatoms)

During snapshot survey 1, the SPI scores were generally low with poor quality scores at Little Caledon at confluence, Caldon River below Ficksburg, Moperispruit and Caledon below Maseru. The Little Caledon River, Caledon at Confluence and Leeu River were of good quality.

The highest score recorded during both snapshots and all the sites sampled, was 16.3 in the Grootspruit (**Figure 161 B**). The diatom index shows a poor water quality in the Caledon at Maseru on both occasions. The percentage pollution tolerant valves (% PTV) were on both occasions also more than 20 that indicate significant organic impact.

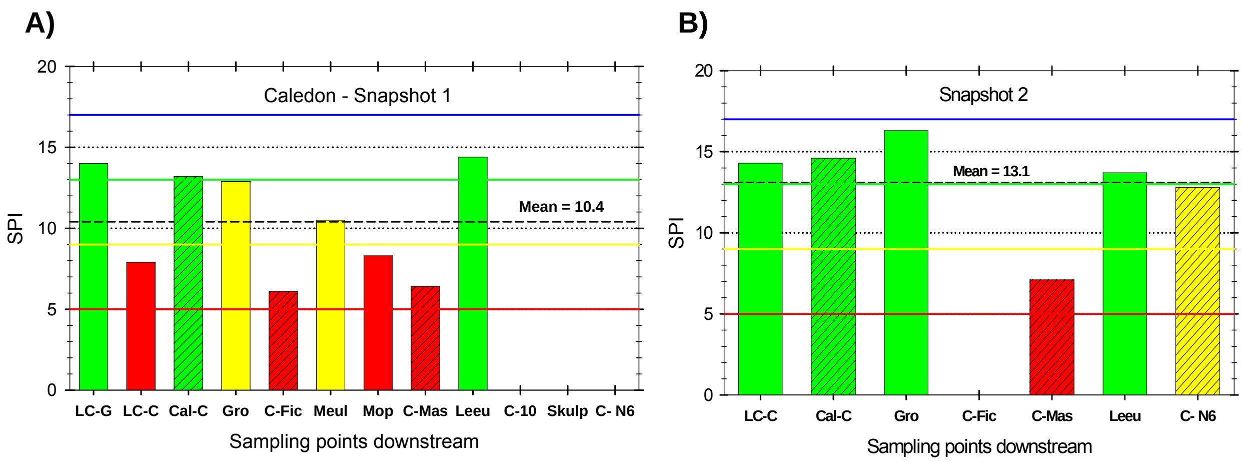


Figure 161: Spatial variation of the specific pollution index (SPI) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), (2008). Red = Poor quality; yellow = Moderate quality; Green = Good quality.

7.3.8 Metals

The metal concentrations in the Caledon River and tributaries were generally low (**Figures 159 & 160**).

The aluminium concentrations were less than 150 µg/ℓ (ideal for domestic use) at all the sites during snapshot 1; higher during snapshot 2, but still acceptable (<500 µg/ℓ) for domestic use, but concentrations >150 µg/ℓ could be detrimental to aquatic ecosystems. The iron concentrations were less than 200 µg/ℓ which is still acceptable for domestic use and irrigation. The arsenic (As) and cadmium (Cd) concentrations were less than the detection limits at all sites (**Figure 162**).

The copper and zinc concentrations were within the ideal range for domestic use. However, the high copper concentration (40 µg/ℓ) below Maseru (**Figure 163 A**) is regarded as potentially hazardous to the aquatic environment.

The relative high manganese concentrations in the Grootspruit (average, 77 µg/ℓ) and the spike (105 µg/ℓ) in the Little Caledon River is a matter of concern and should be investigated further (**Figure 163**).

A) **B)**

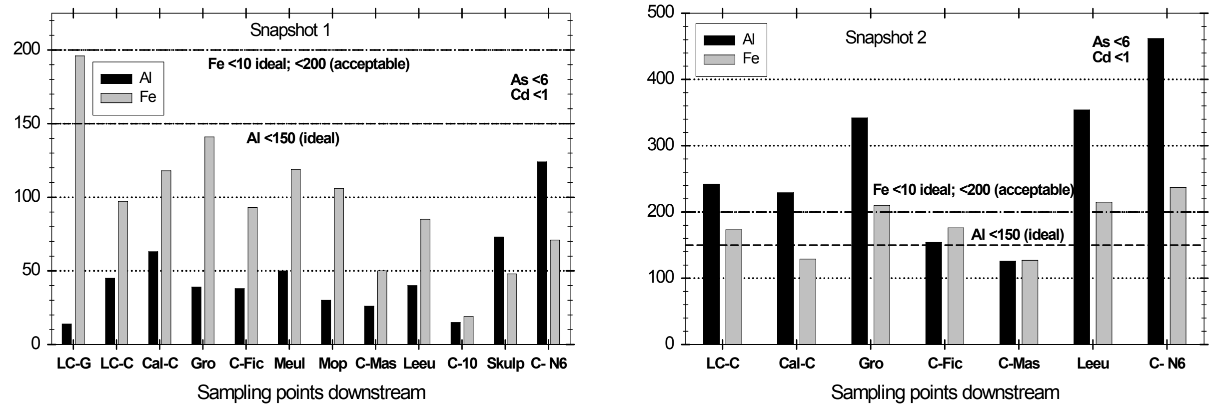


Figure 162: Spatial variation of Aluminium and Iron concentrations (µg/ℓ) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), (2008).

A) **B**)

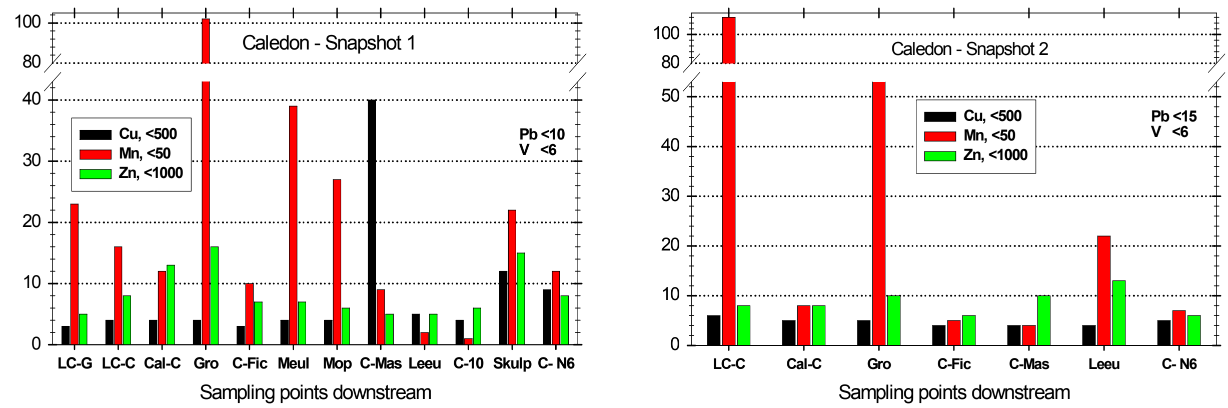


Figure 163: Spatial variation of Copper, Manganese, and Zinc concentrations (µg/ℓ) in the Caledon River and some tributaries during snapshot 1 (A) and 2 (B), (2008).

7.3.9 Other parameters

The water temperatures were generally low and ranged between 7.0 and 15.2 ºC. Interesting to note is that the extreme temperatures were measured about 50 metres apart, *i.e.* at the confluence of the Little Caledon and Caledon Rivers. The temperature in the Little Caledon River, draining from the high cold mountains area from Golden Gate, moving through gorges and well shaded by riparian vegetation, was only 7.0 ºC (28/08/2008), whilst the temperature in the Caledon River was at the same time 15.2 ºC.

The Caledon River is broad, shallow (large area expose to sunlight), and slow moving with limited riparian vegetation that could shade the water.

The pH values in the Caledon River were generally high and ranged between 7.9 and 8.4. The pH values in the tributaries were slightly lower and ranged between 7.4 (Leeu River) and 8.4 (Grootspruit). The higher pH values were usually associated with higher photosynthetic activity.

The dissolved oxygen (DO) concentrations in the Caledon River and tributaries were generally high (>70 %) and occasionally supersaturated. For example, the DO in the Grootspruit was 13.9 mg/ℓ (120 %) although the phytoplankton concentration was very low at only 5 μg/ℓ. The high DO is ascribed to periphyton (attached algae) that produces oxygen through photosynthesis - see gas bubbles in **Figure 164**.

Figure 164: Periphyton (including diatoms) attached to stones in Grootspruit during snapshot 2 (August, 2008) – note oxygen bubbles produced during photosynthesis.

8 STATUS QUO

Clean and safe water is necessary for human beings, as well as all life on earth. How clean is 'clean' and how safe is 'safe' for different users and with respect to the suitability of water for an intended purpose. It is not a simple thing to say that "this water is good," or "this water is bad", thus we rely on scientific measurements and judgements to help answer this question.

At a given river monitoring site water quality depends on many factors: (i) the proportion of surface run-off and groundwater, (ii) reactions within the river system governed by internal processes, (iii) the mixing of water from tributaries of different quality (in case of heterogeneous river basins), and (iv) inputs of pollutants. Based on these factors a water quality issue may arise for a particular user(s). A water quality issue may be defined as a water quality problem or impairment which adversely affects the water to an extent which inhibits or prevents some beneficial water use (Chapman, 1996).

In order to determine the suitability of the water quality in the Orange River for the various user requirements in the catchment the South African Water Quality Guidelines (SAWQGs) (DWAF, 1996) for the different water users was used to compare the observed water quality to the target water quality ranges specified. Currently no resource water quality objectives (RWQOs) have been set for the Orange River thus the reliance on the SAWQGs. See Report No. 5 for RWQOs for the Orange River.

Although there are a lot of data available on the Orange River, little work has been done on the evaluation of the natural conditions that influence the inorganic water chemistry. Therefore natural condition of the Orange River has been evaluated in order to develop baseline information so that it can be used for comparison, monitoring and informed decision-making.

Data for the major parameters were used for the last 3 years (2005 – 2007) and if no data were available (*i.e.* new sites) then data from the snapshot surveys (2008) were used. This includes monitoring sites like Prieska and Alexander Bay where data collection were terminated in 2001 and 2003 respectively.

The 95th percentile values for all the water quality variables were used for the comparison against the water quality criteria except for the Chl-*a* and phosphates (median is used). Comparison was made against DWAF's water quality guidelines for domestic use, agricultural use specifically irrigation, recreational use, industrial use (category 3), and for the Aquatic ecosystem (DWAF, 1996). For domestic use, turbidity and *E. coli* were not considered because it is accepted that the 'raw' water needs to be purified before use. Domestic use includes a variety of activities, including drinking, food and beverage preparation, hot water systems, bathing and personal hygiene, dish washing, laundry, and gardening which may include water for fish ponds.

8.1 Orange River – main stem

8.1.1 Domestic use:

The water quality (excluding turbidity and *E. coli*) from the Upper Orange River (OS1 to OS6), even the raw water concentrations, complied with the Target water quality range (TWQR) for domestic use and with proper treatment, probably ideal for drinking water (**Table 7**). The metal concentrations were mostly in the ideal range, with a few concentrations in the acceptable range It is only the lead concentration in Vanderkloof Dam that was in the tolerable range (>50 µg/ℓ) (**Table 9**).

In the Lower Orange River (OS7 to OS19), the water quality also complied with the domestic use ideal or acceptable ranges (**Table 8**) except for the high lead (tolerable) at Upington, Neusberg weir, and Vioolsdrift. The concentrations of cadmium and lead were unacceptable high at Pella, and the Cd concentration was high (tolerable) at Vioolsdrift (**Table 10**).

8.1.2 Agriculture (Irrigation):

The water in the Upper and Lower Orange River was found to be suitable for irrigation, except for the high suspended solids at Oranjedraai and Vanderkloof Dam (**Tables 11** and **12** & **7**). However, high suspended solids (>100 mg/ℓ) is only a problem for drip irrigation systems and not for flood irrigation. The high pH at Sendelingsdrift and high sodium at Alexander Bay were in the tolerable range but become only unacceptable when Na >460 mg/ℓ.

In the Lower Orange River, the salts concentrations were above the ideal (260 mg/ℓ) for irrigation (except at Prieska) but still in the acceptable range (< 585 mg/ℓ).

The main water users in the Orange River are for irrigation, livestock watering and domestic consumption, thus play an important role in the determination of the resource water quality objectives (RWQOs) – see Report No. 5.

Table 7: Water quality status (2005 – 2007) of the Upper Orange River (WMA 13) – Main stem – level 1 for Domestic use (1/2)

Sample point	Sample description	Station	Domestic (mg/L)										
			Ammonium (NH_4-N)	Calcium (Ca)	Chloride (Cl)	Dissolved solids (TDS)	EC (mS/m)	Fluoride (F)	Magnesium (Mg)	Nitrate (NO_3-N)	Potassium (K)	Sodium (Na)	Sulphate (SO_4)
OS1	Oranjedraai	D1H009	0.138	27.7	7.3	193.8	24.9	0.20	10.1	0.51	1.62	6.3	12.8
OS2	Aliwal North	D1H003	0.101	27.4	8.3	216.3	28.7	0.25	12.2	0.37	1.36	7.2	15.6
Spec	Gariep Dam	D3R002	0.126	22.7	8.4	168.2	23.9	0.21	8.3	0.46	2.15	8.1	15.8
OS4	Roodepoort	D3H013	0.110	22.2	8.0	167.2	22.7	0.23	8.2	0.44	1.72	7.8	16.1
Spec	Vanderkloof Dam	D3R003	0.131	22.4	7.6	161.8	22.6	0.22	8.2	0.49	1.84	7.9	14.5
OS5	Dooren Kuilen	D3H012	0.100	22.5	7.9	163.0	22.1	0.22	8.6	0.49	1.73	7.8	12.8
OS6	Marksdrift	D3H008	0.108	24.8	13.2	196.2	29.7	0.25	10.1	0.53	1.92	13.7	20.8

Water Quality Guidelines:

Ideal	Acceptable	Tolerable	Unacceptable

Table 8: Water quality status (2005 – 2007) of the Lower Orange River (WMA 14) – Main stem – level 1 for Domestic use (1/2)

Sample point	Sample description	Station	Domestic (mg/L)										
			Ammonium (NH_4-N)	Calcium (Ca)	Chloride (Cl)	Total diss solids (TDS)	EC (mS/m)	Fluoride (F)	Magnesium (Mg)	Nitrate (NO_3-N)	Potassium (K)	Sodium (Na)	Sulphate (SO_4)
OS8	Prieska	D7H002	0.155*	26.7*	24.7*	238.4*	30.0*	0.19*	12.4*	0.30*	2.23*	27.0*	36.2*
OS9	Boegoeberg Dam	D7H008	0.132	33.2	44.3	345.6	51.2	0.26	17.9	0.59	3.49	35.7	54.7
OS11	Upington	D7H005	0.135	36.5	53.5	402.5	60.5	0.33	21.5	0.58	3.68	48.9	72.2
OS13	Neusberg weir	D7H016	0.134	36.8	42.2	384.0	55.9	0.34	20.8	0.40	2.73	44.4	56.4
OS15	Pella	D8H008	0.117	41.9	66.1	474.0	68.5	0.42	24.4	0.53	3.33	64.8	77.3
OS16	Vioolsdrift	D8H003	0.125	41.1	78.5	508.9	74.5	0.48	26.2	0.55	3.45	73.4	85.5
OS18	Sendelings-drift	New	0.080*	35.4*	71.0*	433*	61*	0.40*	21.1*	0.24*	3.0*	66.1*	78.0*
OS19	Alexander Bay	D8H012	0.068*	38.6*	79.4*	456.0*	62.5*	0.38*	21.7*	0.18	3.1*	70.8*	83.5*

* 2008 Snapshot 1 & 2 mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 9: **Water quality status (2005 – 2007) of the Upper Orange River (WMA 13) – Main stem – level 1 for Domestic use (2/2)**

Sample point	Sample description	Station	Domestic – metals (µg/L)										
			Aluminium (Al)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)
OS1	Oranjedraai	D1H009	146*	<6*	<1*	–	7*	92*	<10*	7*	–	<6*	9*
OS2	Aliwal North	D1H003	74*	<6*	<1*	–	8*	65*	<10*	11*	–	<6*	8*
Spec	Gariep Dam	D3R002	50*	<6*	<1*	–	4*	52*	<10*	5*	–	<6*	9*
OS4	Roodepoort	D3H013	234*	<6*	<1*	–	6*	133*	<10*	4*	–	8*	10*
Spec	Vanderkloof Dam	D3R003	95	<6*	5	6	20	133	54	11	19	17	33
OS5	Dooren Kuilen	D3H012	58*	<6*	<1*	–	3*	33*	<10*	3*	–	7*	4*
OS6	Marksdrift	D3H008	103	<6*	5	7	11	138	<10*	7	33	11	29

* 2008 Snapshot 1 & 2 mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 10: Water quality status (2005 – 2007) of the Lower Orange River (WMA 14) – Main stem – level 1 for Domestic use (2/2)

Sample point	Sample description	Station	Domestic – metals (µg/L)										
			Aluminium (Al)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)
OS8	Prieska	D7H002	95*	<6*	<1*	–	4*	92*	<10*	9*	–	8*	7*
OS9	Boegoeberg Dam	D7H008	119*	<6*	<1*	–	5*	102*	<10	5*	–	8*	7*
OS11	Upington	D7H005	107	<6*	5	8	22	54	63	6	29	24	104
OS13	Neusberg weir	D7H016	171	<6*	<1*	7	6	56	54	13	38	34	18
OS15	Pella	D8H008	35	<6*	76	3	6	40	358	5	8	13	5
OS16	Vioolsdrift	D8H003	168	<6*	12	9	6	30	54	4	44	37	10
OS18	Sendelings-drift	New	27*	<6*	<1*	–	12*	28*	<10*	11*	–	8*	8*
OS19	Alexander Bay	D8H012	30*	<6*	<1*	–	12*	24*	<10*	<10*	–	<6*	8*

* 2008 Snapshot 1 & 2 mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 11: **Water quality status (2005 – 2007) of the Upper Orange River (WMA 13) – Main stem – level 1 for Agriculture – Irrigation**

Sample point	Sample description	Station	Agriculture – irrigation (mg/L)										
			Aluminium (Al)	Boron (B)	Chloride (Cl)	Iron (Fe)	EC (mS/m)	pH	SAR	Sodium (Na)	Sulphate (SO_4)	Suspended solids	TDS
OS1	Oranjedraai	D1H009	0.146*	–	7.3	0.092*	24.9	7.3 – 8.2	0.30	6.3	12.8	1 126*	193.8
OS2	Aliwal North	D1H003	0.074*	–	8.3	0.065*	28.7	7.3 -8.3	0.37	7.2	15.6	9.26*	216.3
Spec	Gariep Dam	D3R002	0.050*	–	8.4	0.052*	23.9	7.3 – 8.3	0.38	8.1	15.8	80.7	168.2
OS4	Roodepoort	D3H013	0.234*	–	8.0	0.133*	22.7	7.6 – 8.2	0.37	7.8	16.1	37.1*	167.2
Spec	Vanderkloof Dam	D3R003	0.075	0.031	7.6	0.133	22.6	7.5 – 8.2	0.38	8.0	14.5	108.7	161.8
OS5	Dooren Kuilen	D3H012	0.058*	–	7.9	0.033*	22.1	7.5 – 8.1	0.38	7.8	12.8	2.67*	163.0
OS6	Marksdrift	D3H008	0.159	0.143	13.2	0.138	29.7	7.5 – 8.3	0.63	13.7	20.8	20.9*	196.2

* 2008 Snapshot 1 & 2 mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 12: **Water quality status (2005 – 2007) of the Lower Orange River (WMA 14) – Main stem for Agriculture – Irrigation**

Sample point	Sample description	Station	Agriculture – irrigation (mg/L)										
			Aluminium (Al)	Boron (B)	Chloride (Cl)	Iron (Fe)	EC (mS/m)	pH	SAR	Sodium (Na)	Sulphate (SO_4)	Suspended solids	TDS
OS8	Prieska	D7H002	0.095*	-	24.7*	0.092*	30.0*	8.3*	1.08*	27.0*	36.2*	29.3*	238.4*
OS9	Boegoeberg Dam	D7H008	0.119*	-	44.3	0.102*	51.2	7.7 – 8.4	1.24	35.7	54.7	18.8*	345.6
OS11	Upington	D7H005	0.107	0.083	53.5	0.054	60.5	7.7 – 8.4	1.60	48.9	72.2	83.2	402.5
OS13	Neusberg weir	D7H016	0.171	-	42.2	0.056	55.9	8.1 – 8.4	1.48	44.4	56.4	66.7	384.0
OS15	Pella	D8H008	0.035	0.206	66.1	0.044	68.6	7.8 – 8.4	1.97	64.8	77.3	23.6#	474.1
OS16	Vioolsdrift	D8H003	0.168	0.109	78.5	0.030	74.6	7.4 – 8.4	2.23	73.4	85.5	18.7*	508.9
OS18	Sendelings-drift	New	0.027*	-	71.0*	0.018*	48*	8.5 - 8.7*	2.16*	66.1*	78*	15.8*	433.0*
OS19	Alexander Bay	D8H012	0.030*	-	79.4*	0.024*	50*	8.5*	2.24*	141.6*	83.5*	21.4*	456.0*

* 2008 Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

8.1.3 Aquatic Ecosystem:

Trace metals are important in aquatic ecosystems and occur in all waters, sometimes in minute quantities, because they are products of geological weathering. However, technical difficulties involving the chemical form and biotic availability of the minute quantities present have hindered ecological interpretation (Horne & Goldman, 1994).

The metal concentrations in the Upper and Lower Orange River exceeds the upper limits of protection (Acute Effect Values, AEV) of the aquatic ecosystem guidelines (DWAF, 1996), especially for copper (Cu) and lead (Pb), and occasionally for aluminium (Al), and cadmium (Cd) (**Tables 13** and **14**).

The aluminium (Al) concentrations (95 percentile) in the Orange River were relatively high, ranging between 35 and a high 168 μg/ℓ, most in the tolerable range. The world average concentration in unpolluted rivers is 40 μg/ℓ (Chapman, 1996).

The tentative TWQR for aluminium in water (with a pH > 6.5) is ≤10 μg/ℓ; the chronic effect value is 20 μg/ℓ and the acute effect value is 150 μg/ℓ (DWAF, 1996). The high Al concentrations in the Orange pose a significant risk of chronic effects to sensitive organisms. The TWQR and criteria are given as tentative, because the toxicity and bioavailability of Al is governed by complex interactions with other water quality variables, which have not been fully accounted for in the derivations (DWAF, 1996).

The overall mean copper concentration in the Orange River was 8 μg/ℓ and is considered being fairly natural, because the most common natural concentration for Cu in world rivers is 10 μg/ℓ (Martin & Meybeck, 1979; Horne & Goldman, 1994). However, the Target Water Quality Range (TWQR) in medium-hard water systems, like the Orange River, for dissolved copper in aquatic ecosystems is ≤0.8 μg/ℓ; Chronic Effect Value (CEV), 1.5 μg/ℓ; and AEV, 4.6 μg/ℓ (DWAF, 1996). The Cu concentrations in the Orange River therefore exceed regularly all the guidelines set by DWAF, which means that chronic and acute toxicity effects will occur most of the time in the Orange River waters (**Table 13 & 14**). Even the world average concentration of 10 μg/ℓ for rivers would be too high to ensure protection of the aquatic ecosystems. In the light of this, it is believed that the concentration guidelines set for Cu in the aquatic ecosystem water quality guideline by DWAF (1996) are impractically low and should be revised. The Department of Water Affairs and Forestry has initialised the discussion of concepts around the development of risk-based guidelines against the background of reviewing the South African Water Quality Guidelines (SAWQG) of 1996 (Jooste – personal communication).

However, it may be possible that background concentrations of metals are naturally high in the Orange River. For example, the overall mean Cu concentration in the Katse system (upper reaches of the Orange) was also surprisingly high at 55 μg/ℓ (Roos, 2000).

Waters flowing through reaches that are in contact with highly mineralised geology and hence may normally contain metal concentrations that would be considered 'high' in non-mineralised river catchments. As a result, it is possible that the aquatic communities living within the river are composed of species that can tolerate these conditions. Monitoring of biological indicators, like SASS, will also help to determine the potential extent of any ecosystem response.

Lead (Pb) is defined by the USEPA (2000) as potentially hazardous to most forms of life, and is considered toxic and relatively accessible to aquatic organisms. Ninety percent (90 %) of all dissolved lead measurements for the site in question should be within the TWQR. All measurements should be below the Chronic Effect Value (CEV) to ensure protection of aquatic ecosystems. Acute toxicity will occur if lead concentrations exceed the Acute Effect Value (AEV). The TWQR for medium hard water systems, like Orange River, is ≤0.5 µg/ℓ and the CEV 1.0 µg/ℓ and the AEV is 7 µg/ℓ. The TWQR for aquaculture is <10 µg/ℓ, and 30 µg/ℓ is the maximum acceptable upper concentration for brook trout (DWAF, 1996).

The median Pb concentration in the Orange River of 54 µg/ℓ, is much higher than all the above-mentioned criteria values and indicates a potential lead problem in the system, which must be investigated further.

The TWQR and criteria for dissolved zinc is aquatic ecosystems are: TWQR, ≤2 µg/ℓ; CEV, 3.6 µg/ℓ and AEV, 36 µg/ℓ (DWAF, 1996). The present state zinc concentrations in the Orange River were relatively high and ranged 4 and 33 µg/ℓ, which is considered to be tolerable in the aquatic ecosystem.

Ammonia (NH_3) at high concentrations is toxic to fish and the percentage composition in water increases with temperature and higher pH values (DWAF, 1996). Fish kills have been reported in the Lower Orange River that was ascribed to water quality factors including high ammonia concentrations (Van Ginkel & Conradie, 2001). However, the present status was relatively low (acceptable) at 13 µg/ℓ (**Table 14**). The maximum recorded NH_3 concentration (1996 – 2007) at Upington was only 24 µg/ℓ, which is still ideal for cold-water fish (aquaculture) at pH >8 (DWAF, 1996).

It is proposed that the reason (sources) for the general high metal concentrations, specifically the high Al, Cd and Pb concentrations at Upington, Neusberg, Pella, and Vioolsdrift, should be investigated further.

8.1.4 Recreational and Industrial use:

The water in the Upper and Lower Orange River was found to be suitable for recreational and industrial use, except for the high *E. coli* found at Oranjedraai where the water was not suitable for full contact recreational activities (**Tables 15** and **16**).

Table 13: Water quality status (2005 – 2007) of the Upper Orange River (WMA 13) – Main stem – level 1 for Aquatic ecosystems

Sample point	Sample description	Station	Aquatic Ecosystem (µg/L)										
			Aluminium (Al)	Ammonia (NH_3)	Cadmium (Cd)	Chl-a	Copper (Cu)	Fluoride (F)	DIN#	DO (%)	Lead (Pb)	PO_4-P#	Zinc (Zn)
OS1	Oranjedraai	D1H009	146*	8	<1*	2*	7*	200	287	90*	<10*	39	9*
OS2	Aliwal North	D1H003	74*	7	<1*	8*	8*	250	214	92*	<10*	34	8*
Spec	Gariep Dam	D3R002	50*	10	<1*	6*	4*	210	367	80*	<10*	29	9*
OS4	Roodepoort	D3H013	234*	9	<1*	4*	6*	234	350	95*	<10*	32	10*
Spec	Vanderkloof Dam	D3R003	75	68	5	2.4	15	217	277	85*	54	24	33
OS5	Dooren Kuilen	D3H012	58*	5	<1*	6*	3*	219	331	88*	<10*	21	4*
OS6	Marksdrift	D3H008	103	10	5	18*	11	248	344	93*	<10*	22	29

Median – 50 percentile; * 2008 Snapshot 1 & 2 mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 14: **Water quality status (2005 – 2007) of the Lower Orange River (WMA 14) – Main stem – level 1 for Aquatic Ecosystem**

Sample point	Sample description	Station	Aquatic Ecosystem (µg/L)										
			Aluminium (Al)	Ammonia (NH_3)	Cadmium (Cd)	Chl-a#	Copper (Cu)	Fluoride (F)	DIN#	DO (%)	Lead (Pb)	PO_4-P#	Zinc (Zn)
OS8	Prieska	D7H002	95*	8*	<1*	18*	4*	190*	457*	85*	<10*	25*	7
OS9	Boegoeberg Dam	D7H008	119*	10	<1*	15*	5*	264	253	94*	<10*	20	7
OS11	Upington	D7H005	114	13	5	7.7	6	389	204	90*	54	22	22
OS13	Neusberg weir	D7H016	171	15	<1*	4.5	6	335	117	89*	54	18	18
OS15	Pella	D8H008	35	13	77	10.3	6	418	587	99*	358	22	5
OS16	Vioolsdrift	D8H003	168	8	12	22.5*	6	478	96	101*	54	25	10
OS18	Sendelings-drift	New	27*	8*	<1*	34*	12*	397*	322*	105*	<10*	38*	8*
OS19	Alexander Bay	D8H012	30*	7*	<1*	25*	12.5*	375*	247*	104*	<10*	25*	8*

Median – 50 percentile; * 2008 Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 15: **Water quality status (2005 – 2007) of the Upper Orange River (WMA 13) – Main stem – level 1 for Recreational and Industry.**

Sample point	Sample description	Station	Recreation		Industrial (Category 3)			
			pH	*E. coli*	Sulphate (SO_4)	TAL	TDS	Total Hardness
OS1	Oranjedraai	D1H009	7.3 – 8.2	792*	12.8	111.3	193.8	107.5
OS2	Aliwal North	D1H003	7.3 – 8.3	123*	15.6	121.5	216.3	118.7
Spec	Gariep Dam	D3R002	7.3 – 8.3	12*	15.8	89.6	168.2	89.6
OS4	Roodepoort	D3H013	7.6 – 8.2	6*	16.1	87.6	167.2	88.8
Spec	Vanderkloof Dam	D3R003	7.5 – 8.2	66*	14.5	89.0	161.8	87.4
OS5	Dooren Kuilen	D3H012	7.5 – 8.1	5*	12.8	92.3	163.0	87.8
OS6	Marksdrift	D3H008	7.5 – 8.4	50*	20.8	100.4	196.2	101.6

* 2008 Snapshot 1 & 2 mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 16: **Water quality status (2005 – 2007) of the Lower Orange River (WMA 14) – Main stem – level 1 for Recreational and Industry**

Sample point	Sample description	Station	Recreation		Industrial (Category 3)			
			pH	*E. coli*	Sulphate (SO_4)	TAL	TDS	Total Hardness
OS8	Prieska	D7H002	8.3*	52*	36.2*	103*	238.4*	118*
OS9	Boegoeberg Dam	D7H008	7.7 – 8.4	8*	54.7	118.3	345.6	160.8
OS11	Upington	D7H005	7.7 – 8.4	29*	72.2	139.6	402.5	179.4
OS13	Neusberg weir	D7H016	8.1 – 8.4	128*	56.4	157.2	384.0	173.9
OS15	Pella	D8H008	7.8 – 8.4	12*	77.3	167.3	474.1	200.2
OS16	Vioolsdrift	D8H003	7.4 – 8.4	7*	85.5	170.4	508.9	205.3
OS18	Sendelings-drift	New	8.7*	25*	78*	156*	433*	176*
OS19	Alexander Bay	D8H012	8.5*	85*	83.5	160.5	456.0	186*

* Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

8.2 Orange River – tributaries – level 2

The main tributaries include Kornetspruit, Sterkspruit, Kraai River, Stormbergspruit, Seekoei River and Vaal River.

8.2.1 Domestic (drinking water):

The water quality in the tributaries fell in the ideal or acceptable range, except for the high magnesium in the Seekoei River that was within the tolerable range (**Table 17**). Excess magnesium intake, particularly as the sulphate, results in diarrhoea.

8.2.2 Agriculture (Irrigation):

The high suspended solids in the Kornetspruit and Sterkspruit was found to be unacceptable in terms of the TWQR. However, these values were based on only two measurements. The high salts in the Stormbergspruit, Seekoei and Vaal River are with the tolerable range for irrigation and will probably lead to problems in the long-run, e.g. soil salinisation (**Table 19**).

8.2.3 Aquatic Ecosystem:

The aluminium and copper concentrations were also too high for a healthy aquatic environment in many of the tributaries (**Table 20**). The ammonia concentration in Stormbergspruit is unacceptable high and can be toxic to fish. The high phosphate concentrations in Sterkspruit and Stormbergspruit are unacceptable and pose an eutrophication problem to the system.

8.2.4 Recreational and Industrial:

The high *E. coli* concentrations in the Kornetspruit, Sterkspruit and Stormbergspruit make it unsafe for full contact recreation (**Table 21**).

Table 17: **Water quality status of the Orange River tributaries – level 2 for Domestic use (1/2)**

Sample point	Sample description	Station	Domestic (mg/L)										
			Ammonium (NH_4-N)	Calcium (Ca)	Chloride (Cl)	Dissolved solids (TDS)	EC (mS/m)	Fluoride (F)	Magnesium (Mg)	Nitrate (NO_3-N)	Potassium (K)	Sodium (Na)	Sulphate (SO_4)
OSL2/1	Kornetspruit	D1H006	0.110	33.6	7.7	237.4	30.6	0.241	12.1	0.868	1.9	8.7	16.7
OSL2/2	Sterkspruit	New	0.128*	13.4*	4.1*	102.5*	11*	0.12*	3.5*	0.41*	1.4*	8.9*	8.1*
OSL2/3	Kraai River	D1H011	0.124	37.1	9.4	251.9	35.3	0.182	14.1	0.131	1.7	7.9	12.8
OSL2/4	Stormberg spruit	D1H001	1.33	70.5	78.6	845.2	103.7	0.47	44.9	3.86	9.5	100.8	65.4
OSL2/5	Seekoei River	D3H015	0.055	53.4	90.0	834.3	102.3	0.77	56.3	0.454	7.4	108.8	80.6
VS21	Vaal River	New	0.114*	46.7*	185.5*	701.1*	82*	0.33*	43.3*	0.38*	5.7*	114.6*	157.3*

* Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 18: Water quality status of the Orange River tributaries – level 2 for Domestic use (2/2)

Sample point	Sample description	Station	Domestic – metals (µg/L)										
			Aluminium (Al)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)
OSL2/1	Kornetspruit	D1H006	145*	<6	<1	–	6.5	76	<10	5.5	–	<6	7.5
OSL2/2	Sterkspruit	New	384*	<6	<1	–	7.5	206	<10	81	–	<6	7.0
OSL2/3	Kraai River	D1H011	208*	<6	<1	–	5.0	121	<10	6	–	<6	6.0
OSL2/4	Stormberg spruit	D1H001	72*	<6	<1	–	10	64	<10	28	–	<6	7.5
OSL2/5	Seekoei River	D3H015	18*	<6	<1	–	3.0	25	<10	4.5	–	<6	5.0
VS21	Vaal River	New	29*	<6	<1	–	4.5	28	<10	9.5	–	<6	8.0

* Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 19: Water quality status of the Orange River tributaries – level 2 for Agriculture – Irrigation

Sample point	Sample description	Station	Agriculture – irrigation (mg/L)										
			Aluminium (Al)	Boron (B)	Chloride (Cl)	Iron (Fe)	EC (mS/m)	pH	SAR	Sodium (Na)	Sulphate (SO_4)	Suspended solids	TDS
OSL2/1	Kornetspruit	D1H006	0.145*	–	7.7	0.076*	30.6	7.4-8.4	0.368	8.7	16.7	3933*	237.4
OSL2/2	Sterkspruit	New	0.384*	–	4.1*	0.206*	12*	7.8-8.7*		8.9*	8.1*	792*	102.4*
OSL2/3	Kraai River	D1H011	0.208*	–	9.4	0.121*	35.3	7.5-8.3	0.318	7.9	12.8	12.4	251.9
OSL2/4	Stormberg spruit	D1H001	0.072*	–	78.6	0.064*	103.7	7.8-8.5	2.36	100.8	65.4	34.1	845.2
OSL2/5	Seekoei River	D3H015	0.018*	–	90.0	0.025*	102.3	7.9-8.5	2.57	108.8	80.6	5.6	834.3
VS21	Vaal River	New	0.029*	–	185.5*	0.028*	82*	7.5-8.1*		114.6*	157.3*	3.4*	701.1*

* Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 20: **Water quality status of the Orange River tributaries – level 2 for Aquatic Ecosystem**

Sample point	Sample description	Station	Aquatic Ecosystem (µg/L)										
			Aluminium (Al)	Ammonia (NH_3)	Cadmium (Cd)	Chl-a*	Copper (Cu)	Fluoride (F)	DIN*	DO (%)	Lead (Pb)	PO_4-P*	Zinc (Zn)
OSL2/1	Kornetspruit	D1H006	145*	7	<1*	3*	6.5*	241	156	94*	<10*	31	7.5*
OSL2/2	Sterkspruit	New	384*	13*	<1*	5.5*	7.5*	119*	538*	101*	<10*	133*	7.0*
OSL2/3	Kraai River	D1H011	208*	9	<1*	3.0*	5.0*	182	111	89*	<10*	28	6.0*
OSL2/4	Stormberg spruit	D1H001	72*	120	<1*	14.5*	10*	470	1 254	82*	<10*	432	7.5*
OSL2/5	Seekoei River	D3H015	18*	9	<1*	4.0*	3.0*	770	88	94*	<10*	38	5.0*
VS21	Vaal River	New	29*	12*	<1*	28.5*	4.5*	332*	433*	63.5*	<10*	42.5*	8.0*

Median – 50 percentile; * snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 21: Water quality status of the Orange River tributaries – level 2 for Recreational and Industry use

Sample point	Sample description	Station	Recreation		Industrial (Category 3)			
			pH	*E. coli*	Sulphate (SO_4)	TAL	TDS	Total Hardness
OSL2/1	Kornetspruit	D1H006	7.4 – 8.4	2 749*	16.7	130.8	237.4	134.1
OSL2/2	Sterkspruit	New	7.8 – 8.7*	4 908*	8.1*	57*	102.5*	47.7
OSL2/3	Kraai River	D1H011	7.5 – 8.3	55*	12.8	139.5	251.9	154.7
OSL2/4	Stormberg spruit	D1H001	7.8 – 8.5	1 072*	65.4	376.8	845.2	358.2
OSL2/5	Seekoei River	D3H015	7.9 – 8.5	19*	80.6	371.5	834.3	359.7
VS21	Vaal River	New	7.5 – 8.1*	318*	157.3*	143.5*	701.1*	295*

* Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

8.3 Caledon River – main stem and tributaries

8.3.1 Domestic use

The water from the Caledon River and tributaries complied with the domestic water use standards and fell in the target water quality range or acceptable level (**Tables 22 & 23**).

8.3.2 Agriculture (Irrigation):

The water is also suitable for irrigation, but the high suspended solids in the Caledon can cause problems (blocking irrigation systems). The high chloride and SAR in Moperispruit is only tolerable (**Table 24**).

8.3.3 Aquatic Ecosystem:

The aluminium concentrations were unacceptably high in the Caledon at Kommissiedrift, Grootspruit, and Leeu River. The copper concentrations were unacceptable in the Caledon at Maseru and Kommissiedrift and in the Little Caledon at the Poplars. The phosphate concentrations were generally very high and in the tolerable range at most of the sites (**Table 25**).

8.3.4 Recreational and Industrial:

The *E. coli* concentrations were unacceptable for recreation in the Caledon River, Grootspruit, and Leeu River (**Table 26**). The water was however, suitable for industrial use.

Table 22: Water quality status of the Caledon River and tributaries (WMA 13) for Domestic use (1/2)

Sample point	Sample description	Station	Domestic (mg/L)										
			Ammonium (NH_4-N)	Calcium (Ca)	Chloride (Cl)	Dissolved solids (TDS)	EC (mS/m)	Fluoride (F)	Magnesium (Mg)	Nitrate (NO_3-N)	Potassium (K)	Sodium (Na)	Sulphate (SO_4)
CS1	Caledon at confluence	New	0.108*	25.4*	4.4*	175.5*	18.0*	0.05*	9.8*	0.28*	0.96*	9.3*	15.5*
CS2	Caledon at Ficksburg	D2H035	0.087	36.5	7.25	275.0	37.4	0.18	15.1	0.48	1.63	9.7	16.4
CS3	Caledon below Maseru	New	0.351*	28.9*	17.8*	258.6*	27.5*	0.08*	11.2*	0.36*	3.05*	27.4*	37.5*
CS4	Caledon at 10 fontein	New	0.176*	21.9*	10.3*	180.5*	17*	0.17*	7.9*	0.62*	1.95*	19.1*	20.9*
CS5	Caledon at Kommissiesdrift	D2H036	0.098	44.1	19.5	437.4	56.2	0.31	25.7	0.59	3.86	34.2	26.5
CSL2/1	Little Caledon at Golden Gate	New	0.173*	26.8*	2.6*	186.3*	29*	0.03*	9.8*	0.14*	0.82*	12.3*	11.4*
CSL2/2	Little Caledon at the poplars	D2H012	0.093	49.3	10.3	381.3	47.5	0.20	22.2	0.37	2.50	16.1	22.9
CSL2/3	Grootspruit	New	0.099*	46.7*	13.4*	360.5*	37*	0.17*	21.3*	0.11*	2.92*	25.1*	21.1*
CSL2/4	Meulspruit above dam	New	0.195*	31.9*	9.7*	261.4*	30*	0.23*	10.9*	0.02*	4.82*	23.6*	13.9*
CSL2/5	Mopeli River	New	0.128*	24.2*	61.5*	300.0*	38*	0.36*	8.6*	0.20*	13.65*	45.3*	26.8*
CSL2/6	Leeu River at Hobhouse	New	0.108*	27.4*	10.8*	241.4*	25*	0.23*	11.4*	0.29*	5.16*	26.0*	9.4*

* Snapshots mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 23: **Water quality status of the Caledon River and tributaries (WMA 13) for Domestic use (2/2)**

Sample point	Sample description	Station	Domestic – metals (µg/L)										
			Aluminium (Al)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)
CS1	Caledon at confluence	New	146	<6	<1	–	5	124	<10	10	–	<6	11
CS2	Caledon at Ficksburg	D2H035	96	<6	<1	–	4	135	<10	8	–	<6	7
CS3	Caledon below Maseru	New	76	<6	<1	–	22	89	<10	7	–	<6	8
CS4	Caledon at 10 fontein	New	15	<6	<1	–	4	20	<10	1	–	<6	6
CS5	Caledon at Kommissiesdrift	D2H036	293	<6	<1	–	7	154	<10	10	–	<6	7
CSL2/1	Little Caledon at Golden Gate	New	14	<6	<1	–	3	196	<10	23	–	<6	5
CSL2/2	Little Caledon at the poplars	D2H012	144	<6	<1	–	5	135	<10	64	–	<6	8
CSL2/3	Grootspruit	New	190	<6	<1	–	5	176	14	79	–	<6	13
CSL2/4	Meulspruit above dam	New	50	<6	<1	–	4	119	<10	39	–	<6	7
CSL2/5	Mopeli River	New	30	<6	<1	–	4	106	<10	27	–	<6	6
CSL2/6	Leeu River at Hobhouse	New	197	<6	<1	–	5	150	11	12	–	<6	9

Ideal	Acceptable	Tolerable	Unacceptable

Table 24 Water quality status of the Caledon River and tributaries (WMA 13) for Agricultural use (irrigation).

Sample point	Sample description	Station	Agriculture – irrigation (mg/L)										
			Aluminium (Al)	Boron (B)	Chloride (Cl)	Iron (Fe)	EC (mS/m)	pH	SAR	Sodium (Na)	Sulphate (SO_4)	Suspended solids	TDS
CS1	Caledon at confluence	New	0.146*	–	4.4*	0.124*	18*	8.2-8.4*	0.40*	9.3*	15.5*	27.6*	175.5*
CS2	Caledon at Ficksburg	D2H035	0.096*	–	7.3	0.135*	37	7.5- 8.4	0.51	9.7	16.4	20.7*	275.1
CS3	Caledon below Maseru	New	0.076*	–	17.8	0.088*	28*	8.0-8.1*	1.18*	27.4*	37.5*	41.5*	258.6*
CS4	Caledon at 10 fontein	New	0.015*	–	10.3*	0.019*	17*	7.9*	0.89*	19.1*	20.9*	24.4*	180.5*
CS5	Caledon at Kommissiesdrift	D2H036	0.293*	–	19.5	0.154*	56	7.5 -8.3	0.74	34.2	26.5	175*	437.4
CSL2/1	Little Caledon at Golden Gate	New	0.014*	–	2.6*	0.196*	29*	8.2*	0.52*	12.3*	11.4*	6*	186.3*
CSL2/2	Little Caledon at the poplars	D2H012	0.144*	–	10.3	0.135*	48	7.4-8.2	0.60	16.1	22.9	1.0*	381.3
CSL2/3	Grootspruit	New	0.190*	–	13.4*	0.175*	37*	8.3-8.4*	0.76*	25.1*	21.1*	17.3*	360.5*
CSL2/4	Meulspruit above dam	New	0.050*	–	9.7*	0.119*	30*	7.6*	0.92*	23.6*	13.9*	45*	261.4*
CSL2/5	Mopeli River	New	0.030*	–	61.5*	0.106*	38*	7.5*	2.01*	45.3*	26.8*	14*	300.0*
CSL2/6	Leeu River at Hobhouse	New	0.197*	–	10.8*	0.150*	25*	7.4-7.8*	1.05*	26.0*	9.4*	36.8*	241.4*

* Snapshot mean

Ideal	Acceptable	Tolerable	Unacceptable

Table 25: Water quality status of the Caledon River and tributaries (WMA 13) for the Aquatic Ecosystem

Sample point	Sample description	Station	Aquatic Ecosystem (µg/L)										
			Aluminium (Al)	Ammonia (NH_3)	Cadmium (Cd)	Chl-a#	Copper (Cu)	Fluoride (F)	DIN#	DO (%)	Lead (Pb)	PO_4-P#	Zinc (Zn)
CS1	Caledon at confluence*	New	146	11	<1	2	4.5	45	392	93	<10	28	11
CS2	Caledon at Ficksburg	D2H035	96*	9	<1*	6*	3.5*	184	542	97*	<10*	29	7*
CS3	Caledon below Maseru*	New	76	35	<1	10	22	80	708	77	<10	80	8
CS4	Caledon at 10 fontein*	New	15	17	<1	1	4	170	801	90	<10	80	6
CS5	Caledon at Kommissiesdrift	D2H036	293*	11	<1*	7.5*	7*	314	673	88*	<10*	36	7*
CSL2/1	Little Caledon at Golden Gate*	New	14	17	<1	1	3	30	317	88	<10	25	5
CSL2/2	Little Caledon at the poplars	D2H012	144*	10	1*	2*	5*	202	525	93*	<10*	41	8*
CSL2/3	Grootspruit*	New	190	10	1.5	10	4.5	165	200	110	14	63	13
CSL2/4	Meulspruit above dam*	New	50	19	<1	18	4	230	214	74	<10	30	7
CSL2/5	Moperispruit*	New	30	13	<1	30	4	360	330	83	<10	75	6
CSL2/6	Leeu River at Hobhouse*	New	197	11	<1	7.5	4.5	225	394	73	11	38	9

* Snapshot 1 & 2 mean; # Median – 50 percentile

Ideal	Acceptable	Tolerable	Unacceptable

Table 26: Water quality status of the Caledon River and tributaries (WMA 13) for Recreational and Industrial use

Sample point	Sample description	Station	Recreation		Industrial (Category 3)			
			pH	*E. coli*	Sulphate (SO_4)	TAL	TDS	Total Hardness
CS1	Caledon at confluence	New	8.2 – 8.4*	1 244*	15.5*	102.3*	175.5*	103.5*
CS2	Caledon at Ficksburg	D2H035	7.5 – 8.4	1 643*	16.4	158.8	275.1	153.6
CS3	Caledon below Maseru	New	8.0 – 8.1*	>2 419*	37.5*	124.5*	258.6*	118.0*
CS4	Caledon at 10 fontein	New	7.9*	6 488*	21.0*	92.6*	180.5*	87*
CS5	Caledon at Kommissiesdrift	D2H036	7.5 – 8.3	284*	26.5	231.1	437.4	214.5
CSL2/1	Little Caledon at Golden Gate	New	8.2*	179*	11.4*	112.0*	186.3*	103*
CSL2/2	Little Caledon at the poplars	D2H012	7.4 – 8.2	116*	22.8	216.4	381.3	210.9
CSL2/3	Grootspruit	New	8.3 – 8.4*	573*	21.2*	223.5*	360.5*	204.0*
CSL2/4	Meulspruit above dam	New	7.6*	29*	13.9*	161.0*	261.4*	124.0*
CSL2/5	Mopeli River	New	7.5*	96*	26.8*	116*	300.0*	96.0*
CSL2/6	Leeu River at Hobhouse	New	7.4 – 7.8*	1 700*	9.4*	145.7*	241.4*	115.5*

* Snapshots mean

Ideal		Acceptable		Tolerable		Unacceptable	

9 CONCLUSIONS

The main threats to water quality in Africa include pollution, eutrophication, and the proliferation of invasive aquatic plants such as the water hyacinth (*Eichhornia crassipes*) and *Salvinia molesta* weeds (GEO-2000, 1999). In the Orange River, however, flow regulation and water diversions, salinisation, sedimentation and occasional algal blooms are considered to be the main threats.

The status of river ecosystems associated with main rivers in South Africa was assessed based on the extent to which each ecosystem had been altered from its natural condition. The state of main river ecosystems in South Africa is dire: 84 % of the ecosystems (112 main rivers) are threatened, with a disturbing 54 % critically endangered, 18 % endangered, and 12 % vulnerable (Nel *et al*., 2007).

The Orange River and its catchment have a long history of exploitation and modification, especially in terms of flow regulation. Several new developments have been identified, both in Namibia and South Africa, which will result in greater water demands from the Lower Orange River in the future (DWAF, 2008b).

9.1 Stream flow:

Dams were built to provide water for irrigated agriculture, domestic or industrial use, to generate hydropower or help control floods. But dams also altered and diverted river flows, affecting existing rights and access to water, and resulting in significant impacts on livelihoods and the environment (WCD, 2000). Flow alteration imperils freshwater and estuarine ecosystems. Freshwater species and ecosystems are among the most imperilled (IUCN, 2001).

Hydrological factors, especially flow rates, play an important role in water quality. They affect loading rates of materials into reservoirs, flushing rates of materials from reservoirs, and water depth, which itself has a big effect on many ecological processes (Jassby & Goldman, 2003).

As humans have adapted river systems to meet their needs, the natural variability characteristic of rivers has been greatly reduced. Major rivers worldwide have experienced dramatic changes in flow, reducing their natural ability to adjust to and absorb disturbances (Palmer *et al.*, 2008).

Dams are both a blessing and a curse. While they provide water and power, they also cause serious damage to freshwater ecosystems, affecting both nature and people (WWF, 2004). Already, in 60 % of the world's major rivers flows are interrupted by dams, canals and diversions. Many freshwater habitats and species have been lost, with dams and their associated infrastructure, such as irrigation systems, a major culprit (WWF, 2004).

However, the construction and operation of large dams (>15 m high) worldwide during the 20^{th} century has severely altered the global flux of water and sediment from continents to oceans through the world's river basins. From an ecological perspective, the fragmentation of river corridors by dams and the associated modification of fluvial processes and stream flow dynamics pose significant threats to native river biodiversity on a global scale (Poff *et al.*, 2007). The blockage of fish movements upstream can have a very significant and negative impact on fish biodiversity (IUCN, 2001).

Flow regulation by dams and diversions is a key component of virtually all large river development programs. Alteration of flood timing, magnitude, frequency, and duration disturb both terrestrial and aquatic communities, thereby creating conditions that favour the spread of cosmopolitan, non-indigenous species at the expense of locally adapted native biota (Poff *et al.*, 2007). The cold water released at the base of the dam prevents spawning of native fish. The cold water favours alien species at the expense of native fish (Gippel & Blackham, 2002). Water quality and quantity are intimately linked.

A broad consensus has emerged over the last 10 years among ecologists that the function of riverine ecosystems, and the evolutionary adaptations of resident biota, are often dictated by the dynamic nature of a river's natural disturbance regime, which largely reflects time-varying stream flow conditions that vary from region to region (Poff *et al.*, 2007). The ability of rivers and their biota to respond to altered flow regimes is not, however, unbounded. Changes brought on by urbanization, excessive water withdrawals, or climate shifts that occur rapidly and lead to flows outside the natural range of variability will have important consequences for river ecosystems and the people who depend on them (Palmer *et al*., 2008).

An assessment of 292 of the major river basins in the world showed that 36 % of the large rivers (including the Orange River) are strongly affected by fragmentation and altered flows, 23 % are moderately affected, and 41 % are unaffected (Nilsson *et al.*, 2005).

In the Orange River system, a large number of inter-basin and intra-basin water transfer schemes have been built to improve the quantity and reliability of water flows to major urban and industrial demand centres, as well as to supply water needed for irrigation. The flow reaching the lower reaches of the Orange River is now controlled to a large degree by releases from Vanderkloof Dam, supported by water released from Gariep Dam – the two largest storage reservoirs in South Africa.

The controlled releases of water from the major storage reservoirs have improved the reliability of supply to water users along the lower reaches of the Orange-Senqu River in South Africa and Namibia with the result that the river no longer experiences periods of zero flow. However, the construction of dams has also homogenized the flow regimes, chiefly through modification of the magnitude and timing of ecologically critical high and low flows. It also has greatly dampened the seasonal and interannual stream flow variability of the Orange River, thereby altering natural dynamics in ecologically important flows.

Large volumes of water are diverted from the Orange River, starting with the 770 Mm^3/a interbasin-transfer to the Vaal River from the upper catchment. This Lesotho Highlands Water Project has resulted in large volumes of low salinity water being diverted from the Orange River into the Vaal River catchment. This has lead to an increase in salt levels in the Gariep and Vanderkloof dams.

The total virgin mean annual discharge (VMAD, the discharge before any substantial human manipulations) of the Orange River has decreased significantly during the past 45 years. The virgin flow at Oranjedraai, Aliwal North, and annual releases from Gariep Dam are almost the same as recent flow volumes, however, the recent flow volumes are about 34 % lower at Marksdrift, 45 % lower at Boegoeberg Dam, 46 % lower at Upington, about 68 % lower at Pella, and 60 % lower at Vioolsdrift compared to the virgin flow (**Figure 165**). Therefore, water extraction from the lower Orange River (primarily for irrigation) is drastic having severe impacts on the natural environment.

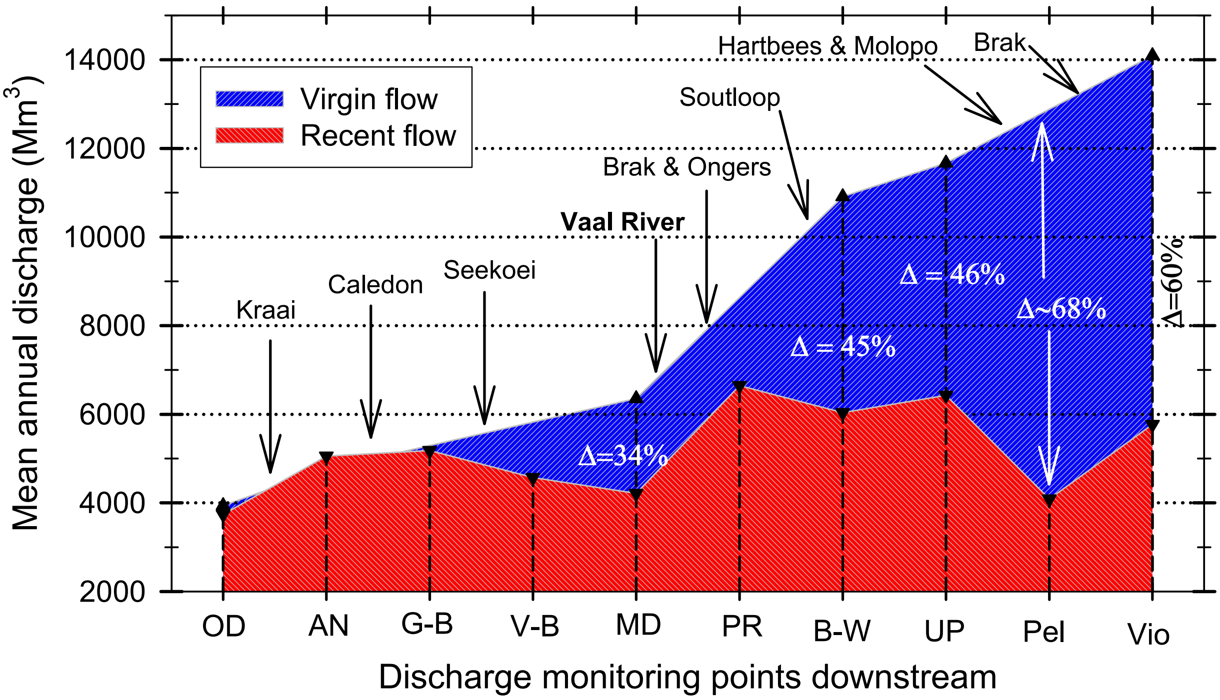


Figure 165: Comparison between the mean annual discharge (Mm^3) before 1970 (assumed to be virgin flow) and recent discharge (last 10 years) in the Orange River at different flow gauging stations.

As the water requirements on the Orange River catchment continue to grow, the water in the catchment is becoming more valuable. The building of further dams as part of the LHWP (recently approved by DWAF) and the subsequent increase in water transfer out of the Orange River system will result in a further inflow reduction. The Orange River is already under a great deal of stress due to excessive water withdrawal (cf. **Figure 166**) and this stress will be exacerbated by future demands and possibly by changes in climate.

If stream flow in a river is reduced, instream concentrations of water quality variables, as well as values of physical variables, will change. Low flows (current speed <0.05 m/s) in Australian rivers were identified as a primary cause of blue-green algal blooms (Davis & Koop, 2006).

Apart from reducing in-stream flows these new flow regimes tend to be delivered at the time and at volumes that suit the needs of Eskom's power generation rather than the needs of irrigators or the in-stream environment. Flow manipulation hinders channel development, drains floodplain wetlands, reduces floodplain productivity, decreases dynamism of deltas, and may cause extensive modification of aquatic communities (Nilsson *et al.*, 2005). The confusion of ecological signals resulting from hydrological and geomorphic changes interferes with breeding/recruitment of fish and macroinvertebrates (Gippel & Blackham, 2002). Regulated releases from the dams also resulted in a constant blackfly problem in the lower Orange. Blackflies breed in rivers in a constant flow of fast-moving water where they attach to rocks and plants and filter out suspended particles.

Lower river flows will concentrate pollutants and increase salinity, as the dilution effects of the Orange River will be reduced. Shallower water can also increase algal growth because in general, there is a tendency for productivity to be correlated negatively with the depth of a lake.

Stream flow influences the susceptibility of a stream to pollution. Large, swiftly flowing rivers can receive pollution discharges and, through dilution, be little affected. Small, slow-flowing streams have a reduced capacity to attenuate and degrade wastes. Well-flushed systems can tolerate higher inputs of nutrients. However, the popular notion that "the solution to pollution is dilution" is dangerous because it does not take into account effects on receiving waters or sediments where the accumulation of pollutants may have significant negative impacts (UNEP-GEMS, 2006).

Lower stream flow will probably lead to longer residence time and it is well documented that increased water residence time leads generally to higher algal abundances (Søballe & Kimmel, 1987). The general effects of a decrease in stream flow on the physical, chemical, and biological conditions in the Orange River are listed in **Table 27**.

The implementation of the new Polihali Dam (second phase of the LHWP) in Lesotho will influence (reduce) the flow of water into the Gariep and Vanderkloof dams, which in turn will have a negative influence on water quality and availability in the lower reaches of the Orange-Senqu River.

In future, additional inter- and intra-basin water transfer schemes will be needed to meet the growing demands for water in the Orange-Senqu and neighbouring basins, as well as to meet international and SADC obligations to share water equitably. The pressure on the aquatic ecosystem will thus also increase with potential devastating effects.

Figure 166: Typical low flow in the lower Orange River close to Brand Kaross (September 2008). Note the riparian vegetation that indicates the actual edges of the river.

Table 27: **Summary of water quality and ecological impacts of flow regulation and diversions (lower stream flow) in the Orange River.**

Physical conditions	Chemical conditions	Biological
• Shallower water and slow moving water, • Longer residence times, especially in weirs, • Warmer water temperatures, • Possible stratification of weir pools; decreased mixing depth (Z_{mix}). • Higher sedimentation, thus lower suspended solids (TSS) • Modification of fluvial processes • Lower turbidity, higher transparency, thus increased underwater light climate; deep euphotic zone (Z_{eu}). • Low Z_{mix}:Z_{eu} ratios • Low dilution rate of algae, chemicals and pollutants	• Higher dissolved salts concentrations (TDS) • Higher alkalinity • Higher DO at the surface, but possible anoxic conditions at bottom. • Higher pH values • Higher SO_4; lower Fe • Possible higher denitrification • Enhance nutrient recycling; internal nutrient loading • Reduced capacity to attenuate and degrade wastes • Reducing the rivers natural ability to adjust to and absorb disturbances	• Higher algal abundance and production with, possible blooms • Decreased macro-invertebrate diversity and abundance • Increased alien fish numbers • Possible higher bacteriological contamination • Reduced wetland quality • Reed intrusion • Habitat loss

9.2 Dissolved salts:

The water quality in South Africa's aquatic ecosystems is declining primarily because of salinisation and eutrophication (DWA, 1986). Anthropogenic increases in salinity and electrical conductivity in surface waters are largely due to agriculture, urbanisation and industrial activities (UNEP-GEMS, 2006).

The TDS concentrations in the upper section of the Orange River (OS1 – OS5, *i.e*. from Oranjedraai to Dooren Kuilen, just downstream of Vanderkloof Dam), were relatively low (mean 134 mg/ℓ). From Marksdrift (OS6) and downstream the dissolved salts increases continuously and reached occasionally concentrations >600 mg/ℓ from Vioolsdrift to Alexander Bay. The average TDS for river waters of the world is approximately 120 mg/ℓ (Wetzel, 2001).

However, anthropogenic impacts on chemistry may not always lead to a deterioration of the aquatic system, e.g. a tenfold increase in K^+ or Cl^- from 2 to 20 mg/ℓ has no biotic impact and does not limit water use.

Although some species are well-adapted to surviving in saline environments, growth and reproduction of many species can be hindered by increases in salinity (UNEP-GEMS, 2006). Available data suggest that aquatic biota will be adversely affected as salinity exceeds 1 000 mg/ℓ, but there is limited information on how increasing salinity will affect the various life stages of the biota.

The dissolved salts composition in the upper Orange River was dominated by bicarbonate ions (HCO_3). The order of ionic prominence in the Orange River was: $HCO_3^- > SO_4^{2-} > Ca^{2+} > Na^+$, $Cl^- > Mg^{2+} > K^+$. The HCO_3^- ion, used as an index of dissolved inorganic carbon, is the dominant form of carbon transport in the river basin. The concentration of major cations showed proportions of $Ca^{2+} \geq Na^+ > Mg^{2+} > K^+$ and major anions of $HCO_3^- > SO_4^{2-} > Cl^-$. The concentration of major anions of many surface waters of the world tends to exist in the same proportion (Wetzel, 2001).

However, the ionic composition in the Orange River changes downstream, with proportionally higher sulphate (SO_4), sodium (Na) and chloride (Cl) concentrations probably originating from the irrigation return flows. Typically, the concentration of sulphate in surface waters is 5 mg/ℓ, although concentrations of several 100 mg/ℓ may occur where dissolution of sulphate minerals or discharge of sulphate rich effluent from acid mine drainage takes place (DWAF, 1996). In the Orange River, the mean sulphate concentration has increased from 7.4 mg/ℓ at Oranjedraai (upper reaches) to 48.7 mg/ℓ at Alexander Bay (lower end).

Sodium concentrations in the Orange River increased at a significantly higher rate downstream compared to Ca and Mg, resulting in a significant increase of the SAR downstream.

A fairly constant variation pattern between the various ions suggested that dissolved substances originated from the same source, therefore it can be concluded that the irrigation areas are the major sources of mineralised water in the Orange River. The salt concentration also followed a clear seasonal pattern in the river with the highest concentrations observed during the winter period.

Salinisation can lead to changes in the physical environment that will affect ecosystem prossesses. The high TDS concentrations in the Orange River evidently influence the turbidity of the water. Because light is a driving force for primary production, therefore, changes in light attenuation will have a direct influence on the trophic dynamics of aquatic ecosystems.

9.3 Irrigation:

On a global basis, approximately 70 % of freshwater is currently used for crop irrigation, ~20 % for industrial purposes, and ~10 % for domestic purposes. Water use in South Africa is dominated by irrigation, representing about 62 % of the total water use in the country, most of which is used consumptively (DEAT, 2006).

As in other dry regions, agriculture is the largest user of water in Africa, accounting for 88 % of total water use, but some 40 – 60 % of the region's irrigation water is currently lost through seepage and evaporation (GEO-2000, 1999).

Agricultural irrigation in the upper Orange River accounts for approximately 81 % of the water demand and approximately 94 % for the lower Orange. This demand will increase with implementation of planned developments in the Lesotho lowlands and the extension of irrigation in Namibia and South Africa (Earle *et al*., 2005). In South Africa the development of 12 000 ha (148 Mm^3/a) of irrigation has been approved for poverty relief and the settlement of emerging farmers (DWAF, 2005). As the water requirements on the Orange River catchment continue to grow, the water in the catchment is becoming more valuable.

Irrigation farming depends on two factors: a supply of irrigation water and the availability of good arable soil, which means that in many of the dolomitic water-rich areas the overlaying soil is not only arable but also fertile. This further drives the demand to use ground water for irrigation. Even today a significant proportion of the total area under irrigation uses very water-wasteful flood irrigation methods. Another negative effect of irrigation is the washout of fertiliser and agrochemicals into the receiving watercourse.

When used for irrigation, a substantial amount of water is lost through evapotranspiration, leaving the salts that naturally occur in water in the soil. Once it rains these concentrated salts are washed out and reach the river as return flows. As the losses through evapotranspiration are higher than the replenishment through naturally occurring rainfall, the overall salt concentration in the river is increased, with negative consequences for the river's ecosystem as well as for crop production further downstream (Earle *et al.*, 2005).

Over-irrigation without adequate drainage can cause rises in groundwater level which result in soil and groundwater salinisation. The addition of further excess irrigation water to leach salts from the soil merely transfers the problem to the underlying groundwater. Preventing or alleviating the problem of groundwater salinity requires more efficient irrigation combined with effective drainage (Chapman, 1996). Little information is available on the interaction between irrigation and groundwater.

Beyond the dam itself, irrigation systems utilised worldwide have water use efficiencies of only 38 % (WWF, 2004), thus, in the Orange River up to 1 500 billion litres of water are theoretically wasted annually. However, it could be much higher because according to Stats SA (2008), the agriculture dryland crops have the largest amount in losses, almost 49 % of the total water losses in SA, mainly due to evaporation.

Some of the water withdrawn for irrigation is returned to the river environment for further use, but its quality is seriously degraded. Return flows from irrigation of agriculture dryland crops contributed only 5 % share of available yield (Stats SA, 2008). However, according to Volschenk and co-workers (2005), irrigation return flow constitutes an important part of the overall water balance of the Orange River and may be as high as 30 % of the water applied to the land.

Salinisation of irrigation schemes has become a major problem in many parts of the world, with detrimental effects varying between reduced crop yields and increased production costs, to the complete withdrawal of irrigation land. In the irrigation area of the Orange-Vaal Water Users Association, 23 % of the total area of 12 556 ha is affected by by salinity problems with13 % slightly affected and 10 % severely affected (van Heerden *et al*., 2001).

Simulation, using the Water Quality Model for the Orange River Catchment, projected that by 2030, salt concentrations would increase by approximately 25 % at Boegoeberg Dam and Kakamas (Volschenk *et al.*, 2005). This is ascribed to the effect of irrigation return flow from the Boegoeberg area and on the reduced flow in the river. This response is an example of a negative-feedback loop.

Thus, both surface water degradation and salt retention are considered to be potential problems in the Lower Orange River, which may impact on sustainability of agriculture.

Large losses of nutrients from agricultural soils are often caused by intensive use of fertilisers, especially in situations when fertiliser use exceeds the nutrient requirements of crops. Nitrogen easily leaks from agricultural and urban landscapes as the very mobile inorganic nitrate ion. A once-off assessment (snapshot 2) of return flow water from irrigation fields showed a significant increase in salts and nutrients that enter the Orange River.

Surprisingly, the dissolved inorganic nitrogen (DIN) in the Orange River decreased continuously from Vanderkloof Dam (mean, 0.547 mg/ℓ) downstream to Alexander Bay (mean, 0.169 mg/ℓ).

Even in the intensive irrigation areas (Boegoeberg Dam to Kakamas), no significant increases in the DIN concentrations in the Orange River were observed. However, the impact on the groundwater was not measured and is largely unknown.

A study on the nutrient depletion in the agricultural soils of Africa by Henao and Baanante (1999), indicated that nutrient depletion in South Africa is low. In 1993 – 95 the difference between nutrient inputs and nutrient losses in the continent ranged between 14 kg of N, P, and K per hectare per year in South Africa to 136 kg in Rwanda (Henao & Baanante, 1999).

Specifically, the N input load in the Orange River was calculated to be 100 kg N km^{-2} a^{-1} and export was 4 kg N km^{-2} a^{-1}; the (Caraco & Cole, 1999). This is comparable to the Nile (input 45; export 3), but much lower than the Zambezi (250, 10); Niger (250, 21); Zaire (150; 30); Amazon (150, 33); Volga (134, 80); Mississippi (611; 177); Thames (993, 1 120) and Rhine (1 455, 1 520) to mention a few (Caraco & Cole, 1999).

9.4 Suspended sediments:

The Orange River has been discharging vast quantities of sediment onto the western continental margin of southern Africa for approximately 125 million years (Bremner *et al.*, 1990). Although the mean annual runoff of 11 km^3/year is small in comparison with most major rivers, the Orange River carries a relatively large suspended load and ranks as the most turbid river in Africa and the fourth most turbid in the World (Bremner *et al.*, 1990).

Water quality is often considered impaired above 80 mg TSS/ℓ (fisheries may be harmed), and waters more than 400 mg/ℓ provide poor fish habitat. Negative impacts of suspended sediments on fish include smothering eggs, interfering with respiration, limiting visibility for sight feeders, and loss of habitat and prey communities (Dodds & Whiles, 2004). Wofsy (1983) concluded that suspended sediment concentration above about 50 mg/ℓ prevents significant algal blooms in all but the shallowest streams.

Stream flow was shown to be the most important variable to influence the total suspended solids and thus transparency of Orange River water (**Figure 66**). Higher stream flow resulted in higher TSS and turbidity and hence, a lower euphotic zone and a lesser under water climate.

The Drakensberg Mountains receive the greatest amount of rainfall and have the steepest slopes of the Upper Orange River catchment. However, the hard basalt bedrock combined with densely rooted grassland vegetation limit the amount of erosion. The sediment load is dominated by the more easily eroded underlying Karoo sedimentary rocks where the river cuts down through the Drakensberg Mountains. Therefore, most of the sediment carried to the western margin by the Orange River is derived from Karoo sedimentary rocks rather than from basalt (Compton & Maake, 2007). However, the sediment derived from the Karoo sedimentary rocks is dominated by quartz sand, much of which ultimately ends up in the Namib Desert (Bremner *et al*., 1990; Compton & Maake, 2007).

Reservoir construction in impounded basins introduces an efficient cascade of sediment traps, which could currently store more than 30 % of river sediments at the global scale (Meybeck, 2003). Large fractions of these clay minerals are silicate minerals that may result in lower dissolved Si concentrations.

However, the suspended solid loads in the lower Orange River have changed dramatically and reduced by up to 97 % from the 'natural' levels. In the upper Orange, the high TSS and turbidity (light limitation) in this rapidly flushed system will restrict algae to low abundances.

The Orange is a highly regulated river. River regulation modifies the sediment regime of a river through retention of material within the reservoirs (dams) and through modification of downstream erosion and deposition processes. The total suspended solids in the Orange River from the Gariep Dam and downstream have decreased drastically after the construction of the dams particularly during the last 10 – 20 years.

9.5 Turbidity:

Turbidity results from the scattering and absorption of light by particles in the water, including silt, clay, detritus, and phytoplankton. It is a measure of the overall concentration of these fine suspended particles. Turbidity is important because it affects the growth rates of phytoplankton, transport of contaminants, and the effectiveness of disinfection (Jassby & Goldman, 2003). It usually varies seasonally in response to runoff from the catchment and biological cycles within the water itself.

Light is required for photosynthesis by all river primary producers, *i.e.* algae and macrophytes. The depth of the euphotic zone (*i.e*. the zone with sufficient light to support photosynthetic activity) in rivers is highly dependent on the water colour and the amount of suspended sediment present.

The high turbidity in the Caledon River will limit algal growth for most of the year.

The relatively low water turbidity in the lower Orange River will obviously increase the light penetration into the water and thus increase the underwater light climate that will increase the algal photosynthesis. Thus, the low turbidity (clear water conditions) is considered to be one of the main driving forces that result in higher algal biomass in the Orange River.

9.6 pH values:

The pH is an important variable in water quality assessment, as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment. The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in diluted waters rich in organic content, and higher values in eutrophic waters, and salt lakes (DWAF, 1996).

However, the pH of the Orange River water (main stream) was generally high (alkaline, overall mean 8.05). The pH values were relatively low in the upper part of the river (mean, 7.8). The higher pH values in the middle and lower part of the Orange River are primarily ascribed to higher algal concentrations.

Water with pH in excess of 8.4 may cause foliar damage, decrease the visual quality of marketable products (if they are wetted during irrigation), affect the availability of several micro and macro-nutrients, and also increase problems with encrustation of irrigation pipes and clogging of drip irrigation systems (DWAF, 1996).

The pH in the Orange River water was significantly influenced by the chlorophyll concentration in the water because photosynthesis by algae during the day increases the pH. For each mole (12 g) of carbon taken up by the algae, 1.196 moles (20.332 g) of hydroxyl ions (OH^-) are released into the water. It is generally observed in eutrophic systems that peak pH levels coincide with peak dissolved oxygen concentrations, with peak levels occurring mid afternoon and minimum levels at pre-dawn (Horne & Goldman, 1994).

An explanation for this could be that higher chlorophyll concentrations are associated with higher rates of photosynthesis. This assimilates carbon dioxide, thus lowering the carbonic acid, which will increase the pH.

9.7 Alkalinity:

Alkalinity is the acid-neutralising capacity of water and is usually expressed as mg $CaCO_3$/ℓ, thus commonly used to indicate a system's capacity to buffer against acid impacts. Buffer capacity is the ability of a body of water to resist or dampen changes in pH. Alkalinity is mostly taken as an indication of the concentration of carbonate, bicarbonate and hydroxide, but may include contributions from borate, phosphates, silicates and other basic compounds. Alkaline compounds in water such as bicarbonates, carbonates, and hydroxides remove H^+ ions and lower the acidity of the water (*i.e.*, increase pH).

Total alkalinity (TAL) is considered as a rather conservative property of natural waters. The total alkalinity concentrations typically found in freshwater system ranged between 50 and 250 mg/ℓ. The overall average alkalinity in the Orange River ranged between 100 and 125 mg/ℓ, indicating a good buffering capacity and is not sensitive to acidification according to UNEP-GEMS (2006).

9.8 Silica (SiO_2):

During periods of high biological productivity by diatoms, silica concentrations may be depleted from the surface waters of lakes by more than a factor of ten, as shown for several lakes and reservoirs (UNEP-GEMS, 2006). Silica depletion below 0.5 mg/l may limit growth of diatoms, which require silica as a component of their cellular casings (Jassby & Goldman, 2003). Thus, the declines in silica in the surface waters usually lead to a rapid decline in diatom populations.

The increased water residence time allows sediments to settle, light penetration to increase, and more diatom production to occur, which is also followed by silica burial. Dissolved silica concentrations were reduced to less than half their pre-dam construction values in the Danube and Nile River (Humborg *et al*., 2000). After the Aswan High Dam was built on the Nile River, the supply of phosphate and silica to the coastal area was reduced to 4 % and 18 % respectively of pre-dam conditions. This drop in nutrients, combined with increased salinity in the delta because of a reduction in the Nile outflow and over-fishing, reduced the productivity of the coastal fisheries significantly (WWF, 2004). Apparently, subtle differences in ratios, such as phosphorus to silicon, can alter competitive relations among algal species.

Regulation of rivers by damming as well as eutrophication in river basins has substantially reduced dissolved silicon (DSi) loads to the Black Sea and the Baltic Sea (Humborg *et al*., 2000). Whereas removal of N and P in lakes and reservoirs can be compensated for by anthropogenic inputs in the drainage basins, no such compensation occurs for DSi. The resulting changes in the nutrient composition (DSi:N:P ratio) of river flow rates seem to be responsible for dramatic shifts in phytoplankton species composition in the Black Sea. In the Baltic Sea, DSi concentrations and the DSi:N ratio have been decreasing since the end of the 1960s, and there are indications that the proportion of diatoms in the spring bloom has decreased while flagellates (potentially toxic) have increased. The effects on coastal biogeochemical cycles and food web structure observed in the Black Sea and the Baltic Sea may be far reaching, because it appears that the reductions in DSi delivery by rivers are probably occurring worldwide with the ever increasing construction of dams for flow regulation (Humborg *et al.*, 2000).

Silicon retention in the Orange River basin has also been observed. The temporal and spatial silica decline in the Orange River is probably mainly due to dam constructions, lower suspended solids, biogenic uptake followed by burial and could also effects the coastal biogeochemical cycles and food web structure.

9.9 Eutrophication:

Nutrients entering rivers, lakes, and oceans from surface runoff water of agricultural lands and urban areas have become a major environmental concern around the world. When excessive amounts of nutrients, especially nitrogen & phosphorus, enter lakes and rivers, it enhances the growth of undesirable algae and aquatic weeds. The large-scale use of fertilizers by commercial agriculture leads to substantially increased levels of phosphates and nitrates in the river. These degrade the quality of the water for downstream users, such as municipalities, communities and farmers and effect river ecosystems through the build-up of nutrients.

Nitrate concentrations in some rivers of Western Europe are now approaching the World Health Organization (WHO) drinking water guideline value of 10 mg/ℓ NO_3-N (Meybeck *et al.*, 1989). Urban wastewaters and some industrial wastes are major sources of nitrate. In regions with intensive agriculture, the use of nitrogen fertilisers and discharge of wastewaters from the intensive indoor rearing of livestock can be the most significant sources.

However, not all nitrogen loaded into rivers is ultimately exported to estuaries or the ocean. Processes such as denitrification, organic matter burial in sediments, sediment sorption, and plant and microbial uptake can remove nitrogen from the river, and thus affect the amount of nitrogen that is transported by rivers to coastal ecosystems (Billen *et al.*, 1991).

Causes of nutrient over-enrichment or eutrophication of aquatic ecosystems can be attributed to agriculture, urbanization, forestry, impoundments, and industrial effluents (UNEP-GEMS, 2006). Increased rates of primary production typical of eutrophic ecosystems is often manifest as excessive growth of algae and the depletion of oxygen (increased BOD), which can result in the death of fish and other animals. Nutrient enrichment can also increase the abundance of cyanobacteria (blue-green algae), which can produce toxins. Mass mortality and anoxia are the ultimate stage of eutrophication.

Problems occur with phytoplankton blooms in European and other rivers around the world. In the Murray Darling river system in South Australia, water withdrawals reduce flow to a near standstill in the river, and excess amounts of nutrients, stratification, and warm water temperature stimulate algal blooms (Davis & Koop, 2006). These blooms are commonly dominated by the hepatotoxic *Microcystis*. Other slow-flowing rivers in the world suffer a similar fate, particularly those with limited quantities of light-intercepting fine sediments (Dodds, 2006).

In rivers, algal abundance often depends more on variations in physical characteristics (temperature, turbidity, flow variations) than on nutrient concentrations (Søballe & Kimmel, 1987).

Eutrophication effects in the upper reach of the Orange River (upstream of Gariep Dam) could not be quantified because of a lack of scientific publications and no algal biomass or chlorophyll-*a* concentrations data were available. However, with the fairly natural high stream flow, high suspended material in the water and limited weirs, we suspect that the probability of algal blooms in the upper reaches of the upper Orange River would be low and not be a matter of concern.

Nevertheless, algal blooms have become a visible water quality problem in South African rivers, including the Orange River (Van Ginkel & Conradie, 2001; Earle *et al.*, 2005). Algal blooms, including cyanobacteria, were recorded in the Gariep Dam (Venter, 2000) and Upington (Van Ginkel & Conradie, 2001). The occurrence of cyanobacteria at high concentrations restricts the use of the water for drinking water, irrigation, and recreation. Harmful algal blooms are dangerous for animal and human drinking water resources due to the release of toxins. Thus, impairment of water quality due to the eutrophication can lead to health-related problems and result in economic losses.

However, the mean chlorophyll-*a* concentrations in Gariep Dam and Vanderkloof Dam from 2000 – 2008 were low (<5 µg/ℓ) and comparable to oligotrophic systems.

The concept of water residence time is particularly important. On the one hand it is known that rapidly flushed systems restrict algae to lower abundance, on the other hand it is well documented that increased water residence time leads to higher algal abundance.

The algal blooms in the lower Orange River are probably not primarily driven by nutrients (chemicals), but are triggered (controlled) by a combination of physical conditions, mainly caused by low flow. Lower flow rates and weirs, both of which produce a marked decrease in flow velocities within the river, result in higher settling rates of suspended material, which are enhanced by higher salt concentrations and results in clearer water with better light penetration (lifting the light limitation on algae). They also increase the residence time (algae have more time to grow) and provide shallower water with probably higher temperatures, and a more stable water-column with possible stratification in the weir pools. All these factors create favourable conditions for an algal bloom.

9.10 N:P ratios:

The ratio of N to P in phytoplankton cells typically averages about 7.2 on a weight basis (16 on a molar basis), and so this number is often taken as the dividing line between N- and P-limited water bodies*, i.e.* water with TN:TP <7.2 should be N-limited. The threshold is not so clear cut in practice, however, and there is a region of ambiguity about this threshold. It is probably best to consider ratios in the range 4 – 14 as ambiguous, with N:P <4 indicating probable N limitation and N:P >14 indicating probable P limitation (Jassby & Goldman, 2003).

High N:P ratios in the Upper Orange River (>14), indicate that phosphorus is limited. However, the N:P ratios drop significantly from Prieska (median, 28) to less than 7 at Pella and downstream indicates a switch to N limitation in the lower end of the river.

The N:P ratios decline in the Lower Orange River because the inorganic nitrogen decreases significantly downstream whilst the phosphorus concentrations were more or less constant. The problem with low N:P ratios is that it usually favours the growth of cyanobacteria.

9.11 Faecal contamination:

Faecal contamination is still the primary water quality issue in rivers, especially in many developing countries where human and animal wastes are not yet adequately collected and treated. Limited bacteriological data are available for the Orange River, however, data at Upington show relatively low *E. coli* concentrations. Results from the snapshot survey also show generally low *E. coli* concentration in the Orange River (<130 cfu/100 mℓ).

Nevertheless, the *E. coli* concentrations were high (>1 000 cfu/100 mℓ) in the Caledon River especially downstream of Ficksburg and Maseru. Most of the tributaries to the Caledon also experience problems with faecal contamination. Stormbergspruit at Burgersdorp is a matter of concern with unacceptable high levels of pollution.

10 RECOMMENDATIONS

Literature worldwide suggests that global water demand is ever increasing as changing lifestyles and increasing population put pressure on the water resources of the world. The pressure is magnified when the water resources are shared between countries. Transboundary water resources management remains a challenge in Africa, which has 60 shared river basins (Wolf *et al*., 1999).

Nevertheless, the Orange River Basin is the most stable international river basin in the entire SADC region, with the highest number of basin-specific regimes, some of which occurred after 1999 when the initial Basin at Risk study was done. It has the most sophisticated water resource management structures and the underlying agreements that have evolved over time, having shown a deepening in complexity, to a point where they have become the foundation of subsequent agreements in the other Basins at Risk (Turton, 2008).

Making decisions with imperfect and incomplete information is never easy, and carries with it considerable risk. With funding the necessary research, it is quite possible to reduce the risks of decisions by improving our knowledge base, and especially extending our long-term studies in the Orange River system.

Monitoring, research and management strategies are listed below.

10.1 Improve monitoring

The historical chemical data sets of DWAF are good at several monitoring sites on the Orange and tributaries, however, serious gaps and low frequency occurred and some critical parameters, like TSS, turbidity, Chl-*a* and *E. coli* are not measured at most of the sites. Upgrading and expansion of the monitoring programme is recommended – see Report No. 6.

Currently very little information is available on pesticides and herbicides in the river system. There is extensive agriculture on the banks of the Vaal and Orange Rivers. The presence of these pollutant types should be determined by designing and carrying out a round of monitoring.

The appeal by Turton (2008) is also supported by this study, *i.e.* ‘every effort should be made by the various riparian states, the SADC Secretariat and the New Partnership for Africa’s Development (NEPAD) Secretariat, to establish a central depository for data, so that it can be assessed by researchers outside of the region’.

10.2 Salinity from Irrigation

Increasing salinity resulting from the effects of irrigated agriculture is one of the oldest and most widespread forms of groundwater pollution (Meybeck *et al.*, 1989). This should be investigated further.

The dissolved salts and nutrient concentrations in the irrigation return flows are orders higher than in the Orange River and apparently contribute significantly to the salt loads in the Orange River. However, the precise volumes of return flows from irrigation along the river are uncertain (DWAF, 2008b) and should be investigated further.

Demand management, reducing consumption, recycling and supply and end-use efficiency measures all have significant potential to reduce pressure on water resources in all countries and regions of the world, *i.e.* investigate best management practices.

10.3 Trace metals

The trace metal concentrations in the Orange River were generally high. The relatively high lead concentration at Upington and Pella (overall mean, of 60 µg/ℓ) and occasionally the aluminium, cadmium, and copper concentrations at certain sites are a matter of concern and should be investigated further to determine the possible source – especially in the Lower Orange River. The role of the numerous mineral mines along the river should be particularly investigated as possible sources of metals.

However, indications are that the concentrations criteria set for Cu (and maybe some or the others metals as well) in aquatic ecosystems by DWAF (1996) are unrealistically low and should be revised. See Report No. 5 on RWQO's.

10.4 The significance of the Wetland above Neusberg

Indications are that the wetland area above Neusberg Weir serves as an important biological filter to reduce nutrient and sediment load. A more detailed study is necessary to determine the significance of the wetland to water quality.

10.5 Eutrophication

In its simplest expression, eutrophication is the biological response to excess nutrient inputs to a lake or river. Nutrients entering rivers, lakes, and oceans from surface runoff water of agricultural lands and urban areas have become a major environmental concern around the world. The effects of eutrophication can be highly detrimental to lake or river water quality and severely limit the uses for which water is suitable.

Nutrient input from the irrigation is apparently insignificant, but a nutrient balance or nutrient modelling is necessary to determine the fate of nutrients.

A more detailed study on the effect of eutrophication on the Orange River system should be undertaken, especially the factors that trigger (initiate) the development of algal blooms and specifically the occurrence of toxic cyanobacteria in the system.

Solutions to reduce nuisance blooms in rivers may lie in hydraulic control. Operational manipulations of flow may result in beneficial effects on the algal blooms, but should be investigated in the Orange River.

The sediments in the Orange River are believed to play an important role in nitrogen removal *via* denitrification. Denitrification is apparently a major N-sink that removes thousands of kilograms from the river and dams annually, hence a key process to understanding and managing eutrophication, therefore should be investigated. Only a complete nutrient mass balance can 'prove' our hypothesis. There is also insufficient knowledge on the behaviour of phosphorus in streams and rivers.

10.6 Vulnerability assessment

Assess the vulnerability of the water resources to environmental change in the Southern Africa Region. Vulnerabilities should be evaluated according to the main physiographic, socio-economic and managerial clusters. Key issues are: Climate change & variability, ecosystems, surface and groundwater, demography, economy, legislation, institutional and knowledge (UNEP, 2005).

Changes brought on by urbanization, excessive water withdrawals or climate shifts that occur rapidly and lead to flows outside the natural range of variability will have important consequences for river ecosystems and the people who depend on them (Palmer *et al*., 2008).

10.7 Modelling of salts

The salinisation of the Orange River was shown to be an important water quality problem. The main variables that impact on the salinity loads in the system should be assessed on a continuous basis to establish the need to update the TDS model and to commission studies accordingly.

Although flow regulation is not necessarily the main cause of salinity problems, flow and river salinity are intimately linked, so it makes sense to co-ordinate their management through an integrated program supported by appropriate salinity modelling.

10.8 Groundwater resources

The groundwater resources of the Orange Basin provide vital sources of additional water to meet the needs of domestic users and irrigation projects, and groundwater use increases in importance towards the downstream (western) portion of the basin.

However, the extent, quality, reliability and safe yield of groundwater resources within each of the four countries comprising the Orange-Senqu Basin needs to be firmly established at a high level of confidence.

10.9 Ecological Reserve Determination

Water flowing to the sea is not wasted. Freshwater that flows into the ocean nourishes estuaries, which provide abundant food supplies, buffer infrastructure against storms and tidal surges, and dilute and evacuate pollutants. Flow alteration imperils freshwater and estuarine ecosystems. These ecosystems have evolved with, and depend upon, naturally variable flows of high-quality freshwater.

The Orange River mouth (estuary) is regarded as the sixth most important coastal wetland in southern Africa, but is currently in a very poor condition and placed on the Montreux Record because changes in ecological character have occurred, *i.e.* following the collapse of the salt marsh component of the estuary. The riparian vegetation has been severely damaged by the diamond mining activities on the South African side of the river mouth. Special efforts and management strategies should be investigated and implemented by DWAF to restore this Ramsar site.

Greater attention to environmental flow needs must be exercised when attempting to manage floods, supply water to cities, farms, and industries; generate power, recreation and drainage. Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.

A comprehensive Reserve must however, still be determined for the Orange River. In the mean time it is essential that proper monitoring must be set in place to monitor the ecological health of the river and the estuary and to collect sufficient data as required for a proper Reserve determination.

10.10 Integrated Water Resources Management Plan

An important rule for the management of freshwater ecosystems is to remember that the conditions, water quality and biota of any body of freshwater are the product and reflection of events and conditions in its catchment. An extremely important factor is that substances added to the atmosphere, land, and water generally have relatively long time scales for removal or clean up (Peters & Meybeck, 2000).

Conserving river ecosystems depends on whole-catchment management, where land and water are managed in an integrated manner to achieve ecological and socio-economic sustainability. This requires the development of integrative assessment and planning approaches that proactively consider the needs of both terrestrial and freshwater ecosystems (Nel *et al*., 2007).

Thus, the development of an integrated water resources management plan (IWMP) for the Orange River, which can link up with the Vaal River's plan, is of paramount importance. The IWMP is a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives.

The establishment of a Catchment Management Agency (CMA) and the implementation of a Catchment Management Strategy are essential to ensure the sustainability of the water resource. Proactive management efforts will minimize risks to ecosystems and people and may be less costly than reactive efforts taken only once problems have arisen.

However, the Orange River is an international watercourse with an obligation for it to be managed and used in terms of the relevant rules of international law. The underlying principles thereof are to adopt a holistic approach, with respect to its use, protection and regulation.

11 LITERATURE

ARTP JMB (2008). *Lower Orange River Management Plan - Unlocking the Ecotourism Potential of the River*, Draft Report to Ai-Ais-Richterveld Transfrontier Park (ARTP) Joint Management Board (JMB), xiii + 153 pp.

Basson, M.S., Van Niekerk, P.H., and Van Rooyen, J.A. (1997). *Overview of Water Resources availability and utilisation in South Africa.* Department of Water Affairs and Forestry, DWAF, Report P RSA/00/0197, ISBN 0 7970 3540 0. Printed by CTP Book Printers (Pty) Ltd, Cape Town.

Billen, G., Lancelot, C. and Meybeck, C. (1991). N, P, and Si retention along the aquatic continuum from land to ocean. In: Matoura, R.F.C., Martin, J.M. and Wollast, R. (eds), *Ocean Margin Processes in Global Change*. Wiley & Sons, Chichester, England: pp. 19 – 44.

Bremner, J.M., Rodgers, J., and Willis, J.P. (1990). Sedimentological aspects of the 1988 Orange River floods. *Trans Roy. Soc. S. Afr.*, **47:** 247 – 294.

Caraco, N.F. and Cole, J.J. (1999). Human impact on nitrate export: an analysis using major World Rivers. *Ambio*, **28:** 167 – 170.

Chapman, D. (ed.) (1996). *Water Quality Assessments. A guide to the use of biota, sediments and water in environmental monitoring* (2nd edition). Published on behalf of UNESCO, WHO, and UNEP by E & FN Spon, London and New York, 626 pp.

Compton, J.S. and Maake, L. (2007). Source of the suspended load of the upper Orange River, South Africa. *South African Journal of Geology,* **110:** 339 – 348.

Conley, A. and Van Niekerk, P. (1998). *Sustainable Management of International Waters: The Orange River Case*, In Savenije, H. and Van der Zaag, P., The Management of Shared River Basins: Experiences from SADC and EU. Delft, Netherlands: Ministry of Foreign Affairs.

Davies, B., and Day, J. (1998). *Vanishing Waters.* UCT Press, University of Cape Town, ISBN 1-919713-11-5, 487 pp.

Davis, J.R. and Koop, K. (2006). Eutrophication in Australian rivers, reservoirs and estuaries – a southern hemisphere perspective on the science and its implications, Review. *Hydrobiologia* **559:** 23 – 76.

DEAT, Department of Environmental Affairs and Tourism (2006). *South Africa Environment Outlook*. A report on the state of the environment. Department of Environmental Affairs and Tourism, Pretoria. 371 pp.

Degens, E.T., Kempe, S., and Richey, J.E. (Eds) (1991). *Biogeochemistry of Major World Rivers,* SCOPE42, John Wiley, Chrichester, 356 pp. Available from: www.icsu-scope.org/downloads/scope42/contents.html

Dodds, W.K., Jones, J.R., and Welch, E.B. (1998). Suggested classification of stream trophic state: distribution of temperate stream types by chlorophyll, total nitrogen, and phosphorus. *Water Research*, **32:** 1455 – 1462.

Dodds, W.K. (2006). Eutrophication and trophic state in rivers and streams. *Limnol. Oceanogr.*, **51 (1, part 2):** 671 – 680.

Dodds, W.K., and Whiles, M.R. (2004). Quality and quantity of suspended particles in rivers: Continent-scale patterns in the United States. *Environmental Management*, **33 (3)**: 355 – 367.

DTEC, Department of Tourism, Environment & Conservation (2005). *Northern Cape State of the Environment Report 2004*. Freshwater Resources Specialist Report, Final version January 2005. Department of Tourism, Environment & Conservation, Kimberley.

DWA, Department of Water Affairs, (1986). *Management of the water resources of the Republic of South Africa*. Department of Water Affairs, CTP Book Printers, Cape Town, South Africa.

DWAF, Department of Water Affairs and Forestry, (1996). *South African Water Quality Guidelines for Freshwater.* Edition 2. Volumes 1 – 7. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF, Department of Water Affairs and Forestry, (2002). *National Eutrophication Monitoring Programme. Implementation Manual.* Compiled by K. Murray, M. du Preez and C.E. van Ginkel. Pretoria, South Africa.

DWAF, Department of Water Affairs and Forestry, (2003). *Water Quality Management Series. A Review and Discussion Document. Project: Phase 1, Development of a strategy to Control Eutrophication in South Africa.*

DWAF, Department of Water Affairs and Forestry, South Africa (2004). *Internal Strategic Perspective: Orange River System Overarching.* Prepared by PDNA, WRP Consulting Engineers (Pty) Ltd, WMB and Kwezi-V3 on behalf of the Directorate: National Water Resource Planning. DWAF Report No P RSA D000/00/0104.

DWAF, Department of Water Affairs and Forestry, South Africa (2005). *Main Report – Prefeasibility study into measures to improve the management of the Lower Orange River and to provide for future developments along the border between Namibia and South Africa.* Prepared by Lower Orange River Consultants on behalf of the Permanent Water Commission. DWAF Report No PB D000/00/4703.

DWAF, Department of Water Affairs and Forestry, South Africa (2008a). Directorate: Water Resources *Planning* Systems: Water Quality Planning. *Orange River system: Assessment of water quality data requirements for planning purposes. Inception Report.* Pretoria, South Africa.

DWAF, Department of Water Affairs and Forestry, South Africa (2008b). *Orange River system: Real-time operation system for the Lower Orange River. Draft Report to Directorate: Water Resources Planning Systems*. DWAF Report No P WMA 14/000/000/….

DWAF, Department of Water Affairs and Forestry, South Africa (Website). *Introduction to the Orange River Basin.* Online available at*:* *www.dwaf.gov.za/orange/*

Earle, A., Malzbender, D., Turton, A., and Manzungu, E. (2005). *A preliminary Basin Profile of the Orange/Senqu River*. INWENT in cooperation with the African Water Issues Research Unit, CIPS, University of Pretoria, in support to the SADC Water Division and ORASECOM. Published by AWIRU, University of Pretoria, South Africa. ISBN: 1-86854-618-7.

Gippel, C.J. and Blackham, D. (2002). *Review of environmental impacts of flow regulation and other water resource developments in the River Murray and Lower Darling River system.* Final Report by Fluvial Systems Pty Ltd, Stockton, to Murray-Darling Basin Commission, Canberra, ACT.

GEO-2000 (1999). Clarke, R. (ed.). *Global Environmental Outlook 2000*. Division of Environmental Information, Assessment and Early Warning (DEIA&EW). United Nations Environment Programme (UNEP), Nairobi, Kenya. Website: http://www.unep.org.

Haggard, B.E., Ekka, S.A., Matlock, M.D., and Chaubey, I. (2004). Phosphate equilibrium between stream sediments and water: Potential effect of chemical amendments. *Trans. ASAE,* **47:** 1113 – 1118.

Henao, J. and Baanante, C. (1999). Nutient depletion in the agricultural soils of Africa. International Food Policy Research Institute (IFPRI), 2020 Brief No. 62. Available from: www.ifpri.org/2020/briefs/number62.htm.

Hill, A.R. (1979). Denitrification in the nitrogen budget of a river ecosystem. *Nature*, **281**: 291 – 292.

Horne, A.J. and Goldman, C.R. (1994). *Limnology (2nd edition)*. McGraw-Hill, Inc., New York, 576 pp.

Hughes, D.A. (ed.) (2005). *Spatsim, an Integrating Framework for Ecological Reserve Determination and Implementation. Incorporating Water Quality and quantity Components for Rivers.* WRC Report No. TT 245/04. Water Research Commission, Pretoria.

Humborg, C., Conley, D.J., Rahm, L., Wulff, F., Cociasu, A., and Ittekkot, V. (2000). Silicon retention in river basis: far-reaching effects on biogeochemistry and aquatic food webs in coastal marine environments. *Ambio,* **29:** 45 – 50.

IUCN, International Union for Conservation of Nature and Natural Resources and the United Nations Environmental Programme (2001). *Biodiversity impacts of Large Dams.* Background Paper Nr. 1 Prepared for IUCN/UNEP/WCD.

Jassby, A.D. and Goldman, C.R. (2003). *Water quality of the upper Big Thompson Watershed.* Available from: <www.btwatershed.org/jassbyreport.pdf>.

Kunin, R. (1972). *Water softening by Ion Exchange*, Proceedings Fourteenth Water Quality Conference, University of Illinois, Urbana, Il, USA.

Measurement of denitrification in rivers: an integrated, whole reach approach. *Hydrobiologia*, **485:** 67 – 81.

Laursen, A.E. and Seitzinger, S.P. (2002). Measurement of denitrification in rivers: an integrated, whole reach approach. *Hydrobiologia*, **485:** 67 – 81.

Lund, J.W.G. (1965). The ecology of freshwater phytoplankton. *Biol. Rev.* **40:** 231 – 293.

Martin, J.M. and Meybeck, M. (1979). Elemental mass-balance of material carried by the world major rivers. *Mar. Chem.*, **7:** 173 – 206.

McKenzie, R.S. and Craig, A.R. (2001). Evaluation of river losses from the Orange River using hydraulic modelling. *Journal of Hydrology*, **241:** 62 – 69.

Meybeck, M. (1982). Carbon, nitrogen, and phosphorus transport by World Rivers. *American Journal of Science*, **282:** 401 – 450.

Meybeck, M. (2003). Global analysis of river systems: from Earth system controls to Anthropocene syndromes. *Phil. Trans. R. Soc. Lond. B,* 03TB050B.1 – 21.

Meybeck, M., Chapman, D., and Helmer, R. [Eds] (1989). *Global Freshwater Quality: A First Assessment.* Blackwell Reference, Oxford, 306 pp.

Meybeck, M., and Helmer, R. (1989). The quality of rivers: from pristine stage to global pollution. *Palaeogeogr., Palaeoclimatol., Palaeecol.* (Global Planet. Change Sect.) **75:** *283 -309.*

Nel, J.L., Roux, D.J., Maree, G., Kleynhans, C.J., Moolman, J., Reyers, B., Rouget, M., and Cowling, M. (2007). Rivers in peril inside and outside protected areas: a systematic approach to conservation assessment of river ecosystems. *Diversity Distributions,* **13:** 341 – 352, Journal compilation, 2007 Blackwell Publishing Ltd.

NEMP (2000). *National Eutrophication Management Program.* Factors controlling growth and composition in reservoirs: Report of Reservoir Managers' Workshops January 2000. http://freshwater.canberra.edu.au

Nilsson, C., Reidy, C.A., Dynesius, M., and Revenga, C. (2005). Fragmentation and Flow Regulation of the World's Large River Systems. *Science*, **308:** 404 – 408. www.sciencemag.org.

Pallett, J. (ed.) (1997). *Sharing water in southern Africa.* Desert Research Foundation of Namibia, Windhoek, 121 pp.

Palmer, M.A., Reidy Liermann, C.A., Nilsson, C., Flörke, M., Alcamo, J., Lake, P.S., and Bond, N. (2008). Climate change and the world's river basins: anticipating management options. *Front Ecol Environ*., **6:** 81 – 89.

Palmer, R.W., Rivers-Moore, N., Mullins, W., McPherson, V., and Hatting, L. (2007). *Guidelines for integrated control of pest blackflies along the Orange River.* WRC Report No. 1558/1/07. Water Research Commission, Pretoria, South Africa.

Peters, N.E. and Meybeck, M. (2000). Water quality degradation on freshwater availability: Impacts of human activities. *IWRA, Water International*, **25:** 185 – 193.

Poff, N.L., Olden, J.D., Merritt, D.M., and Pepin, D.M. (2007). Homogenization of regional river dynamics by dams and global biodiversity implications. *Proc Natl Acad Sci USA*, **104:** 5 732 – 37. www.pnas.org/cgi/doi/10.1073/pnas.0609812104.

Revenga, C., Brunner, J., Henninger, N., Kassem, K. and Payne, R. (2000). *Pilot analysis of global ecosystems: Freshwater Systems,* WRI, ISBN: 1-56973-460-7.

Roos, J.C. (2000). *Katse Dam and the proposed Kruisvallei Dam, water quality study.* Confidential report prepared for Rand Water, Scientific Services, Vereeniging, 119 pp.

Roos, J.C. (2007). *Nitrogen assimilation capacity of the Vaal River, South Africa.* Water Resources Management, Proceedings of the Second IASTED International Conference, August 20 – 22, 2007, Honolulu Hawaii, USA, ISBN Hardcopy: 978-0-88986-679-9, 118 – 122.

Roos, J.C. and Pieterse, A.J.H. (1994). Light, temperature and flow regimes of the Vaal River at Balkfontein, South Africa. *Hydrobiologia*, **277**: 1 – 15.

Søballe, D.M. and Kimmel, B.L. (1987). A large-scale comparison of factors influencing phytoplankton abundance in rivers, lakes, and impoundments. *Ecology*, **68:** 1 943 – 1 954.

Stats SA, Statistics South Africa (2008). *Environmental-Economic Accounting for Water*. Statistics South Africa, Pretoria. www.statssa.gov.za.

Taylor, J.C., De La Rey, P.A., and Van Rensburg, L. (2005). Recommendations for the Collection, Preparation and Enumeration of Diatoms from Riverine Habitats for water quality monitoring in South Africa. *African Journal of Aquatic Sciences* 30 (1): 65-75.

Turton, A.R. (2005). *Hydro Hegemony in the context of the Orange River Basin.* CSIR Report No: ENV-P-CONF 2005-003.

Turton, A.R. (2008). *The Southern African Hydropolitical Complex.* In: Varis, O., Biswas, A.K. and Tortajada, C. (Eds.). Management of Transboundary Rivers and Lakes. Springer Berlin Heidelberg. Book Series, Water Resources Development and Management, ISBN 978-3-540-74926-4, Book Chapter 2, 21 – 79 pp.

UNEP (2005). Beekman, H.E., Abu-Zeid, K., Afouda, A., Hughes, S., Kane, A., Kulindwa, K.A., Odada, E.O., Opere, A., Oyebande, L. and Saayman, I.C. *Facing the Facts: Assessing the Vulnerability of Africa's Water Resources to Environmental Change.* Early Warning and Assessment Report Series, UNEP/DEWA/RS, United Nations Environmental Programme, Nairobi, Kenya.

UNEP-GEMS (2006). *Water Quality for Ecosystems and Human Health.* United Nations Environment Programme Global Environment Monitoring System (GEMS)/Water Programme. ISBN 92-95039-10-6. PDF version available online from: www.gemswater.org

UNP (United Nations Publications) (2000). Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication. Technical Publication Series 11. UNEP/Earthprint, 375 pp.

USEPA (United States Environmental Protection Agency) (2000). *Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria: Rivers and Streams in Nutrient Ecoregion XII*. EPA 822-B-00-021. Office of Water, Washington, DC.

Van Ginkel, C.E. and Conradie, B. (2001). Potential toxic algal incident in the Orange River, Northern Cape, 2000. Draft Report No. N/D801/12/DEQ/0800. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

Van Heerden, P.S., Crosby, C.T. and Crosby, C.P. (2001) *Using SAPWAT to estimate the water requirements of crops in selected irrigation areas managed by the Orange-Vaal and Orange-Riet Water Users Associations.* WRC report no. **TT 163/01**, October 2001. Water Research Commission, Pretoria.

Van Niekerk, H. (2005). *A strategy for linking South Africa to the Water Programme of the United Nations Global Environmental Monitoring System (GEMS)*. Unpublished Ph.D. thesis, University of the Free State, Bloemfontein, RSA, 127 pp.

Vegter, J. R. 1995. *Groundwater Resources of South Africa: An explanation of a set of national groundwater maps*, WRC Report No. TT74/95, Water Research Commission, Pretoria.

Vegter, J. R. 2001. *Groundwater Development in South Africa and an introduction of the hydrogeology of groundwater regions*, WRC Report No. TT134/00, WRC, Pretoria.

Venter, G.C. (2000). *Water quality of the upper Orange River*. Unpublished M.Sc dissertation, University of the Free State, Bloemfontein, RSA, 205 pp.

Volschenk, T., Fey, M.V., and Zietsman, H.L. (2005). *Situation analysis of problems for water quality management in the lower Orange River region with special reference to the contribution of the foothills to salinization.* WRC Report No. 1358/1/05, Water Research Commission, Pretoria.

Walmsley, R.D. and Butty, M. (eds.) (1980). *Limnology of some selected South African impoundments.* A collaborative report by Water Research Commission and National Institute for Water Research, CSIR, Pretoria, 229 pp.

WCD, World Commission on Dams (2000). *Dams and Development: A new Framework for Decision-making.* The Report of the World Commission on Dams, WCD, Earthscan Publications Ltd, London and Sterling, VA.

Wikipedia, the free Encyclopedia. Website online available at: http://en.wikipedia.org/wiki/Main_Page

Wetzel, R.G. (2001). *Limnology: Lake and River Ecosystems*. Third Edition, Academic Press, USA.

Wofsy, S.C. (1983). A simple model to predict extinction coefficients and phytoplankton biomass in eutrophic waters. *Limnol. & Oceanogr.* **28:** 1 144 – 1 155.

Wolf, A.T., Natharius, J.A., Danielson, J.J., Ward, B.S., and Pender, J.K. (1999). International River Basins of the World. *International Journal of Water Resources Development*. **15 (4):** 387 – 427.

WWF (World Wildlife Fund). (2004). *Rivers at Risk: Dams and the future of freshwater ecosystems.* http://assets.panda.org/downloads/riversatriskfullreport.pdf, 48pp, viewed 25 June 2008.

Young, K., Morse, G.K., Scrimshaw, M.D., Kinniburgh, J.H., MacLeod, C.L., and Lester, J.N. (1999). The relation between phosphorus and eutrophication in the Thames catchment, UK. *The Science of the Total Environment,* **228:** 157 – 183.

APPENDIX A

ORANGE RIVER MONITORING SITES – MAIN STEM – LEVEL 1 AND TRIBUTARIES – LEVEL2

(Satellite images, on site pictures and additional graphs)

1 ORANGE RIVER MONITORING SITES – MAIN STEM – LEVEL 1

1.1 OS1 – Oranjedraai – D1H009 (S30.33772; E27.36277)

A)

B)

Figure A1: A) Satellite image (Google Earth) and **B)** on site picture of the new gauging weir at Oranjedraai (OS1). River width at weir was approximately 160 m.

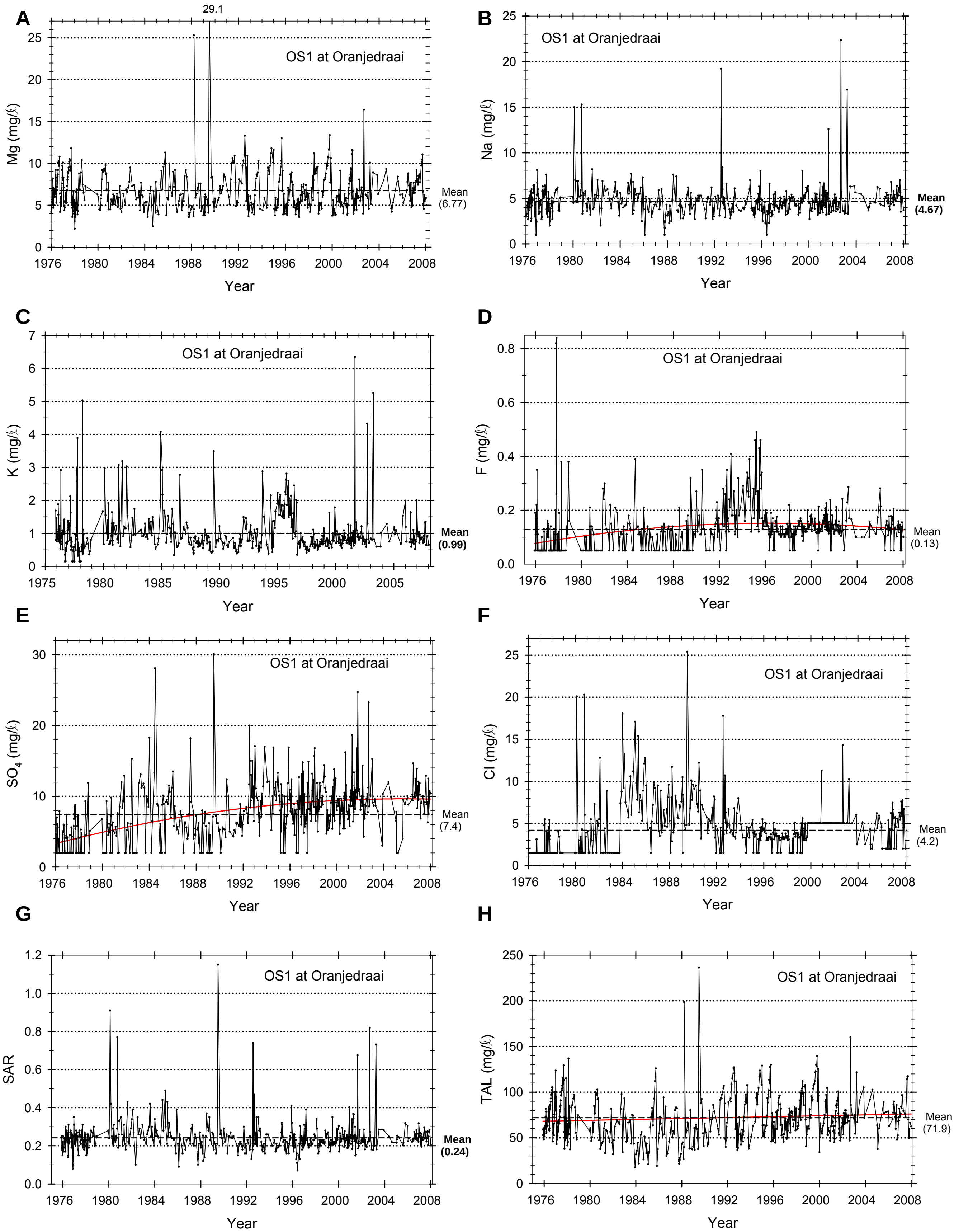


Figure A2: Temporal variation in A) Mg, B) Na, C) K, D) Fe, E) SO4, F) Cl, G) SAR and H) Alkalinity (mg/ℓ) in the Orange River at Oranjedraai (1976 – 2007).

1.2 OS2 – Aliwal North – D1H003 (S30.68612; E26.70600)

A)

B)

Figure A3: A) Satellite image (Google Earth) and **B)** on site picture at Aliwal North (OS2) - at iron bridge (General Hertzog bridge). River width was approximately 100 m.

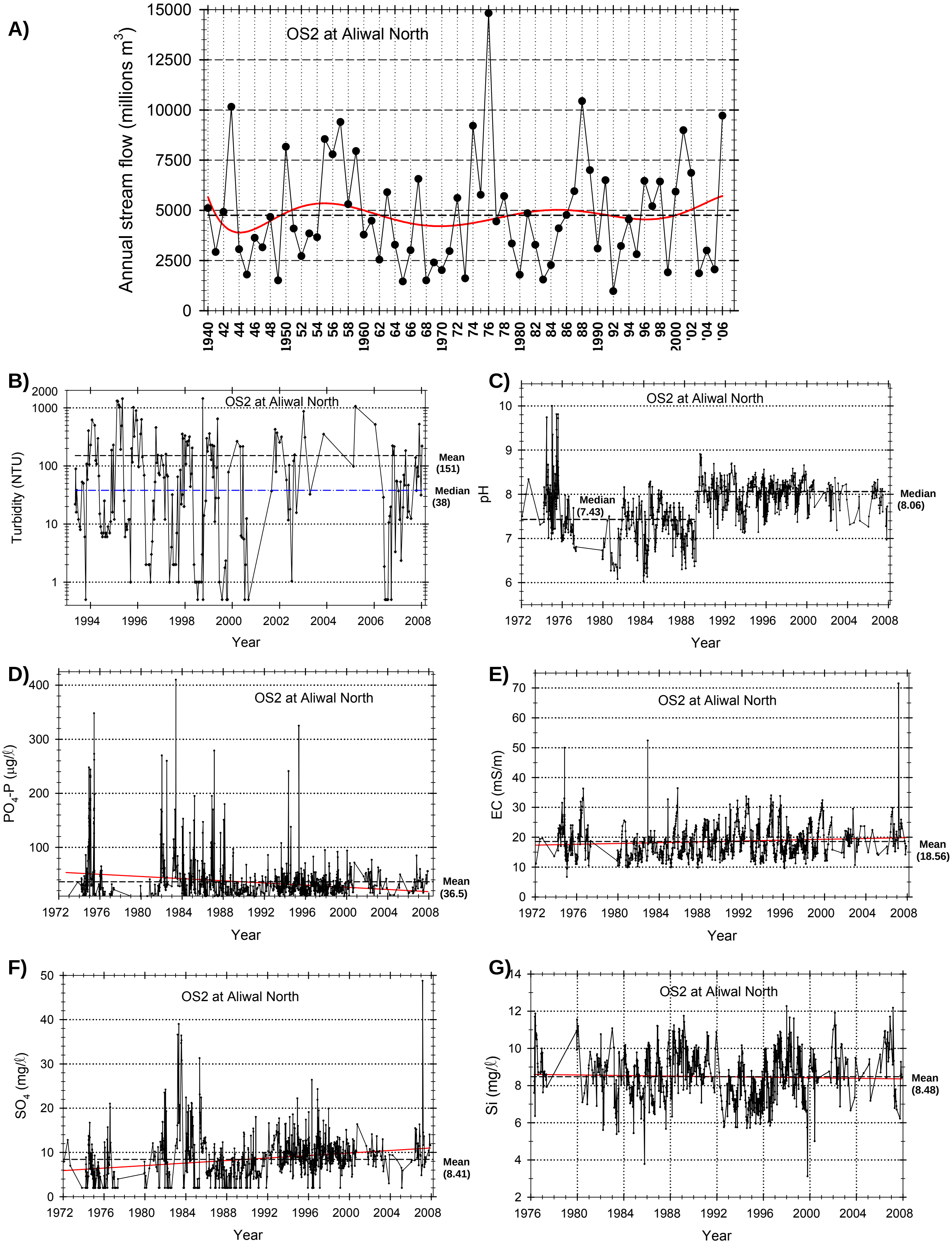


Figure A4: Temporal variation in A) Stream flow, B) Turbidity, C) pH, D) PO_4, E) EC, F) SO_4, and G) Silica (mg/ℓ) in the Orange River at Aliwal North (1976 – 2007).

1.3 OS3 – Saamwerk (S30.57622; E26.45638) – new site

A)

B)

Figure A5: A) Satellite image (Google Earth) and **B)** on site picture at Saamwerk (OS3) – farm upstream of Gariep Dam and just downstream of confluence with Stormbergspruit. River width ranged between 138 and 185 m. No historical data.

1.4 OSD1 – Gariep Dam – D3R002 (S30.60794; E25.50465)

A)

B)

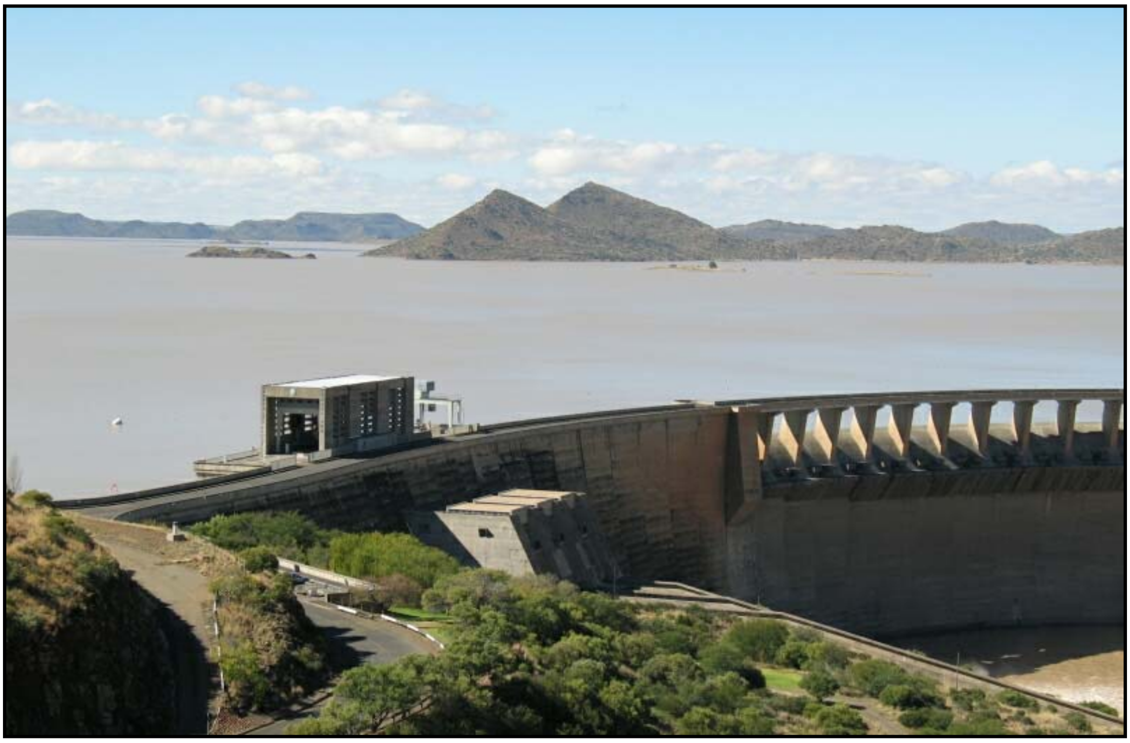


Figure A6: A) Satellite image (Google Earth) near dam wall and **B)** picture of Gariep Dam.

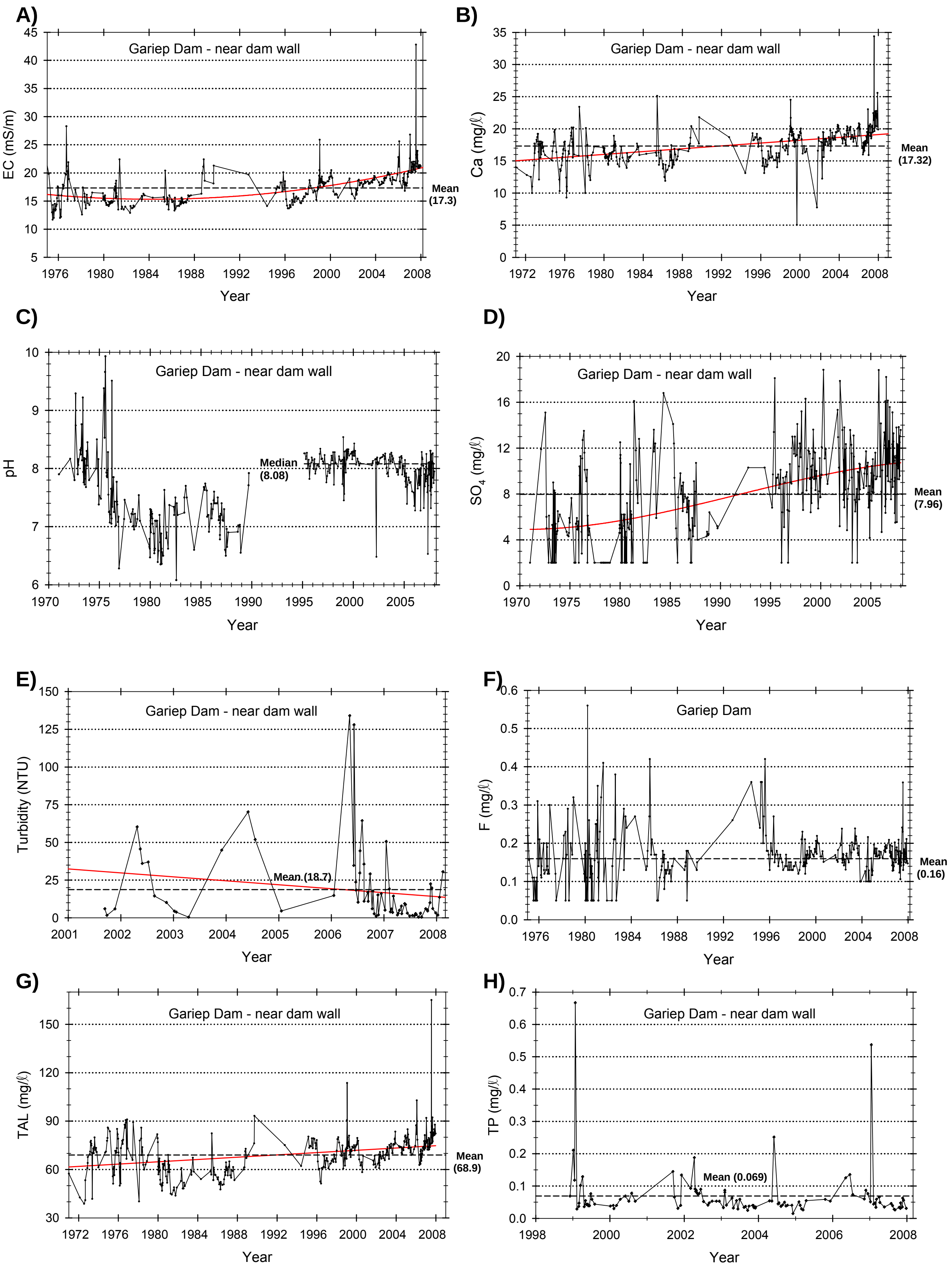


Figure A7: Temporal variation in A) EC, B) Ca, C) pH, D) SO_4, E) Turbidity, F) Fluoride, G) TAL and H) Total phosphorus (mg/ℓ) in Gariep Dam (1972 – 2007).

1.5 OS4 Roodepoort (Waschbank) – D3H013 (S30.62062; E25.46511)

A)

B)

Figure A8: A) Satellite image (Google Earth) and **B)** on site picture at Waschbank (OS4) – at old iron bridge. The DWAF monitoring site Roodepoort (D3H013) is a few kilometres downstream.

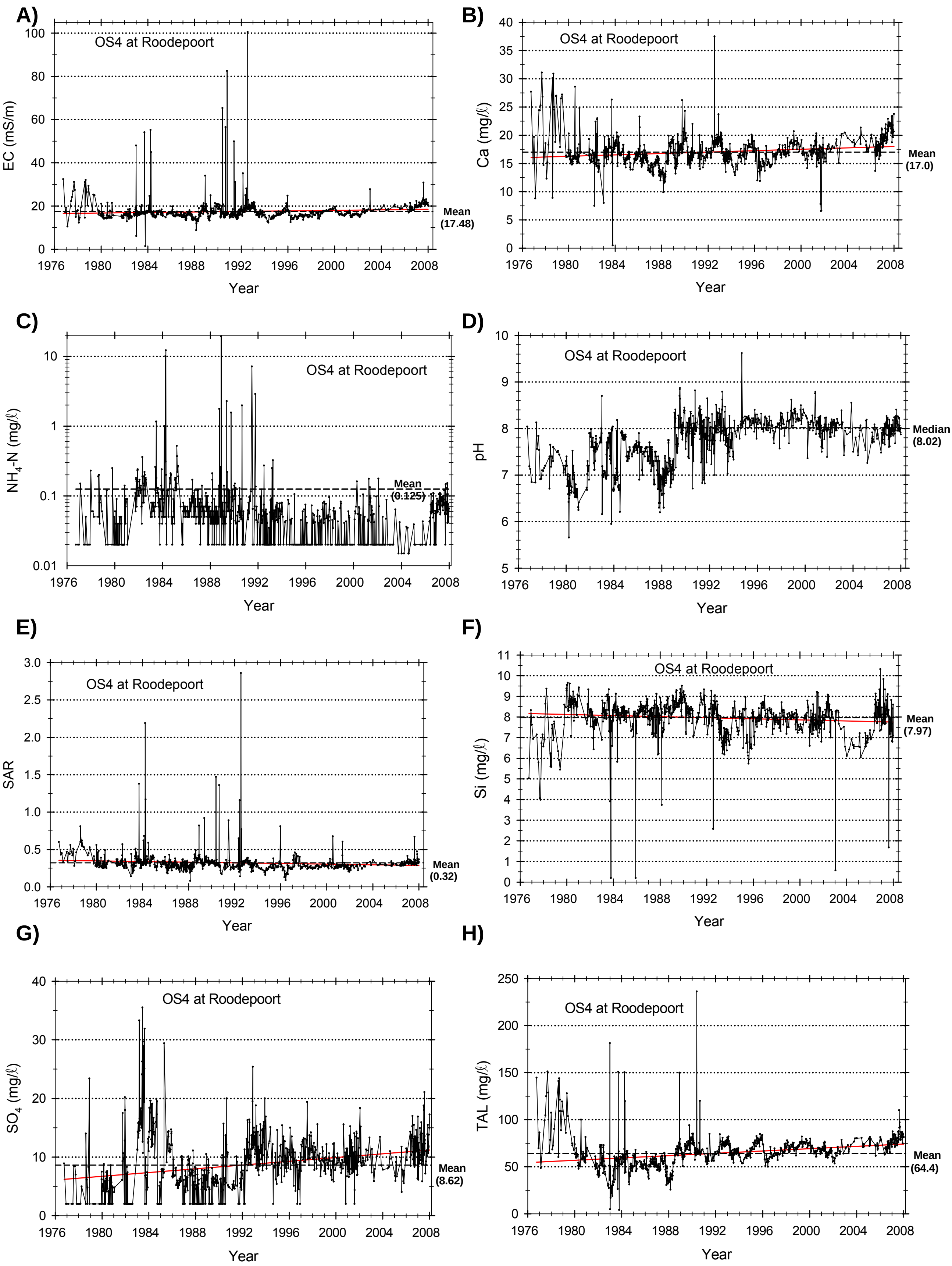


Figure A9: Temporal variation in A) EC, B) Ca, C) NH_4, D) pH, E) SAR, F) Si, G) SO_4 and H) Alkalinity (mg/ℓ) in the Orange River at Roodepoort (1976 – 2007).

1.6 OSD2 – Vanderkloof Dam – D3R003 (S29.99447; E24.73524)

A)

B)

Figure A10: **A)** Satellite image (Google Earth) and **B)** on site picture of Vanderkloof Dam – near dam wall.

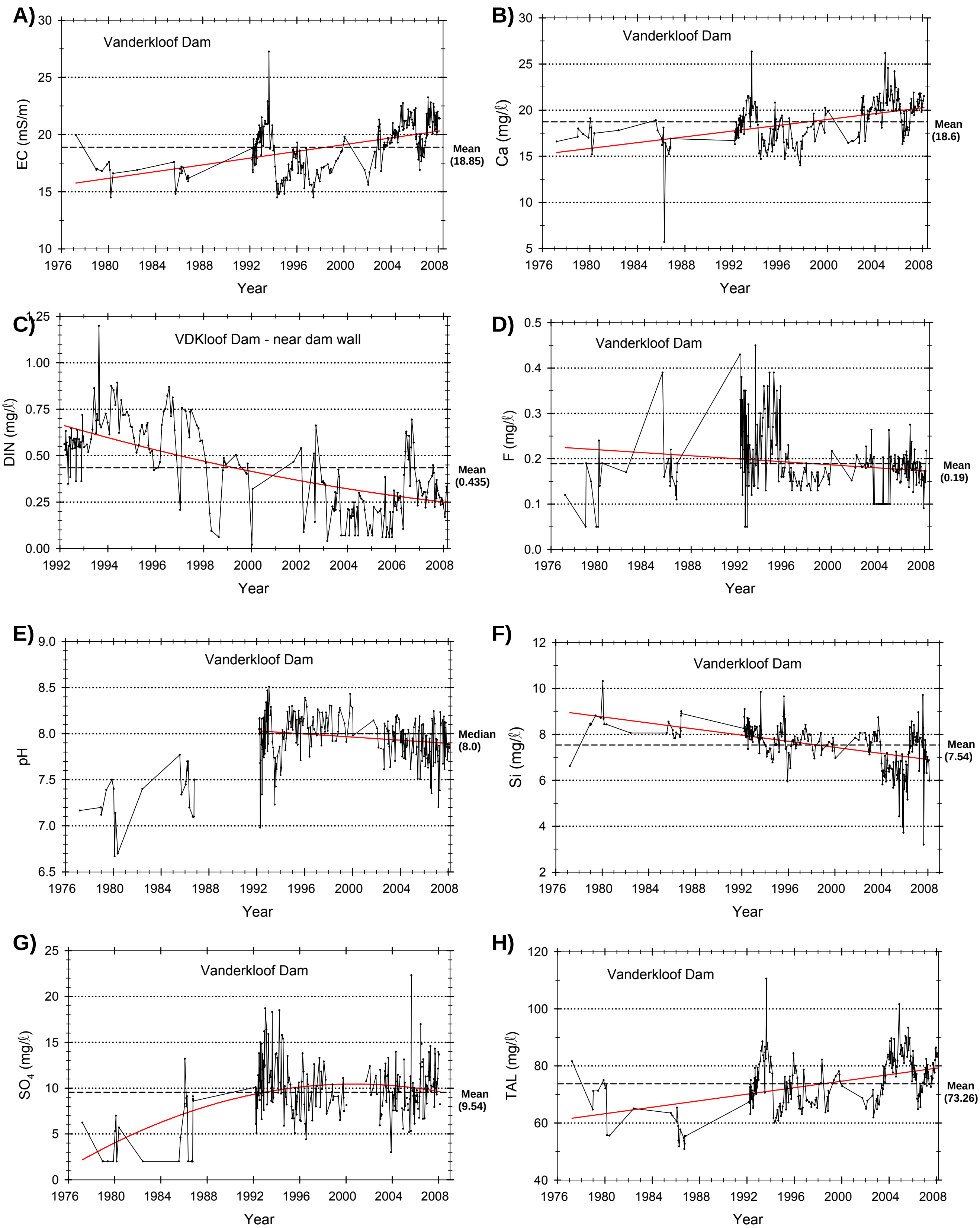


Figure A11: Temporal variation in A) EC, B) Ca, C) DIN, D) Fluoride, E) pH, F) Si, G) SO_4 and H) TAL, Alkalinity (mg/ℓ) in Vanderkloof Dam, near dam wall (1976 – 2007).

1.7 OS5 – Dooren Kuilen – D3H012 (S29.99141; E24.72414)

A)

B)

Figure A12: **A)** Satellite image (Google Earth) and **B)** on site picture of Dooren Kuilen – downstream of Vanderkloof Dam. River width ranged between 70 and 132 m.

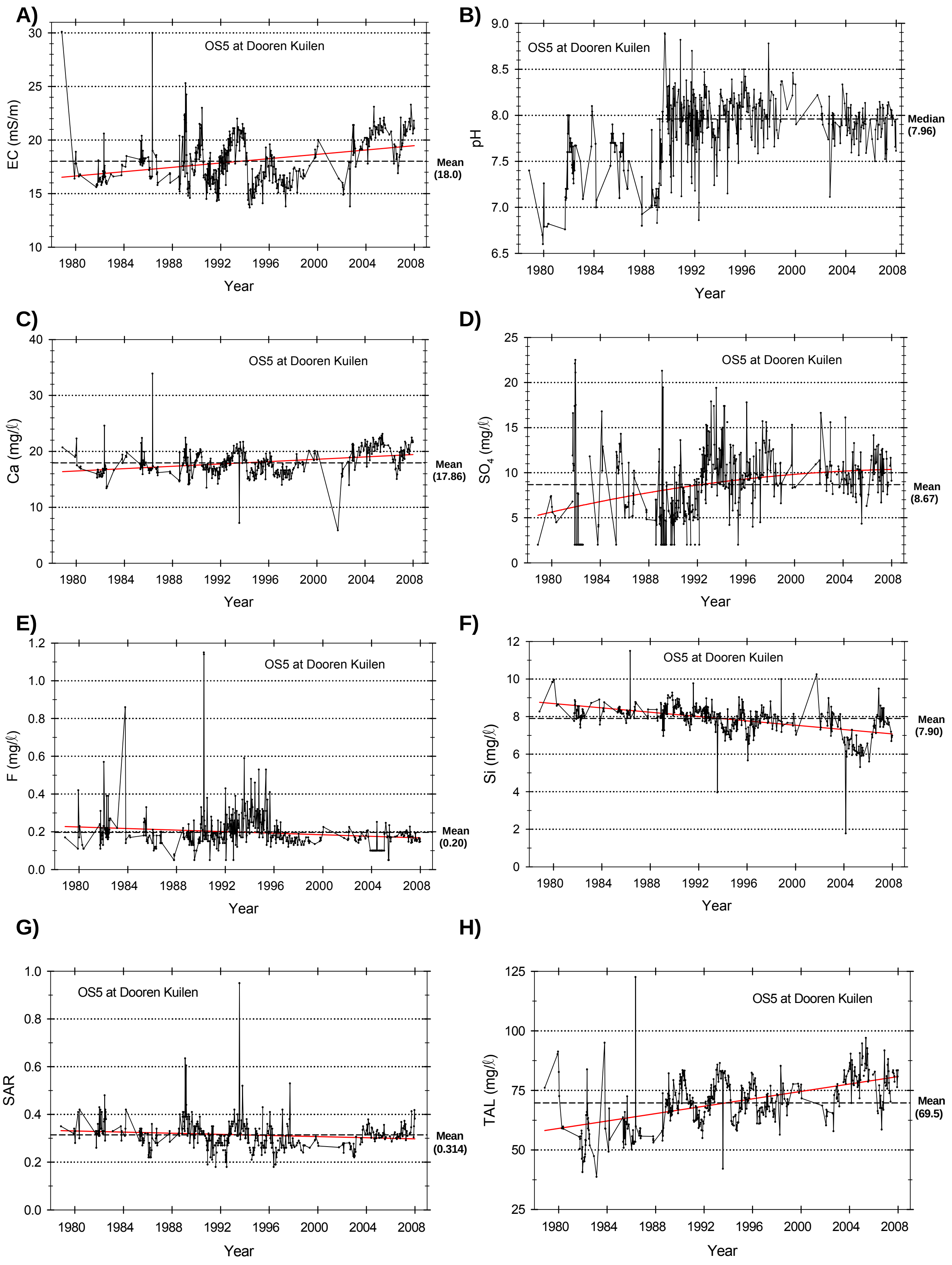


Figure A13: Temporal variation in A) EC, B) pH, C) Ca, D) SO_4, E) Fluoride, F) Silica, G) SAR and H) Alkalinity (mg/ℓ) at Dooren Kuilen (1980 – 2007).

1.8 OS6 – Marksdrift – D3H012 (S29.16201; E23.69447)

A)

B)

Figure A14: **A)** Satellite image (Google Earth) and **B)** on site picture of site at Marksdrift (OS6) – below weir. River width is about 115 m at the weir and 55 m at the bridge (sampling site) just downstream of the weir.

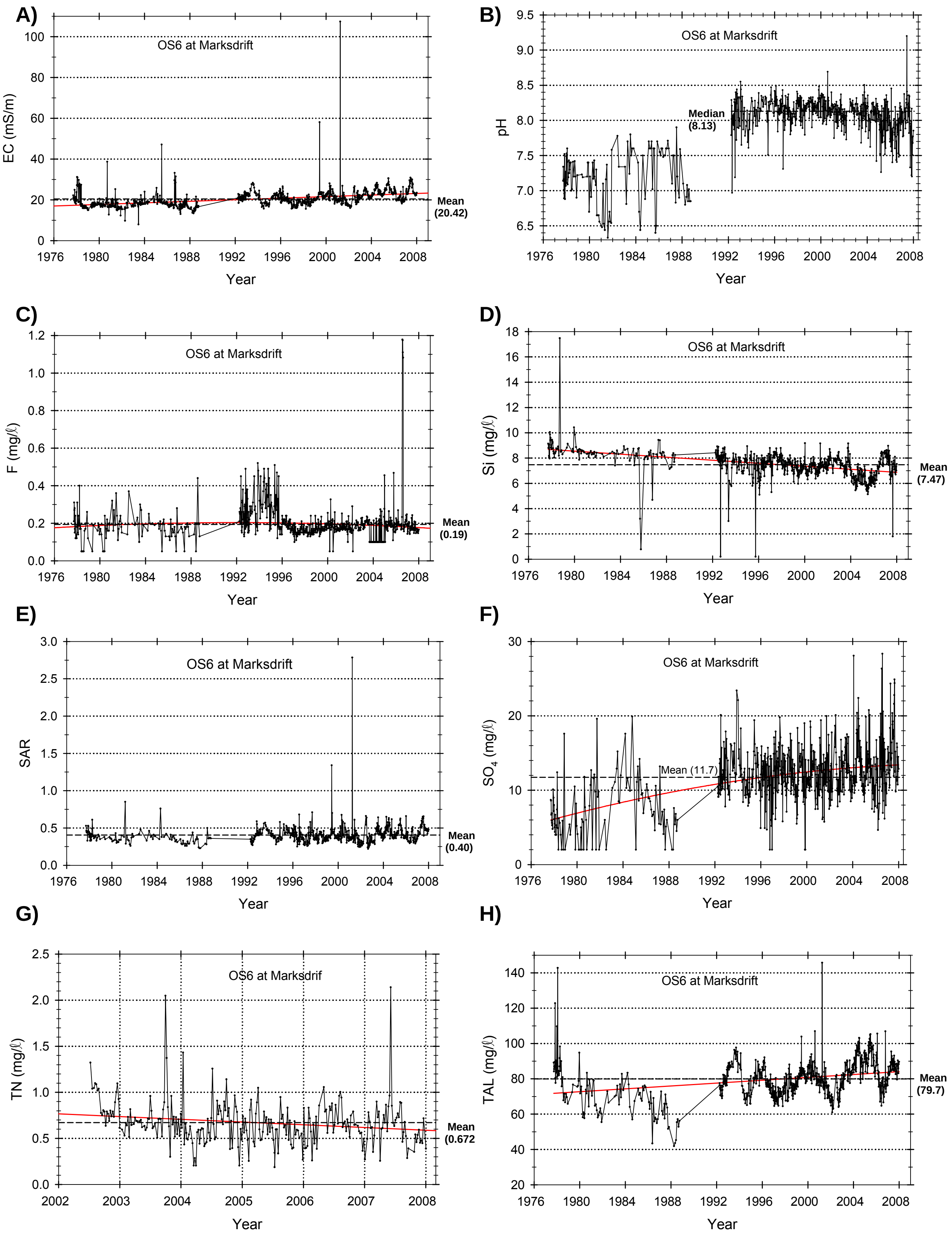


Figure A15: Temporal variation in A) EC, B) pH, C) F, D) Si, E) SAR, F) SO_4, G) TN and H) Alkalinity (mg/ℓ) in the Orange River at Marksdrift (1976 – 2007).

1.9 OS7 – De Hoek – New site (S29.18512; E23.57332)

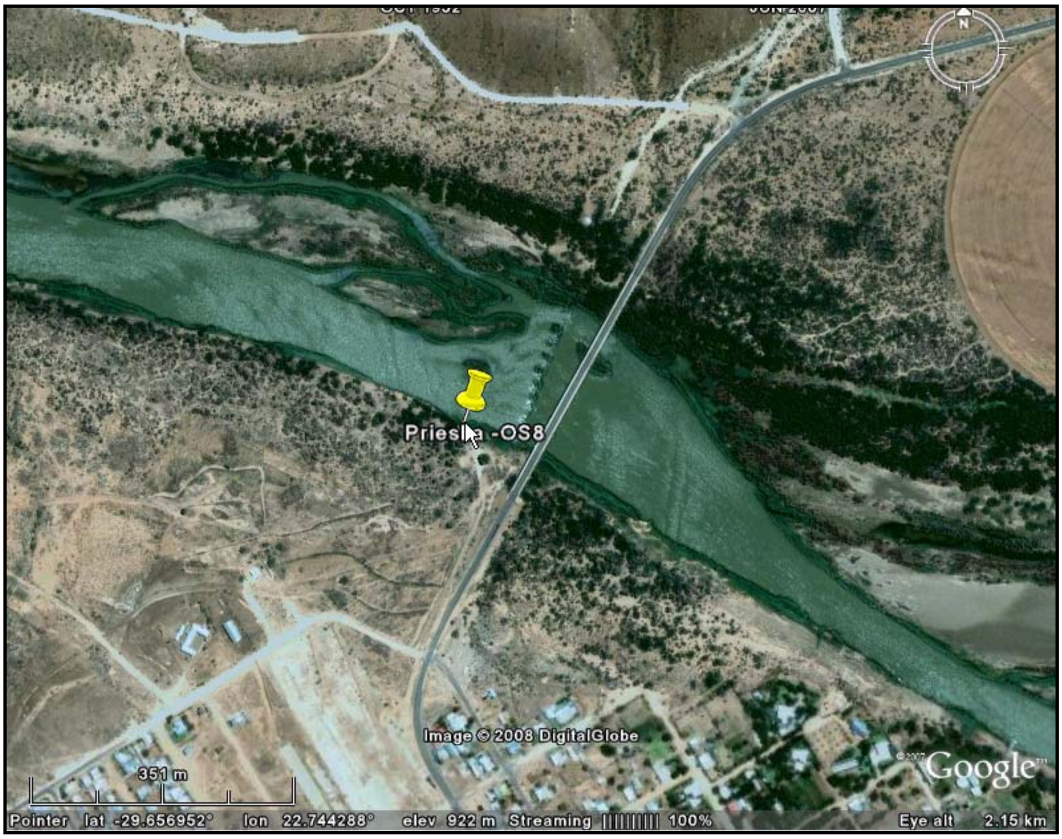
A)

B)

Figure A16: **A)** Satellite image (Google Earth) showing pivot irrigation and **B)** on site picture of sampling site at De Hoek farm, H.J. Cillie (OS7). Proposed new site. River width was about 156 m. No historical data.

1.10 OS8 – Prieska – D7H002 (S29.65700; E22.74415)

A)



B)

Figure A17: **A)** Satellite image (Google Earth) and **B)** on site picture of sampling site at Prieska (OS8) – at road bridge. River width was about 150 m.

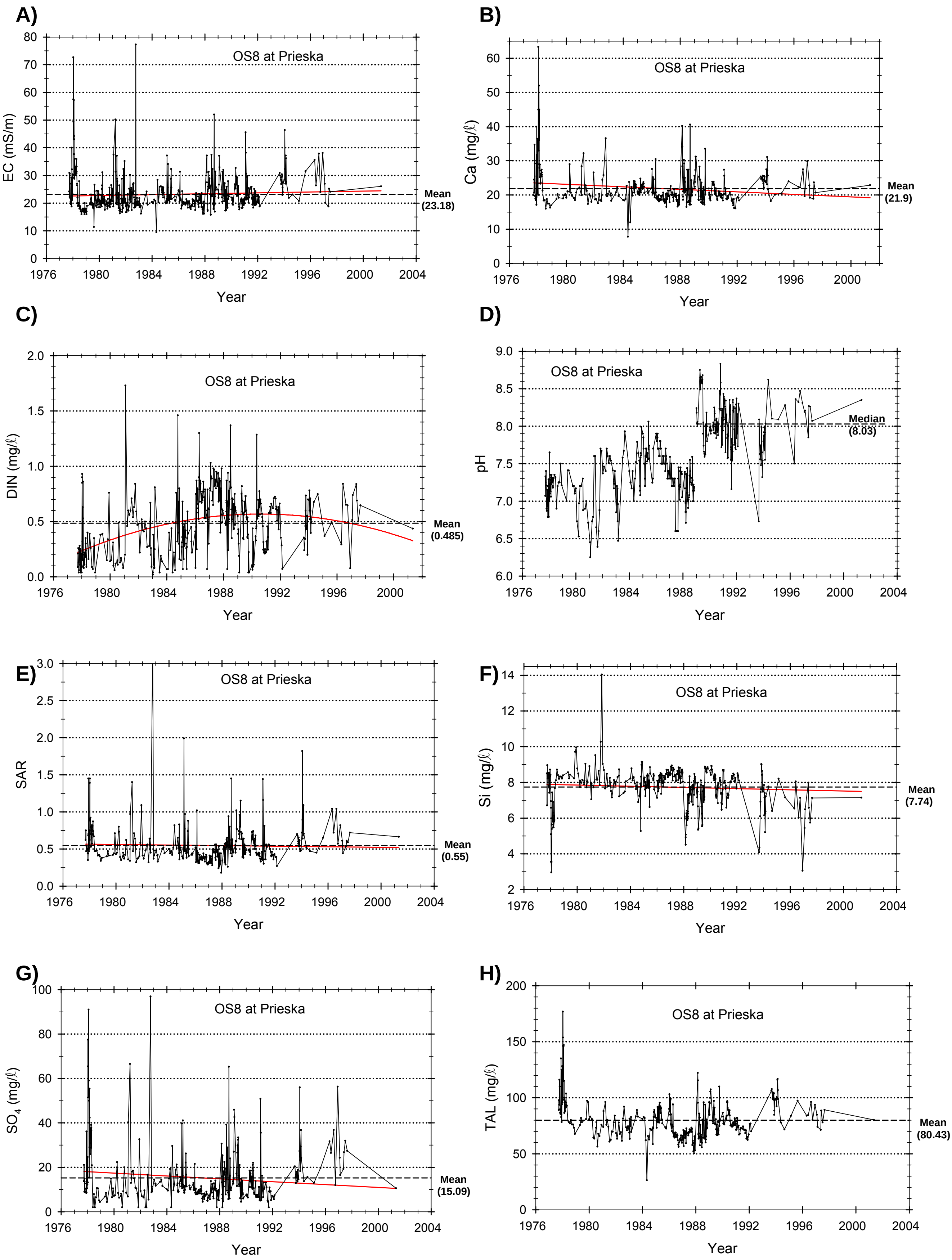


Figure A18: Temporal variation in A) EC, B) Ca, C) DIN, D) pH, E) SAR, F) Si, G) SO_4 and H) Alkalinity (mg/ℓ) in the Orange River at Prieska (1976 – 2003).

1.11 OS9 – Boegoeberg Dam – D7H008 (S29.02625; E22.18608)

A)

B)

Figure A19: **A)** Satellite image (Google Earth) and **B)** on site picture of sampling site at Boegoeberg Dam – below weir. River width ranged between 185 and 230 m.

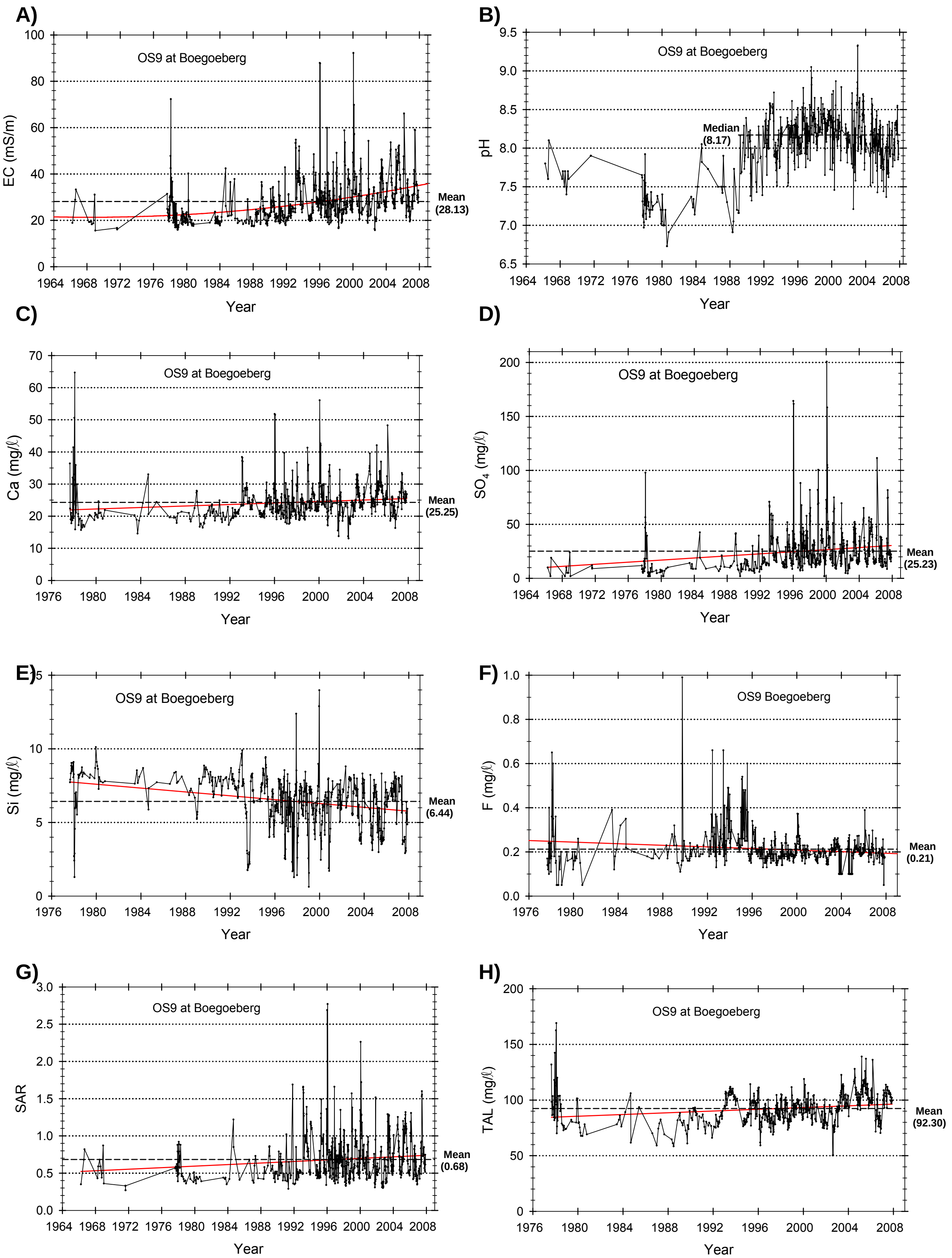


Figure A20: Temporal variation in A) EC, B) pH, C) Ca, D) SO_4, E) Si, F) F, G) SAR and H) Alkalinity (mg/ℓ) in the Orange River at Boegoeberg Dam (1977 – 2007).

1.12 OS11 – Upington – D7H005 (S28.45259; E21.25994)

A)

B)

Figure A21: **A)** Satellite image (Google Earth) and **B)** onsite picture of sampling site at Upington Water works – close to railway bridge. River width was about 60 m.

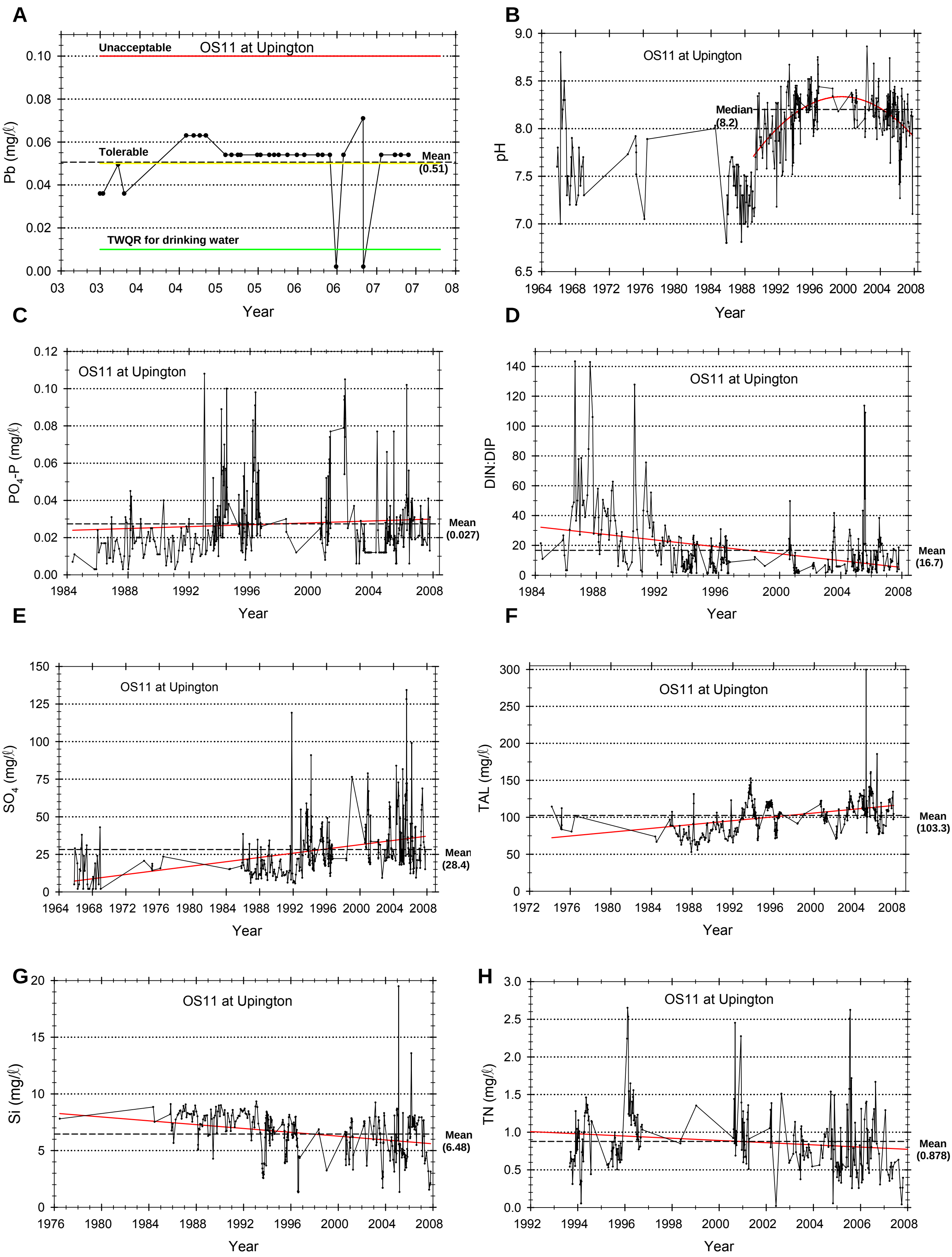
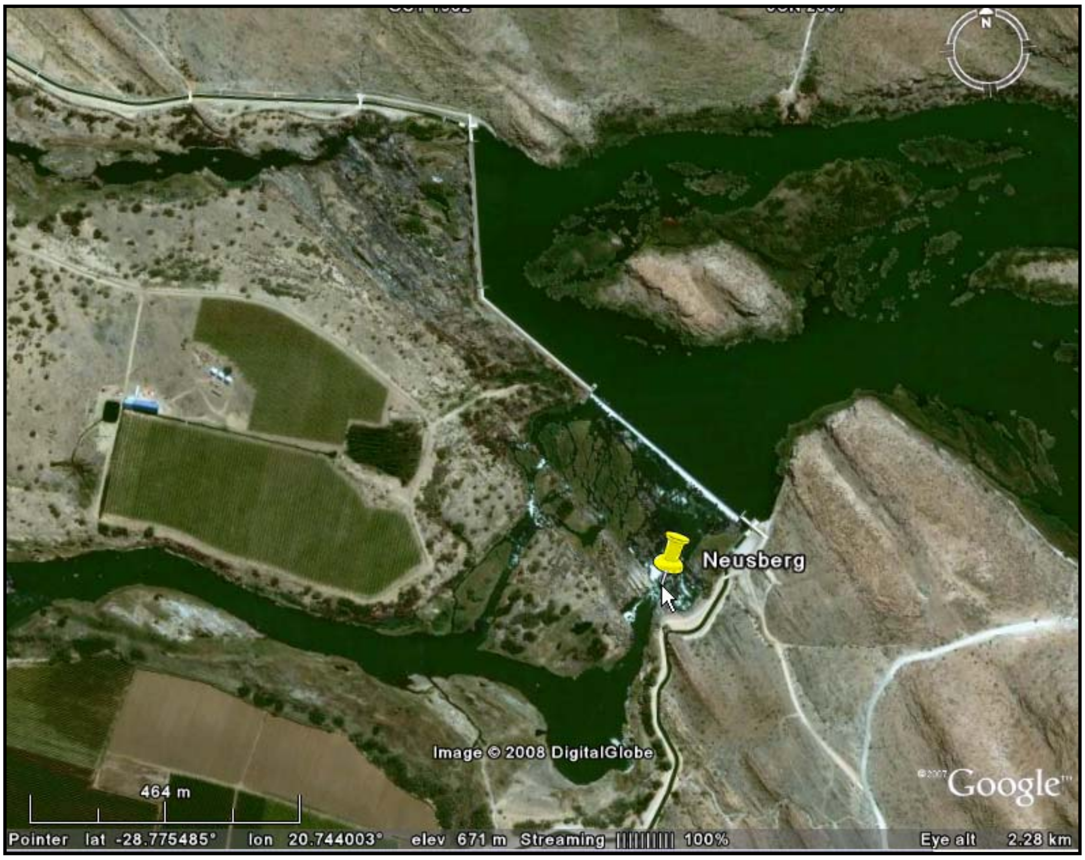


Figure A22: Temporal variation in A) Pb, B) pH, C) PO_4, D) DIN:DIP, E) SO_4, F) TAL, G) Si and H) Total Nitrogen (mg/ℓ) in the Orange River at Upington (1976 – 2007).

1.13 OS13 – Neusberg weir (Kakamas) – D7H016 (S28.77392; E20.74297)

A)



B)

Figure A23: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Neusberg weir – at weir. River width ranged between 180 and 288 m.

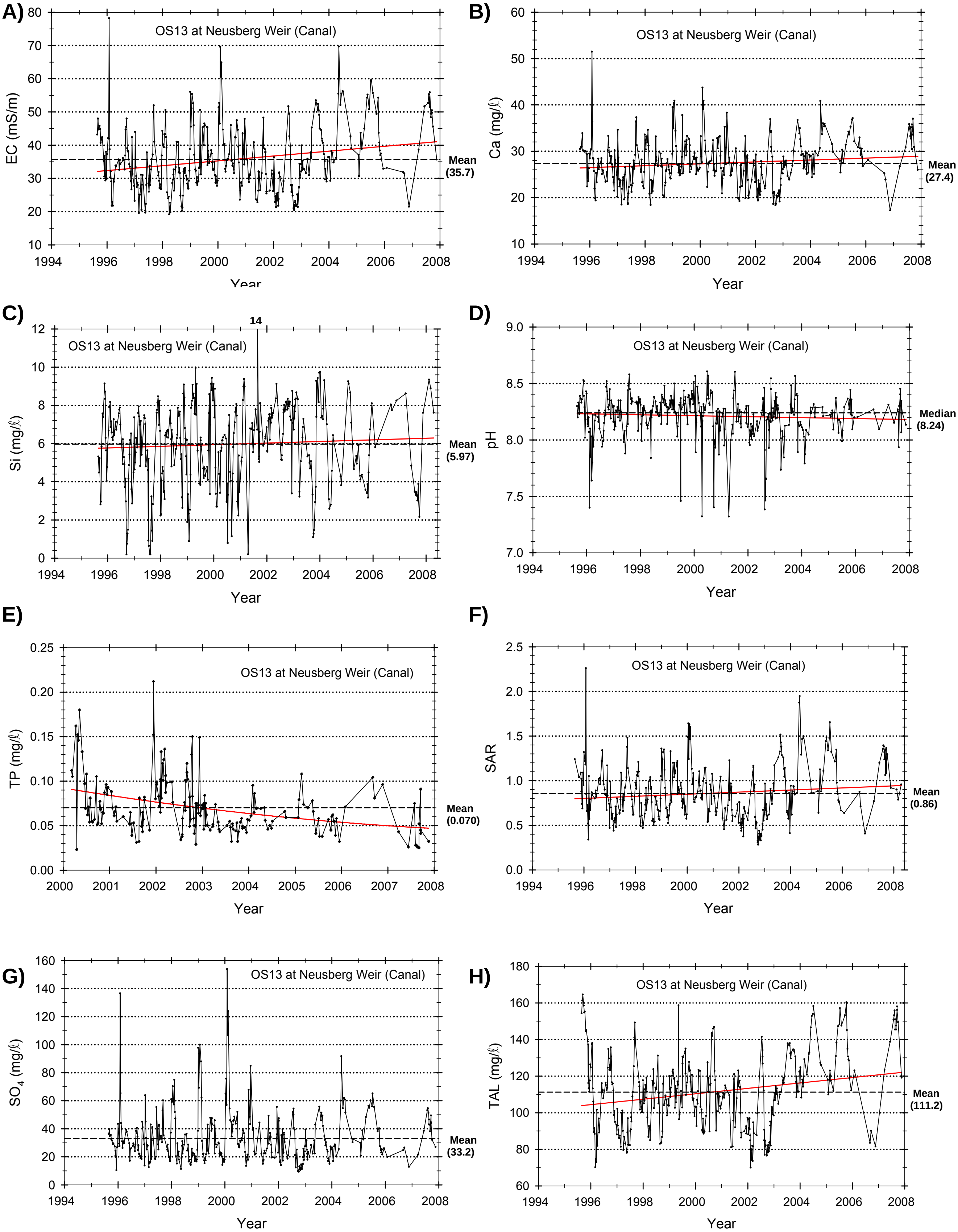


Figure A24: Temporal variation in A) EC, B) Ca, C) Si, D) pH, E) TP, F) SAR, G) SO_4 and H) Alkalinity (mg/ℓ) in the Orange River at Neusberg (1995 – 2007).

1.14 OS14 – Blouputs Bridge – new site (S28.51409; E20.18518)

A)

B)

Figure A25: **A)** Vineyards at Blouputs farms and **B)** onsite picture of the sampling site at Blouputs – at road bridge. River width was about 140 m. – no historical data.

1.15 OS15 – Pelladrift – D8H008 (S28.96443; E19.15276)

A)

B)

Figure A26: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Pelladrift – downstream of water intake tower. River width was about 133 m.

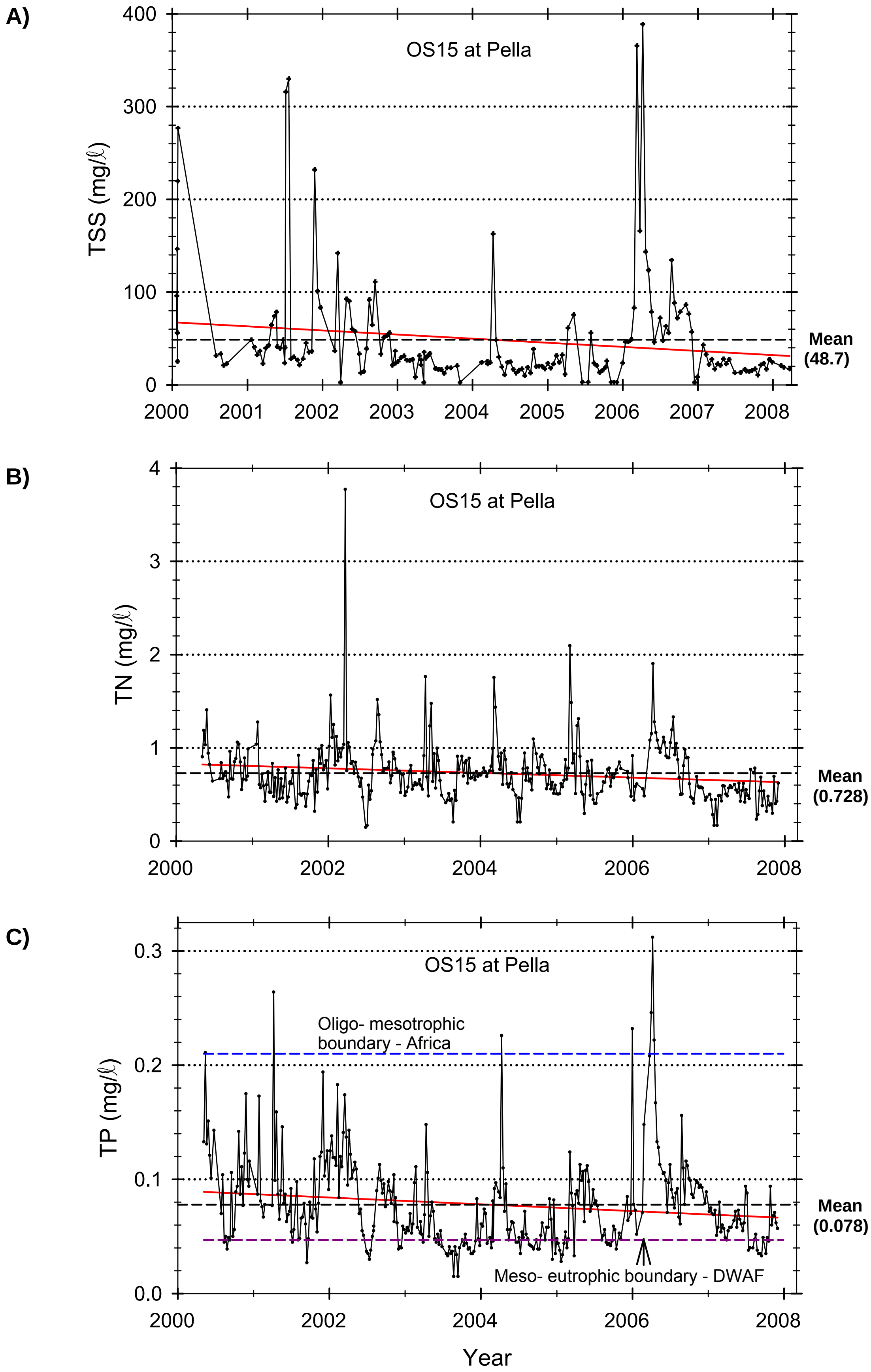


Figure A27: Temporal variation in A) Total Suspended Solids, B) Total Nitrogen, and C) Total phosphorus (mg/ℓ) in the Orange River at Pella (2000 – 2007).

1.16 OS16 Vioolsdrift – D8H003 (S28.76208; E17.72631)

A)

B)

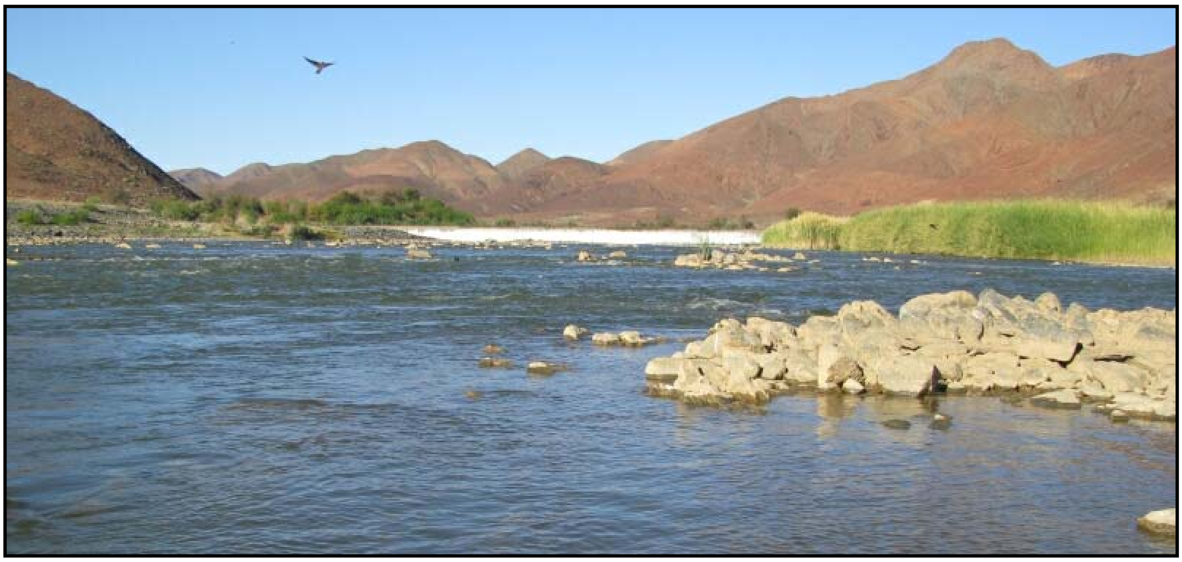


Figure A28: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Vioolsdrift – downstream of weir. River width ranged between 58 and 101 m.

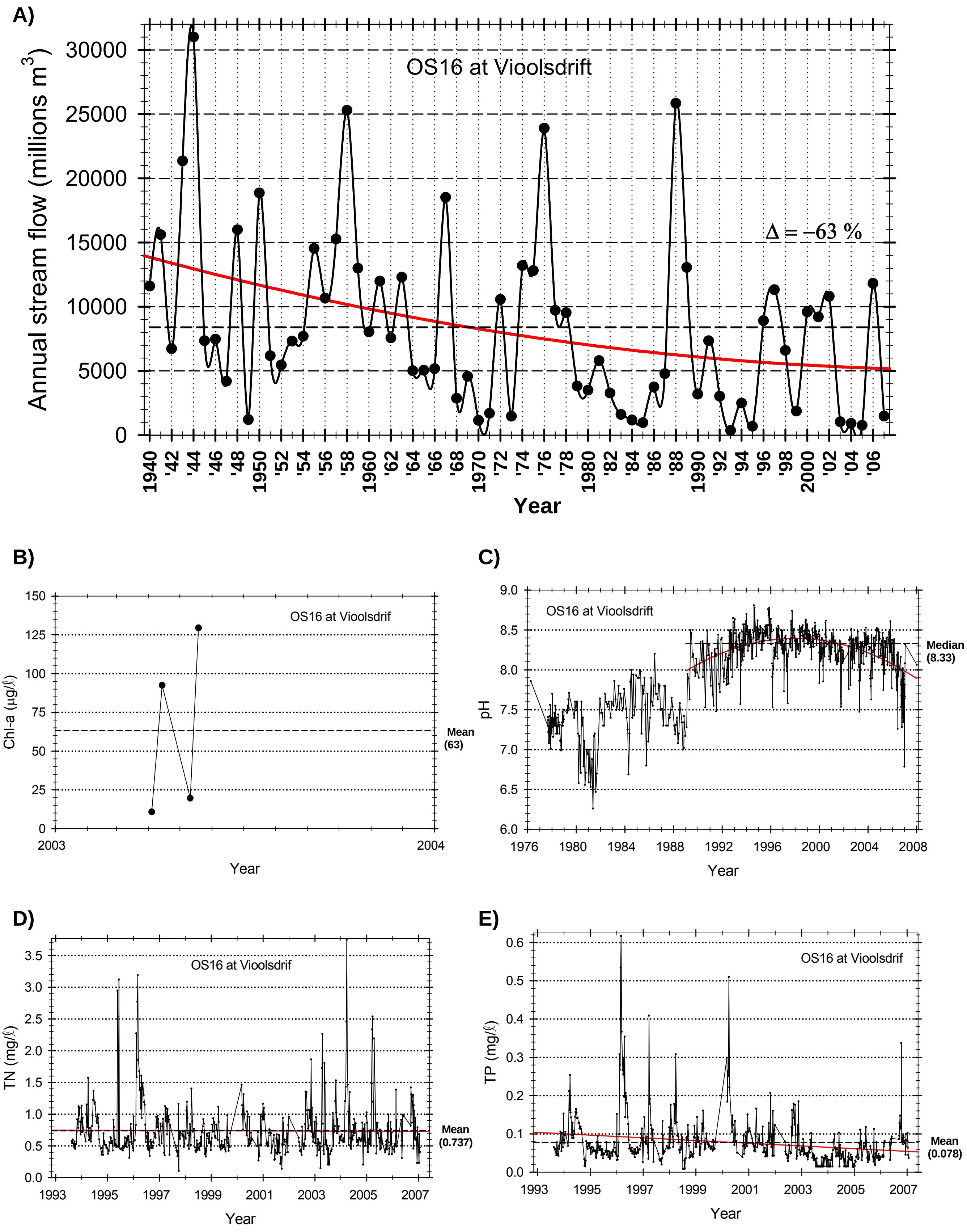


Figure A29: Temporal variation in A) Annual discharge (1940 – 2007), B) Chl-*a*, C) pH, D) TN, and E) TP (mg/ℓ) in the Orange River at Vioolsdrift (1993 – 2007).

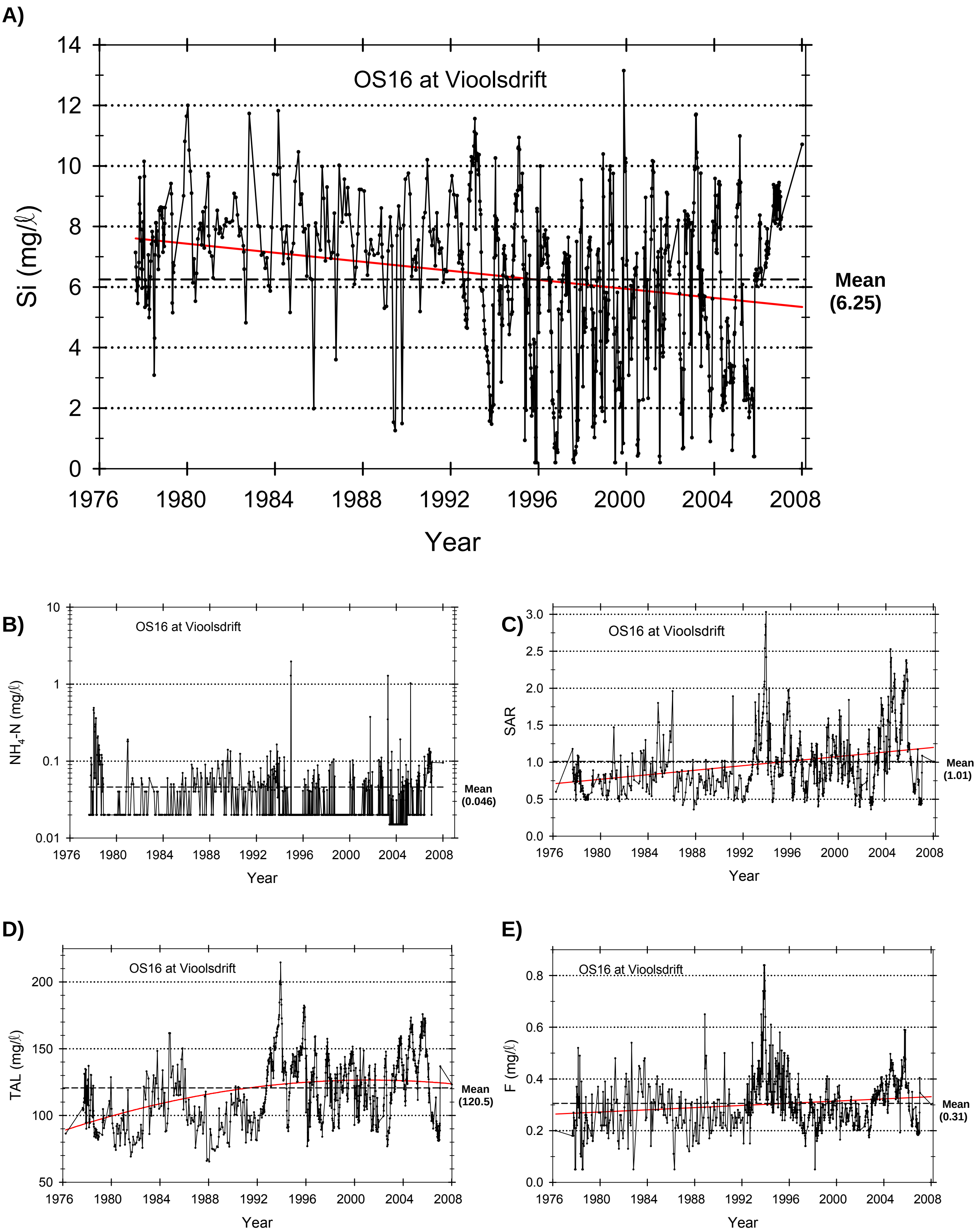


Figure A30: Temporal variation in A) Silica, B) Ammonium, C) SAR, D) Alkalinity, and E) fluoride (mg/ℓ) in the Orange River at Vioolsdrift (1976 – 2007).

1.17 OS17 – Sendelingsdrift – new site (S28.12288; E16.89032)

A)

B)

Figure A31: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Sendelingsdrift (OS17) – at South Africa/Namibia border post.

Proposed new site – River width was about 100 m – no historical data.

1.18 OS18 – Brand Kaross – D8H007 (S28.48570; E16.69444)

A)

B)

Figure A32: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Brand Kaross – downstream of water intake tower. River width was 166 m.

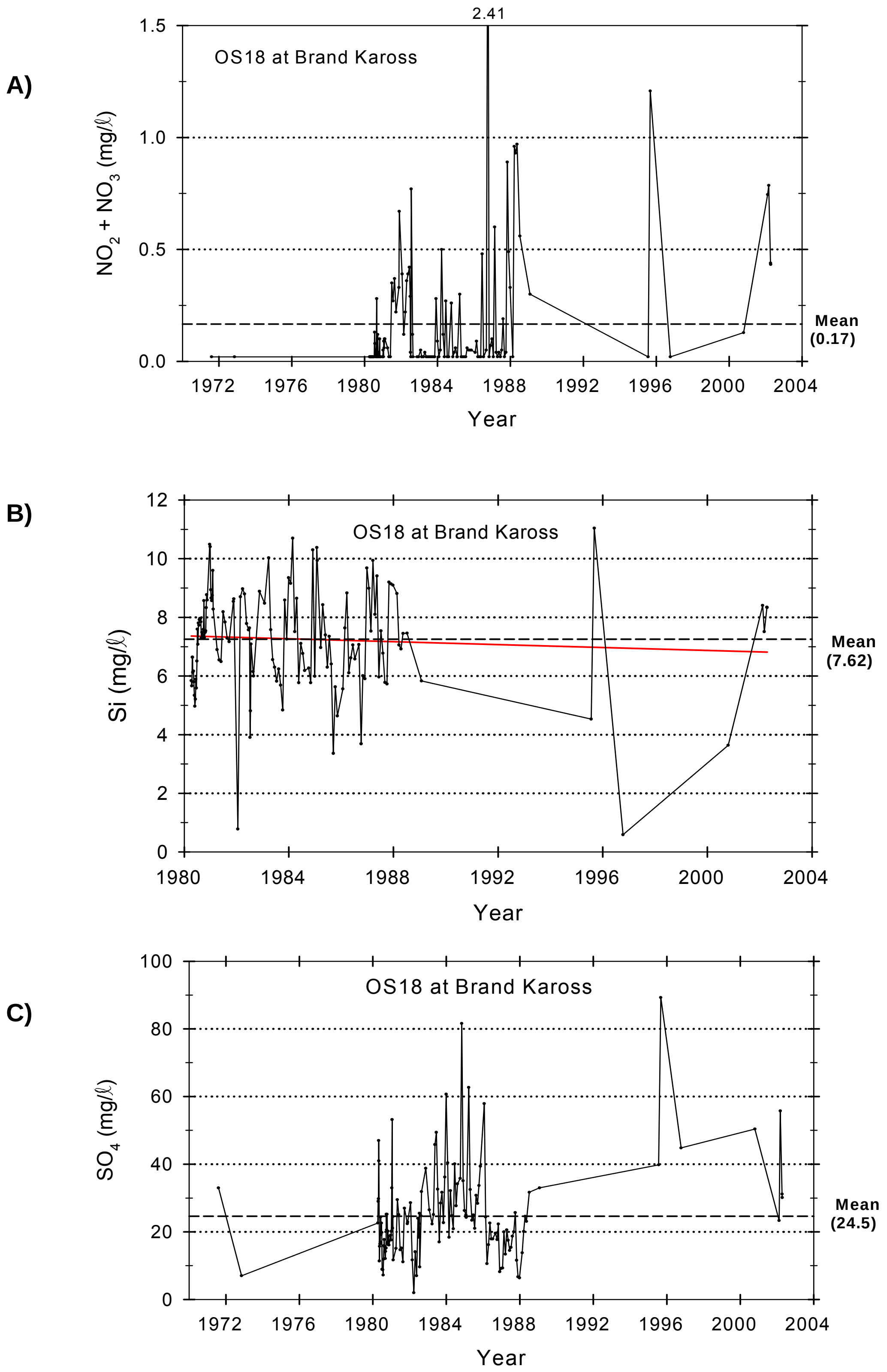


Figure A33: Temporal variation of **A)** Nitrate and nitrite, **B)** Silica, and **C)** Sulphate (mg/ℓ) in the Orange River at Brand Kaross (1972 – 2003).

1.19 OS19 – Alexander Bay – D8H012 (S28.56689; E16.50728)

A)

B)

Figure A34: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Alexander Bay – close to bridge. River width ranged between 126 and 222 m.

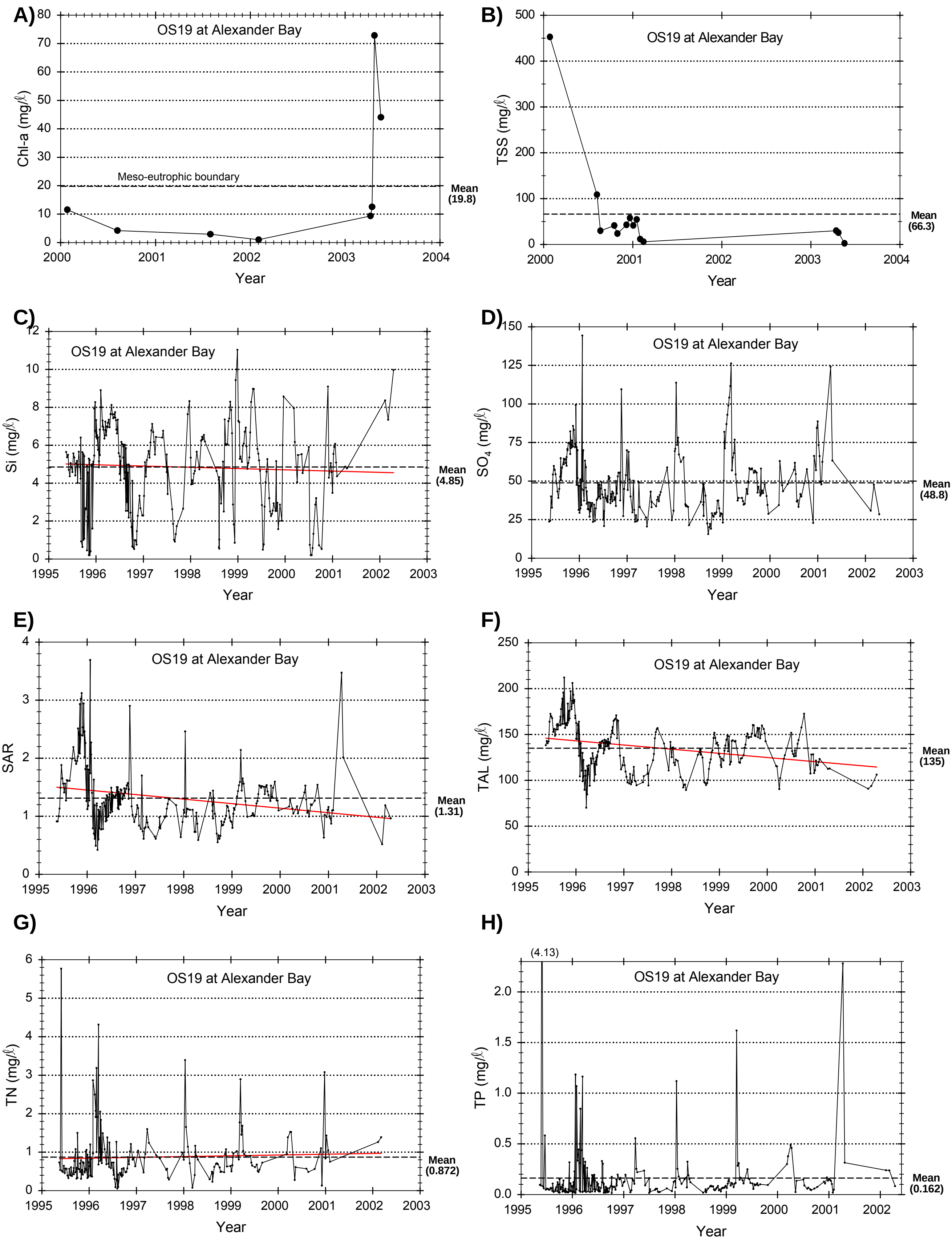


Figure A35: Temporal variation in A) Chl-a, B) TSS, C) Si, D) SO_4, E) SAR, F) TAL, G) TN and H) TP (mg/ℓ) in the Orange River at Alexander Bay (1995 – 2002).

2 ORANGE RIVER MONITORING SITES – TRIBUTARIES – LEVEL 2

2.1 OSL2/1 – Kornetspruit at Makhaleen – D1H006 (S30.16003; E27.40145)

A)

B)

Figure A36: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Kornetspruit – at Watermill. Close to border post. River width is about 35 m.

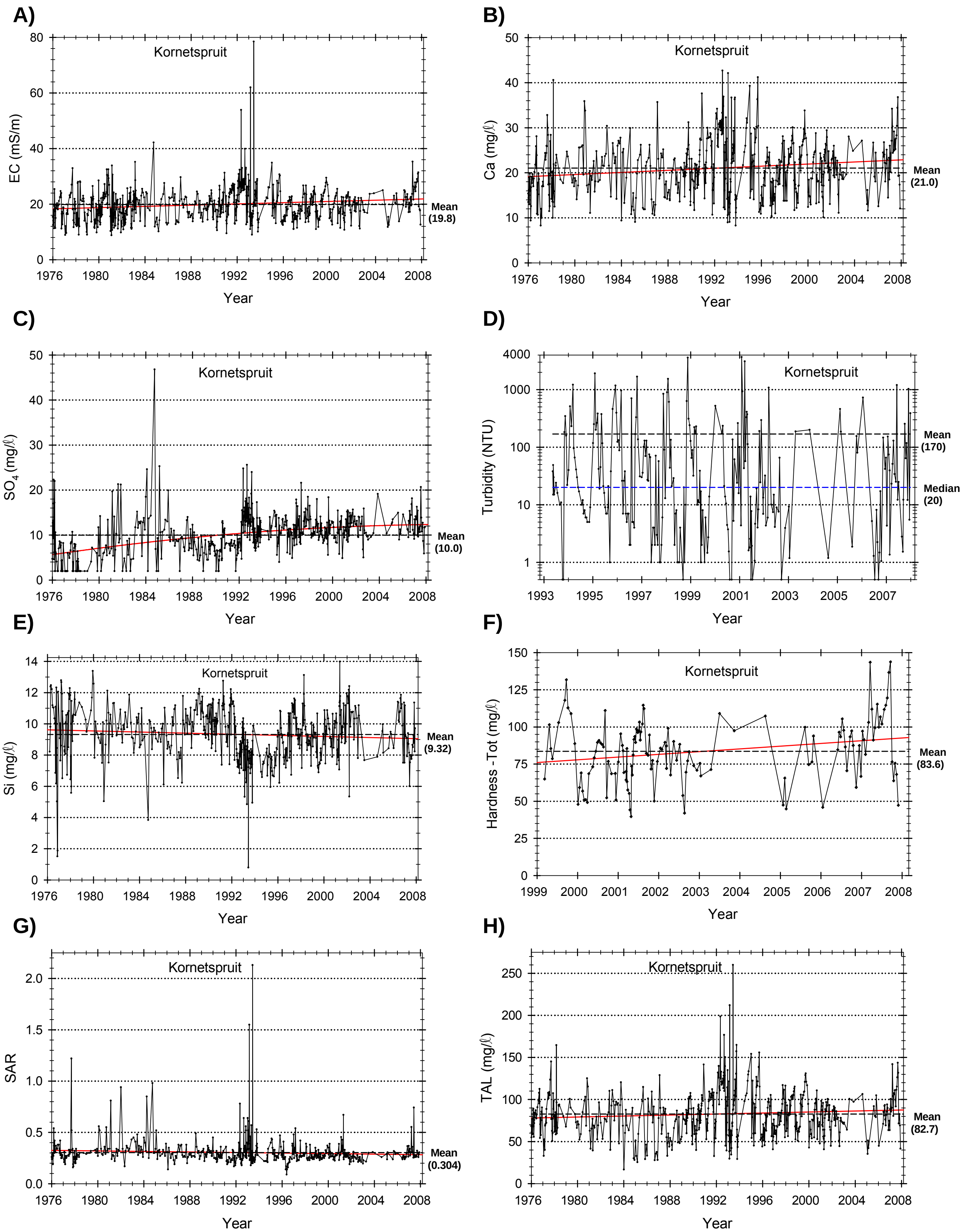


Figure A37: Temporal variation of A) EC, B) Ca, C) SO_4, D) Turbidity, E) Si, F) Hardness, G) SAR and H) Alkalinity (mg/ℓ) in Kornetspruit at Maghaleen. (1976 – 2007).

2.2 OSL2/2 – Sterkspruit at R382 bridge in town – new site (S30.52694; E27.37484)

A)

B)

Figure A38: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Sterkspruit – in town at road bridge. Proposed new site – no historical data.

2.3 OSL2/3 – Kraai River at Roodewal – D1H011 (S30.73707; E26.98440)

A)

B)

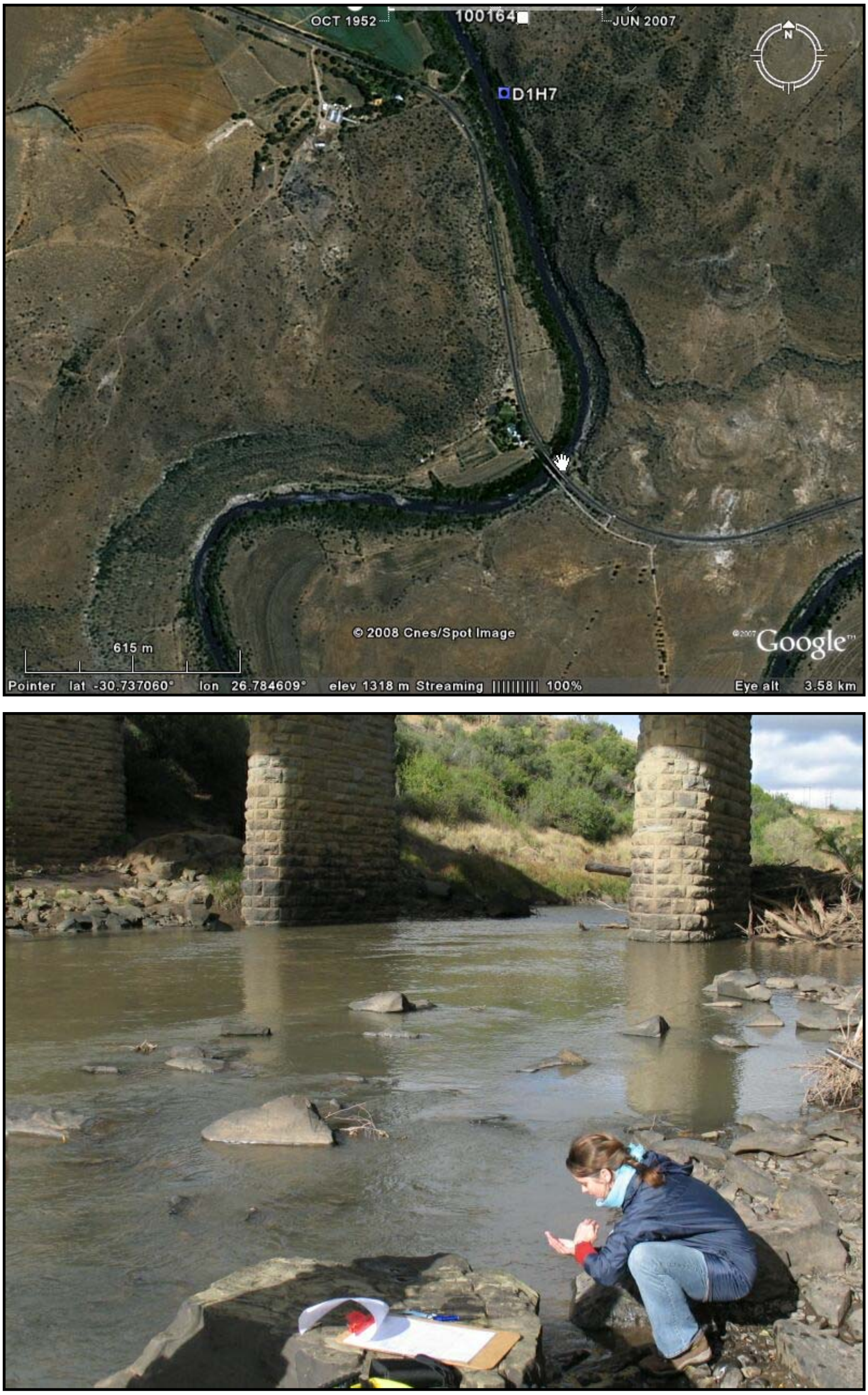


Figure A39: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site in the Kraai River at Roodewal – at old road bridge. River width was about 20 m.

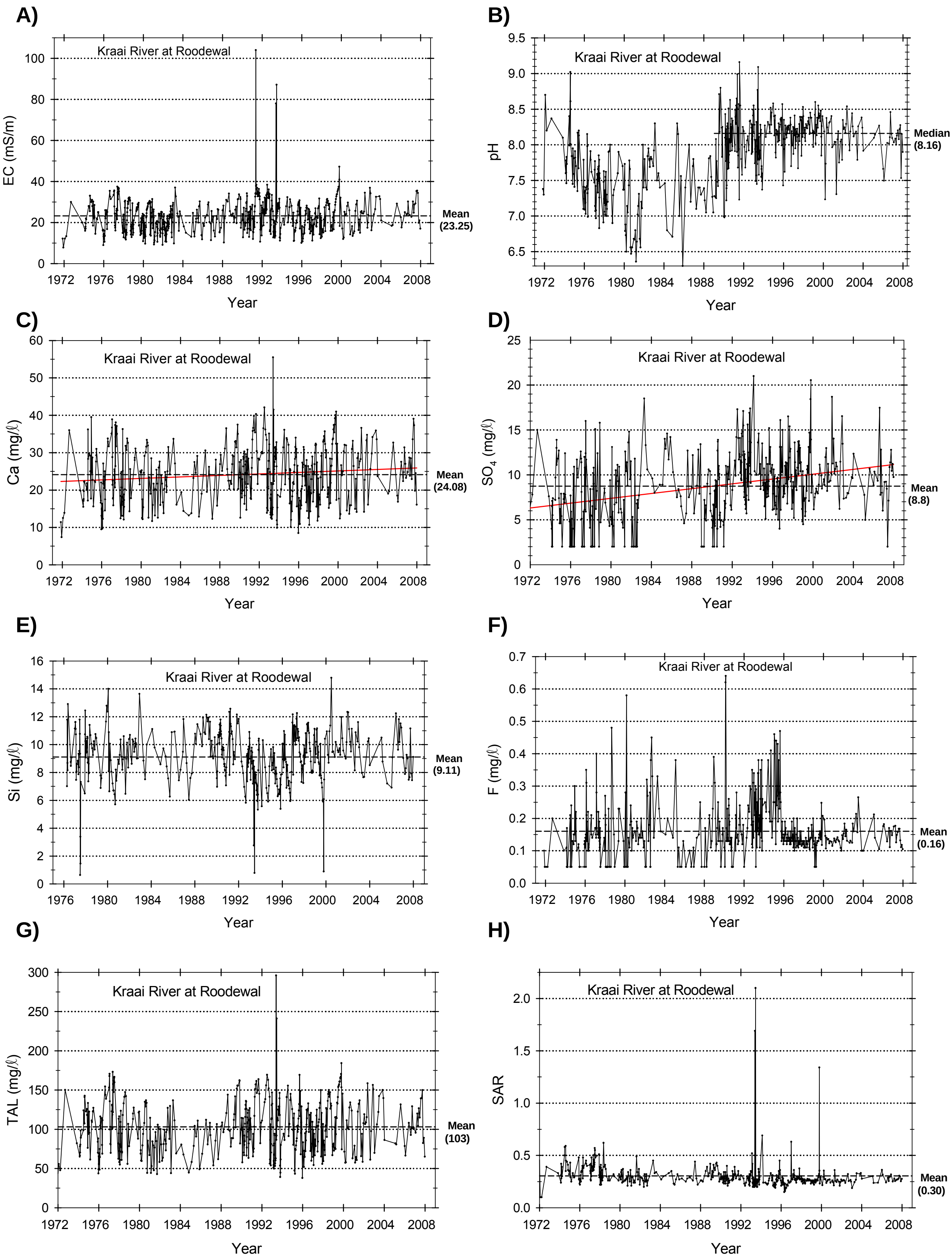


Figure A40: Temporal variation in A) EC, B) pH, C) Ca, D) SO_4, E) Si, F) F, G) TAL and H) SAR (mg/ℓ) in the Kraai River at Roodewal (1972 – 2007).

2.4 OSL2/4 – Stormbergspruit at Burgersdorp (D1H001) – (S31.00109; E26.35314)

A)

B)

Figure A41: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Stormbergspruit weir near Burgersdorp. River width was about 45 m.

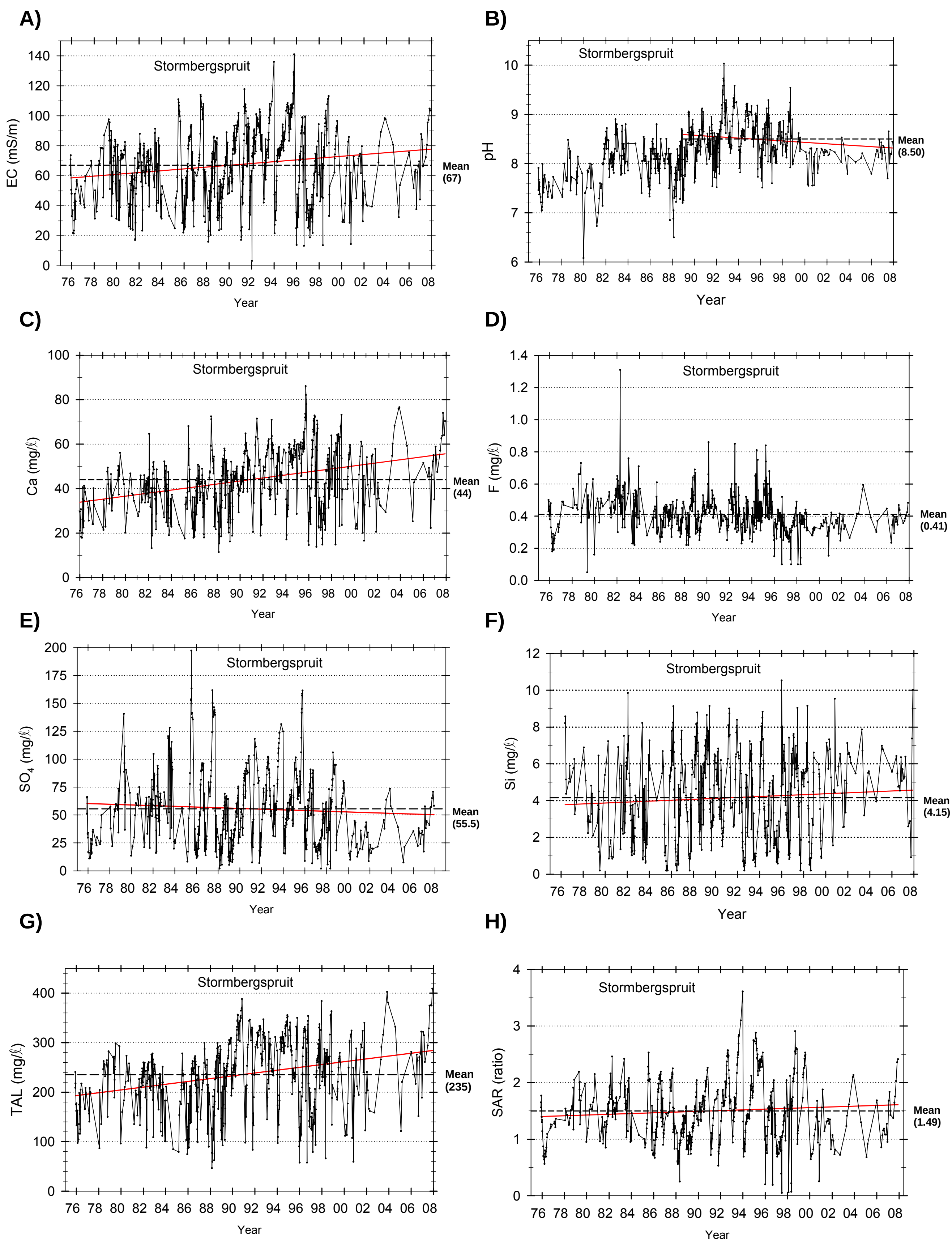


Figure A42: Temporal variation in A) EC, B) pH, C) Ca, D) F, E) SO_4, F) Si, G) TAL and H) SAR (mg/ℓ) in the Stormbergspruit at Burgersdorp (1976 – 2007).

2.5 OSL2/5 – Seekoei River at De Eerste Poort (D3H015) – (S30.53480; E24.96250)

A)

B)

Figure A43: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site at Seekoei River (road bridge, R369). River width ranged between 48 and 64 m.

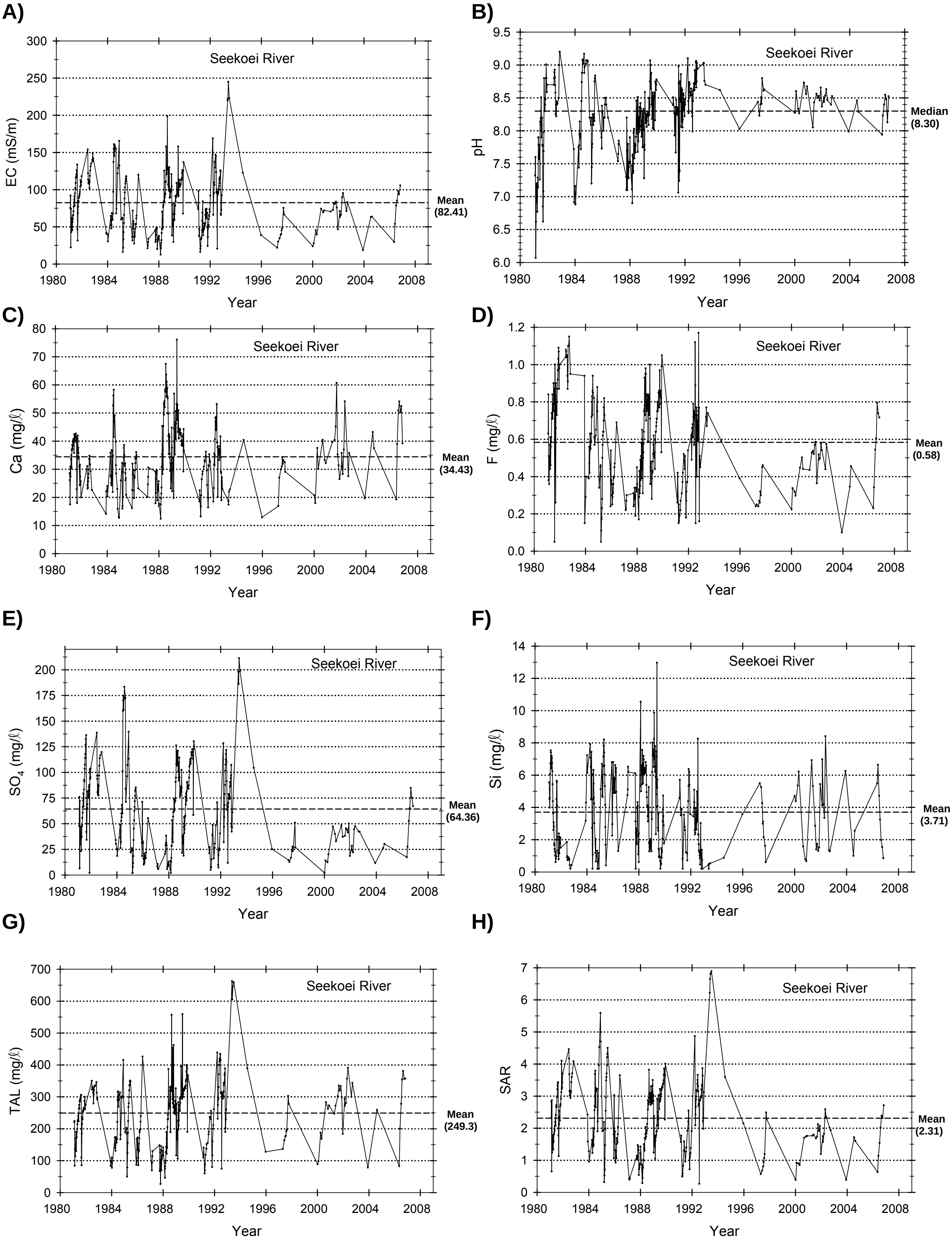


Figure A44: Temporal variation of A) EC, B) pH, C) Ca, D) F, E) SO_4, F) Si, G) TAL and H) SAR (mg/ℓ) in the Seekoei River at De Eerste Poort (1980 – 2007).

2.6 VS21 – Vaal River at Douglas Bridge – new site (S29.04885; E23.76822)

A)

B)

Figure A45: **A)** Satellite image (Google Earth) and **B)** onsite picture of the sampling site in Vaal River – at road bridge in Douglas. River width was about 135 m.

APPENDIX B

CALEDON RIVER MONITORING SITES: MAIN STEM – LEVEL 1 AND TRIBUTARIES – LEVEL 2

(Satellite images, onsite pictures and additional graphs)

1 CALEDON RIVER MONITORING SITES – MAIN STEM, LEVEL 1

1.1 CS1 – Caledon River at Caledonpoort (bridge at RSA-Lesotho border) – Proposed new site (S28.69363; E28.23445)

A)

B)

Figure B1: **A)** Satellite image (Google Earth) and **B)** on site picture of the monitoring site in Caledon River at Caledonpoort; confluence with Little Caledon River. River width ranged between 6 and 25 m. Proposed new site - no historical data.

1.2 CS2 – Caledon River at Ficksburg – D2H035 (S28.90409; E27.83084)

A)

B)

Figure B2: A) Satellite image (Google Earth) and **B)** on site picture of Caledon River at Ficksburg (CS2) – downstream of town. River width was about 40 m.

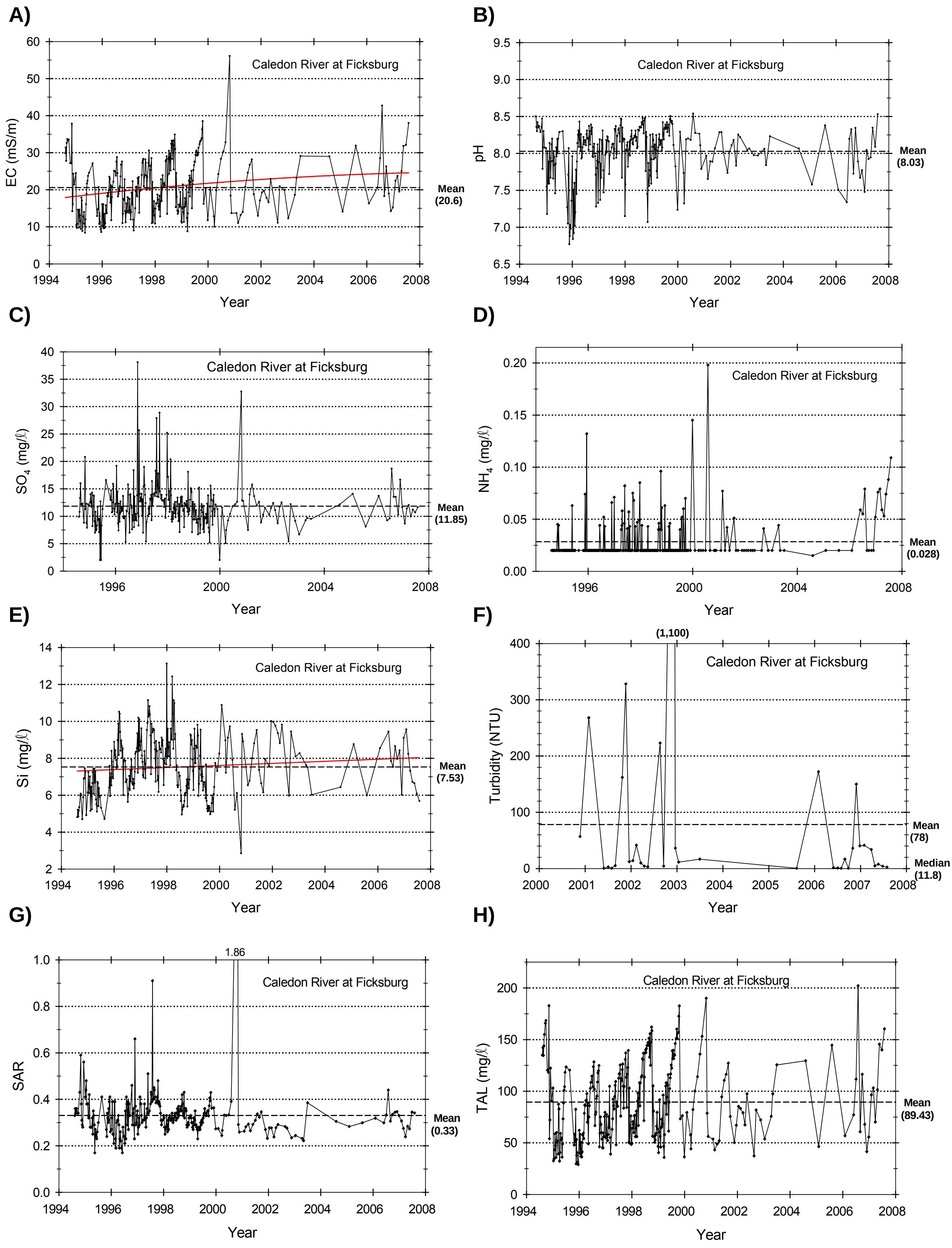


Figure B3: Temporal variation in A) EC, B) pH, C) SO_4, D) NH_4, E) Si, F) F, G) SAR and H) Alkalinity (mg/ℓ) in the Caledon River at Ficksburg (1994 – 2007).

1.3 CS3 – Caledon River at Maseru – new site (S29.38042; E27.41203)

A)

B)

Figure B4: A) Satellite image (Google Earth) and **B)** on site picture of Caledon River downstream of Maseru – new site. River width was 35 m. No historical data.

1.4 CS4 – Caledon River at 10-Fontein pump station – new site (S29.78357; E26.90998)

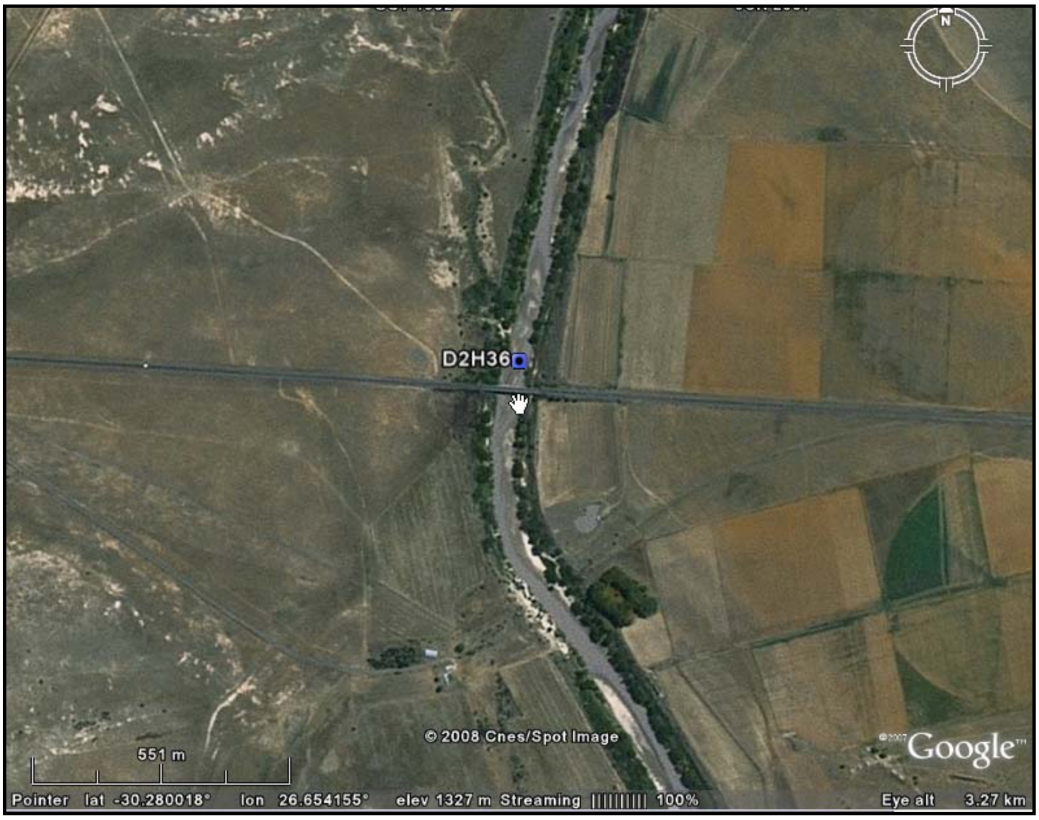
A)

B)

Figure B5: A) Satellite image (Google Earth) and **B)** on site picture of Caledon River at Tienfontein pump station, upstream of Welbedacht Dam – new site, no historical data. River width was 95 m.

1.5 CS5 – Caledon River at Kommissiedrift – at N6 road crossing – D2H036 (S30.27994; E26.65427)

A)



B)

Figure B6: A) Satellite image (Google Earth) and **B)** on site picture of Caledon River at Kommissiedrift (CS5) - at N6 road bridge. River width ranged between 16 – 68 m.

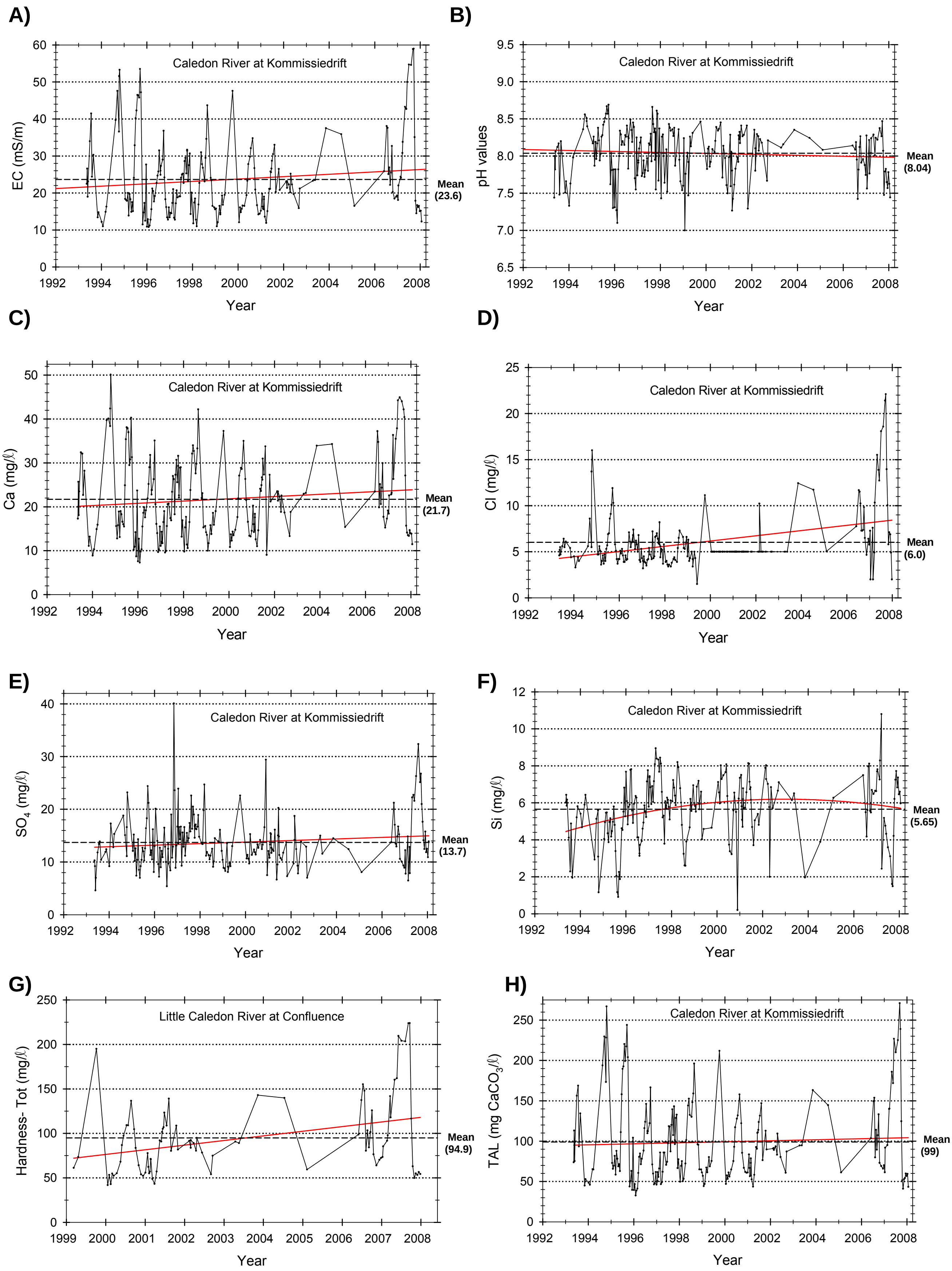
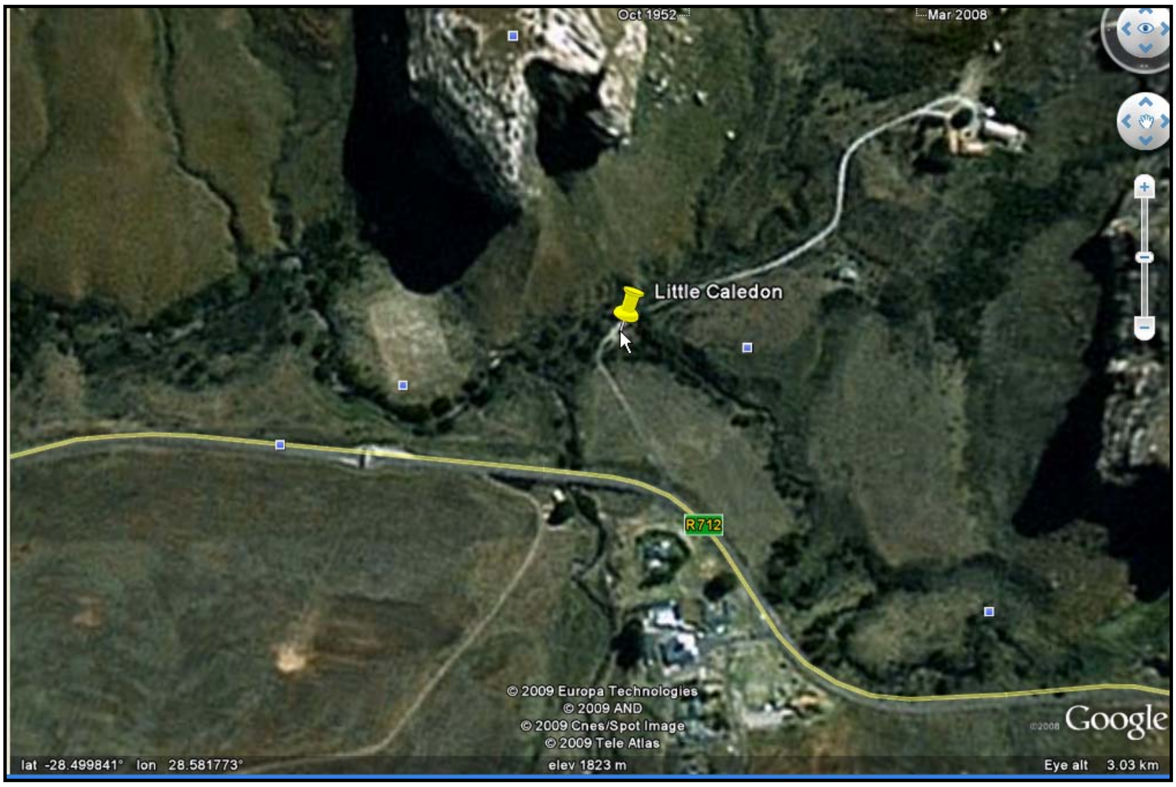


Figure B7: Temporal variation in A) EC, B) pH, C) Ca, D) Cl, E) SO_4, F) Si, G) Hardness and H) Alkalinity (mg/ℓ) in Caledon River at Kommissiedrift (1993 – 2007).

2 CALEDON RIVER MONITORING SITES – TRIBUTARIES – LEVEL 2

2.1 CSL2/1 Little Caledon River downstream of Golden Gate – new site (S28.49980; E28.58196)

A)



B)

Figure B8: A) Satellite image (Google Earth) and **B)** on site pictures of the Little Caledon River downstream Golden Gate – next to R712 road. Note the exceptional clear water. River width ranged between 4 and 8 m. New site; no historical data.

2.2 CSL2/2 Little Caledon River at the Poplars (D2H012) – at confluence with Caledon River (S28.69477; E28.23486)

A)

B)

Figure B9: A) Satellite image (Google Earth) and **B)** on site picture of the Little Caledon River at The Poplars (D2H012) - at confluence with Caledon River – at Caledonpoort border bridge. River width ranged between 7 and 15 m.

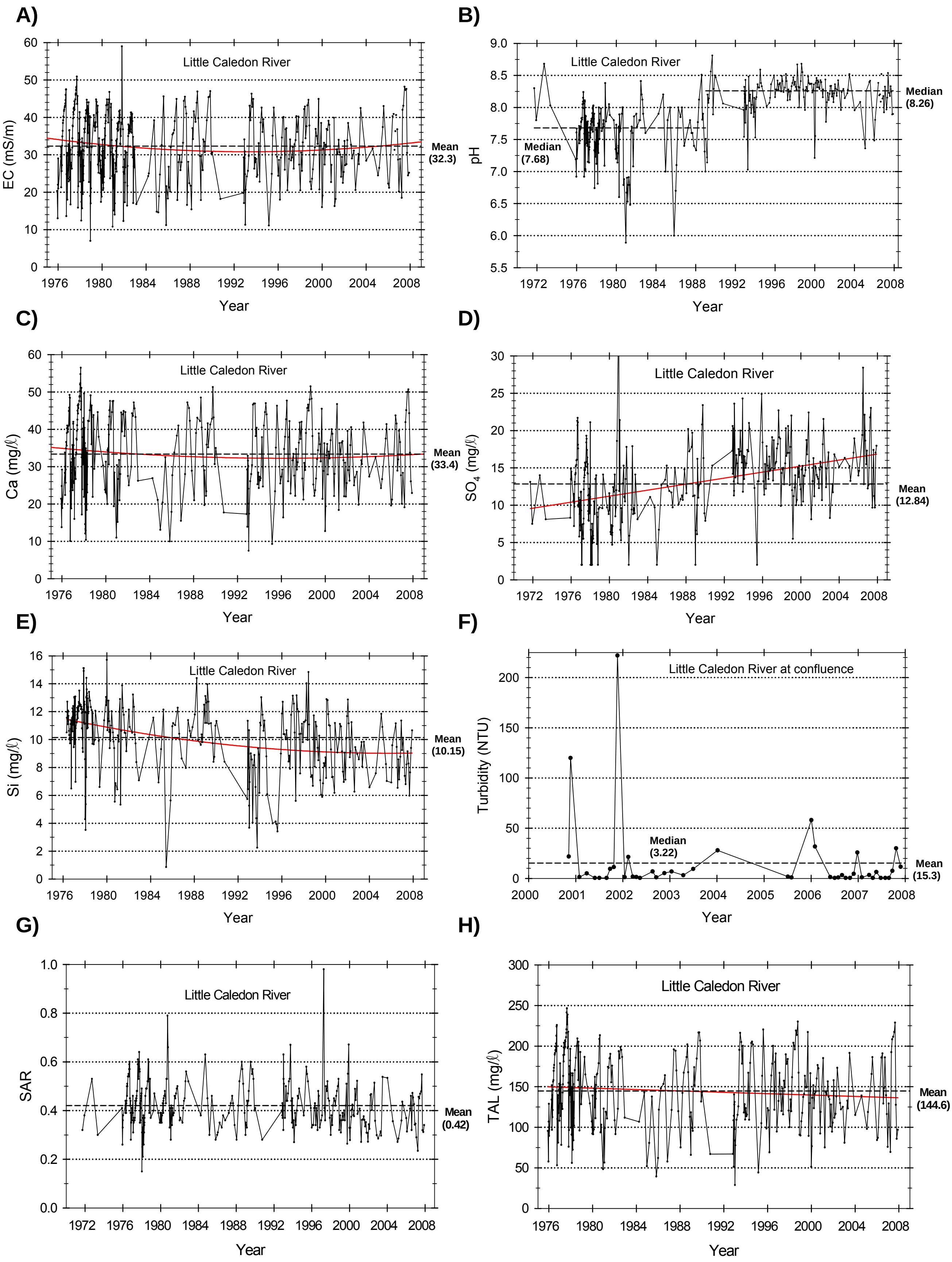
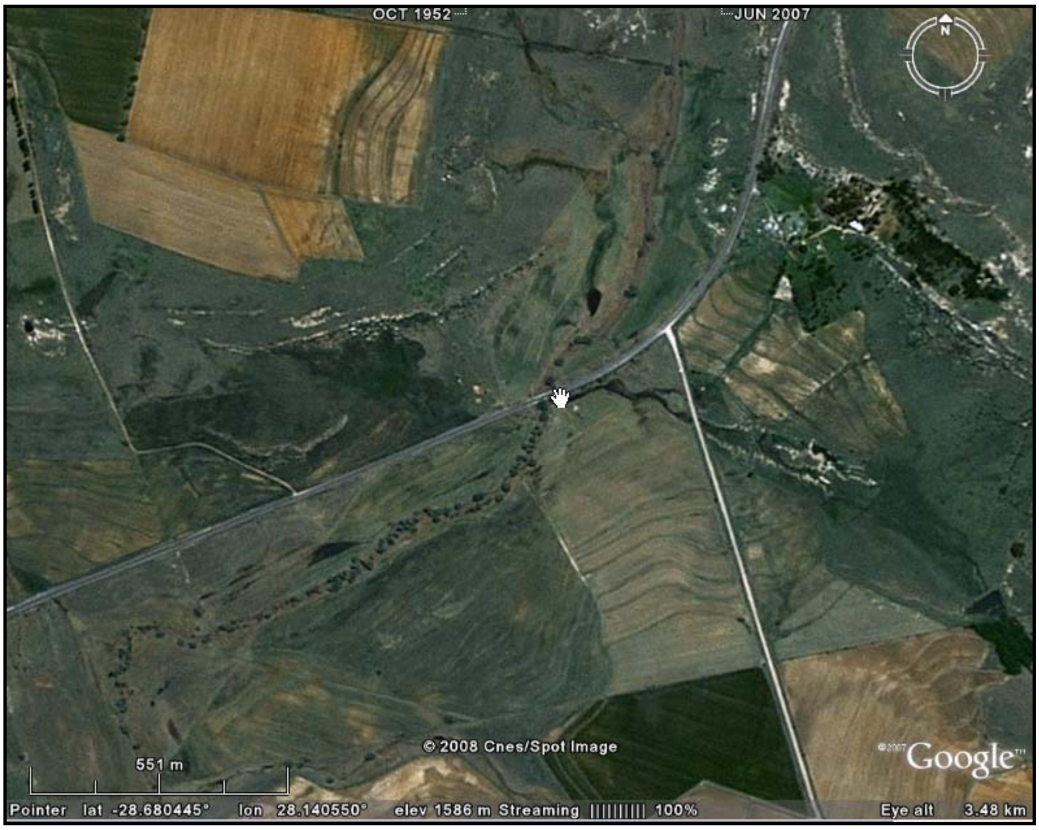


Figure B10: Temporal variation in A) EC, B) pH, C) Ca, D) SO_4, E) Si, F) Turbidity, G) SAR and H) Alk. (mg/ℓ) in the Little Caledon River at The Poplars (1976 – 2007).

2.3 CSL2/3 – Grootspruit at R26 road bridge – new site (S28.68026; E28.13996)

A)



B)

Figure B11: **A)** Satellite image (Google Earth) and **B)** on site picture at Grootspruit, also known as Brandwaterspruit - at R26 road bridge to Fouriesburg.

2.4 CSL2/4 – Meulspruit above dam – new site (S28.83528; E27.83340)

A)

B)

Figure B12: **A)** Satellite image (Google Earth) and **B)** on site picture at Meulspruit upstream of dam, close to Ficksburg on S67 road. Proposed new site, no historical data.

2.5 CSL2/5 Moperispruit at R26 road bridge – new site (S28.96011; E27.56664)

A)

B)

Figure B13: **A)** Satellite image (Google Earth) and **B)** picture of Moperispruit, also known as Mopeli River, close to Clocolan. Proposed new site, no historical data.

2.6 CSL2/6 Leeu River at Hobhouse – new site (S29.52155; E27.13577)

A)

B)

Figure B14: **A)** Satellite image (Google Earth) and **B)** on site picture at Leeu River – near Hobhouse.

APPENDIX C

SUMMARY OF STATISTICS ON HISTORICAL DATA AT THE MONITORING SITES ON THE ORANGE AND CALEDON RIVERS AS WELL AS MAIN TRIBUTARIES

Table C1: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Upper Orange River.

Site	Stats	EC (mS/m)	DMS (mg/ℓ)	TAL (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)
OS1 Oranjedraai (D1H009) (1975-2007)	Mean	16.84	133.1	71.97	18.45	6.77	4.67	0.99
	Min	7.80	56.0	17.40	5.65	2.20	1.00	0.15
	Max	51.00	460.0	236.40	56.00	29.10	22.35	6.35
	Median	16.00	127.1	68.20	17.60	6.30	4.58	0.82
	95 º%	24.46	196.9	113.32	28.24	10.40	6.62	2.14
	n	748	561	588	586	584	585	584
OS2 Aliwal North (D1H003) (1974-2007)	Mean	18.56	140.78	75.22	19.26	7.40	5.61	1.19
	Min	6.70	56.00	2.00	7.40	1.50	1.00	0.15
	Max	71.50	471.11	166.70	41.44	17.10	63.19	16.09
	Median	17.70	134.25	72.80	18.6	6.90	5.20	0.96
	95 º%	28.00	221.85	121.78	29.95	12.00	9.40	2.51
	n	1219	976	1136	1131	1128	1130	1127
OSD1 Gariep Dam (D3R002) (1972-2007)	Mean	17.34	130.35	68.98	17.32	6.36	5.77	1.54
	Min	9.80	18.60	38.80	5.05	1.00	0.03	0.13
	Max	42.80	317.38	165.04	34.38	14.15	26.90	6.40
	Median	17.37	133.59	70.10	17.46	6.40	5.61	1.39
	95 º%	21.68	157.41	85.42	21.24	8.00	7.78	2.74
	n	386	329	385	385	383	385	379
OS4 Roodepoort (D3H013) (1976-2007)	Mean	17.48	127.00	64.18	17.01	6.25	6.19	1.60
	Min	1.40	11.00	4.10	0.50	0.50	1.00	0.35
	Max	100.50	470.00	236.30	37.50	28.70	109.50	10.15
	Median	16.60	125.20	64.10	16.80	6.10	5.62	1.35
	95 º%	21.51	160.97	84.25	21.21	7.81	8.53	2.91
	n	1020	949	962	952	953	954	954
OSD2 Vanderkloof Dam (D3R003) (1979-2007)	Mean	18.85	139.47	73.26	18.59	6.73	6.06	1.55
	Min	13.30	100.00	24.60	5.00	0.37	3.50	0.15
	Max	27.25	214.00	110.60	26.35	15.20	9.21	6.35
	Median	19.00	140.00	73.74	18.70	6.71	6.20	1.40
	95 º%	22.14	160.97	86.87	21.79	8.01	7.93	2.67
	n	257	251	255	255	255	255	252
OS5 Dooren Kuilen (D3H012) (1980-2007)	Mean	18.00	133.82	69.46	17.86	6.57	6.11	1.59
	Min	13.30	98.00	24.60	5.00	4.00	3.40	0.75
	Max	30.10	227.00	122.60	33.90	13.70	15.20	3.51
	Median	17.65	132.00	69.70	17.60	6.50	6.10	1.39
	95 º%	21.50	158.43	85.45	21.51	7.90	7.90	2.71
	n	472	442	451	450	450	450	447
OS6 Marksdrift (D3H008) (1966-2007)	Mean	20.42	156.06	79.71	20.08	7.44	8.33	1.51
	Min	8.00	87.00	23.80	5.00	2.00	2.00	0.15
	Max	107.40	683.93	145.73	51.11	22.25	47.20	4.25
	Median	19.80	153.57	79.87	20.00	7.30	8.00	1.39
	95 º%	27.02	189.78	96.60	23.93	9.47	12.57	2.64
	n	1099	792	810	809	808	812	800

º% = 95th percentile

Table C2: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Upper Orange River.

Site	Stats	SO_4 (mg/ℓ)	Cl (mg/ℓ)	F (mg/ℓ)	pH	T-Hard (mg/ℓ)	SAR	CORR
OS1 Oranjedraai (D1H009) (1975-2007)	Mean	7.39	4.19	0.13	7.61	75.16	0.24	0.24
	Min	2.00	1.50	0.05	6.20	41.60	0.07	0.08
	Max	30.10	25.40	0.84	9.10	141.11	1.15	0.59
	Median	7.50	3.80	0.12	7.68	72.58	0.23	0.22
	95 ^{o}%	13.37	9.50	0.28	8.30	107.48	0.34	0.42
	n	584	585	586	592	145	580	143
OS2 Aliwal North (D1H003) (1974-2007)	Mean	8.41	5.49	0.17	7.77	83.58	0.28	0.23
	Min	2.00	1.50	0.05	6.03	42.67	0.01	0.10
	Max	48.77	63.30	1.11	10.00	173.03	2.09	1.64
	Median	8.10	4.80	0.15	7.86	82.11	0.26	0.20
	95 ^{o}%	16.39	11.15	0.33	8.43	124.08	0.42	0.37
	n	1127	1131	1130	1177	98	1121	96
OSD1 Gariep Dam (D3R002) (1972-2007)	Mean	7.97	3.93	0.16	7.72	75.03	0.30	1.23
	Min	2.00	0.24	0.05	6.08	1.08	0.10	0.08
	Max	18.83	19.50	0.56	9.93	144.12	0.98	140.72
	Median	8.21	3.90	0.16	7.87	74.41	0.30	0.24
	95 ^{o}%	13.81	7.02	0.27	8.32	87.97	0.40	0.34
	n	381	386	383	383	141	378	142
OS4 Roodepoort (D3H013) (1976-2007)	Mean	8.62	5.90	0.18	7.68	72.58	0.32	0.25
	Min	2.00	1.50	0.05	4.56	52.79	0.08	0.12
	Max	35.50	97.20	1.13	9.62	91.67	2.86	0.46
	Median	8.35	5.15	0.17	7.82	71.78	0.30	0.25
	95 ^{o}%	16.79	9.90	0.33	8.32	87.26	0.44	0.34
	n	952	953	953	1014	201	945	201
OSD2 Vanderkloof Dam (D3R003) (1979-2007)	Mean	9.54	4.58	0.19	7.90	78.97	0.31	0.23
	Min	2.00	1.50	0.05	6.67	63.91	0.19	0.11
	Max	22.31	9.40	0.45	8.51	97.55	0.53	0.37
	Median	9.54	4.60	0.18	7.95	79.73	0.30	0.23
	95 ^{o}%	14.66	7.05	0.34	8.29	87.22	0.38	0.32
	n	255	255	255	257	115	254	115
OS5 Dooren Kuilen (D3H012) (1980-2007)	Mean	8.68	5.31	0.20	7.83	78.07	0.31	0.23
	Min	2.00	1.50	0.05	6.60	54.81	0.18	0.11
	Max	22.50	25.30	1.15	8.89	90.27	0.95	0.37
	Median	8.82	5.00	0.18	7.90	79.89	0.31	0.23
	95 ^{o}%	15.27	8.70	0.33	8.32	87.12	0.41	0.31
	n	448	449	450	471	99	448	96
OS6 Marksdrift (D3H008) (1966-2007)	Mean	11.62	6.63	0.19	7.96	84.86	0.40	0.29
	Min	2.00	1.50	0.05	6.33	60.28	0.08	0.11
	Max	28.36	53.50	1.18	9.71	290.72	2.79	2.58
	Median	11.63	6.00	0.18	8.10	84.44	0.39	0.27
	95 ^{o}%	17.91	11.46	0.32	8.35	98.64	0.56	0.42
	n	808	809	806	808	389	800	387

Table C3: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Upper Orange River.

Site	Stats	Flow (m^3/s)	NO_3-N (mg/ℓ)	NH_4-N (mg/ℓ)	DIN (mg/ℓ)	KJel-N (mg/ℓ)	TN (mg/ℓ)	OC (mg/ℓ)
OS1 Oranjedraai (D1H009) (1975-2007)	Mean	126.65	0.300	0.051	0.347	–	–	–
	Min	1.68	0.020	0.015	0.020	–	–	–
	Max	934.20	2.361	0.710	3.146	–	–	–
	Median	63.84	0.252	0.020	0.300	–	–	–
	95 ^{o}%	450.65	0.784	0.142	0.828	–	–	–
	n	556*[1]	587	563	564	–	–	–
OS2 Aliwal North (D1H003) (1974-2007)	Mean	150.85	0.329	0.051	0.312	2.52	2.89	27.19
	Min	1.49	0.020	0.015	0.020	0.05	0.07	0.10
	Max	1710.00	3.060	1.530	4.090	20.40	20.81	152.77
	Median	78.05	0.232	0.020	0.252	0.98	1.53	22.28
	95 ^{o}%	528.46	1.126	0.110	0.780	9.60	10.19	60.23
	n	804*[2]	1135	976	982	247	247	230
OSD1 Gariep Dam (D3R002) (1972-2007)	Mean	–	0.507	0.088	0.556	0.70	1.08	–
	Min	–	0.020	0.015	0.040	0.10	0.26	–
	Max	–	5.910	5.954	6.020	15.00	15.02	–
	Median	–	0.404	0.040	0.436	0.35	0.75	–
	95 ^{o}%	–	1.249	0.137	0.958	1.27	1.70	–
	n	–	382	330	327	121	120	–
OS4 Roodepoort (D3H013) (1976-2007)	Mean	210.22	0.589	0.125	0.716	0.83	1.57	28.41
	Min	17.38	0.020	0.015	0.040	0.02	0.04	0.10
	Max	2301.0	18.403	19.210	20.380	35.18	35.87	208.99
	Median	138.25	0.560	0.051	0.614	0.45	1.23	25.28
	95 ^{o}%	600.6	0.997	0.174	1.079	1.07	1.95	50.83
	n	394*[3]	978	967	967	284	284	276
OSD2 Vanderkloof Dam (D3R003) (1979-2007)	Mean	–	0.408	0.044	0.455	0.33	0.61	13.55
	Min	–	0.020	0.015	0.020	0.10	0.18	1.56
	Max	–	0.860	0.483	1.199	1.78	2.05	24.16
	Median	–	0.433	0.020	0.455	0.30	0.53	13.32
	95 ^{o}%	–	0.800	0.104	0.850	0.59	1.26	22.71
	n	–	256	254	254	121	121	39
OS5 Dooren Kuilen (D3H012) (1980-2007)	Mean	153.34	0.497	0.046	0.547	0.43	1.08	22.61
	Min	20.27	0.020	0.015	0.040	0.12	0.42	0.10
	Max	2445.0	1.132	0.191	1.167	2.23	2.42	37.48
	Median	94.54	0.520	0.042	0.563	0.34	0.98	22.47
	95 ^{o}%	419.01	0.800	0.110	0.840	0.90	1.79	33.64
	n	299*[4]	450	446	447	69	69	56
OS6 Marksdrift (D3H008) (1966-2007)	Mean	152.31	0.421	0.043	0.469	0.403	0.67	13.71
	Min	1.13	0.020	0.015	0.020	0.045	0.19	3.14
	Max	1494.0	3.110	0.980	3.180	7.958	2.14	25.66
	Median	87.18	0.410	0.020	0.452	0.352	0.65	12.40
	95 ^{o}%	451.60	0.791	0.094	0.840	0.653	1.040	23.17
	n	489*[5]	814	799	801	259	261	74

*[1] (1961 – 2007); *[2] (1940 – 2007); *[3] (1974 – 2007) ; *[4] (1982 – 2007) ; *[5] (1963 – 2007)

Table C4: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Upper Orange River.

Site	Stats	TSS (mg/ℓ)	Turb (NTU)	Si (mg/ℓ)	DIP (mg/ℓ)	TP (mg/ℓ)	DIN:DIP	Chl-a (µg/ℓ)
OS1 Oranjedraai (D1H009) (1975-2007)	Mean	995.52	160.4	8.63	0.046	–	23.5	–
	Min	2.50	0.50	3.67	0.003	–	0.03	–
	Max	9844.0	4000.0	11.46	2.024	–	373.3	–
	Median	210.00	14.5	8.68	0.025	–	10.7	–
	95 °%	4657.25	673.7	10.50	0.102	–	80.0	–
	n	136*[1]	255	560	585	–	561	–
OS2 Aliwal North (D1H003) (1974-2007)	Mean	982.46	143.36	8.48	0.039	0.391	16.4	–
	Min	2.50	0.50	3.12	0.003	0.008	0.1	–
	Max	20334.00	1447.00	12.27	2.431	4.820	233.0	–
	Median	121.50	40.53	8.49	0.026	0.182	9.4	–
	95 °%	5070.10	626.15	10.60	0.12	1.295	53.3	–
	n	510*[2]	228	974	1118	247	971	–
OSD1 Gariep Dam (D3R002) (1972-2007)	Mean	230.94	18.68	8.02	0.030	0.069	28.5	3.8
	Min	2.00	0.50	5.48	0.003	0.015	0.8	0.5
	Max	7037.33	134.00	10.97	0.275	0.667	273.6	69.2
	Median	79.50	9.10	8.17	0.025	0.050	16.1	1.3
	95 °%	717.56	62.15	9.18	0.065	0.146	103.8	15.2
	n	302	72	329	382	118	326	120
OS4 Roodepoort (D3H013) (1976-2007)	Mean	43.40	48.47	7.97	0.058	0.130	26.9	–
	Min	1.00	0.50	0.20	0.003	0.019	0.5	–
	Max	66.00	784.00	10.32	3.410	3.580	327.1	–
	Median	56.00	22.80	8.12	0.030	0.091	18.0	–
	95 °%	65.80	142.40	9.02	0.118	0.240	70.7	–
	n	5	264	969	969	284	966	–
OSD2 VanderKloof Dam (D3R003) (1979-2007)	Mean	34.26	9.33	7.54	0.031	0.052	23.5	2.3
	Min	2.50	0.50	3.20	0.003	0.005	0.5	0.5
	Max	216.50	54.20	10.32	0.677	0.734	160.0	18.1
	Median	15.50	4.44	7.75	0.022	0.039	19.4	1.0
	95 °%	104.48	39.69	8.75	0.063	0.105	58.2	5.9
	n	37	76	253	253	119	253	29
OS5 Dooren Kuilen (D3H012) (1980-2007)	Mean	31.93	25.00	7.90	0.031	–	25.7	–
	Min	2.50	0.50	1.78	0.003	–	1.5	–
	Max	63.00	239.00	11.49	0.281	–	236.7	–
	Median	44.00	13.85	8.02	0.025	–	19.8	–
	95 °%	61.50	84.55	8.91	0.068	–	60.2	–
	n	7	190	445	450	–	445	–
OS6 Marksdrift (D3H008) (1966-2007)	Mean	26.967	27.61	7.47	0.028	–	26.14	2.15
	Min	2.500	0.50	0.20	0.003	–	0.16	1.25
	Max	68.800	383.00	17.48	0.816	–	325.62	2.61
	Median	9.600	10.00	7.54	0.021	–	20.50	2.58
	95 °%	62.880	112.80	8.76	0.059	–	67.23	2.61
	n	3	285	797	808	–	798	3

*[1] data only from 1963 – 1986; *[2] 1968 – 1986

Table C5: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Upper Orange River.

Site	Stats	Al (mg/ℓ)	B (mg/ℓ)	Ba (µg/ℓ)	Cd (µg/ℓ)	Cr (µg/ℓ)	Cu (µg/ℓ)	Fe (µg/ℓ)
OS1 Oranjedraai (D1H009)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS2 Aliwal North (D1H003)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OSD1 Gariep Dam (D3R002)	Mean	–	0.49	–	–	–	–	–
	Min	–	0.00	–	–	–	–	–
	Max	–	18.93	–	–	–	–	–
	Median	–	0.01	–	–	–	–	–
	95 ^{o}%	–	0.06	–	–	–	–	–
	n	–	40	–	–	–	–	–
OS4 Roodepoort (D3H013)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OSD2 Vanderkloof Dam (D3R003) (2003-2007)	Mean	0.043	0.017	0.025	0.004	0.004	0.009	0.087
	Min	0.011	0.006	0.001	0.001	0.002	0.002	0.001
	Max	0.101	0.075	0.048	0.005	0.014	0.062	2.162
	Median	0.035	0.014	0.029	0.005	0.003	0.006	0.013
	95 ^{o}%	0.095	0.033	0.043	0.005	0.006	0.020	0.122
	n	31	46	32	31	29	31	32
OS5 Dooren Kuilen (D3H012)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS6 Marksdrift (D3H008) (2002-2007)	Mean	0.192	0.021	0.016	0.005	0.004	0.010	0.047
	Min	0.021	0.006	0.001	0.001	0.001	0.002	0.003
	Max	6.647	0.260	0.050	0.005	0.008	0.022	1.374
	Median	0.035	0.011	0.007	0.005	0.003	0.006	0.014
	95 ^{o}%	0.190	0.076	0.042	0.005	0.008	0.022	0.137
	n	54	55	55	52	54	54	55

Table C6: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Upper Orange River.

Site	Stats	Mn (µg/ℓ)	Mo (µg/ℓ)	Ni (µg/ℓ)	Pb (µg/ℓ)	Sr (mg/ℓ)	V (µg/ℓ)	Zn (µg/ℓ)
OS1 Oranjedraai (D1H009) (1975-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS2 Aliwal North (D1H003) (1974-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OSD1 Gariep Dam (D3R002) (1972-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS4 Roodepoort (D3H013) (1976-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OSD2 Vanderkloof Dam (D3R003) (1979-2007)	Mean	0.205	0.013	0.007	0.047	0.102	0.008	0.011
	Min	0.001	0.001	0.001	0.001	0.077	0.003	0.002
	Max	6.302	0.019	0.047	0.063	0.278	0.022	0.082
	Median	0.001	0.016	0.004	0.054	0.097	0.007	0.007
	95 ^{o}%	0.011	0.016	0.019	0.054	0.139	0.017	0.033
	n	32	32	29	30	32	32	30
OS5 Dooren Kuilen (D3H012) (1980-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS6 Marksdrift (D3H008) (1966-2007)	Mean	0.055	0.014	0.011	–	0.137	0.008	0.008
	Min	0.001	0.001	0.004	–	0.031	0.003	0.002
	Max	2.855	0.021	0.084	–	0.836	0.036	0.120
	Median	0.001	0.016	0.008	–	0.107	0.007	0.004
	95 ^{o}%	0.007	0.019	0.028	–	0.313	0.016	0.025
	n	55	57	53	–	58	58	55

– = no data available

Table C7: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Lower Orange River.

Site	Stats	EC (mS/m)	DMS (mg/ℓ)	TAL (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)
OS8	Mean	23.18	172.36	80.43	21.98	8.76	12.30	1.76
Prieska	Min	9.50	65.00	26.40	7.80	3.70	3.40	0.15
(D7H002)	Max	77.30	510.00	176.80	63.30	24.10	91.90	18.96
(1977-1997)	Median	21.30	158.50	77.80	20.60	8.10	10.00	1.53
	95 °%	33.59	263.50	110.00	30.53	13.00	24.70	3.28
	n	593	386	407	400	401	401	388
OS9	Mean	28.13	210.32	92.29	24.25	10.39	16.52	2.29
Boegoeberg Dam	Min	15.60	98.25	32.80	7.00	4.06	4.00	0.15
(D7H008)	Max	92.20	631.88	169.10	64.70	30.89	96.50	16.73
(1966-2007)	Median	26.10	197.00	91.79	23.52	9.60	13.55	1.92
	95 °%	45.35	317.13	113.48	33.09	16.51	33.42	4.25
	n	931	711	724	726	725	725	713
OS11	Mean	34.07	241.46	102.90	26.05	11.92	21.79	2.43
Upington	Min	14.90	128.00	53.10	8.50	5.00	2.00	0.96
(D7H005)	Max	94.50	674.75	299.66	55.72	27.48	102.71	5.67
(1975-2007)	Median	31.55	226.74	102.70	25.20	11.10	17.49	2.19
	95 °%	54.58	378.01	136.05	35.45	19.12	44.49	4.28
	n	392	360	391	391	391	392	366
OS13	Mean	35.71	255.02	111.28	27.41	12.46	22.31	2.53
Neusberg	Min	19.20	144.12	70.08	17.24	6.40	5.66	1.14
(D7H016)	Max	78.20	530.00	164.60	51.50	24.24	76.10	7.46
(1995-2007)	Median	33.80	244.00	111.28	27.06	11.77	20.20	2.10
	95 °%	53.93	374.69	150.93	35.94	19.43	41.04	4.85
	n	376	375	376	376	376	376	376
OS15	Mean	40.44	286.46	120.56	29.94	13.85	28.03	2.69
Pella	Min	18.50	147.00	70.59	15.48	6.90	5.79	0.86
(D8H008)	Max	75.20	513.23	179.00	51.56	26.27	76.72	27.96
(1980-2007)	Median	38.90	276.83	121.89	29.80	13.30	25.15	2.32
	95 °%	64.30	447.79	163.37	40.21	22.04	57.28	4.89
	n	606	599	604	600	601	601	598
OS16	Mean	36.14	278.94	120.48	29.135	13.58	27.39	2.52
Vioolsdrift	Min	19.10	132.00	55.00	15.039	6.28	7.30	0.15
(D8H003)	Max	83.80	597.00	214.60	48.530	32.80	96.80	6.95
(1977-2007)	Median	33.10	267.29	120.62	29.200	12.70	23.70	2.29
	95 °%	61.54	461.73	166.09	39.178	23.04	60.86	4.54
	n	1369	924	940	932	934	936	932
OS18	Mean	34.56	241.90	105.04	27.54	11.33	23.86	1.99
Brand Kaross	Min	18.10	126.70	64.00	10.00	5.00	7.30	1.01
(D3H007)	Max	88.00	616.00	227.80	42.88	23.20	122.80	4.19
(1980-2002)	Median	33.30	233.10	101.80	26.75	10.80	21.30	1.88
	95 °%	48.78	341.46	149.35	36.40	16.40	42.50	3.19
	n	412	412	144	141	141	141	140
OS19	Mean	47.97	341.97	134.99	34.48	15.34	37.98	3.66
Alexander Bay	Min	23.40	163.00	70.00	20.40	5.40	8.60	1.45
(D8H0012)	Max	93.90	626.00	212.00	50.60	31.80	101.90	8.10
(1995-2003)	Median	47.10	336.00	135.20	34.60	15.60	34.48	3.59
	95 °%	72.96	514.50	177.33	44.07	22.08	76.97	5.62
	n	263	263	263	263	263	263	263

Table C8: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Lower Orange River.

Site	Stats	SO_4 (mg/ℓ)	Cl (mg/ℓ)	F (mg/ℓ)	pH	Hard (mg/ℓ)	SAR	CORR
OS8 Prieska (D7H002) (1977-2001)	Mean	15.09	12.49	0.23	7.58	–	0.55	–
	Min	2.00	1.50	0.05	4.79	–	0.18	–
	Max	96.90	118.90	2.11	8.83	–	3.20	–
	Median	10.70	10.50	0.20	7.57	–	0.48	–
	95 °%	39.70	24.98	0.44	8.36	–	0.97	–
	n	401	400	398	437	–	401	–
OS9 Boegoeberg Dam (D7H008) (1966-2007)	Mean	24.98	16.43	0.21	8.07	108.78	0.68	0.56
	Min	2.00	1.50	0.05	6.73	49.33	0.27	0.10
	Max	164.30	106.30	0.99	9.33	267.18	2.77	3.02
	Median	19.65	13.23	0.20	8.13	102.95	0.60	0.48
	95 °%	56.56	38.45	0.35	8.56	155.84	1.24	1.00
	n	720	722	716	729	311	717	309
OS11 Upington (D7H005) (1975-2007)	Mean	28.23	21.51	0.25	8.03	126.12	0.86	0.65
	Min	2.00	1.50	0.05	6.80	76.43	0.07	0.21
	Max	134.32	126.40	1.24	8.86	255.73	2.87	1.89
	Median	22.93	17.07	0.23	8.14	118.36	0.75	0.55
	95 °%	64.23	46.24	0.41	8.45	177.94	1.52	1.08
	n	392	392	376	391	160	390	160
OS13 Neusberg (D7H016) (1995-2007)	Mean	33.19	20.19	0.25	8.21	121.29	0.86	0.56
	Min	9.41	5.00	0.14	7.32	75.57	0.283	0.20
	Max	153.86	101.0	0.64	8.61	209.01	2.26	2.26
	Median	28.40	17.60	0.24	8.24	116.78	0.81	0.49
	95 °%	62.64	42.18	0.32	8.45	169.31	1.40	0.94
	n	375	377	376	376	215	362	214
OS15 Pella (D8H008) (1980-2007)	Mean	37.64	26.29	0.29	8.25	135.89	1.03	0.64
	Min	4.17	3.70	0.05	6.85	78.43	0.29	0.19
	Max	145.28	76.27	1.15	8.81	234.49	2.73	1.88
	Median	32.85	22.54	0.28	8.28	131.96	0.96	0.61
	95 °%	74.55	56.64	0.41	8.52	195.19	1.82	1.06
	n	601	600	599	607	395	595	395
OS16 Vioolsdrift (D8H003) (1965-2007)	Mean	33.64	24.56	0.31	8.09	138.29	1.01	0.66
	Min	2.00	4.90	0.05	6.26	80.10	0.36	0.16
	Max	145.50	94.00	0.84	8.81	224.38	3.03	1.95
	Median	28.33	19.80	0.29	8.26	135.39	0.91	0.58
	95 °%	79.00	60.20	0.48	8.54	203.55	1.93	1.21
	n	937	937	934	943	351	918	354
OS18 Brand Kaross (D3H007) (1980-2002)	Mean	24.48	20.13	0.297	7.43	120.59	0.92	0.69
	Min	2.00	1.50	0.05	6.08	93.68	0.35	0.45
	Max	89.30	76.90	0.70	9.26	178.66	2.29	1.05
	Median	22.40	17.40	0.28	7.40	111.01	0.86	0.62
	95 °%	50.40	38.80	0.47	8.29	165.20	1.47	0.99
	n	141	141	141	144	5	139	5
OS19 Alexander Bay (D8H0012) (1995-2003)	Mean	48.76	35.99	0.31	8.38	146.93	1.31	0.77
	Min	15.60	7.40	0.17	7.54	95.63	0.42	0.41
	Max	144.30	102.00	0.71	8.76	186.65	3.69	1.94
	Median	43.88	32.10	0.29	8.41	151.08	1.20	0.73
	95 °%	84.31	73.05	0.50	8.60	174.69	2.40	1.21
	n	263	263	263	263	47	252	47

Table C9: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the **Lower Orange River**.

Site	Stats	Flow (m^3/s)	NO_3-N (mg/ℓ)	NH_4-N (mg/ℓ)	DIN (mg/ℓ)	KJel-N (mg/ℓ)	TN (mg/ℓ)	OC (mg/ℓ)
OS8 Prieska (D7H002) (1977-2001)	Mean	236.8	0.416	0.058	0.486	–	–	–
	Min	17.8	0.020	0.020	0.020	–	–	–
	Max	4389.0	1.420	1.570	1.730	–	–	–
	Median	112.8	0.430	0.040	0.494	–	–	–
	95 ^{o}%	820.8	0.820	0.120	0.883	–	–	–
	n	389*	407	389	395	–	–	–
OS9 Boegoeberg Dam (D7H008) (1966-2007)	Mean	250.32	0.283	0.049	0.337	–	–	–
	Min	0.39	0.020	0.015	0.040	–	–	–
	Max	4432.00	1.208	0.448	1.228	–	–	–
	Median	109.55	0.247	0.040	0.305	–	–	–
	95 ^{o}%	984.79	0.667	0.119	0.725	–	–	–
	n	898*[2]	726	713	712	–	–	–
OS11 Upington (D7H005) (1975-2007)	Mean	274.36	0.297	0.042	0.347	0.65	0.88	10.46
	Min	0.00	0.020	0.015	0.040	0.14	0.02	2.37
	Max	4458.00	2.017	0.440	2.037	2.25	2.65	33.07
	Median	112.30	0.192	0.020	0.260	0.59	0.80	4.74
	95 ^{o}%	1050.00	0.797	0.108	0.840	1.15	1.54	25.29
	n	761*[3]	392	360	360	256	265	61
OS13 Neusberg (D7H016) (1995-2007)	Mean	230.9	0.165	0.035	0.199	0.56	0.71	10.16
	Min	38.5	0.020	0.015	0.015	0.09	0.09	0.25
	Max	1485.0	3.187	0.231	0.914	3.97	4.03	39.31
	Median	136.2	0.055	0.020	0.113	0.50	0.61	5.05
	95 ^{o}%	760.9	0.572	0.085	0.630	0.96	1.26	31.47
	n	167*[4]	376	376	276	188	135	128
OS15 Pella (D8H008) (1980-2007)	Mean	143.44	0.143	0.035	0.179	0.59	0.73	9.85
	Min	4.39	0.020	0.015	0.040	0.10	0.15	2.08
	Max	4914.00	3.170	0.378	3.266	2.06	3.77	98.25
	Median	81.91	0.051	0.020	0.079	0.56	0.68	4.41
	95 ^{o}%	443.07	0.529	0.096	0.576	0.97	1.24	30.95
	n	334	607	601	601	358	358	164
OS16 Vioolsdrift (D8H003) (1965-2007)	Mean	265.54	0.118	0.046	0.161	0.64	0.74	10.55
	Min	0.00	0.020	0.015	0.040	0.09	0.11	1.46
	Max	5328.00	3.090	1.961	3.130	3.69	3.75	82.87
	Median	116.35	0.040	0.020	0.070	0.56	0.62	5.07
	95 ^{o}%	1000.90	0.521	0.109	0.585	1.15	1.41	29.17
	n	812*[5]	938	928	928	600	600	150
OS18 Brand Kaross (D3H007) (1980-2002)	Mean	–	0.168	0.039	0.208	0.64	1.12	3.26
	Min	–	0.020	0.020	0.020	0.26	0.39	1.89
	Max	–	2.410	0.130	2.450	1.01	1.79	4.05
	Median	–	0.040	0.040	0.090	0.66	1.16	3.71
	95 ^{o}%	–	0.766	0.080	0.810	0.96	1.78	3.99
	n	–	144	139	142	8	8	5
OS19 Alexander Bay (D8H0012) (1995-2003)	Mean	–	0.151	0.032	0.169	0.75	0.87	4.35
	Min	–	0.020	0.020	0.040	0.08	0.05	1.35
	Max	–	2.128	0.545	2.148	11.61	5.77	16.76
	Median	–	0.040	0.020	0.073	0.61	0.69	3.68
	95 ^{o}%	–	0.607	0.067	0.582	1.48	2.02	10.04
	n	–	263	263	188	245	185	31

*1 (1972-2007); *2 (1933-2007); *3 (1944-2007); *4 (1994-2007); *5 (1940-2007)

Table C10: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the **Lower Orange River**.

Site	Stats	TSS (mg/ℓ)	Turb (NTU)	Si (mg/ℓ)	DIP (mg/ℓ)	TP (mg/ℓ)	DIN:DIP	Chl-a (µg/ℓ)
OS8 Prieska (D7H002) (1977-2001)	Mean	855.0	78.42	7.74	0.023	–	43.3	–
	Min	2.5	14.00	2.96	0.003	–	0.4	–
	Max	11500.0	352.00	14.04	0.230	–	290.0	–
	Median	116.0	66.00	8.02	0.014	–	27.9	–
	95 ^{o}%	5137.0	197.00	8.88	0.060	–	119.0	–
	n	965*	43	389	389	–	387	–
OS9 Boegoeberg Dam (D7H008) (1966-2007)	Mean	–	8.56	6.44	0.027	–	18.3	–
	Min	–	0.50	0.63	0.003	–	0.5	–
	Max	–	43.30	13.98	0.456	–	140.0	–
	Median	–	3.34	6.79	0.021	–	13.6	–
	95 ^{o}%	–	30.34	8.59	0.060	–	49.4	–
	n	–	92	711	714	–	711	–
OS11 Upington (D7H005) (1975-2007)	Mean	1114.6	–	6.46	0.030	–	16.8	16.9
	Min	2.0	–	1.31	0.003	–	0.9	1.0
	Max	61301.0	–	19.49	0.323	–	143.3	346.7
	Median	373.0	–	6.81	0.022	–	10.3	9.0
	95 ^{o}%	4596.0	–	8.62	0.077	–	50.2	30.7
	n	3565*[2]	–	360	372	–	356	58
OS13 Neusberg (D7H016) (1995-2007)	Mean	48.6	–	5.95	0.030	0.070	8.5	14.3
	Min	2.0	–	0.20	0.006	0.023	0.3	1.0
	Max	293.3	–	14.05	0.469	0.212	152.3	211.2
	Median	25.3	–	6.29	0.023	0.062	5.7	7.0
	95 ^{o}%	164.6	–	8.98	0.062	0.133	23.1	43.8
	n	75	–	376	376	187	203	82
OS15 Pella (D8H008) (1979-2007)	Mean	48.38	–	5.63	0.029	0.078	7.2	16.9
	Min	2.50	–	0.20	0.003	0.015	0.4	1.0
	Max	388.80	–	13.76	0.237	0.312	70.3	157.1
	Median	27.60	–	5.95	0.022	0.069	5.4	11.2
	95 ^{o}%	146.40	–	9.66	0.068	0.148	20.9	45.1
	n	181	–	600	601	354	601	168
OS16 Vioolsdrift (D8H003) (1965-2007)	Mean	545.5	–	6.25	0.025	0.078	9.7	63.1
	Min	8.2	–	0.20	0.003	0.008	0.4	10.8
	Max	2923.0	–	13.14	0.215	0.617	290.0	129.5
	Median	228.0	–	6.67	0.020	0.063	4.4	56.0
	95 ^{o}%	1929.0	–	9.94	0.063	0.178	30.9	123.9
	n	10	–	929	933	596	929	4
OS18 Brand Kaross (D3H007) (1980-2002)	Mean	–	–	7.26	0.017	–	15.3	–
	Min	–	–	0.59	0.003	–	1.1	–
	Max	–	–	11.04	0.097	–	144.1	–
	Median	–	–	7.39	0.013	–	9.3	–
	95 ^{o}%	–	–	9.95	0.046	–	45.1	–
	n	–	–	139	140	–	139	–
OS19 Alexander Bay (D8H0012) (1995-2003)	Mean	66.32	–	4.86	0.037	–	5.8	18.1
	Min	2.50	–	0.20	0.006	–	0.2	1.0
	Max	452.70	–	11.03	0.422	–	74.1	72.8
	Median	35.60	–	5.16	0.026	–	3.0	10.4
	95 ^{o}%	229.04	–	8.25	0.087	–	16.5	59.9
	n	14	–	263	263	–	150	10

*1 (1952 – 1992); *2 (1952 – 2007)

Table C11: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Lower Orange River.

Site	Stats	Al (mg/ℓ)	B (mg/ℓ)	Ba (µg/ℓ)	Cd (µg/ℓ)	Cr (µg/ℓ)	Cu (µg/ℓ)	Fe (µg/ℓ)
OS8 Prieska (D7H002) (1977-2001)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS9 Boegoeberg Dam (D7H008) (1966-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS11 Upington (D7H005) (2003-2007)	Mean	0.051	0.035	0.015	0.005	0.004	0.008	0.022
	Min	0.012	0.006	0.001	0.001	0.001	0.002	0.001
	Max	0.157	0.183	0.053	0.021	0.008	0.022	0.260
	Median	0.035	0.029	0.007	0.005	0.003	0.006	0.006
	95 ^{o}%	0.107	0.083	0.046	0.005	0.008	0.022	0.054
	n	32	33	32	32	32	32	32
OS13 Neusberg (D7H016) (2003-2007)	Mean	0.066	–	–	–	0.007	0.014	0.023
	Min	0.009	–	–	–	0.001	0.003	0.006
	Max	0.192	–	–	–	0.046	0.056	0.125
	Median	0.042	–	–	–	0.005	0.006	0.014
	95 ^{o}%	0.149	–	–	–	0.008	0.022	0.090
	n	25	–	–	–	25	25	24
OS15 Pella (D8H008) (2005-2007)	Mean	0.034	0.090	0.026	0.020	0.003	0.006	0.015
	Min	0.026	0.024	0.001	0.001	0.001	0.003	0.003
	Max	0.035	0.306	0.066	0.087	0.003	0.006	0.076
	Median	0.035	0.055	0.022	0.005	0.003	0.006	0.006
	95 ^{o}%	0.035	0.194	0.057	0.076	0.003	0.006	0.040
	n	20	20	20	20	20	20	20
OS16 Vioolsdrift (D8H003) (2005-2007)	Mean	0.062	0.049	0.026	0.006	0.004	0.007	0.013
	Min	0.035	0.006	0.001	0.005	0.003	0.006	0.006
	Max	0.204	0.110	0.114	0.033	0.032	0.036	0.117
	Median	0.035	0.034	0.028	0.005	0.003	0.006	0.006
	95 ^{o}%	0.168	0.109	0.048	0.012	0.009	0.006	0.030
	n	34	35	35	35	35	35	35
OS18 Brand Kaross (D3H007) (1980-2002)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS19 Alexander Bay (D8H0012) (1995-2003)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–

Table C12: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Lower Orange River.

Site	Stats	Mn (mg/ℓ)	Mo (mg/ℓ)	Ni (mg/ℓ)	Pb (mg/ℓ)	Sr (mg/ℓ)	V (mg/ℓ)	Zn (mg/ℓ)
OS8 Prieska (D7H002) (1977-2001)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS9 Boegoeberg Dam (D7H008) (1966-2007)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS11 Upington (D7H005) (1975-2007)	Mean	0.002	0.014	0.010	0.051	0.177	0.009	0.025
	Min	0.001	0.002	0.004	0.002	0.031	0.003	0.002
	Max	0.007	0.019	0.036	0.071	0.455	0.030	0.469
	Median	0.001	0.016	0.004	0.054	0.173	0.007	0.002
	95 ^{o}%	0.006	0.019	0.029	0.063	0.248	0.024	0.104
	n	33	33	32	32	32	32	31
OS13 Neusberg (D7H016) (2003-2007)	Mean	0.005	0.016	0.015	0.051	0.177	0.014	0.015
	Min	0.001	0.001	0.000	0.000	0.102	0.003	0.002
	Max	0.046	0.019	0.104	0.063	0.281	0.090	0.232
	Median	0.001	0.016	0.006	0.054	0.165	0.011	0.007
	95 ^{o}%	0.006	0.019	0.040	0.063	0.239	0.035	0.023
	n	25	25	25	25	25	25	25
OS15 Pella (D8H008) (2003-2007)	Mean	0.002	0.014	0.005	0.098	0.193	0.006	0.003
	Min	0.001	0.004	0.004	0.002	0.111	0.003	0.002
	Max	0.011	0.016	0.008	0.500	0.268	0.013	0.007
	Median	0.001	0.016	0.004	0.054	0.188	0.003	0.002
	95 ^{o}%	0.005	0.016	0.008	0.341	0.259	0.013	0.005
	n	20	20	20	20	20	20	20
OS16 Vioolsdrift (D8H003) (1965-2007)	Mean	0.004	0.020	0.011	0.056	0.179	0.014	0.004
	Min	0.001	0.016	0.004	0.054	0.001	0.003	0.002
	Max	0.088	0.063	0.046	0.120	0.289	0.046	0.047
	Median	0.001	0.016	0.004	0.054	0.201	0.009	0.002
	95 ^{o}%	0.004	0.045	0.044	0.054	0.276	0.037	0.010
	n	35	35	35	35	35	35	35
OS18 Brand Kaross (D3H007) (1980-2002)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–
OS19 Alexander Bay (D8H0012) (1995-2003)	Mean	–	–	–	–	–	–	–
	Min	–	–	–	–	–	–	–
	Max	–	–	–	–	–	–	–
	Median	–	–	–	–	–	–	–
	95 ^{o}%	–	–	–	–	–	–	–
	n	–	–	–	–	–	–	–

Table C13: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on Orange River tributaries (level 2).

Site	Stats	EC (mS/m)	DMS (mg/ℓ)	TAL (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)
OSL2/1 Kornetspruit (D1H006) (1975-2007)	Mean	19.87	155.30	82.86	21.05	7.59	6.39	1.27
	Min	8.80	60.00	16.80	8.30	3.00	1.00	0.15
	Max	78.50	625.00	260.00	42.70	40.60	78.60	11.44
	Median	19.50	152.00	81.37	20.80	7.31	5.90	1.04
	95 ^{o}%	28.68	224.70	127.11	31.25	11.49	9.25	2.52
	N	804	594	615	612	612	612	612
OSL2/3 Kraai River (D1H011) (1967-2007)	Mean	23.25	185.30	102.89	24.08	10.16	7.09	1.13
	Min	7.80	80.00	32.20	7.40	1.50	1.00	0.15
	Max	104.00	654.00	296.00	55.50	42.90	80.70	7.72
	Median	22.90	181.00	102.30	24.20	9.72	6.49	0.96
	95 ^{o}%	34.5	276.9	158.24	36.28	16.68	11.28	2.222
	N	741	455	507	505	504	505	500
OSL2/4 Stormbergspruit (D1H001) (1975-2007)	Mean	66.99	539.98	234.90	43.97	32.62	55.40	5.18
	Min	3.20	100.00	46.50	11.40	4.60	1.00	0.31
	Max	141.00	1012.00	409.00	86.10	72.00	148.80	17.68
	Median	69.20	553.22	241.70	44.30	34.10	54.50	4.18
	95 ^{o}%	103.69	812.55	337.20	64.17	52.60	100.32	11.96
	N	843	710	738	726	729	729	728
OS4L2/5 Seekoei River (D3H015) (1981-2007)	Mean	82.41	621.65	249.31	34.43	39.24	88.51	3.69
	Min	12.60	89.00	27.10	12.40	4.90	4.70	1.26
	Max	245.00	1856.00	662.40	76.10	123.70	371.30	25.31
	Median	80.50	626.00	263.20	33.80	39.70	78.50	3.37
	95 ^{o}%	145.00	1058.05	399.96	54.20	70.80	167.38	5.56
	N	368	340	343	341	341	342	341

Table C14: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on tributaries of the Orange River (level 2).

Site	Stats	SO_4 (mg/ℓ)	Cl (mg/ℓ)	F (mg/ℓ)	pH	Hard (mg/ℓ)	SAR	CORR
OSL2/1 Kornetspruit (D1H006) (1975-2007)	Mean	10.18	4.67	0.172	7.77	83.60	0.31	0.25
	Min	2.00	1.50	0.05	6.00	39.66	0.09	0.11
	Max	70.50	53.00	0.94	9.13	143.77	2.13	0.57
	Median	10.10	4.49	0.15	7.88	84.89	0.28	0.23
	95 ^{o}%	17.00	8.50	0.360	8.38	114.83	0.46	0.41
	n	611	611	612	649	135	602	134
OSL2/3 Kraai River (D1H011) (1967-2007)	Mean	9.01	5.16	0.16	7.87	107.73	0.30	0.19
	Min	2.00	1.50	0.05	6.30	47.57	0.10	0.08
	Max	75.80	65.60	0.64	9.16	177.53	2.10	0.49
	Median	8.84	4.80	0.14	7.99	107.94	0.28	0.16
	95 ^{o}%	14.8	9.28	0.338	8.50	157.60	0.45	0.33
	n	505	505	505	522	67	499	67
OSL2/4 Stormberg-spruit (D1H001) (1975-2007)	Mean	55.47	43.40	0.411	8.30	233.91	1.50	0.31
	Min	2.00	1.50	0.050	6.08	61.50	0.05	0.13
	Max	197.30	147.60	1.310	10.03	381.83	3.61	0.60
	Median	53.20	37.80	0.400	8.30	244.44	1.48	0.29
	95 ^{o}%	113.30	99.06	0.600	9.08	363.59	2.46	0.48
	n	729	729	729	775	53	718	53
OS4L2/5 Seekoei River (D3H015) (1981-2007)	Mean	64.36	84.61	0.58	8.22	237.04	2.31	0.37
	Min	2.00	1.50	0.05	6.07	77.63	0.27	0.20
	Max	211.40	350.90	1.17	9.20	363.31	6.89	0.59
	Median	61.85	75.40	0.58	8.30	249.55	2.21	0.36
	95 ^{o}%	128.42	175.40	1.000	9.00	355.26	3.96	0.55
	n	342	341	341	366	31	341	31

Table C15: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on tributaries of the Orange River (level 2).

Site	Stats	Flow (m^3/s)	NO_3-N (mg/ℓ)	NH_4-N (mg/ℓ)	DIN (mg/ℓ)	KJel-N (mg/ℓ)	TN (mg/ℓ)	OC (mg/ℓ)
OSL2/1 Kornetspruit (D1H006) (1975-2007)	Mean	18.5	0.382	0.072	0.428	–	–	–
	Min	0.06	0.020	0.015	0.015	–	–	–
	Max	152.0	10.321	10.530	10.346	–	–	–
	Median	9.27	0.275	0.020	0.308	–	–	–
	95 °%	70.14	0.924	0.112	0.980	–	–	–
	n	598*	614	595	683	–	–	–
OSL2/3 Kraai River (D1H011) (1967-2007)	Mean	20.69	0.13	0.046	0.136	0.48	0.55	–
	Min	0.00	0.02	0.015	0.040	0.05	0.09	–
	Max	215.10	9.23	1.386	9.292	1.78	1.82	–
	Median	7.97	0.02	0.020	0.070	0.33	0.38	–
	95 °%	85.38	0.346	0.103	0.255	1.220	1.29	–
	n	495*2	505	456	456	21	20	–
OSL2/4 Stormberg-spruit (D1H001) (1975-2007)	Mean	1.21	2.185	0.101	2.330	0.98	1.25	46.43
	Min	0.00	0.020	0.015	0.020	0.16	0.26	0.10
	Max	55.80	25.517	4.963	25.537	2.50	24.89	210.07
	Median	0.13	0.320	0.050	0.400	0.84	1.02	44.87
	95 °%	6.29	10.823	0.276	11.024	1.853	2.19	76.107
	n	1124*3	739	711	723	156	156	147
OS4L2/5 Seekoei River (D3H015) (1976-2007)	Mean	0.51	0.175	0.882	1.059	1.34	1.68	59.14
	Min	0.00	0.020	0.020	0.040	0.20	0.22	0.10
	Max	28.40	26.540	55.400	55.420	56.00	56.00	385.56
	Median	0.00	0.020	0.050	0.090	0.72	0.79	46.90
	95 °%	1.93	0.349	0.237	0.865	1.47	1.74	152.770
	n	324*4	344	339	339	103	103	94

* (1950 -2007); *2 (1966 – 2007); *3 (1913 – 2007); *4 (1981 – 2007)

Table C16: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on tributaries of the Orange River (level 2).

Site	Stats	TSS (mg/ℓ)	Turb (NTU)	Si (mg/ℓ)	DIP (mg/ℓ)	TP (mg/ℓ)	DIN:DIP	Chl-a (µg/ℓ)
OSL2/1 Kornetspruit (D1H006) (1975-2007)	Mean	**1582.3**	**168.46**	**9.32**	0.058	–	26.9	–
	Min	**2.50**	**0.50**	**0.80**	0.003	–	0.2	–
	Max	**14999.0**	**3686.00**	**13.99**	5.493	–	413.8	–
	Median	**109.0**	**20.00**	**9.33**	0.026	–	11.9	–
	95 °%	**5972.3**	**866.00**	**11.80**	0.103	–	98.9	–
	n	**39**	**256**	**596**	612	–	502	–
OSL2/3 Kraai River (D1H011) (1967-2007)	Mean	452.05	47.58	9.11	0.039	–	–	–
	Min	2.50	0.50	0.64	0.003	–	–	–
	Max	8824.00	1664.00	14.79	2.097	–	–	–
	Median	74.50	7.00	9.12	0.022	–	–	–
	95 °%	2105.75	197.6	11.82	0.085	–	–	–
	n	174	193	456	508	–	–	–
OSL2/4 Stormberg-spruit (D1H001) (1975-2007)	Mean	**3721.3**	**236.60**	**4.16**	0.367	0.159	15.5	–
	Min	**67.0**	**7.00**	**0.20**	0.003	0.003	0.01	–
	Max	**9160.0**	**857.00**	**10.53**	4.362	1.740	558.1	–
	Median	**1937.0**	**58.00**	**4.28**	0.072	0.106	5.6	–
	95 °%	**8437.7**	**734.80**	**7.64**	1.527	0.465	43.3	–
	n	**3**	**5**	**711**	728	156	709	–
OS4L2/5 Seekoei River (D3H015) (1976-2007)	Mean	–	**11.84**	**3.71**	0.160	–	–	–
	Min	–	**0.50**	**0.20**	0.003	–	–	–
	Max	–	**86.00**	**12.97**	6.531	–	–	–
	Median	–	**3.00**	**3.55**	0.028	–	–	–
	95 °%	–	**49.99**	**7.40**	0.007	–	–	–
	n	–	**44**	**341**	343	–	–	–

Table C17: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Caledon River and Little Caledon River.

Site	Stats	EC (mS/m)	DMS (mg/ℓ)	TAL (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)
CS2 Ficksburg (D2H035) **(1994-2007)**	Mean	**20.60**	**164.69**	**89.43**	**20.76**	**8.08**	**6.96**	**1.71**
	Min	**8.40**	**68.00**	**29.00**	**6.60**	**2.60**	**2.70**	**0.68**
	Max	**56.10**	**422.01**	**202.02**	**47.17**	**22.81**	**53.16**	**9.42**
	Median	**19.70**	**154.23**	**83.30**	**19.80**	**7.20**	**6.40**	**1.39**
	95 °%	**33.130**	**264.20**	**153.65**	**34.69**	**14.59**	**10.46**	**2.94**
	n	**295**	**295**	**295**	**295**	**293**	**295**	**295**
CS5 Kommissie-drift (D2H036) (1993-2007)	Mean	**23.70**	**186.50**	**99.13**	**21.76**	**8.97**	**10.67**	**2.22**
	Min	**10.80**	**86.00**	**32.70**	**7.30**	**2.80**	**3.80**	**0.97**
	Max	**59.00**	**490.73**	**270.99**	**50.10**	**34.80**	**40.09**	**5.71**
	Median	**20.90**	**161.00**	**85.68**	**19.54**	**7.30**	**8.70**	**2.00**
	95 °%	**46.780**	**379.12**	**210.93**	**38.98**	**23.25**	**23.29**	**3.75**
	n	**213**	**212**	**212**	**212**	**212**	**212**	**212**
CSL2/1 Little Caledon at the Poplars (D2H012) (1972-2007)	Mean	**32.33**	**257.96**	**145.00**	**33.48**	**14.02**	**11.56**	**1.82**
	Min	**7.00**	**79**	**28.90**	**7.50**	**3.00**	**3.60**	**0.15**
	Max	**59.00**	**415**	**246.50**	**56.50**	**23.07**	**21.90**	**5.00**
	Median	**32.10**	**251.21**	**143.20**	**33.70**	**13.60**	**11.10**	**1.64**
	95 °%	**44.900**	**375.70**	**216.20**	**48.47**	**21.60**	**18.72**	**3.33**
	n	**509**	**334**	**347**	**347**	**347**	**347**	**345**

Table C18: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Caledon River and Little Caledon River.

Site	Stats	SO_4 (mg/ℓ)	Cl (mg/ℓ)	F (mg/ℓ)	pH	Tot-Hard (mg/ℓ)	SAR	CORR
CS2 Ficksburg (D2H035) (1994-2007)	Mean	**11.85**	**4.64**	**0.16**	**8.03**	**93.29**	**0.33**	**0.24**
	Min	**2.00**	**1.50**	**0.05**	**6.77**	**37.98**	**0.17**	**0.10**
	Max	**38.10**	**43.13**	**0.53**	**8.54**	**211.72**	**1.86**	**0.65**
	Median	**11.62**	**4.50**	**0.15**	**8.11**	**84.55**	**0.32**	**0.21**
	95 ^{o}%	**17.38**	**6.43**	**0.320**	**8.432**	**154.06**	**0.43**	**0.48**
	N	**295**	**295**	**295**	**294**	**63**	**282**	**63**
CS5 Kommissie-drift (D2H036) (1993-2007)	Mean	**13.82**	**6.01**	**0.237**	**8.04**	**94.00**	**0.47**	**0.27**
	Min	**4.60**	**1.50**	**0.120**	**7.00**	**41.83**	**0.26**	**0.10**
	Max	**40.10**	**22.10**	**0.610**	**8.69**	**223.96**	**1.17**	**0.63**
	Median	**12.90**	**5.00**	**0.220**	**8.10**	**84.03**	**0.43**	**0.25**
	95 ^{o}%	**23.40**	**12.14**	**0.382**	**8.48**	**199.72**	**0.79**	**0.47**
	N	**211**	**212**	**212**	**213**	**90**	**200**	**90**
CSL2/1 Little Caledon at the Poplars (D2H012) (1972-2007)	Mean	**12.84**	**5.11**	**0.158**	**7.87**	**132.48**	**0.42**	**0.19**
	Min	**2.00**	**1.50**	**0.050**	**5.89**	**54.86**	**0.15**	**0.08**
	Max	**37.60**	**28.20**	**2.800**	**8.81**	**218.57**	**0.98**	**0.43**
	Median	**13.10**	**5.00**	**0.140**	**7.9**	**132.47**	**0.41**	**0.17**
	95 ^{o}%	**21.07**	**10.09**	**0.307**	**8.47**	**198.49**	**0.59**	**0.30**
	N	**347**	**347**	**347**	**349**	**65**	**346**	**65**

Table C19: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Caledon and Little Caledon River.

Site	Stats	Flow (m^3/s)	NO_3-N (mg/ℓ)	NH_4-N (mg/ℓ)	DIN (mg/ℓ)	KJel-N (mg/ℓ)	OC (mg/ℓ)
CS2 Ficksburg (D2H035) (1994-2007)	Mean	17.71	0.294	0.028	0.323	–	–
	Min	0.00	0.020	0.015	0.040	–	–
	Max	130.50	1.290	0.198	1.310	–	–
	Media	7.59	0.238	0.020	0.266	–	–
	95 °%	63.34	0.899	0.072	0.921	–	–
	n	178	294	294	294	–	–
CS5 Kommissie-drift (D2H036) (1993-2007)	Mean	–	0.383	0.042	0.438	–	–
	Min	–	0.020	0.015	0.040	–	–
	Max	–	1.163	0.360	1.465	–	–
	Media	–	0.371	0.020	0.422	–	–
	95 °%	–	0.954	0.095	0.992	–	–
	n	–	213	213	166	–	–
CSL2/1 Little Caledon at the Poplars (D2H012) (1972-2007)	Mean	0.97	0.094	0.049	0.144	–	–
	Min	0.00	0.020	0.015	0.040	–	–
	Max	6.80	1.380	1.209	1.490	–	–
	Media	0.42	0.040	0.020	0.088	–	–
	95 °%	3.56	0.429	0.120	0.530	–	–
	n	447*	343	336	333	–	–

* (1970 – 2007)

Table C20: Summary of statistical data of all the historical chemical values available on the DWAF database at the different monitoring sites on the Caledon and Little Caledon River.

Site	Stats	TSS (mg/ℓ)	Turb (NTU)	Si (mg/ℓ)	DIP (mg/ℓ)	TP (mg/ℓ)	DIN:DIP	Chl-a (µg/ℓ)
CS2	Mean	–	**78.17**	**7.53**	**0.033**	–	**11.9**	–
Ficksburg	Min	–	**0.50**	**2.86**	**0.003**	–	**0.5**	–
(D2H035)	Max	–	**1100.00**	**13.13**	**0.253**	–	**75.7**	–
	Median	–	**11.80**	**7.43**	**0.029**	–	**8.0**	–
(1994-2007)	95 °%	–	**283.00**	**10.04**	**0.069**	–	**36.7**	–
	n	–	**36**	**295**	**295**	–	**294**	–
CS5	Mean	–	**400.4**	**5.66**	**0.042**	–	**14.6**	–
Kommissie-	Min	–	**0.5**	**0.20**	**0.006**	–	**0.2**	–
drift	Max	–	**10000.0**	**10.80**	**0.557**	–	**128.7**	–
(D2H036)	Median	–	**89.7**	**5.84**	**0.033**	–	**10.4**	–
(1993-2007)	95 °%	–	**1495.3**	**8.10**	**0.085**	–	**38.6**	–
	n	–	**195**	**213**	**213**	–	**143**	–
CSL2/1	Mean	–	**14.96**	**10.15**	**0.035**	–	**8.0**	–
Little	Min	–	**0.50**	**0.86**	**0.003**	–	**0.4**	–
Caledon at	Max	–	**222.00**	**15.71**	**0.244**	–	**236.7**	–
the Poplars	Median	–	**3.22**	**10.65**	**0.025**	–	**3.5**	–
(D2H012)	95 °%	–	**54.14**	**13.14**	**0.103**	–	**24.8**	–
(1975-2007)	n	–	**45***	**334**	**344**	–	**332**	–

* (2000 – 2007)