AN OVERVIEW OF SURFACE WATER QUALITY IN THE OLIFANTS RIVER CATCHMENT

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

The Olifants River is one of South Africa's major river systems and is an important tributary to the Limpopo River and is recognized as one of the "hardest working rivers" in South Africa. The demands for water for industry, mining, power generation, agriculture and domestic use have increased steadily over the years, exceeding the rate of population growth, and have been accompanied by large increases in the quantity of effluents that are discharged to the river system and its tributaries. The seasonal and inter-annual extremes of river flow, combined with the steady decline in water quality have increased the vulnerability of all the aquatic ecosystems in the catchment, while also increasing the vulnerability of the people who rely on the water resources of this river system for their lives and livelihoods.

The discharge of treated, partly treated and untreated effluents from mines, industries and sewage treatment plants, combined with seepage of acidic mine drainage from several active and abandoned coal mines in the upper reaches, contribute nutrients, salts and metal ions and microbial contaminants to the river system. Steadily rising nutrient concentrations indicate that water storage reservoirs are becoming increasingly eutrophied, and increased concentrations of aluminium and iron are often above those suggested in national water quality guidelines. Blooms of the toxic cyanobacterium *Microcystis aeruginosa* in Lake Loskop are thought to be responsible for recent fish kills and human users of water from this reservoir also face risks to health. The water quality situation in the lower Olifants River recently received considerable public attention when over 170 crocodiles were reported dead inside the KNP and the crocodile population in the upper reaches of the catchment has also declined.

The need for this study arose during discussions between the Water Research Commission and CSIR's Natural Resources and the Environment business unit. It was clear that while a lot of information was available on water quality issues across the Olifants River catchment, much of this information was contained in a variety of confidential project-specific documents, consultancy reports, theses and published papers. An important additional consideration was the need to evaluate the implications of so-called "emerging pollutants", including organic compounds, pharmaceuticals, endocrine disrupting compounds and even nano-sized materials, as potential health risks to humans, livestock and aquatic biota. This study provides an overview of our existing knowledge on the water quality in the Olifants River catchment and the likely sources of poor water quality, outlines the potential risks that these substances pose to all water users and the aquatic ecosystems, and highlights the need for targeted research and urgent remedial actions.

This study collated and evaluated the available water quality data as a basis for an overview of water quality across the entire Olifants River catchment and has also identified many of the likely sources or causes of poor water quality. This will enable water resource decision-makers in central, provincial and local government, industry and agriculture to define those areas that require priority attention and urgent remediation. In addition, the information also provides a scientifically defensible rationale for developing and implementing measures to improve land use practices across the catchment, as well as a basis for working with counterpart authorities in Mozambique. The ultimate beneficiaries of the recommendations presented in this study will be the aquatic ecosystems within the Olifants River catchment, as well as every person in the catchment that relies on good quality water for their lives and livelihoods.

This study focussed on the quality characteristics of the surface waters present in the Olifants catchment and has compiled a wealth of detail on the seasonal and inter-annual variations in water quality and the trends of change in water quality. There has been a progressive decline in water quality along the main stem of the Olifants River and in several important tributaries over the last twenty years. While the water quality data and indices

provide clear indications as to the type of land-use activity that has contributed to this poor water quality, it is important to emphasize that the available data are not sufficient to allow a precise determination to be made as to the specific source of a particular contaminant. Therefore, it is important to understand the implications of the wording in the ***Caveat*** presented below.

CAVEAT

It is important to stress a ***Caveat*** to readers of this report in relation to the interpretation of general statements that attribute the causes of poor water quality to past and / or current mining activities in the different portions of the Olifants catchment. The numerous mines in the catchment range from large to small operations – of different ages – and employ a range of different mining techniques, while their respective operating companies have widely differing economic resources at their disposal. Many of the older mines – particularly coal mines in the upper portion of the Olifants catchment – have been worked out and abandoned; custodial responsibility for these mines now rests with the National Government. All mines that are still operating with valid mining permits and water use licences are responsible for controlling their water use and for the quality of any effluent that may seep out of or be discharged from their properties. Several mines are known to operate highly effective pollution control systems and it is likely that these mines would contribute very little in the way of "problematic" water quality constituents. In contrast, some other mines - including abandoned mines - appear not to have effective pollution control measures in place. Therefore, while it is definitely possible to link instances of certain water quality variables (*e.g.* low pH values or high concentrations of sulphate, total dissolved salts and some metal ions) to the broad category of causes that are labelled "mining activities", we do not have the fine-scale, more detailed data that would allow us to indicate which specific mines or mining operations are responsible for specific cases of water quality problems in particular rivers. This issue can only be resolved by obtaining a much more detailed data set from those rivers where mining activities appear to be responsible for water quality problems. These data would allow a clear distinction to be made between the mines and mining operations that are effectively managed from those where additional or more stringent management efforts and interventions are required.

It is equally important to stress that the broad-scale of the analysis conducted in this study could not provide information at a sufficiently fine scale of resolution that would allow definition of the specific industries, wastewater treatment works or areas and types of farming operations that are responsible for specific water quality constituents or for specific water quality problems. This finer level of detail will require more detailed studies in specific sub-catchments to determine which specific land-use activities are responsible for particular types of water quality problems. This information can then be used to design customized solutions to each specific problem.

Our evaluation of the water quality data collected by the DWA routine water quality monitoring programme for the Olifants River system revealed several short-comings of this programme. In particular, the relatively high proportion of samples with unreliable analyses represents a significant waste of scarce time, money and human resources. A related issue was the finding that the elapsed time between sequential samples was often very long with almost half of the DWA sampling sites having a sampling interval of 50 days or more. This makes it difficult to properly interpret changes in water quality and hampers the formulation and implementation of remedial actions.

While the DWA routine water quality monitoring programme has been structured to provide a balance between effective evaluation of water quality and the costs of collecting, analyzing and processing the data, relatively few water quality variables are measured routinely. These few variables are not sufficient to provide a clear and unambiguous 'picture' of all the changes in water quality. The routine water quality monitoring programme needs to be expanded to include trace metals, pesticides, organic compounds, microbial contaminants and suspended sediments to ensure that these can provide a more accurate assessment of the potential health risks associated with poor water quality.

The practice of reporting or relying on mean or median values as a measure of the water quality status at a particular site should be discontinued as soon as possible, because these values on their own are meaningless. All water quality monitoring reports should include the percentile analysis of the data and a comparison of the percentile data with specific limits for each water quality variable. In addition, time series analyses should be used to illustrate trends of change and times of the year when water quality worsens.

Every local authority, industry, institution or commercial farming operation that has been granted a water use licence and an effluent discharge licence by the Department of Water Affairs (DWA) is required to submit regular reports to DWA on the quantity of water used and quantity and quality of effluent discharged. These reports and their associated monitoring and audit data are often considered to be ‘confidential’ or ‘commercial in confidence’ and the information in these reports was not available for examination. These data would have helped to provide a much clearer ‘picture’ of the water quality status in the catchment and would also have enabled specific effluent dischargers to be identified and prioritized for actions designed to improve the treatment of their effluents.

Very few data are available on the concentrations of trace metals that are present in the Olifants system. Many of these metal ions pose important health risks to humans, livestock and aquatic biota. It is therefore important to determine the precise sources of these metals and the quantities involved so that appropriate management actions can be taken to improve water quality across the catchment. In this regard, it is important that the Department of Water Affairs review and revise the existing sets of water quality guidelines so that these provide more useful guidance to regulators.

While the primary source area for a large proportion of the suspended sediments that enter the Olifants River has been known for several years, no corrective actions have been taken to date. Given the likelihood that the suspended sediments are likely to be linked to fish kills and crocodile deaths in the lower Olifants River, it is essential that suitable actions are taken to reduce the entry of these sediments into the river system.

Some independent studies have revealed the presence of unacceptably high numbers of faecal bacteria and pathogenic organisms in some of the tributary rivers in the upper Olifants catchment. These data indicate clearly that at least some of the wastewater treatment works are not functioning properly and need to be rehabilitated. Rural communities and single households that may draw their water directly from the river seldom have access to sufficient resources to allow them to treat the water before use, and are therefore at greatest risk from these contaminants. The Department of Water Affairs needs urgently to work with the local authorities and institutions that are responsible for operating wastewater treatment works and bring all these works back to full operational efficiency.

The few data available on the chemistry of rainwater samples collected in the upper Olifants catchment reveal that most rainwater samples are sufficiently acidic to be classed as ‘acid rain’. This acidic rainfall has the definite potential to acidify soils and also to influence the productivity of croplands in areas where this rain falls. There is an urgent need to understand the full extent and implications of the acidic deposition across the upper Olifants catchment and to work with those institutions responsible for the source emissions to find cost-effective ways to reduce these emissions. In addition, the Departments of Agriculture and Water Affairs need to work closely with the farming community to devise and apply the most cost-effective solutions to counter increased soil acidity.

The available water quality data indicate that significant acidic mine drainage with its associated low pH values and elevated concentrations of sulphate and other dissolved salts and metal ions has been present in some tributary streams and rivers in the upper reaches of the Olifants catchment for at least the last 25 years. In some instances, there are clear indications that the situation has worsened in recent years. Remedial management attention should be directed to identifying the specific sources of the contaminants that enter these rivers and then working with the operators of these mining activities and associated industries to rectify the problems. In addition, the presence of elevated concentrations of aluminium in several tributary streams and in Lake Loskop suggests that there is a need to understand the speciation chemistry of aluminium in river and reservoir waters that receive acidic mine drainage so that a fuller assessment can be made of the potential health risks of this aluminium to humans, aquatic biota and livestock, as well as the implications for the design and operation of water and wastewater treatment works.

The precise sources of the elevated nutrient (N and P) concentrations recorded for most of the streams and rivers in the Olifants catchment are not easy to identify. While there is clear evidence that significant proportions of these nutrients are derived from non-functional or improperly operated wastewater treatment works, return flows from irrigated agriculture also contribute nutrients to the river system. The combination of nutrients from wastewater treatment works and agricultural sources has resulted in high to very high nutrient concentrations in every tributary river in the Olifants catchment. This has led to the progressive accumulation of nutrients in reservoirs such as Lake Loskop and has resulted in the development of extensive blooms of potentially toxic cyanobacteria. The toxins produced by these organisms are known to persist in water for relatively long periods of time and are not removed or eliminated in conventional secondary water treatment processes. This situation should not be allowed to continue and the Department of Water Affairs must work with local authorities and agricultural organizations to prevent further eutrophication of the rivers in the catchment, and enforce the existing policies and statutes to ensure that the current situation can be reversed.

Perhaps the most worrying issue related to the water quality data for the Olifants catchment is what appears to be an apparent absence of effective management actions to deal with easily identifiable situations where water quality has been compromised. This suggests that the officials and water resource managers who are responsible for water quality management are not receiving the correct information. If this is true, then it indicates a breakdown of the monitoring process, which includes every aspect from sample collection, analysis and interpretation to remedial management response and checking. This situation suggests that there is a need to review the ways in which water resource managers interpret water quality data and information, and – if necessary – change these processes so that there is a clear and direct link between the appearance of poor water quality and a carefully considered and targeted management response.

The data analyzed in this study revealed that impacts of acidic mine drainage in some tributary rivers has progressively worsened over time. In the case of the Spookspruit and Klein Olifants River, this deterioration has continued unabated since at least 1990. Despite some management attention having been directed towards the Klipspruit in the form of treating a portion of the acidic seepage in this river, the quality of the water in the Klipspruit has continued to decline.

Similar trends of worsening water quality occur in Lakes Witbank and Loskop. In Lake Loskop, the deterioration in water quality has continued unabated since at least 1975. Because water storage reservoirs retain and accumulate a proportion of their inflowing loads of salts, nutrients and sediments, the quality of the water in these reservoirs will continue to deteriorate if there is no improvement to the water quality of their inflowing rivers. However, even if the inflowing water quality is dramatically improved, it will take a period of time equal to approximately 5-7 times the water residence time in the lake for the lake to reach a new equilibrium and for the full benefits of the improvement to be visible. Another important consideration is that while water quality deteriorates during the drier winter months, the coincidence of this worsening water quality with low water temperatures accentuates the adverse effects on aquatic organisms at this time.

The available data on temporal trends in water quality do not appear to have prompted sufficient meaningful and effective remedial management responses. Praise-worthy small-scale efforts such as the treatment of some acid mine drainage in the Brugspruit are simply too small to deal with the scale of the water quality problems in the catchment.

Many of the characteristics of poor water quality are present to varying degrees along the length of the Olifants River – a situation that is shared by several other South African rivers. While there is a gradual improvement in water quality with increasing distance down the Olifants River, tributary inputs of untreated or incompletely treated domestic effluent, as well as industrial and mining effluents, plus return flows from irrigated lands, ensure that the water quality remains poor. In the lower reaches of the Olifants River, the contribution of the Ga-Selati River maintains poor water quality in the lower reaches of the Olifants River.

There is clear evidence that several wastewater treatment works in the upper reaches of the Olifants catchment are either not operating effectively or large volumes of sewage effluent are leaking / being discharged directly into the rivers. The combination of poorly treated or untreated sewage effluent with acidic mine drainage accentuates the poor water quality already present in the Klipspruit, and eventually contributes to the progressively worsening water quality in Lake Loskop. In some tributary rivers, the presence of endocrine disrupting compounds (EDCs) and both pharmaceutical and veterinary antibiotics poses health risks to all users and could promote development of antibiotic resistance in certain microorganisms.

This overview of the changes in water quality along the length of the Olifants River shows that while some of the sampling sites in the lower reaches of the Olifants River had relatively good water quality (compared to upstream sites), these sites also experienced periodic worsening of water quality. The water quality of the Great Letaba and Shingwidzi rivers appear to contribute relatively few salts, nutrients and metal ions to the lower reaches of the Olifants River. The periodic cessation of flow in both of these rivers also reduces the size and importance of their contributions to water quality in the lower Olifants River.

The spatial trends in water quality across the Olifants catchment reveal that numerous sources of different contaminants are contributing to the overall water quality situation. The apparent absence of any meaningful or sustained improvements in water quality across the catchment suggests that whatever management actions may have been taken to date have not been fully effective. The Department of Water Affairs is in the process of completing the compilation and implementation of an integrated water resource management plan for the upper and middle reaches of the Olifants River catchment. This welcome development will need to be fully embraced by all stakeholders in the catchment if it is to succeed.

The continued inflow of poor quality water from the South African portion of the Olifants River into Mozambique would appear to contravene some of the provisions in the revised SADC Water Protocol. While this Protocol does not deal specifically with water quality issues, it requires all signatory Parties to ensure that their water use in a shared river basin does not cause appreciable harm to a neighbouring country. In effect, the provisions of the SADC Water Protocol appear to carry greater weight than, and thereby over-ride, the provisions of earlier bilateral agreements and treaties between countries.

If poor quality water continues to flow into Mozambique from South Africa, and water quality continues to deteriorate further over time, this is likely to contravene to the content and intent of the revised SADC Water Protocol and could give rise to future claims for compensation from Mozambique. While it is clear that this situation should be halted and reversed as quickly as possible, this will require a far greater emphasis on effective water quality management across the entire Olifants catchment. In turn, this will require a far closer association with, and continuous co-operation between, water resource managers, local authorities, industries and land-owners at all levels. All stakeholders will need to be involved in the process and everyone will need to contribute to solving the many problems linked to or caused by the catchment's poor water quality.

This study has exposed several areas where the available data and information are not sufficient to provide a clear and unambiguous assessment of many of the causes of poor water quality in the Olifants River catchment. A summary of the most important research needs to resolve these problems include investigations aimed at defining the extent and exact sources of critical pollutants and contaminants, followed by their control or remediation. The suggested research topics include:

- Evaluate the effluent quality data that are currently considered to be 'confidential' or 'commercial in confidence' to determine which industries, institutions, local authorities or landowners need to be prioritized in terms of urgent remedial treatment of their effluents;
- Review and revise the current DWA water quality monitoring programmes so that they include trace metals, bacteria and other microbial organisms, organic compounds and suspended sediment evaluations;
- Develop and enforce effective resource quality objectives (RQOs) for each river reach in the Olifants River catchment;
- Find ways to strengthen and enhance the abilities of water user groups such as the Olifants River Forum (ORF) so that their efforts to improve the water quality situation in the catchment are more likely to succeed;
- Develop and refine ways to streamline some of the management approaches (such as the resource classification system which is presently cumbersome to use and often deters potential applications) so that water quality management approaches can be less time-consuming and more cost-effective;
- Review and if necessary revise the chemical composition conditions of all effluent discharge licences issued to effluent dischargers in the Olifants River catchment;
- Determine the longevity in natural aquatic systems of the microbial contaminants indicative of domestic sewage pollution and the implications of this for water users located downstream of points where these organisms originate;
- Define the types, extent, exact sources and implications of endocrine disrupting compounds (EDCs, including pharmaceutical and veterinary antibiotics) and other new and emerging pollutants such as nano-sized particles;
- Pin-point the sources, followed by determination of their character and extent, of acidic drainage from operating and abandoned mines and devise or compile suitable options to control and minimize these;
- Define the exact sources of pathogenic organisms (especially *Cryptosporidium* and *Giardia*) and the most suitable treatment or preventative processes to stop the input of these organisms to the aquatic systems;
- Accurately quantify the extent to which water storage reservoirs are retaining salts, nutrients and sediments, the conditions under which this happens, the factors that control the rates of retention and transfer between sediments and water, and the implications of the retained loads for water quality in these reservoirs;
- Accurately quantify the extent to which coal-fired power plants and heavy industries are contributing atmospheric emissions that contain potentially acidic materials to the catchment and identify the most appropriate treatment and preventative processes to minimize the impacts of these substances on aquatic systems and cultivated areas;
- Identify which trace metals originate from which type of mining or industrial activity and specify how best to prevent the entry of these trace metals into the aquatic systems;
- Evaluate alternative mining methods for coal mines in the upper catchment that would allow proper exploitation of the available reserves whilst minimizing the generation of acid mine drainage from their associated pyrite deposits;
- Implement a monitoring system to conduct routine evaluations of the presence and toxicity of cyanobacteria in reservoirs and selected river sites in the catchment;

- Evaluate simple water treatment systems for small communities and possibly also for single households that would allow individuals to obtain reliable supplies of wholesome water for domestic use and reduce their health risks;
- Gauge the extent to which "Payments for Ecosystem Services" (PES) approaches could be used as a mechanism to improve water quality across the Olifants River catchment and, if found to be economically feasible, how best to implement such approaches;
- Confirm and quantify the exact origins of the suspended sediments present in the Olifants River and determine when and where these sediments are transported and settled out;
- Quantify the extent to which trace metals and other contaminants are associated with suspended sediments and evaluate their implications for water quality, aquatic biota and water treatment processes;
- Review the existing water treaties and agreements between Mozambique and South Africa to determine if there are mechanisms that can be incorporated to strengthen their applicability to water quality management for the benefit of both countries;
- Investigate the most cost-effective technical solution for treating water that contains cyanobacterial toxins so that the water is both affordable to consumers and safe for use;
- Determine those aspects of the speciation chemistry of aluminium associated with waters that receive acidic mine drainage and the implications of this for aquatic biota, human health and the design and operation of water treatment systems;
- Evaluate the full implications of introducing phosphorus-free detergents for domestic use on the effectiveness and efficiency of wastewater treatment works, and the resulting reduction in phosphorus loads entering rivers in the Olifants catchment;
- Determine what remedial techniques and technologies could be deployed to successfully improve water quality in water storage reservoirs;
- Compile a comprehensive water quality management plan for the Olifants River catchment to complement the DWA integrated water resource management plan for the catchment;
- Assess the extent to which passive water treatment systems such as natural and man-made wetland systems could be used to improve water quality, and evaluate the implications of seasonal changes in climatic factors and inflowing loads on the functioning of these systems;
- Determine the extent to which nutrients derived from livestock are influencing water quality in the Olifants catchment and derive effective land management options to prevent this source of nutrients from entering the river systems;
- Determine the exact water quality conditions and components that are implicated in the pansteatitis incidents amongst fish and crocodiles;
- Determine the most appropriate options for treating acidic mine drainage to a state where it can safely be used over the long-term for alternative uses such as irrigation;
- Develop and implement suitable operating procedures for the Phalaborwa Barrage and other water storage reservoirs to reduce the quantity of sediments released to downstream river sections; and
- Review and revise the existing sets of water quality guidelines, expanding these to include inorganic and organic substances where no guideline exists.

This list of research needs reflects the extent to which our collective knowledge and understanding of the Olifants River system and its water quality are deficient. Clearly, the required research cannot be carried out over-night and it may be several years before all the water quality issues can be dealt with effectively. Nevertheless, it is essential to start a process whereby research funding institutions, academic institutions, local authorities, industries, water user organizations and water quality researchers can examine and prioritize the research needs. This will provide a structured approach that will help to provide the information that is required to successfully restore the water quality in the Olifants catchment to acceptable levels. In addition, this process will require improvements to be made to the effectiveness of several institutional structures and organizations that share responsibility for managing water resources and water quality in the Olifants River catchment.

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LIST OF ABBREVIATIONS USED

AEV	Acute Effect Value
CEV	Chronic Effect Value
CMA	Catchment Management Agency
CPR	Corrosion Potential Ratio
CSIR	Council for Scientific and Industrial Research, South Africa
DEA	Department of Environmental Affairs, South Africa
DEAT	Department of Environmental Affairs and Tourism, South Africa
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity (of water)
EDCs	Endocrine-disrupting compounds
EIA	Environmental Impact Assessment
GDP	Gross Domestic Product
GIS	Geographical Information System
IBT	Inter-basin transfer (of water)
INPR	Inorganic Nitrogen to Phosphorus Ratio
ITCZ	Inter-Tropical Convergence Zone
KNP	Kruger National Park
KNPRRP	Kruger National Park Rivers Research Programme
mg/litre	milligramme per litre
Mm^3	One million cubic metres (of water)
NAEBP	National Aquatic Ecosystem Biomonitoring Programme
NEMA	National Environmental Management Act (Act No. 107 of 1998)
NIWR	National Institute for Water Research, CSIR, South Africa
NRE	Natural Resources and the Environment business unit, CSIR, South Africa
NSBA	National Spatial Biodiversity Assessment
NWA	National Water Act (Act No. 36 of 1998)
ORF	Olifants River Forum
ORWRDP-2	Olifants River Water Resources Development Project – Phase 2
RHP	River Health Programme
RQO	Resource Quality Objective
RQS	Directorate: Resource Quality Services, Department of Water Affairs, South Africa
RSA	Republic of South Africa
RWQO	Receiving Water Quality Objective
SADC	Southern African Development Community
SAR	Sodium Adsorption Ratio
SANBI	South African National Biodiversity Institute
SANParks	National Parks, South Africa
SCR	Sulphate to Chloride Ratio
TCTA	Trans-Caledon Tunnel Authority
TDS	Total Dissolved Salts
TWQR	Target Water Quality Range
WMA	Water Management Area
WRC	Water Research Commission, South Africa
WSA	Water Services Act (Act No. 108 of 1997)

1. INTRODUCTION

1.1 Background to this study

The Olifants River is one of South Africa's major river systems and flows from its source on the Highveld region in a north-north-easterly direction before flowing into Mozambique, where it joins the Limpopo River. Within South Africa, the Olifants River is recognized – euphemistically – as one of the "hardest working rivers" in the country (Van Vuuren, 2009). The demands for water for industry, mining, power generation, agriculture and domestic use have increased steadily over the years, exceeding the rate of population growth, and have been accompanied by equally important increases in the quantity of effluents that are discharged to the river system and its tributaries (Ashton, 2007, 2010). Variable patterns of rainfall lead to periodic droughts that are often 'broken' by unanticipated floods, while the eastern portion of the Olifants River catchment in Mozambique regularly experiences the effects of tropical cyclones (Christie and Hanlon, 2001). The extremes of river flow, combined with the steady decline in water quality, have caused a dramatic decline in water quality in recent years, increasing the vulnerability of all the aquatic ecosystems in the catchment, while also increasing the vulnerability of the people who rely on the water resources of this river system for their livelihoods (Ashton *et al.*, 2008; Steyn, 2008; Dabrowski *et al.*, 2010).

The discharge of treated, partly treated and untreated effluents from mines, industries and sewage treatment plants – particularly in the upper reaches of the Olifants River – combined with seepage of acidic mine drainage from several active and abandoned coal mines in the upper reaches, contribute nutrients, salts and metal ions to the river system (Allanson, 1961; Butty *et al.*, 1979; Ashton *et al.*, 1992). A large proportion of these substances accumulate in the sediments and water column of the water storage reservoirs located along the Olifants River and its tributaries (Bruwer and Ashton, 1989; Ashton and Murray, 1992; Ashton, 1993; Dreischer, 2008; Dabrowski *et al.*, 2010). Steadily rising nutrient concentrations indicate that water storage reservoirs are becoming increasingly eutrophied, and the increased concentrations of aluminium and iron are often above those suggested in national water quality guidelines. Blooms of the toxic cyanobacterium *Microcystis aeruginosa* in Lake Loskop are thought to be responsible for recent fish kills and it is clear that human users of water from this reservoir also face risks to health (Oberholster *et al.*, 2010). The water quality situation in the Olifants River recently received considerable public attention when over 170 crocodiles were reported dead inside the KNP and the crocodile population in the upper reaches of the catchment has also declined (Steyn, 2008; Botha, 2010; Van Vuuren, 2009).

The need for a study of this nature arose during discussions between the Water Research Commission and CSIR's Natural Resources and the Environment business unit. It was clear that while considerable information was available on water quality issues across the Olifants River catchment, much of this information was in the form of raw or unprocessed data or was in a variety of confidential project-specific documents, consultancy reports, academic theses and published papers (De Villiers and Mkwelo, 2009). An important additional consideration was the need to take account of so-called "emerging pollutants", or substances that have only recently been deemed to be important or to pose potential health risks to humans and the aquatic environment. In this category, organic compounds, pharmaceuticals, endocrine disrupting compounds and even nano-sized materials are rapidly gaining recognition for their potential to disrupt water quality and cause health risks to human water users and components of the aquatic ecosystem. This study would include an overview of our existing knowledge on presence of these materials in the Olifants River catchment, the potential risks they pose to water users and the aquatic ecosystems, and the need for targeted research.

This combination of factors and circumstances emphasizes the need to compile and collate the available information on water quality into a coherent form that can provide an overview of water quality across the entire Olifants River catchment, and also identify the likely sources or causes of poor water quality. Such an overview would enable water resource decision-makers in central and provincial government, industry, agriculture and local authorities to ascertain those areas that require priority attention and urgent remediation. In addition, the information could also provide a scientifically defensible rationale for developing and implementing measures to improve land use practices across the catchment, as well as a firm basis for working with counterpart authorities in Mozambique. Overall, the information is intended also to identify those issues and activities that may require both national and international sources of funding to resolve. The ultimate beneficiaries of this study will be the aquatic ecosystems within the Olifants River catchment, as well as every person in the catchment that relies on good quality water for their lives and livelihoods.

1.2 Scope of this study

This study draws together existing, accessible information from an array of published and unpublished sources on the current state and probable or possible causes of adverse surface water quality across the Olifants River catchment. It is well known that – as with every catchment in South Africa – groundwater sources within the Olifants River catchment provide vital quantities of water during the drier months of the year when the absence of rainfall has reduced surface and water flows. During the dry winter months, the visible surface water flows in river channels becomes increasingly dominated by groundwater contributions. Therefore, while no specific attention was directed to groundwater data obtained from borehole logs and other sources, the low winter river flows tend to reflect the quality of groundwater contributions.

Importantly, the catchment and the tributary rivers draining the South African portion of the Olifants catchment have received considerable scientific and media attention to date and this area therefore forms the core of this study. Flows from the Great Letaba and Shingwidzi rivers enter the Olifants River within the Kruger National Park (Great Letaba River) or in Mozambique (Shingwidzi River) and their contribution to water quality in the main stem of the Olifants River within South Africa are minor. Therefore, only data from the lowest (downstream) monitoring points in these two tributaries are considered in the analysis as inputs to the patterns of water quality in the lower reaches of the Olifants River.

1.3 Approach adopted for this study

This desk-top study relied on the sourcing and examination of a wide range of published information on water quality and related issues in the Olifants River catchment (*See List of References at the end of this document*). The information available in the literature was supplemented by an analysis of the water quality and river flow data that were downloaded from the excellent Department of Water Affairs (DWA) website designed by the Directorate: Resource Quality Services (www.dwa.gov.za-iwqs-wms-data-000key.asp). All of the available data for a total of twenty-seven (27) water quality monitoring points were extracted and analysed in this study. In addition, the available water quality data for ten (10) key water storage reservoirs in the Olifants River catchment were also extracted and analyzed. This report contains full details of the analytical methods that were used.

After checking the DWA data for consistency, standard statistical analyses were carried out to derive measures of central tendency, illustrate seasonal changes and extremes, and to highlight long-term trends of change. While no specific field studies were carried out to collect new data for this study, some recent data were sourced from the investigation conducted by the CSIR and its team of specialists in the upper Olifants River catchment, upstream of Lake Loskop. Where possible, data were also sourced from other technical reports and records of water quality investigations carried out in the Olifants River catchment.

1.4 Structure of this document

This document has been structured to provide a broad overview of the current water quality situation and most likely causes of poor water quality in the Olifants River catchment.

The first chapter provides the background to the need for this study, defines the scope of the study and the purpose of this document. The second chapter provides a summary of the catchment characteristics that influence water quality and how these features and human activities have shaped the current patterns of water flow and water quality. The third chapter forms the core of this document, and describes the methods used, illustrates the historical and current patterns of water quality across the catchment and identifies those tributary rivers and human activities that appear to have had the most significant impacts on water quality. The fourth chapter provides a summary overview of the main water quality features in the Olifants River catchment together with their strategic importance for future management of the catchment. The chapter also identifies those areas that should be considered as a priority for targeted remedial actions. The fifth and final chapter provides a list of all the reference materials that were consulted.

A set of appendices at the end of this document provides tables of statistical data for each river and reservoir water quality monitoring point that has been evaluated, plus a series of diagrams for each site to illustrate the trends of change in key water quality variables or indices at each site.

1.5 Purpose of this document

This water quality information presented here for the Olifants River catchment will enable researchers and decision-makers to identify those areas or issues that require additional investigation, and to agree on those concerns that need to receive priority attention for remediation. In addition, the information will provide a scientifically sound basis for extending and enhancing collaboration with counterpart water decision-makers in Mozambique.

Ultimately, the information should contribute to the development of cost-effective, practical ways to address specific causes of adverse water quality at different points in the catchment. The ultimate beneficiaries of this will be the aquatic ecosystems within the catchment, every person within the Olifants River catchment that relies on good quality water for their livelihoods, as well as downstream water users in Mozambique.

2. CHARACTERISTICS OF THE OLIFANTS RIVER CATCHMENT

The quality of the surface and ground waters located within or draining a river catchment are shaped by the natural characteristics of the catchment, the prevailing climatic patterns plus the frequency and intensity of extreme events, the distribution and density of human and animal populations, and the types of land uses that are practiced within the catchment. The natural (unmodified) background water quality characteristics reflect the impacts of natural catchment processes (Balance *et al.*, 2001). Human activities within a catchment then exert a wide range of additional impacts that influence the quantity, quality and suitability for use of the water within groundwater and river systems.

2.1 Extent of the catchment

The Olifants River catchment is the largest sub-catchment of the much larger Limpopo River basin, which is shared by Botswana, Mozambique, South Africa and Zimbabwe. The Olifants River catchment is approximately 85,000 km^2 in extent, comprising portions of Mozambique

(11,458 km^2) and South Africa (73,542 km^2), and is located between 21.5° and 26.5° South latitude and between 28.4° and 32.8° East longitude (**Figure 1**). The areas contributed by the Olifants, Great Letaba and Shingwidzi catchments to the South African portion of the overall Olifants River catchment are 54,563 km^2, 13,669 km^2 and 5,310 km^2, respectively (Middleton and Bailey, 2008). The different sub-catchments are shown in **Figure 2** while their surface area and mean annual runoff characteristics are listed in **Table 1**. No runoff data were available for the Mozambique portion of the Olifants catchment.

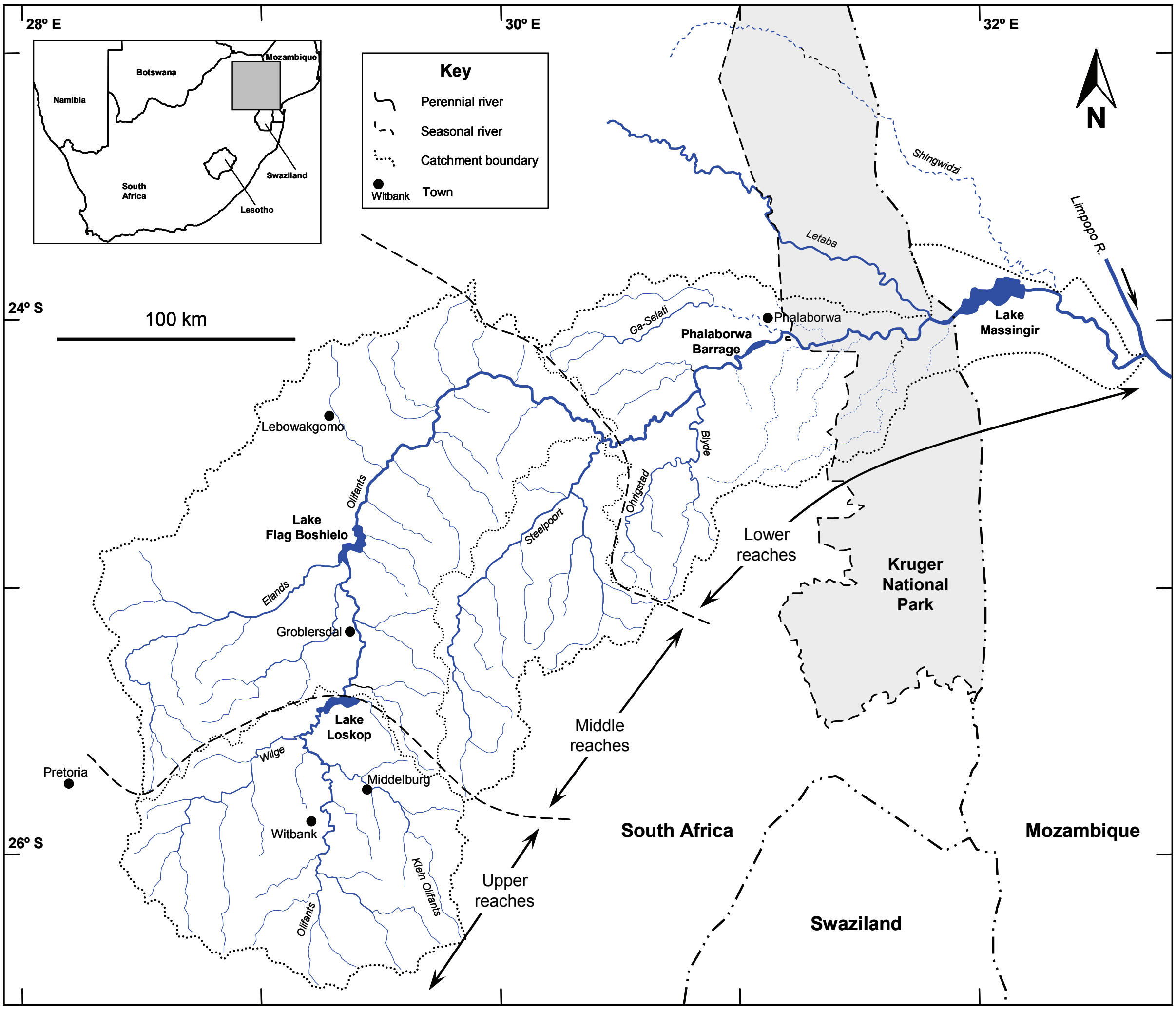

Figure 1. Sketch map showing the extent of the Olifants River catchment, as well as sub-catchments containing major tributaries and water storage reservoirs, in relation to the Kruger National Park (KNP) and Mozambique. Dashed lines mark the approximate extent of the upper, middle and lower reaches of the catchment. Inset shows area of map within southern Africa. (Map drawn from DWA data).

The Olifants River rises in the Highveld region of South Africa, flowing north-north-eastwards and then eastwards towards Mozambique, where it is joined by the Letaba River immediately before flowing into Mozambique, and by the ephemeral Shingwidzi River, which joins the Olifants River (now called Rio des Elephantes) downstream of Lake Massingir (**Figure 1**). In the South African segment of the catchment, the most important tributaries (in terms of their flow contributions or in terms of their economic importance) are: the Steenkoolspruit, Klein Olifants, Wilge and Elands rivers in the upper reaches; the Selons, Moses, Elands and Steelpoort rivers in the middle reaches; and the Blyde, Ga-Selati, Klaserie and Great Letaba rivers along the lower reaches (DWAF, 2004b). The seasonal Shingwidzi River contributes its flow to the Olifants River downstream of Lake Massingir (**Figure 1**).

Table 1. Surface area and mean annual runoff characteristics for the 10 sub-catchments comprising the Olifants River catchment.

Sub-Catchment	Surface Area (km^2)	Mean Annual Runoff (Mm^3/year)
Upper Olifants	7,105	318.20
Wilge	4,356	174.84
Elands	11,242	219.30
Steelpoort	7,136	342.80
Middle Olifants	9,728	83.30
Blyde	2,842	385.69
Lower Olifants	12,154	395.60
Letaba	13,669	645.33
Shingwidzi	5,310	84.40
Mozambique sector	11,458	No data
Total:	85,000	2,649.46

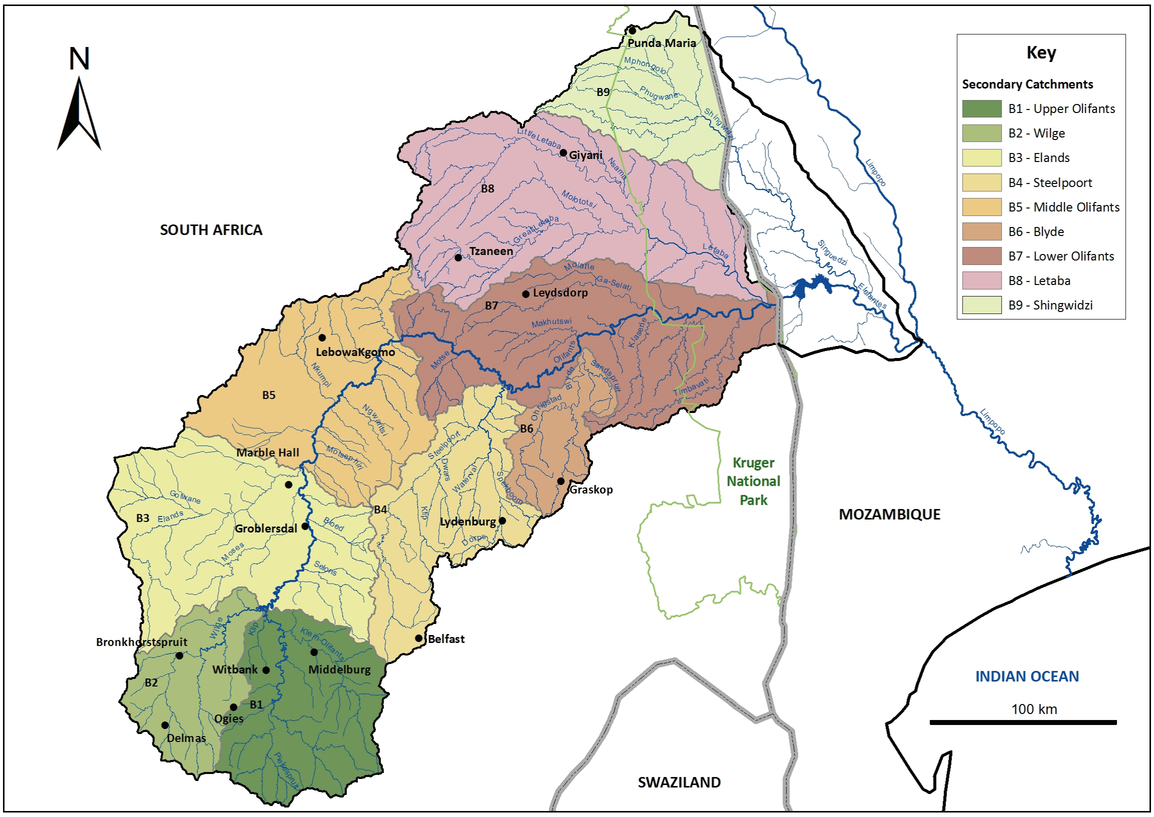

Figure 2. Sketch map of the Olifants River catchment showing the 10 sub-catchments, nine in South Africa and 1 in Mozambique (uncoloured).

The Olifants River has a relatively dense network of tributary streams and rivers, though most of the tributaries in the lower (eastern) reaches of the catchment only have seasonal or episodic flows (DWAF, 2004a). In historical times, the Olifants River was considered to be a strong-flowing perennial river but is now regarded as a weakly perennial river where flows frequently cease and, during drought periods, flows may be hardly discernable over large stretches of the lower reaches of the river (Joubert, 2007).

Listed in clockwise order from east to north, the major catchments located around the periphery of the Olifants River catchment are the: Inkomati (comprising the smaller Nwanedzi, Sabie, Crocodile (East) and Komati rivers), upper Vaal, Middle Vaal, Crocodile (West), Mogolokwena and Sand catchments; (the last three named also form part of the larger Limpopo River basin (Middleton and Bailey, 2008).

2.2 Geological, geomorphological and topographic features

The Olifants River catchment – comprising the Olifants, Great Letaba and Shingwidzi rivers – is located over the eastern lobe of the Kalahari Craton and forms the largest and one of the most economically important sub-basins of the Limpopo basin. The Archaean cratonic rocks comprise predominantly crystalline granitic and gneissic rocks, intruded by various greenstone belts as well as dolerite dykes and sills, and silicified sedimentary formations. Karoo System rocks overlie large areas of the southwestern (upper) portion of the catchment and these are also associated with younger sedimentary and crystalline rocks consisting predominantly of sandstones, carbon-rich mudstones, conglomerates and shales. Recent sedimentary deposits line most of the river valleys and provide important farming areas (Johnson *et al.*, 2006). A simplified geological map of the western portion of the catchment illustrates the major lithological units that are present in the catchment (**Figure 3**).

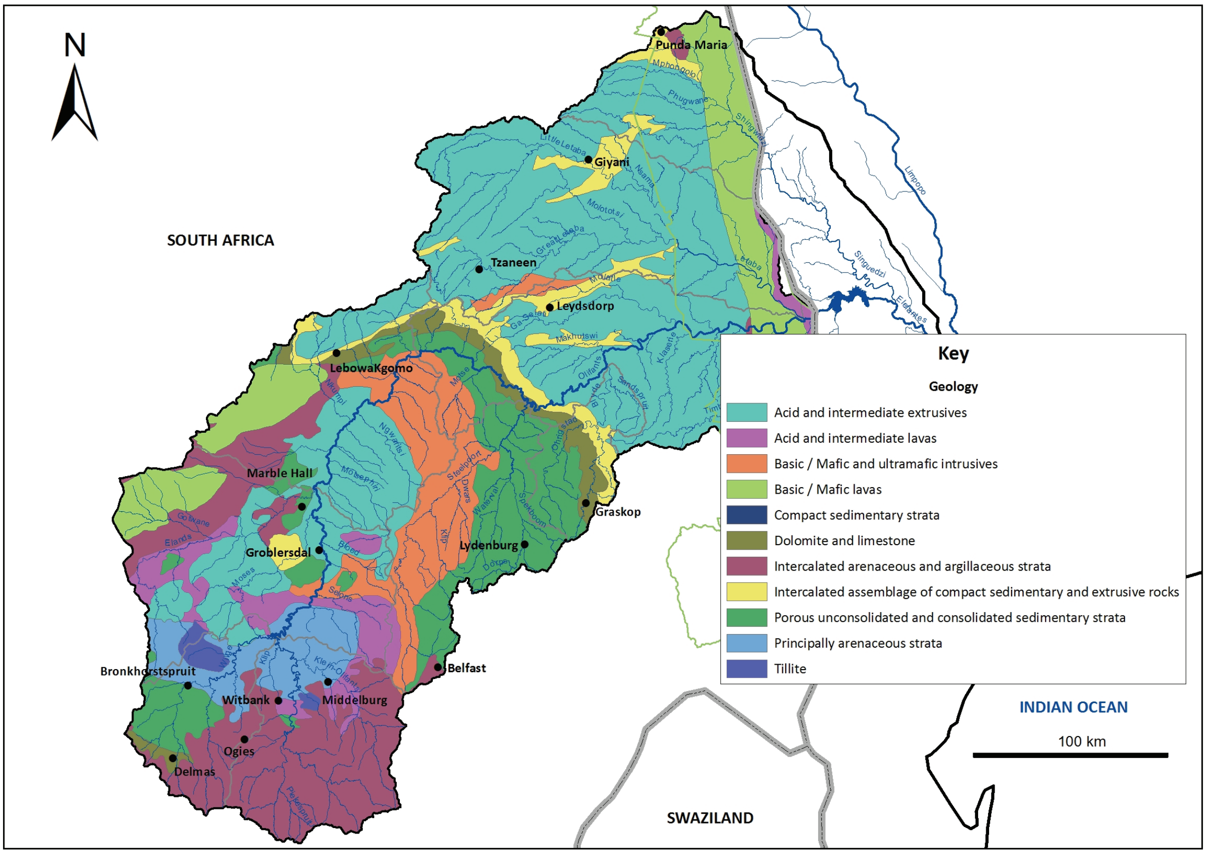

Figure 3. Simplified geological map of the western (South African) portion of the Olifants River catchment showing the major lithological units; no spatial geological data could be obtained for the eastern (Mozambique) portion of the catchment.

In the western (South African) portion of the Olifants basin, the Bushveld Igneous Complex forms an extremely important feature and contains a very large proportion of the region's mineral wealth. The geological features of this area consist mostly of basic mafic and ultramafic intrusive rocks, accompanied by extensive areas of acidic and intermediate intrusive rocks. At the southern and eastern periphery of this area, large dolomite and limestone formations occur, accompanied by extensive mineralization along their contact zones. Several areas of the northern portion of the Olifants basin contain deposits of consolidated and unconsolidated sedimentary rocks, with important belts of intrusive greenstone rocks that are heavily mineralised (Johnson *et al.*, 2006).

The north-south trending rhyolites and lavas of the Lebombo Mountains mark the eastern border between South Africa and Mozambique, and separate the South African and Mozambican portions of the catchment. The eastern (Mozambique) portion of the Olifants catchment consists largely of unconsolidated and consolidated sedimentary rocks with granitic intrusions exposed as erosional remnants in the landscape

In the southern portion of the basin, the extensive, carbon-rich sedimentary rocks of the Karoo System contain enormous economic reserves of coal and are the site of intensive coal mining activities (Bullock and Bell, 1997). Elsewhere, and particularly prominent in the northern and eastern parts of the basin, harder silicified sandstone and chert, as well as syenitic and granitic outcrops, form stack-like erosional remnants that protrude above the generally undulating terrain (*e.g.* the area around Phalaborwa town; Johnson *et al.*, 2006).

The topography of the Olifants River catchment is extremely varied, ranging from approximately 150 metres above sea level where it joins the Limpopo River in Mozambique, to over 2,000 metres in the mountainous region marking the transverse position of the northern extension of the Drakensberg Mountains. Most of the catchment consists of relatively undulating terrain separated by ranges of steep-sided hills and mountains. The north-eastward flowing Olifants River and its major tributaries have incised deep gorges through the hills and mountain ranges that now form spectacular landscape units (**Figure 9**). Generally, the river valleys tend to be broad and flat-bottomed, with river channels that are slightly or moderately incised into the surrounding parent material. The Olifants River has incised a spectacular gorge through the Lebombo Mountains, which mark the eastern border of the KNP. Portions of this gorge have recently been flooded by the rising waters of Lake Massingir following the raising of the dam wall in 2007 (A. Deacon, KNP, personal communication). The topography of the Mozambique portion of the catchment is generally one of low and undulating relief with small erosional remnants protruding as low hills above the otherwise flat countryside. The Shingwidzi River and the Olifants River downstream of Lake Massingir flow within relatively broad channels that are incised into wider macro-channels with broad vegetated levees; these macro-channels only fill during flood events.

Several small sections of the north-eastern parts of the Olifants basin (especially in the portions of the Shingwidzi and Great Letaba sub-catchments inside the KNP) have very little flow or poor drainage, and are usually considered to be endorheic (internally draining). These areas are often marked by the formation of clay-bottomed pans where rainfall collects and evaporates to leave small deposits of salts (DWAF, 2004b). The western portion of the middle reaches of the Olifants River catchment also has limited surface drainage and the area is characterized by the formation of small inward-draining pans and extensive deposits of calcrete. The drier northern and eastern portions of the catchment tend to experience more mechanical (physical) weathering processes, in contrast to the predominance of chemical weathering processes in the wetter mountainous areas and the headwater regions of most tributaries (Ashton *et al.*, 2001). The balance between mechanical and chemical weathering processes at a site influences the type, extent and depth of soils in that area.

2.3 Soils

Soil formations across the Olifants basin reflect the strong influence of underlying parent rock material, climatic features and biological activity. The dominant soil types in the basin are moderately deep sandy to sandy-clay loams in the west and south, grading to shallower, sandy or sometimes gravelly soils in the north and east (Fey, 2010). The deeper loam soils are extremely important for agricultural activities and support extensive irrigation developments along the Olifants River as well as many of its tributaries. A few areas of black vertisols in the southern and western parts of the basin also support important agricultural developments when sufficient water is available for irrigation (Fey, 2010).

The valley bottom soils along all of the tributary rivers and the Olifants main channel are generally of colluvial or alluvial origin and support extensive areas of commercial and subsistence agriculture. In contrast, hilly or steeply sloping areas tend to have fragile, shallow, stonier soils with less agricultural potential and these areas are particularly vulnerable to over-grazing by livestock (Moolman *et al.*, 1999). In the endorheic areas, most soils have a relatively high sodium and clay content and are dispersive (Fey, 2010).

2.4 Climatic features

Because of its geographic position, the prevailing wind systems, including tropical cyclones from the Indian Ocean, have a strong influence on the climate of the Olifants catchment. The most important of the rain-bearing winds are the south-easterly wind systems that bring summer rainfalls from the Indian Ocean (Tyson, 1987). In some years, southward movements of the Inter-Tropical Convergence Zone (ITCZ) exert a strong influence on rainfalls in the northern and central parts of the Olifants catchment for short periods of time. The mean annual rainfall and mean annual evaporation for the catchment are shown in **Figure 4**; mean monthly rainfall histograms for selected stations are shown in **Figure 5**. Mean monthly evaporation rates exceed mean monthly rainfalls for most months of the year over the catchment, except for those higher elevation areas that receive the highest rainfalls. In these areas, summer rainfalls exceed summer evaporation rates (Schulze, 1997).

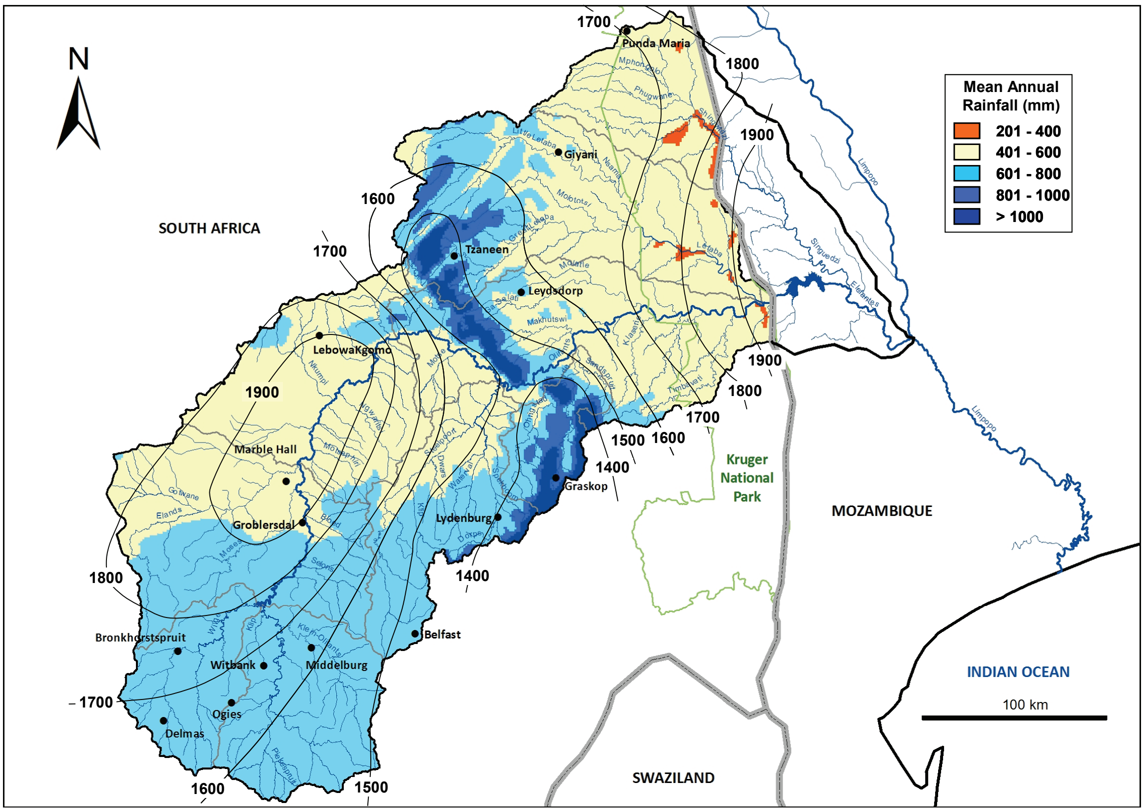

Figure 4. Mean annual rainfall isohyets (colours) and mean annual evaporation isolines for the Olifants River catchment; all values are given in mm/year.

Evaporation rates across the Olifants catchment are both high and variable, ranging from some 1,900 mm/year in the eastern areas of the catchment to some 1,400 mm/year in the cooler, mountainous regions in the south-western portion of the catchment (Schulze, 1997; **Figure 4**).

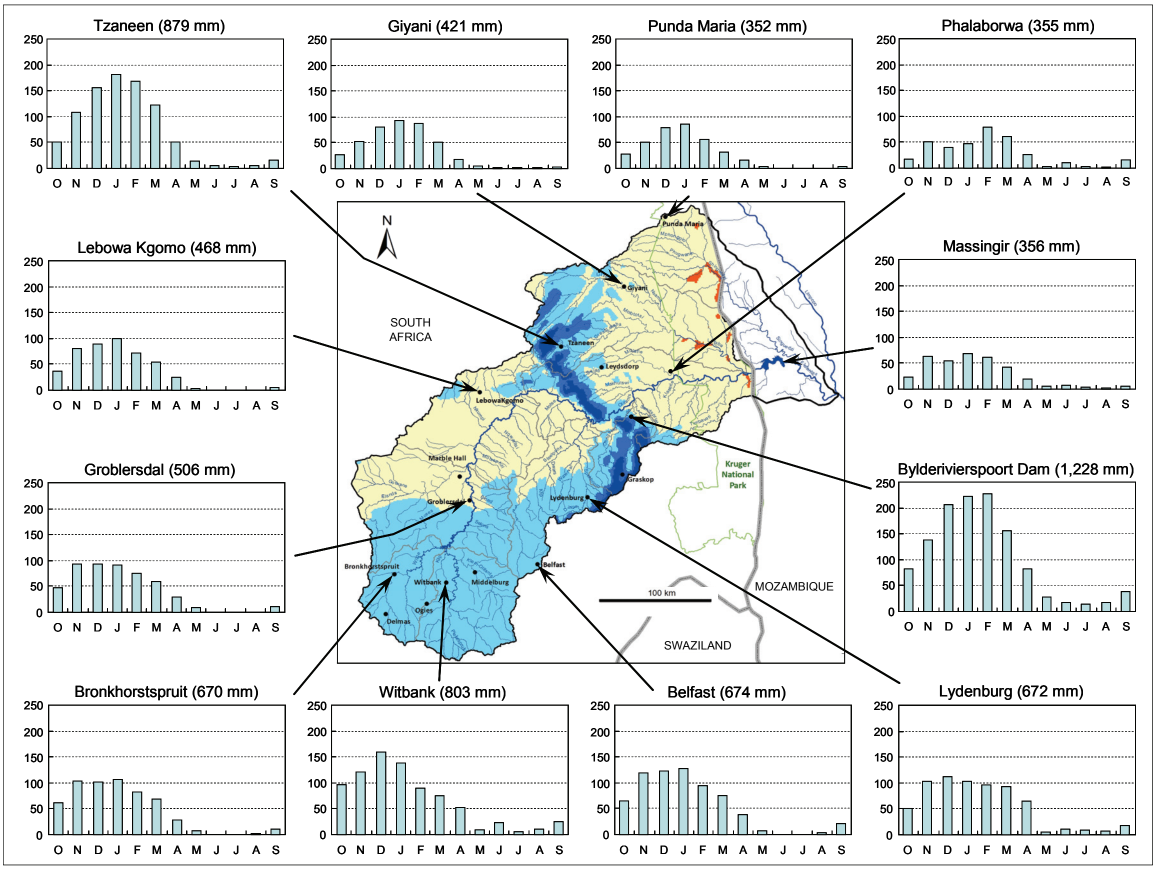

Figure 5. Mean monthly rainfall histograms for twelve selected weather stations in the Olifants River catchment. (Rainfall data South African sites taken from: www.saexplorer.co.za/south_africa/climate; rainfall data for the Massingir Dam site taken from Mussagy, 2008).

Rainfalls are highly seasonal, falling predominantly as intense convective thunderstorms during the warmer summer months, occasionally accompanied by hail. Rainfalls vary from below 400 mm/year in the north-eastern parts of the Olifants catchment, along the border with Mozambique, to over 1,000 mm/year on the Drakensberg Mountains that traverse the central portion of the catchment and receive orographic rainfall (**Figure 4**).

The mean monthly rainfall data for the twelve weather stations shown in **Figure 5** illustrate clearly the seasonal nature of rainfall across the catchment. Very little rainfall is received during the drier winter months, except for those stations located at higher elevations in the cooler and wetter central parts of the catchment.

Air temperatures across the Olifants River catchment show a marked seasonal cycle, with hottest temperatures recorded during the early- and mid-summer months and lowest temperatures during the cool, dry winter months. Frosts are common during the winter months on higher elevation portions of the catchment, while light snowfalls are occasionally recorded – also on the highest elevation portions of the catchment (Tyson, 1987).

In view of these evaporation rates, and the relatively low volumes of rainfall received each year, several portions of the Olifants catchment show clear evidence of the dominance of physical weathering processes (with Weinert N values greater than 5.0; Weinert, 1964). These areas are located predominantly in the eastern and north-eastern portions of the basin and along the lower reaches of the Olifants, Great Letaba and Shingwidzi sub-catchments. Areas with lower evaporation rates and higher rainfalls are increasingly subjected to chemical weathering processes. These may be either seasonally dominant during the summer months when Weinert N values are between 2.0 and 4.0, or continually when Weinert N values are less than 2.0 (Weinert, 1964).

2.5 Population numbers and distribution

The South African portion of the Olifants catchment is home to some 4 million people (approximately 8% of the South African population; Van Vuuren, 2009). The Mozambique portion of the Olifants catchment has a population of approximately 150,000 – equivalent to approximately 0.9% of the 2001 Mozambique population (Leira and McNabb, 2003).

Within South Africa, the catchment contains a proportion of the population of South Africa's Gauteng Province, as well as parts of the populations of the Northern and Mpumalanga Provinces. The Olifants River catchment contains virtually all of the important coal mines and thermal power stations, as well as critically important agricultural areas, towns and cities. Consequently, the Olifants catchment is correctly considered to house the energy heartland of South Africa (Dabrowski *et al.*, 2010).

In Mozambique, the Olifants catchment supports several scattered communities and small to moderate-sized settlements – mostly located around Lake Massingir and along the lower reaches of the Olifants River (now called the Rio des Elephantes). The population in the Mozambican portion of the Olifants catchment is essentially rural in character and lifestyle.

In contrast, the much larger South African sector of the Olifants catchment supports several large and medium-sized towns as well as numerous smaller communities and subsistence farmers (McCartney and Arranz, 2007). Throughout the South African portions of the Olifants catchment, a wide variety of mining operations as well as different forms of agriculture (subsistence and commercial cultivation, game farming, livestock and dairy production) provide the economic cornerstone for development in the basin (Dabrowski *et al.*, 2010).

Both South Africa and Mozambique have "skewed" population distributions, and experience large-scale migration from rural areas to urban settlements. The Olifants catchment in South Africa contains areas of extensive rural and peri-urban populations that occupy former Apartheid self-governing "homelands". As a consequence of past inequities, a large proportion of the basin's population is extremely poor and lacks access to basic services and amenities such as clean water and adequate sanitation (Ashton *et al.*, 2008).

Similar to other parts of southern Africa, land is a critically important resource throughout the Olifants catchment and the livelihoods of residents and the national economies of both Mozambique and South Africa depend on access to land (Chenje, 2000). However, the specific types of land use that are practiced in the catchment are controlled by climatic factors, water availability and, importantly, by land tenure arrangements. A large proportion of the land in the Olifants catchment is under communal or customary forms of tenure, and land ownership is considered to be one of the major constraints to proper land use and conservation (Chenje, 2000).

Overcrowding and insecure ownership in the smaller communal farming areas (*e.g.* in the Shingwidzi, Ga-Selati, and middle Olifants sub-catchments) are the primary causes of land degradation in the catchment (Moolman *et al.*, 1999). This feature is a critically important driver of poverty within the Olifants catchment and is associated closely with declining indices of *per capita* agricultural production (Dalal-Clayton, 1997). In many parts of the Olifants catchment, progressive urbanization has been accompanied by the development of peripheral "informal" settlements around the major urban areas (McCartney *et al.*, 2004).

Some portions of the South African and Mozambique portions of the Olifants catchment are relatively densely settled. Whilst the Olifants catchment does not contain any very large cities, there are numerous medium- and small-sized towns and villages. In the Mozambique portion of the basin, the population is more evenly spread and the only sizeable groups of people are those associated with fishing and irrigation activities near Lake Massingir and the Chokwe Irrigation Scheme, which is located downstream of Lake Massingir, close to the confluence of the Olifants and Limpopo rivers (Leira and McNabb, 2003).

2.6 Land cover and land use patterns

The major categories of land cover across the Olifants catchment are shown in **Figure 6**. No spatial data on land cover could be obtained for the Mozambique portion of the catchment.

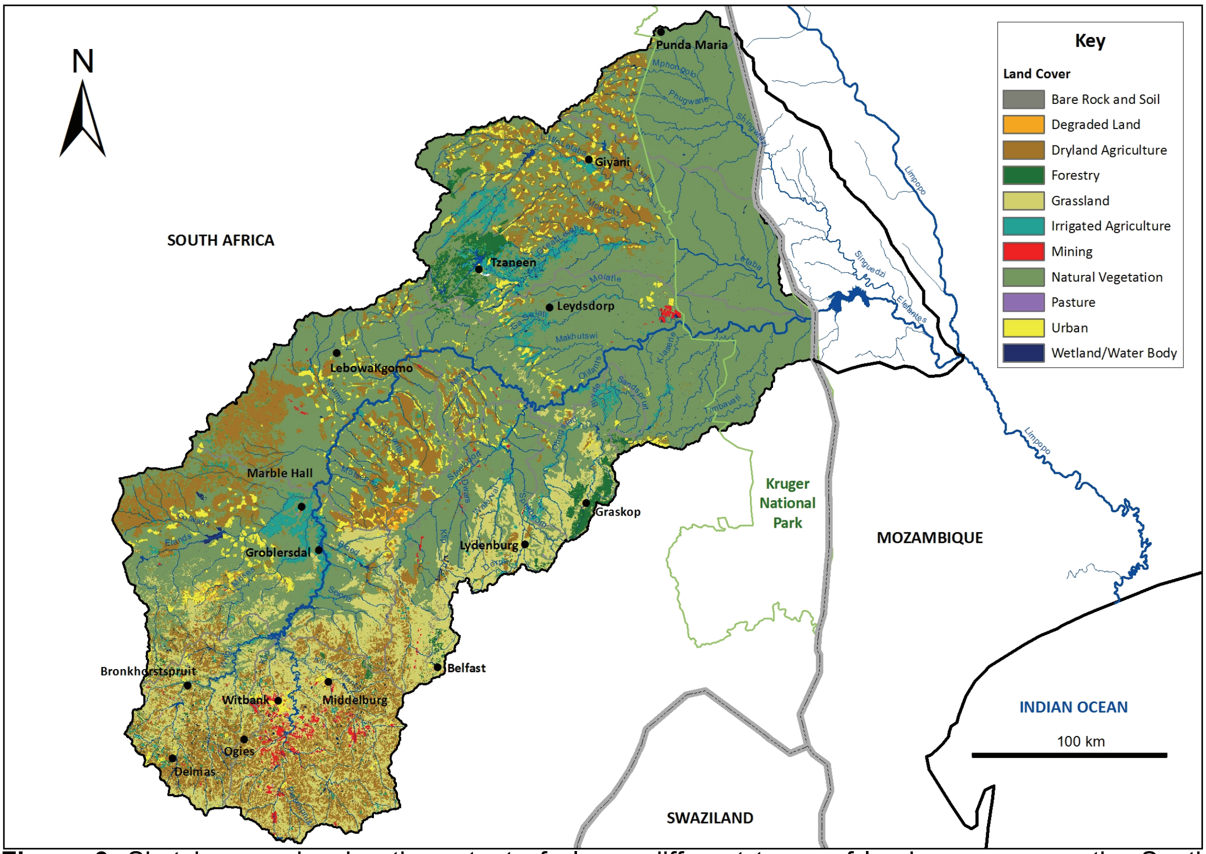

Figure 6. Sketch map showing the extent of eleven different types of land cover across the South African portion of the Olifants River catchment.

In South Africa, the upper reaches of the Olifants River and its main tributary the Wilge River (**Figure 6**) drain the important Mpumalanga Coalfields. Coal has been mined in this area for over 100 years, supporting the vitally important generation of electricity by coal-fired power plants (**Figure 7**), as well as providing an important source of foreign exchange through coal exports. In addition, the coal-fired power plants burn large quantities of coal and emit large (though as yet not accurately quantified) amounts of sulphur and nitrogen oxides (Zunckel *et al.*, 2000). Much of these atmospheric emissions appear to be deposited across the upper catchment, thereby affecting soil structure and chemistry, and also enter the Olifants River tributaries and other river systems to the south (notably the Vaal River and its tributaries).

The upper and middle reaches of the Olifants catchment also support many areas of irrigated and dryland agriculture, where the crops are destined for local markets as well as for export to the European Union (Dabrowski *et al.*, 2010).

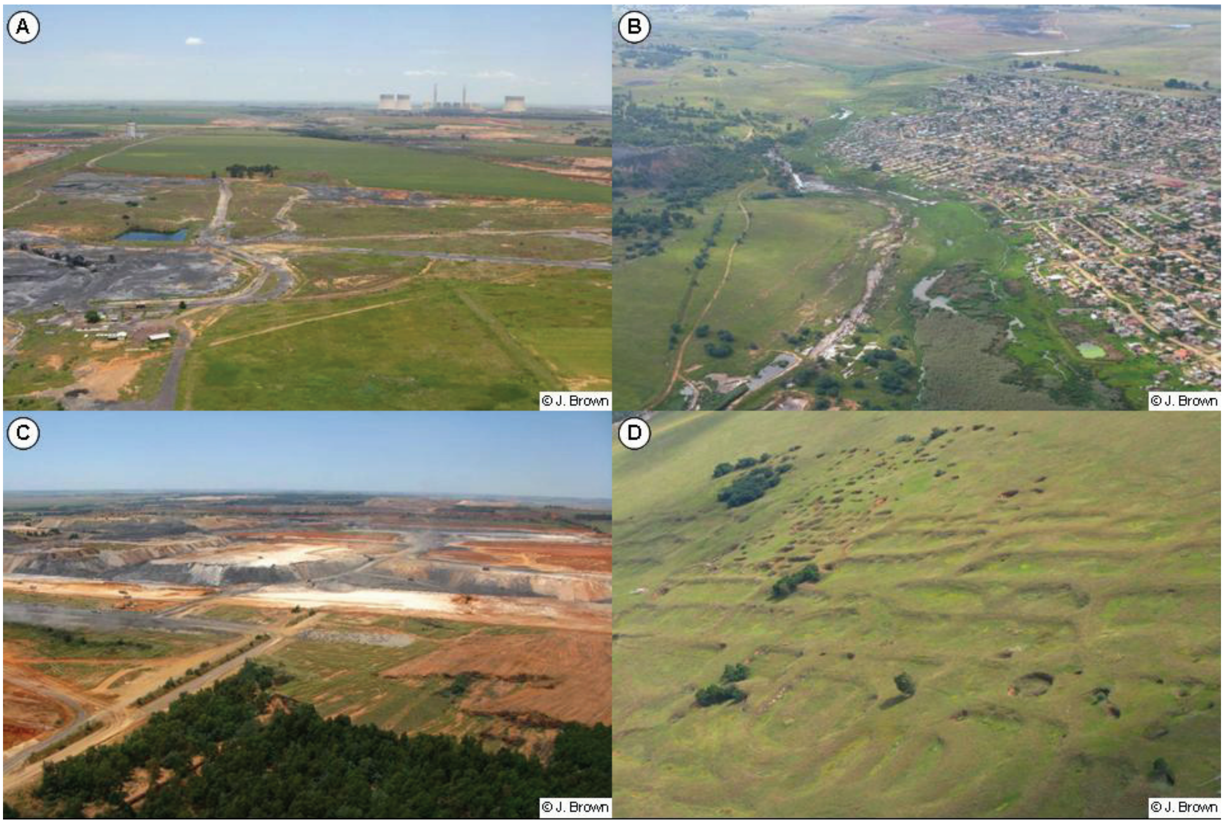

Figure 7. Aerial views of representative portions of the upper Olifants River catchment showing predominant land uses. A: Coal-fired power plant with coal mine and commercial agriculture in close proximity; B: High-density housing settlement located close to the Brugspruit and a nearby coal mine; C: Large-scale open cast coal mine with plantation forestry in foreground; D: Collapsed surface area overlying an abandoned bord and pillar coal mine.

A large area in the middle reaches of the Olifants catchment formed part of the Lebowa, KwaNdebele and Gazankulu 'homelands' under the previous Apartheid regime. These previous 'homeland' areas are characterized by dense and scattered human settlements – many of which have no formal water supply or sanitation and waste disposal systems – and poor land use practices with extensive areas of erosion (Moolman *et al.*, 1999; **Figure 8**).

In addition, the middle reaches of the Olifants River catchment (*i.e.* downstream of Lake Loskop) form part of the Bushveld Igneous Complex and contain economically important deposits of the platinum group metals, as well as nickel, copper, chrome, iron and asbestos (N.B. All asbestos mines have now been closed and rehabilitated). Existing mining and refining operations (**Figure 8**) and their associated urban developments to house staff and supporting activities, place relatively heavy demands for water on the river system and, in turn, also contribute different types of effluent. The commissioning of new mines will increase the demands for water and increase the quantities of effluent that are discharged.

The lower reaches of the Olifants River system outside of the Kruger National Park (KNP) support large areas of game farming as well as a wide variety of subsistence and commercial agricultural enterprises, many of which rely on irrigation, and the large mining and industrial complex of Phalaborwa. The lowest reach of the Olifants River in South Africa runs through the KNP (**Figure 9**) and flows into Lake Massingir in Mozambique, where people living in the vicinity of the dam rely on fish from the lake for their livelihoods and food supplies (Mussagy, 2008). Flows released from Lake Massingir support the important Chokwe Irrigation Scheme at the junction of the Olifants and Limpopo rivers in Mozambique.

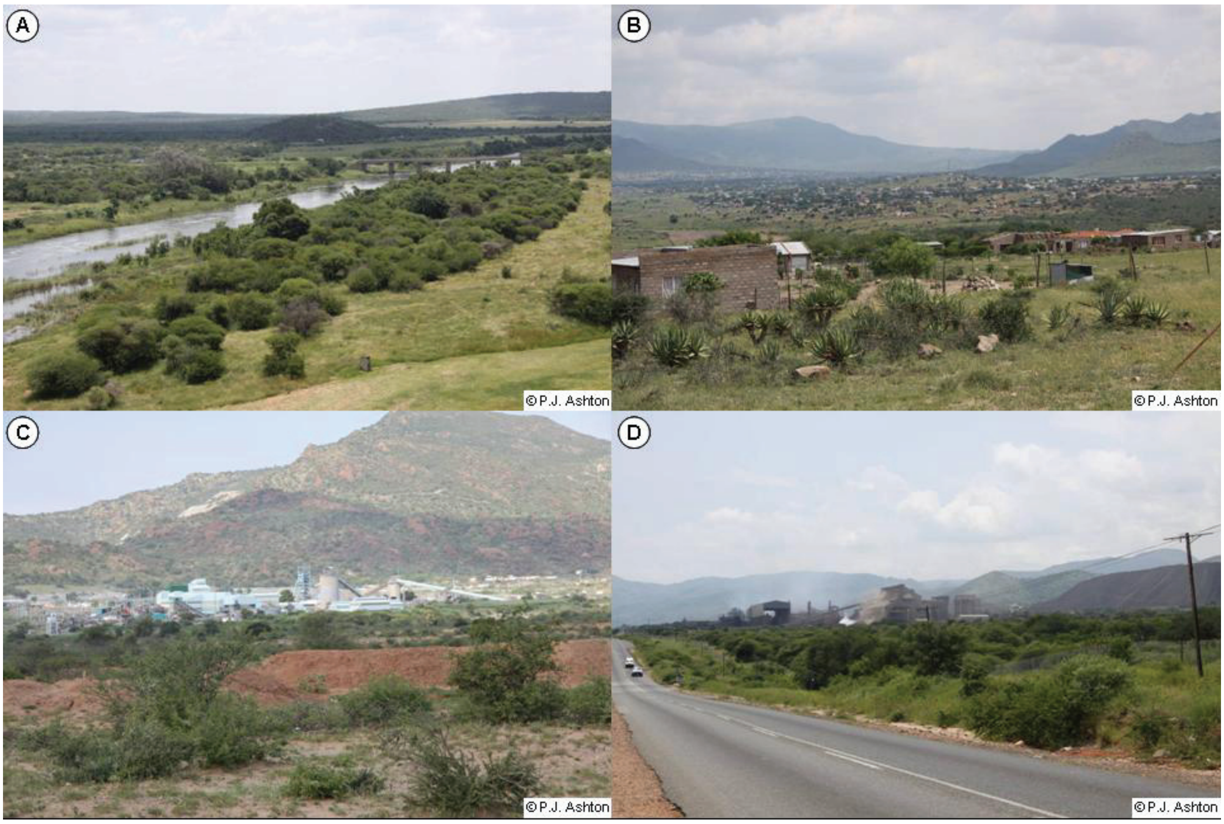

Figure 8. Views of typical scenery and types of land use in the middle reaches of the Olifants River catchment. A: Olifants River downstream of Flag Boshielo Dam; B: Densely populated rural area in Sekhukuniland; C: Mapochs Platinum Mine in Sekhukuniland; D: Tubatse Ferrochrome Refinery in the Steelpoort Valley.

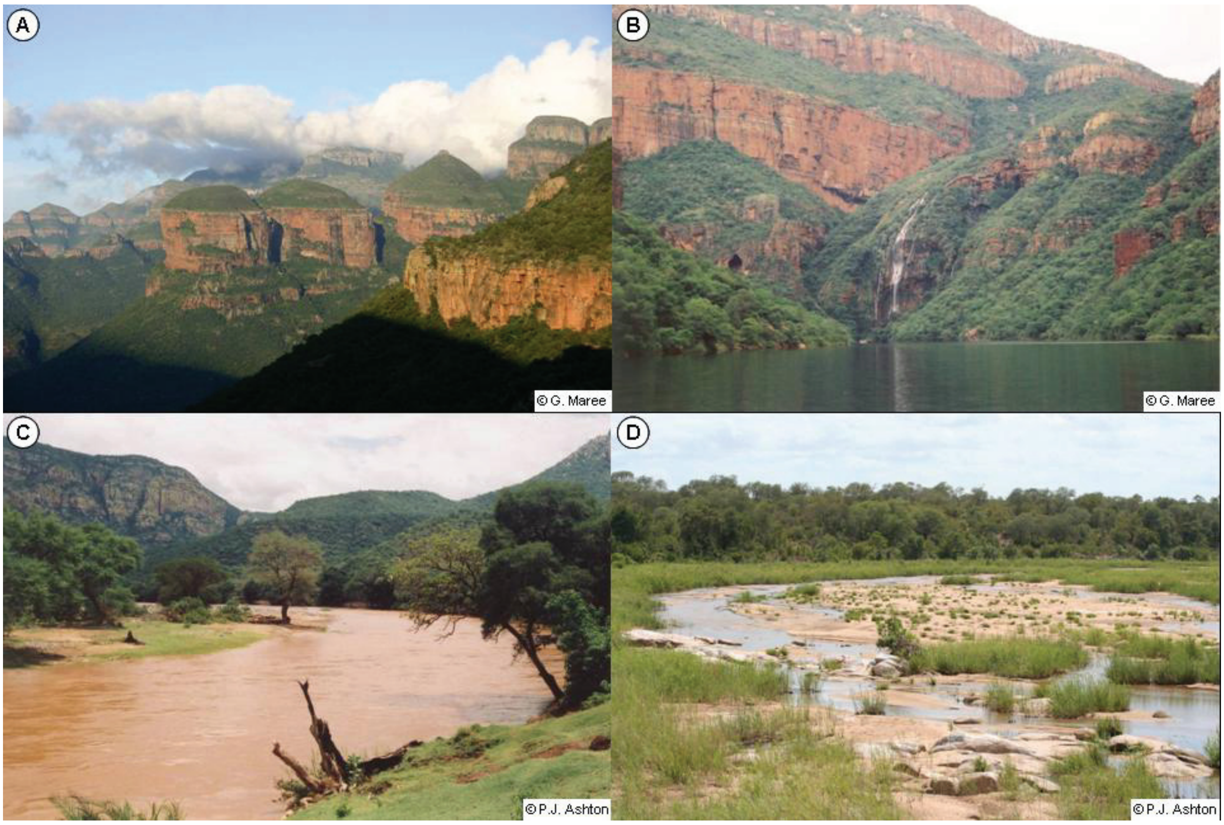

Figure 9. Views of typical scenery along the lower reaches of the Olifants River catchment. A: Sheer cliffs of the Drakensberg Escarpment; B: Tufa waterfall flowing into Blyderivierspoort Dam; C: High suspended sediment load in the Olifants River near the Abel Erasmus Pass; D: Braided river channel of the Olifants River in the Kruger National Park.

The catchment downstream of Lake Loskop contains several platinum, chrome and vanadium mines (**Figure 10**), two ferro-chrome and ferro-manganese refineries (**Figure 8**), numerous smaller urban centres and several large livestock and game ranches (Ashton *et al*., 2001). A total of 328 mines and quarries are located in the Olifants catchment and produce a broad spectrum of mineral commodities (DME, 2004). The locations and types of minerals produced by these mines and quarries are shown in **Figure 10**.

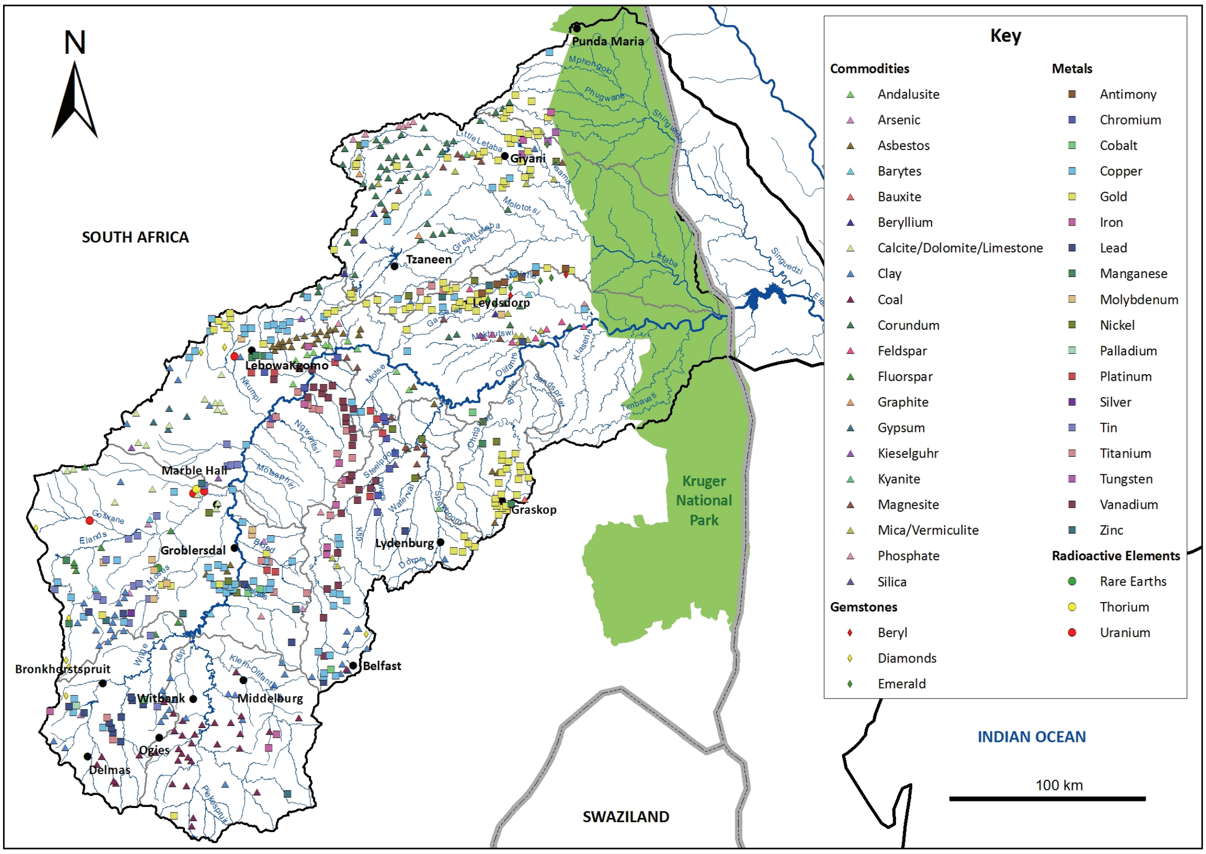

Figure 10. Sketch map showing the locations and types of mineral commodities mined within the Olifants catchment.

Most of the mines located in the Great Letaba and Shingwidzi sub-catchments (**Figure 10**) are relatively small and have low production volumes of their respective minerals. This is in contrast to many of the much larger coal mines in the upper reaches of the catchment and the medium-sized platinum, chrome and vanadium mines in the middle reaches of the catchment (Ashton *et al.*, 2001). The array of mineral products produced by the mining sector in the Olifants catchment makes a significant contribution to the national Gross Domestic Product (GDP) of South Africa (Dabrowski *et al.*, 2010). However, each mining operation also has different impacts on the water resources of the catchment in terms of the volumes of water used and the contribution of salts and other materials in seepage and effluents discharged from mine properties (Ashton *et al.*, 2001).

In the upper reaches of the Olifants catchment the economically exploitable ore reserves in several of the older coal mines have been worked out and the mines have been abandoned or are under a ‘care and maintenance’ routine managed by the Department of Water Affairs (Limpitlaw *et al.*, 2005; Dabrowski *et al.*, 2010). However, in recent years, the Department of Mineral Resources (DMR) has granted a large number of permits for additional exploration, prospecting and mining activities – principally for coal deposits – in the upper reaches of the Olifants catchment (DME, 2004). This will increase the impact of mining in the Olifants catchment (Dabrowski *et al.*, 2010) and will also influence both the availability and quality of water resources in the catchment (DWAF, 2004a).

A small number of artisan gold mining operations work on alluvial gold deposits associated with the Giyani greenstone formations located in or close to the Shingwidzi River (**Figure 7**). These activities are illegal in terms of current South African legislation and they will have direct impacts on water quality in the Shingwidzi River (Ashton *et al.*, 2001). No mining activities have been recorded to date for the Mozambique portion of the Olifants catchment (Leira and McNabb, 2003).

The different types of land use that occur within the Olifants catchment have a wide range of implications for both water supply (*i.e.* water quantity) and water quality. The main stem of the Olifants River and the upper and middle reaches of several of its larger tributaries (*e.g.* the Wilge, Moses, Elands, Steelpoort, Blyde and Ga-Selati rivers) are important sources of water for intensive and extensive areas of irrigated agriculture (Joubert, 2007). Most of the smaller rivers in the lower elevation, eastern portion of the Olifants River catchment (*e.g.* Klaserie River) have highly seasonal flows, with low to no flow during the dry winter months; water needs in these areas have to be met by conjunctive use of groundwater via boreholes.

In the middle reaches of the catchment, extensive soil erosion in densely populated areas contributes large quantities of suspended sediments to the river systems (Moolman *et al.*, 1999) while return flows from irrigated agricultural lands contribute a variety of agricultural chemicals to the Olifants River (Ashton *et al*., 2001). Large volumes of sediment are trapped in water storage reservoirs, thereby reducing their capacity to store water (Seymore *et al.*, 1994). Water released from the Phalaborwa Barrage can contain high concentrations of suspended sediment while concentrations of metal ions and total dissolved salts are also high at times (Ashton *et al*., 2001). The substances present in these discharges to the Olifants River have been recorded downstream into Lake Massingir (Mussagy, 2008).

The growing demands for water to meet domestic needs and to support mining, industrial and agricultural activities – particularly in the upper and middle reaches of the catchment – have progressively reduced flows in the lower reaches of the Olifants River within the KNP; surface flows in the lower reaches of the Olifants River have ceased for short periods during recent dry periods (Biggs and Rogers, 2003). Water released from Lake Massingir is used for the large Chokwe irrigation scheme located along the banks of the Limpopo River, downstream of its confluence with the Olifants River (now Rio des Elephantes) in Mozambique (McCartney *et al.*, 2004; McCartney and Arranz, 2007).

2.7 Hydrological characteristics

The quantity and timing of rainfall received in the Olifants basin, plus the position and operating rules of water storage reservoirs, controls the quantity, timing and duration of flows in the different tributary rivers. The uneven seasonal and spatial distribution of rainfall in the basin is reflected in the very uneven distribution of surface and groundwater resources in the different sub-catchments (Smakhtin, 2001). In turn, these influence the types of economic activities that can be undertaken by the residents in each area (McCartney *et al.*, 2004).

The uneven seasonal and spatial distribution of water across the catchment (**Figure 11**), the difficulty in producing reliable predictions of flow, coupled with increasing competition for the dwindling available water resources, has made it difficult for water resource managers to ensure that all water users can access reliable water supplies – particularly during the drier winter months when river flows are at their lowest (Middleton and Bailey, 2008).

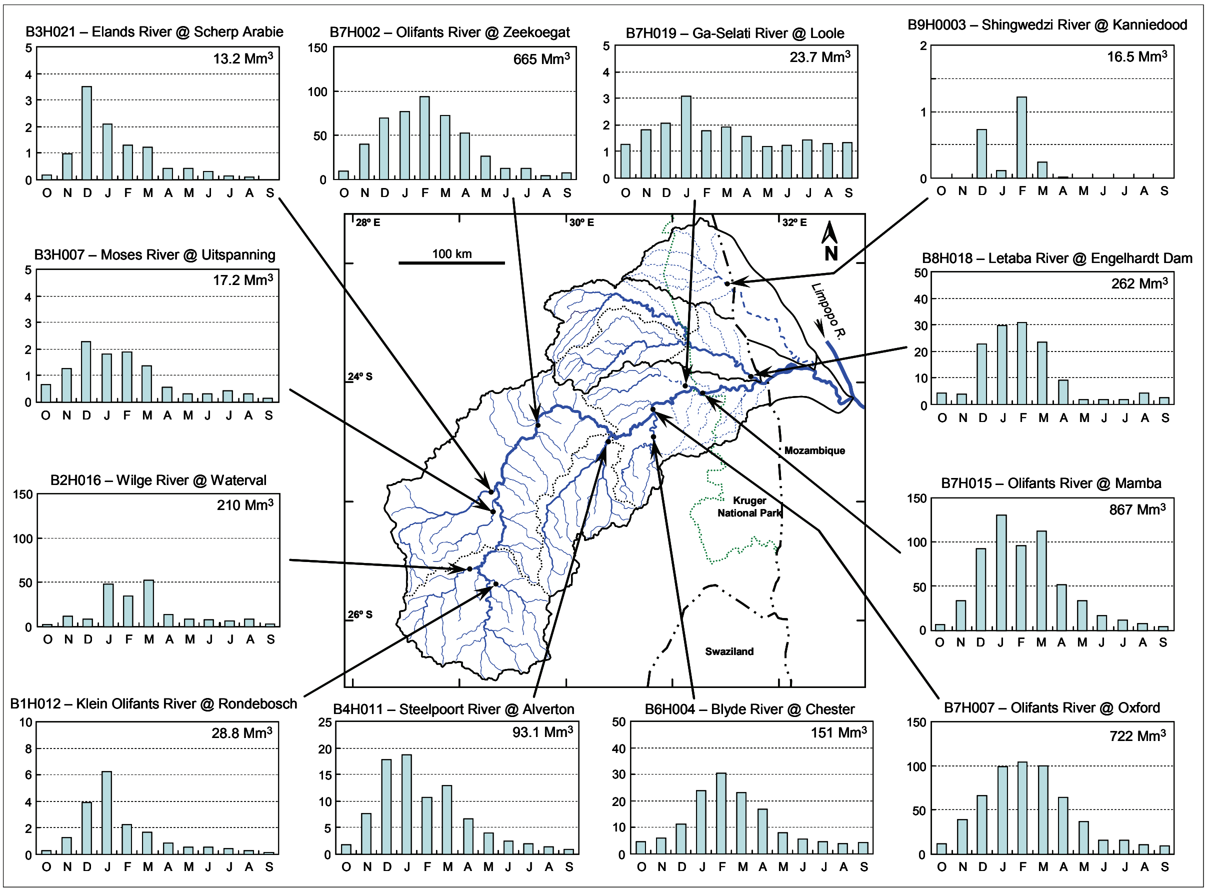

Figure 11. Histograms of mean monthly river flow at twelve DWA flow gauging sites in the Olifants River catchment. (Data sourced from the DWA hydrological database).

The histograms in **Figure 11** reveal clearly the highly seasonal patterns of mean monthly flows in every river in the Olifants catchment. It is important to note that mean values – and not median values were used for this illustration because most of the flow gauging stations in the drier areas had numerous months where zero flow was recorded (McCartney *et al.*, 2004). Flows in the Shingwidzi River, in particular, are highly episodic and only occur for short periods following a rainfall event (Chutter *et al.*, 1992; DWAF, 2004b; **Figure 11**).

River flows throughout the Olifants River catchment are heavily dependent on groundwater base flows – especially during the drier months of the year. Naturally occurring sources of fluoride and nitrate in the groundwater of the middle reaches of the Olifants River present minor health risks for human and wildlife users of water. However, contamination of groundwater by mining, industrial and domestic effluents appears to be becoming increasingly problematic across the entire Olifants River catchment.

2.8 Water demand and water supply

The demand for water throughout the Olifants catchment is both high and unevenly spread (McCartney and Arranz, 2007). In particular, water demands by power generation, industry, mining and especially the formal (irrigation) agricultural sector account for over 75% of all water used (Cullis and Van Koppen, 2007). Coupled with high evaporation losses from the numerous small dams and larger water supply impoundments, flows in the lower reaches of the Olifants River are usually relatively low (Ashton *et al.*, 1992; Joubert, 2007). In some years, river flows are "boosted" by unusually high rainfalls or by the arrival of a tropical cyclone (*e.g.* the cyclone that arrived in 2000 and flooded large coastal areas of Mozambique; Christie and Hanlon, 2001; Leira and McNabb, 2003).

A direct consequence of the difficulty in providing reliable water supplies – especially during the low flow winter months – has been the construction of numerous water storage reservoirs – particularly during the 20th Century (Bruwer and Ashton, 1989; **Figure 12**) – to ensure that adequate volumes of water can be stored to meet needs for water during dry periods (Basson *et al.*, 1997). The South African portion of the Olifants catchment contains 299 water storage reservoirs (55 of which have volumes larger than 1 Mm^3), while the huge Massingir Dam (with a full supply storage capacity of 2,844 Mm^3 after the wall had been raised in 2007) commands the lower reaches of the Olifants River in Mozambique and is the only water storage reservoir in the Mozambique portion of the catchment (**Figure 13**).

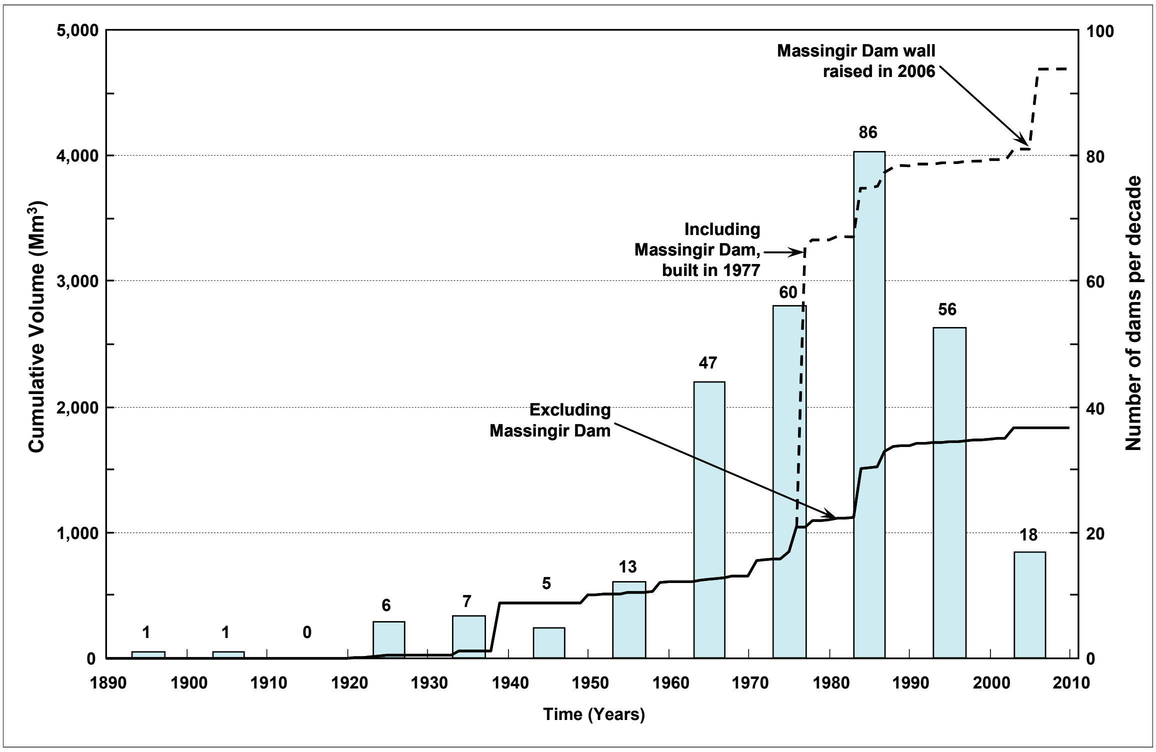

Figure 12. Comparison of the number of water storage reservoirs constructed per decade (Histograms) in the Olifants River catchment since 1890 with the cumulative storage volume (lines), including and excluding Massingir Dam. (Data obtained from the DWA Dams Register, courtesy of Mr B. Haasbroek).

The data in **Figure 12** reveal that there was a concerted drive to construct water storage reservoirs with greatest activity occurring between 1950 and 2000. Many of these reservoirs were constructed inside the former Apartheid 'homelands' to meet the needs of people who had been placed there (McCartney *et al.*, 2004). The combined capacity of all the large water storage reservoirs in the Olifants catchment (4,688 Mm^3) is almost double (x1.8) the mean annual runoff of the entire catchment (2,629 Mm^3; Middleton and Bailey, 2008). A small selection of important reservoirs in the Olifants River catchment is illustrated in **Figure 14**.

In addition to all the dams noted above, which are listed individually on the DWA Dam Safety Database and where each has a volume larger than 50,000 m^3, there are also an estimated 3,500 smaller farm dams that have been built in the Olifants catchment to provide small-scale water storage for household use and livestock watering.

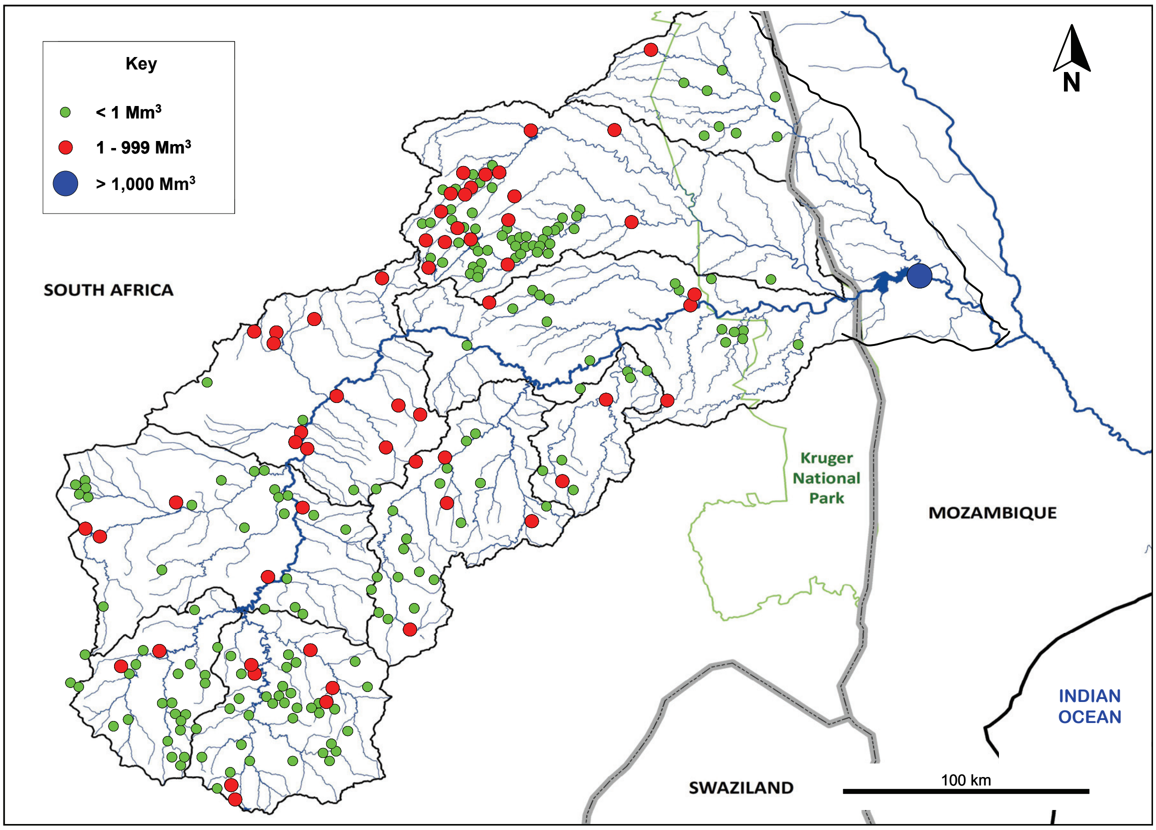

Figure 13. Sketch map showing the distribution of all water storage reservoirs with a volume greater than 50,000 m^3 listed on the DWA Dam Safety Database, segmented into three size classes. (Data sourced from DWA Dams Safety Database).

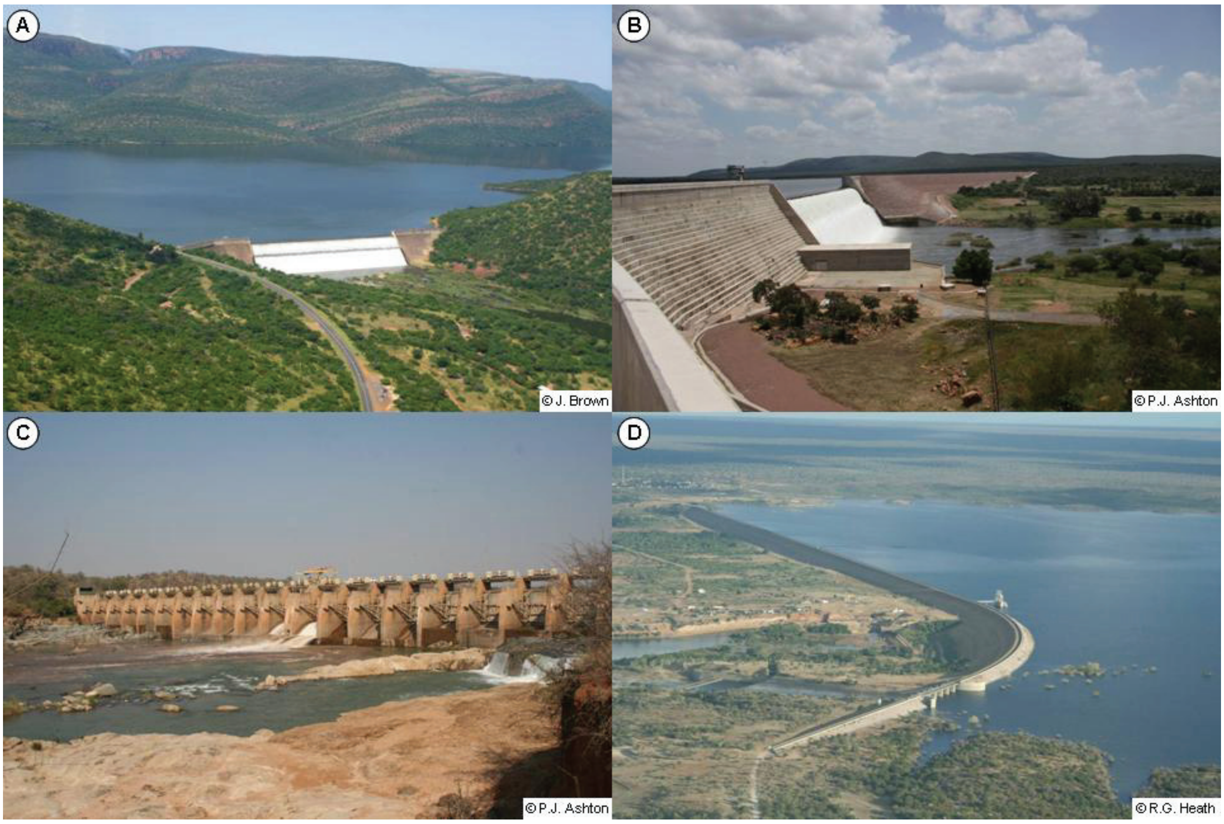

Figure 14. Views of four important reservoirs in the Olifants River Catchment. A: Loskop Dam; B: Flag Boshielo Dam; C: Phalaborwa Barrage; D: Massingir Dam.

Overall, the surface water flows in the Olifants River catchment are close to their full exploitation potential that is possible by conventional engineering approaches, but new dams are still being constructed on tributary rivers (*e.g.* the De Hoop Dam on the Steelpoort River) to meet the growing demands for water from mines and towns in the middle reaches of the Olifants River catchment and in the drier catchments to the west (Couzens and Dent, 2006).

Relatively large volumes of water (approximately 172 Mm^3/year) are transferred into the upper Olifants River catchment from the Komati, Vaal and Usutu catchments to the south and east (ACER-CSIR, 2004; **Figure 15**). Most of this water is used consumptively as cooling water in the eight large coal-fired power plants that are situated in the upper parts of the catchment. Small additional volumes of water (approximately 0.7 Mm^3/year) are transferred into the Olifants River catchment from the upper reaches of the Great Letaba catchment (**Figure 15**).

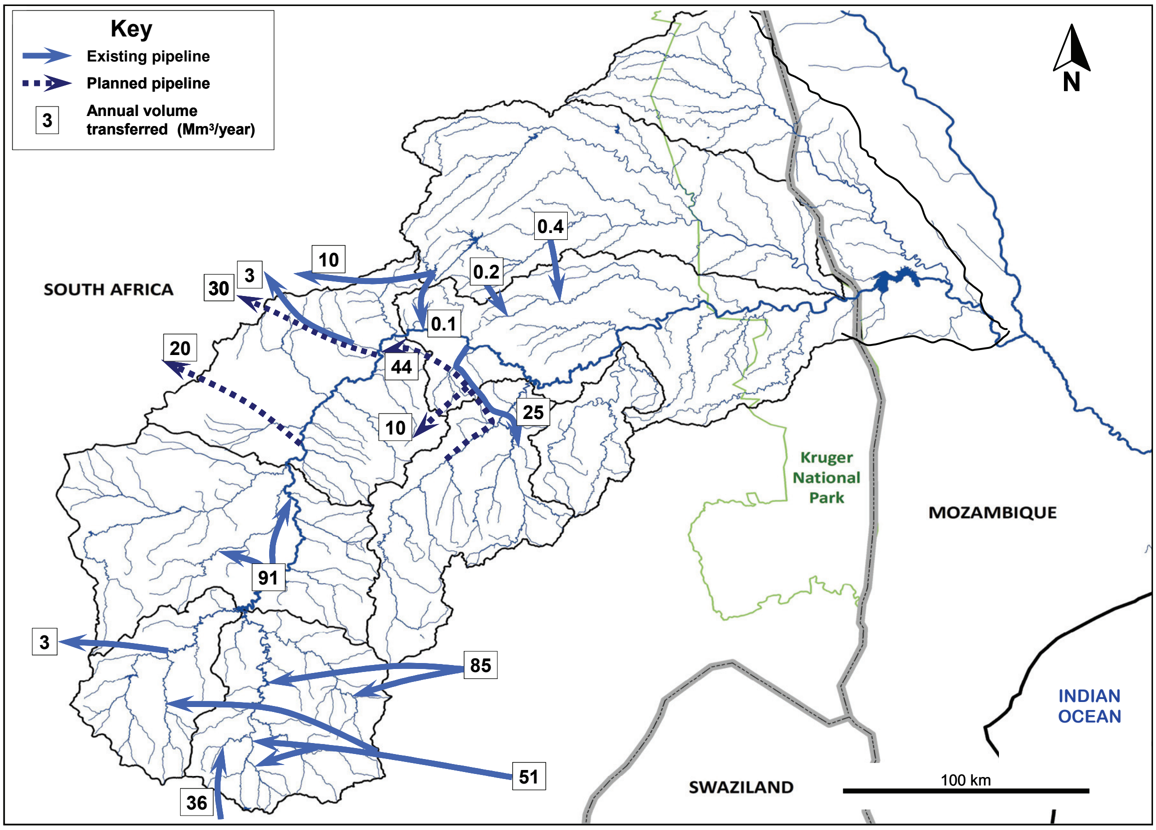

Figure 15. The location and size of existing and planned water transfers into and out of the Olifants catchment, as well as “internal” water transfers within the catchment. (Data on existing water transfers sourced from DWAF, 2004a supplemented with data on planned new water transfer pipelines obtained from the Trans-Caledon Tunnel Authority (TCTA)).

Small volumes of water are transferred out of the Olifants and Great Letaba catchments (approximately 16 Mm^3/year) to meet the water needs of the towns of Cullinan, Mokopane and Polokwane – located respectively in the Pienaars, Mogolokwena and Sand river catchments to the west (**Figure 15**). The second phase of the Olifants River Water Resources Development Project (ORWRDP-2) is presently under construction; this project consists of a major set of water supply pipelines that will take water from the De Hoop Dam on the Steelpoort River to the communities and mines located in the middle reaches of the Olifants River catchment (ACER-CSIR, 2004). Additional pipelines forming part of this project will supply water to the towns of Polokwane (30 Mm^3/year) and Mokopane (20 Mm^3/year).

In addition to the water transfers into and out of the Olifants River catchment, there are also two important internal water transfers within the Olifants River catchment (**Figure 15**). The first of these transfers provides water to the Groblersdal Irrigation Board (91 Mm^3/year from Lake Loskop), while the second – the Leballelo Pipeline – transfers water from the middle reaches of the Olifants River to nearby communities and mines (approximately 25 Mm^3/year).

In addition to water abstracted for domestic use, large volumes of water are also withdrawn for irrigation; for example: the extensive irrigation areas along the main stem of the Olifants River and many of its major perennial tributaries (Dabrowski *et al.*, 2010). Most small-scale farmers have to rely either on red-fed agriculture or on water drawn from shallow wells or nearby watercourses. Overall, the competition for the limited water resources available is likely to become more intense in future (DWAF, 2004a, b).

3. ESTABLISHING THE CATCHMENT WATER QUALITY CHARACTERISTICS

A considerable amount of information is available on water quality issues across the Olifants River. Unfortunately, most of this information is contained in a variety of project-specific documents – some of which are considered to be confidential – and a variety of consultancy reports, academic theses and published papers. The compilation and synthesis of this information is problematic because most reports do not provide details of the specific techniques used to assess whether or not the data used were reliable.

Throughout the length of the Olifants River and its tributaries, there are considerable differences in opinion as to the fitness-for-use of the water in the river system. In some areas, the water quality is considered to be reasonably good and the water is usually fit for most designated uses. However, several areas located in the upper, central and lower reaches of the catchment (**Figure 1**) experience serious water quality problems due to increasing salinity or the presence of high concentrations of sulphate, making the water less suitable for irrigation purposes and for domestic use (Balance *et al.*, 2001). In addition, most cities, towns and smaller communities discharge untreated or partially treated domestic and industrial effluent into the various rivers (*e.g.* the cities and towns of the Mpumalanga Highveld). As long as the waste material is innocuous and there is sufficient dilution (Ashton, 1993; Ashton and Van Vliet, 1997), this practice seldom has long-term or large-scale detrimental effects. However, with increasing quantities of effluent and declining river flows driven by escalating demands for water, water quality problems now occur more frequently (Bruwer and Ashton, 1989). Water quality problems caused by effluent seepages and discharges tend to become more acute further downstream, as more and more towns, mines and industry contribute their effluent to the total river flow, while evaporative concentration accentuates the effects of rising salinity and increasing eutrophication.

In some sub-catchments where the rivers are normally seasonal and only flow during the wet summer months, effluent discharges and seepage from mining operations have transformed the river into a perennially flowing system. In the case of the Ga-Selati River, effluent discharges and seepage from Phalaborwa now comprise the entire dry season flow of the lower reaches of this river (Ashton *et al.*, 1992). These dry season flows often equal the volume of the dry season low flows released from the Phalaborwa Barrage, the last water supply reservoir in the South African portion of the lower Olifants River.

This study relied heavily on data collected as part of the DWA national flow and water quality monitoring programmes in the Olifants catchment. Therefore, great care was exercised to determine the reliability of all the water quality data that were used. The routine monitoring data provided by DWA allow evaluation of the key water quality problems that occur in the Olifants River catchment, namely: salinization through high concentrations of total dissolved salts, with linked implications for the suitability of water for irrigation; nutrient (nitrogen and phosphorus) concentrations that reflect the trophic status of the river; and concentrations of major cations and anions that allow evaluation of the corrosion potential of the water and the influence of mining and industrial activities. The virtual absence of any routine monitoring data on trace metal concentrations prevented detailed evaluation of potentially toxic metals.

3.1 Selection of representative data collection sites

The Department of Water Affairs (DWA) operates an excellent website (www.dwa.gov.za-iwqs-wms-data-000key.asp) through their Directorate: Resource Quality Services (RQS) that provides easy access to all of the flow data and water quality data collected during official monitoring programmes across South Africa. The extent of data holdings for each monitoring site can be examined using GoogleEarth© via the DWA website, after which data from the chosen sites can be selected and downloaded to a standard Excel spreadsheet for analysis.

A total of twenty-seven (27) river water quality monitoring sites and eight (8) reservoir water quality monitoring sites were selected in the Olifants River catchment as representing the main stem of the Olifants River plus inflows from important tributaries. An additional two (2) reservoir monitoring sites were selected – one each for the Great Letaba (site R-9) and Shingwidzi (site R-10) catchments; these reservoirs were the most downstream reservoir in each sub-catchment and provided an indication of the water quality provided by these sub-catchments to the Olifants River (**Figure 16**).

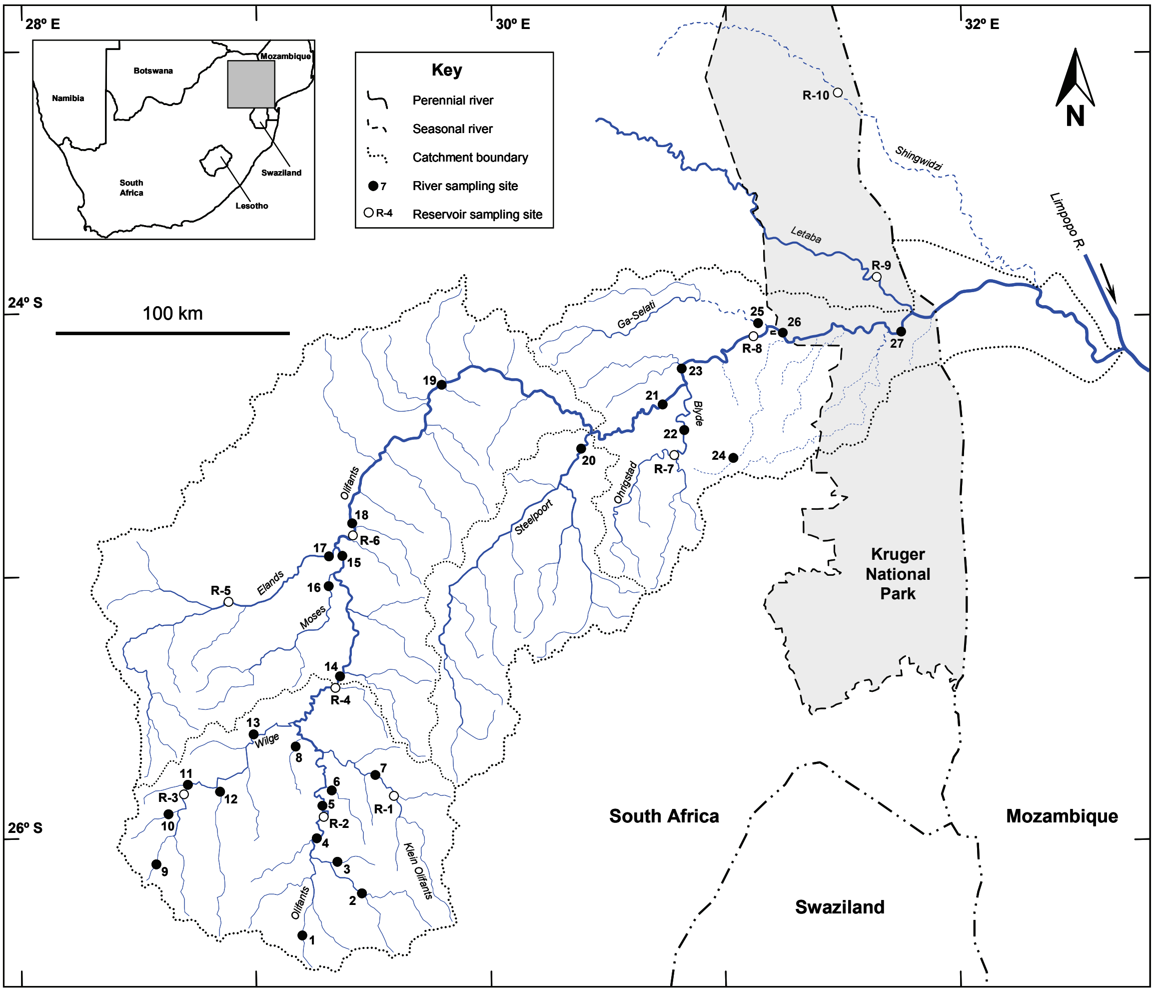

Figure 16. Sketch map of the Olifants River catchment showing the locations of 27 river monitoring sites and 10 reservoir monitoring sites where water quality data were extracted for analysis. (Inset shows the area of the map within southern Africa).

The total data record for each selected site was downloaded into an Excel spreadsheet, and carefully evaluated to determine the reliability of the data in each set. The location of each monitoring site is shown in **Figure 16**.

3.2 Evaluation of data reliability

The routine DWA water quality monitoring programme provides chemical analyses of a standard set of water quality variables (electrical conductivity, pH, major cations, major anions, fluoride and nutrients), though a set of analyses for a particular water sample might contain no data for one or more water quality variables.

The process of evaluating the reliability of the water quality data for each monitoring site consisted of the following sequence of steps:

- Within each data set, water samples that had the same date of sample collection were examined; the first complete set of analyses for a particular date was accepted while the rest of the analyses for that date were rejected as duplicates;
- Calculated values such as total dissolved salts (TDS) and Sodium Adsorption Ratio (SAR) were removed for each sampling date, together with analytical results for Kjeldahl Nitrogen and Total Phosphorus;
- The concentration of total dissolved salts (TDS) in each sample was calculated by summing the concentrations of all cations (calcium, magnesium, sodium, potassium, ammonium-N and silica) and anions (sulphate, chloride, carbonate – calculated from the total alkalinity concentration, fluoride, orthophosphate, nitrate). A check of the commonly used conversion ratio (x 6.5) that is often used to convert electrical conductivity measurements to total dissolved solids revealed considerable variation across the different sampling sites. This ratio was therefore not used to calculate total dissolved salt concentrations;
- The ionic activity balance for each water sample was calculated using calcium, magnesium, sodium, potassium, ammonium-N for cations and chloride, sulphate carbonate (calculated from total alkalinity measurements), fluoride and nitrate as anions;
- The difference in ionic activity for the sum of cations and the sum of anions (expressed as a percentage of the ionic activity of the sum of cations plus anions – Appelo and Postma, 2007) – was calculated for each set of analyses. Where the difference between the total cation charge and total anion charge was greater than 5% of the total (combined) ionic charge, that sample was rejected as being unreliable for decision-making.
- The inorganic N:P ratio was then calculated for each sample, using the sum of ammonium-N plus nitrate-N to reflect total inorganic nitrogen and orthophosphate to reflect total inorganic phosphorus.

The resulting data set of data for a particular site was regarded as reliable for further statistical analysis. The characteristics of each river and reservoir data set (DWA site number, site name, river name, start and end date of sampling, number of unreliable samples, average sample collection frequency) are listed in **Table 2**.

It is clear from the information presented in **Table 2** that thirteen (13) of the river sampling sites and two (2) of the reservoir sampling sites had relatively low proportions of reliable samples (*i.e.* below 90% of samples were reliable), with one site having only 26% of samples reliable. This is unfortunate because it indicates that the benefits to be gained from regular sampling and analysis of water samples are not being fully realized.

In a similar vein, the average sampling frequency was calculated for each set of data from each sampling site, after removal of unreliable samples, taking into account that most data sets also displayed large gaps where no sampling had taken place. These sampling frequency data are also listed in **Table 2**. It is clear from the data in **Table 2** that eighteen (18) of the river sampling sites and all ten (10) of the reservoir sampling sites had a sampling interval of more than fourteen (14) days between samples, with some sites (*e.g.* on the Ga-Selati River and the Moses River having an average sampling interval of greater than 50 days between samples). Similar long intervals were recorded for all ten (10) of the reservoir sampling sites. As a general 'rule of thumb' in water quality monitoring, a sampling interval should ideally not be longer than 14 days. Counter arguments that are based on the results of auto-correlation analyses that indicate a direct relationship between subsequent samples are often suspect, because there should be a relationship (similarity) between samples that are representative of the same drainage area. It is the shorter (*i.e.* less than 14-day intervals) sampling frequencies that are able to discern individual unusual events – such as an effluent spill – that occur within a catchment (Appelo and Postma, 2007).

3.3 Calculation of statistical values

A simple sequence of percentile values (minimum, 5%, 25%, 50%, 75%, 95%, maximum) was calculated for each water quality variable at each site, using the entire data record available for each site, to provide a set of characters that describe the behaviour of each water quality variable at that site. The resulting summary statistics for each water quality variable at each river and reservoir monitoring site are presented in **Appendix Table A3** and **Appendix Table A4** for river and reservoir sites, respectively.

In each of these appendix tables, percentile values that exceed the Chronic Effect Value (CEV) for aquatic ecosystems, domestic uses and irrigation uses are indicated by appropriate coloured shading. Arithmetic mean values were not calculated for the water quality variables because the data sets displayed non-normal, or skewed data distributions, indicating that parametric statistics should not be used (Appelo and Postma, 2007).

The percentile values calculated for each water quality variable were used to draw box and whisker plots for selected river and reservoir monitoring sites along the length of the Olifants River, and to illustrate the influence of inflows from tributary streams. These longitudinal profiles are presented and discussed in **Section 4.4** of this report.

A set of Stiff diagrams (sometimes known as 'kite diagrams') was also drawn for the median concentration values of the major water quality constituents at each river and reservoir monitoring site. These diagrams are displayed in **Figure 17** (river sites) and **Figure 18** (reservoir sites), with an indication to a central map as to where the specific site is located. The Stiff diagram for each site also includes a value for the median sum of cations at that site, indicated in the top right-hand corner of the diagram. These diagrams provide a broad overview of the typical (median) ionic composition of the water at each site over the entire period of record (Appelo and Postma, 2007).

For each sampling site, the water quality data set was examined and the data collected on a date on or close to the middle of each month (*i.e.* between the 10^{th} and the 20^{th} day of the month) was chosen as a representative for the month in question. Where only a single sample was available for a particular month (*e.g.* the third day of the month) then this set was used to represent that month. These 'monthly' representative data were then used to plot eight (8) time-series graphs for each sampling site: Total Dissolved Salts; pH; Sulphate:Chloride ratio; Corrosion Ratio; Sodium Adsorption Ratio; Inorganic N:P ratio; Sulphate; and Orthophosphate. All of these graphs for each of the twenty-seven (27) river sampling sites and ten (10) reservoir sampling sites are shown in **Appendix A1** and **Appendix A2**, respectively. A seven-point moving average was used to illustrate trends over time in each of these graphs. The monthly representative values for TDS, sulphate and orthophosphate were also used to estimate the monthly loads of these constituents contributed by the various tributary rivers to the Olifants River.

Table 2. Summary details (number, name, river system, location, start and end sampling dates, number of samples) for the Department of Water Affairs river and reservoir water quality sampling sites analyzed in this study. Shaded cells in the body of the table indicate sites with a low proportion of reliable samples and average sampling frequency is regarded as too high. (All data obtained from DWA website: www.dwa.gov.za-iwqs-wms-data-000key.asp).

Site Code No.	DWA Site No.	Quarternary Catchment No.	River Name	Gauging Station Name	Sampling Start Date	Sampling End Date	Elapsed Time (Days)	Total No. of Samples Analyzed	No. of Unreliable Samples	Proportion of Reliable Samples (%)	Average Sampling Frequency (days)
River Sites											
1	B1H006	B11D	Trichardtspruit	Rietfontein	22-Nov-82	17-Jun-08	9373	760	139	81.7	15.1
2	B1H018	B11A	Olifants	Middelkraal	27-May-91	17-Jun-08	6227	580	70	87.9	12.2
3	B1H021	B11E	Steenkoolspruit	Middeldrift	02-Jul-90	17-Jun-08	6556	668	28	95.8	10.2
4	B1H005	B11F	Olifants	Wolwekrans	20-Nov-79	01-Apr-08	9986	823	39	95.3	12.7
5	B1H010	B11J	Olifants	D/S Witbank Dam	26-Jun-85	06-May-08	8345	614	10	98.4	13.8
6	B1H002	B11H	Spookspruit	Elandspruit	05-May-79	31-Mar-08	10551	792	93	88.3	15.1
7	B1H015	B12D	Klein Olifants	D/S Middelburg Dam	01-Feb-83	29-Mar-08	9182	1131	31	97.3	8.3
8	B1H004	B11K	Klipspruit	Zaaihoek	17-Sep-76	31-Mar-08	11511	841	163	80.6	17.0
9	B2H008	B20B	Koffiespruit	Rietvallei	26-Aug-85	18-Jun-08	8158	508	63	87.6	18.3
10	B2H004	B20C	Osspruit	Boschkop	27-Oct-84	21-May-08	8602	839	127	84.9	12.1
11	B2H003	B20D	Bronkhorstspruit	Bronkhorstspruit	03-May-83	23-Apr-08	9115	586	82	86.0	18.0
12	B2H014	B20F	Wilge	Onverwacht	19-Jan-91	18-Jun-08	6345	536	72	86.6	13.7
13	B2H015	B20J	Wilge	Zusterstroom	05-Jan-94	18-Jun-08	5275	457	61	86.6	13.3
14	B3H017	B32C	Olifants	D/S Loskop Dam	01-Sep-93	22-May-08	5374	432	11	97.5	12.8
15	B3H001	B32J	Olifants	Loskop North	12-Oct-76	11-Apr-08	11496	593	23	96.1	20.2
16	B3H005	B32H	Moses	Mosesriviermond	12-Oct-76	14-Dec-04	6635	143	11	92.3	50.3
17	B3H021	B31J	Elands	Scherp Arabie	06-Jan-94	03-Apr-08	5197	292	0	100.0	17.8
18	B5H004	B51E	Olifants	D/S Flag Boshielo Dam	01-Sep-93	26-Dec-07	5221	411	304	26.0	48.8
19	B5H002	B52G	Olifants	Zeekoegat	26-May-81	09-Jun-93	4405	117	8	93.2	40.4
20	B4H011	B41K	Steelpoort	Alverton	02-Nov-84	28-Feb-08	7339	485	32	93.4	16.2
21	B7H009	B71H	Olifants	Finale Liverpool	10-May-79	08-Oct-07	10005	438	34	92.2	24.8
22	B6H004	B60J	Blyde	Chester	12-Apr-78	12-Mar-08	10555	778	201	74.2	18.3
23	B7H007	B72D	Olifants	Oxford	17-Nov-75	24-Sep-08	12059	754	88	88.3	18.1
24	B7H004	B73A	Klaserie	Fleur-de-Lys	20-May-77	06-May-08	11316	333	174	47.7	71.2
25	B7H019	B72K	Ga-Selati	Loole	05-Jan-89	03-Jul-08	7054	388	11	97.2	18.7
26	B7H015	B73C	Olifants	Mamba	18-Oct-83	10-Mar-08	8904	616	24	96.1	15.0
27	B7H017	B73H	Olifants	Balule Rest Camp	18-Oct-83	29-May-08	8993	400	11	97.3	23.1
Water Storage Reservoir Sites											
R1	B1R002	B12C	Klein Olifants	Middelburg Dam	13-Nov-78	27-Mar-08	10719	345	15	95.7	33.5
R2	B1R001	B11J	Olifants	Witbank Dam	19-Mar-75	05-Mar-08	12031	497	11	97.8	24.8
R3	B2R001	B20C	Bronkhorstspruit	Bronkhorstspruit Dam	21-Jun-73	07-Jul-08	10967	375	39	89.6	38.1
R4	B3R002	B32A	Olifants	Loskop Dam	12-Jun-73	27-Nov-08	13219	445	39	91.2	32.6
R5	B3R005	B31F	Elands	Rhenosterkop Dam	05-Apr-83	20-Jun-08	9271	346	18	94.8	28.3
R6	B5R002	B51B	Olifants	Flag Boshielo Dam	06-Jan-94	03-Apr-08	4864	193	1	99.5	25.3
R7	B6R003	B60H	Blyde	Blyderivierspoort Dam	13-Apr-78	16-Jun-06	10253	268	80	70.1	54.5
R8	B7R002	B72D	Olifants	Phalaborwa Barrage	17-Nov-75	31-Jan-98	8440	167	11	93.4	54.1
R9	B8R018	B83E	Great Letaba	Engelhard Dam	29-Nov-83	30-May-08	8793	152	10	93.4	61.9
R10	B9R003	B90H	Shingwidzi	Kanniedood Dam	07-Feb-84	16-Dec-07	8725	239	19	92.1	39.7

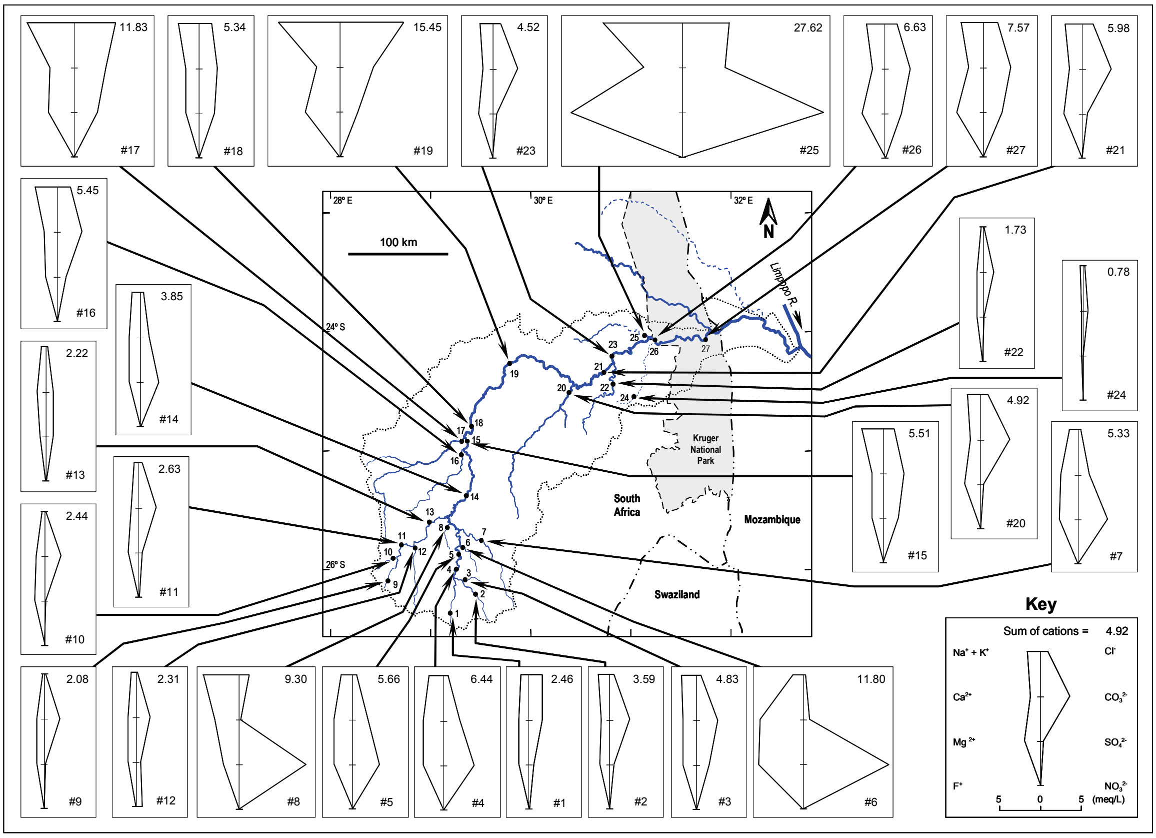

Figure 17. Stiff diagrams of the median concentrations of cations and anions at twenty-seven (27) river monitoring sites in the Olifants River catchment. The key diagram in the lower left-hand corner illustrates the position of each cation and anion in the Stiff diagram.

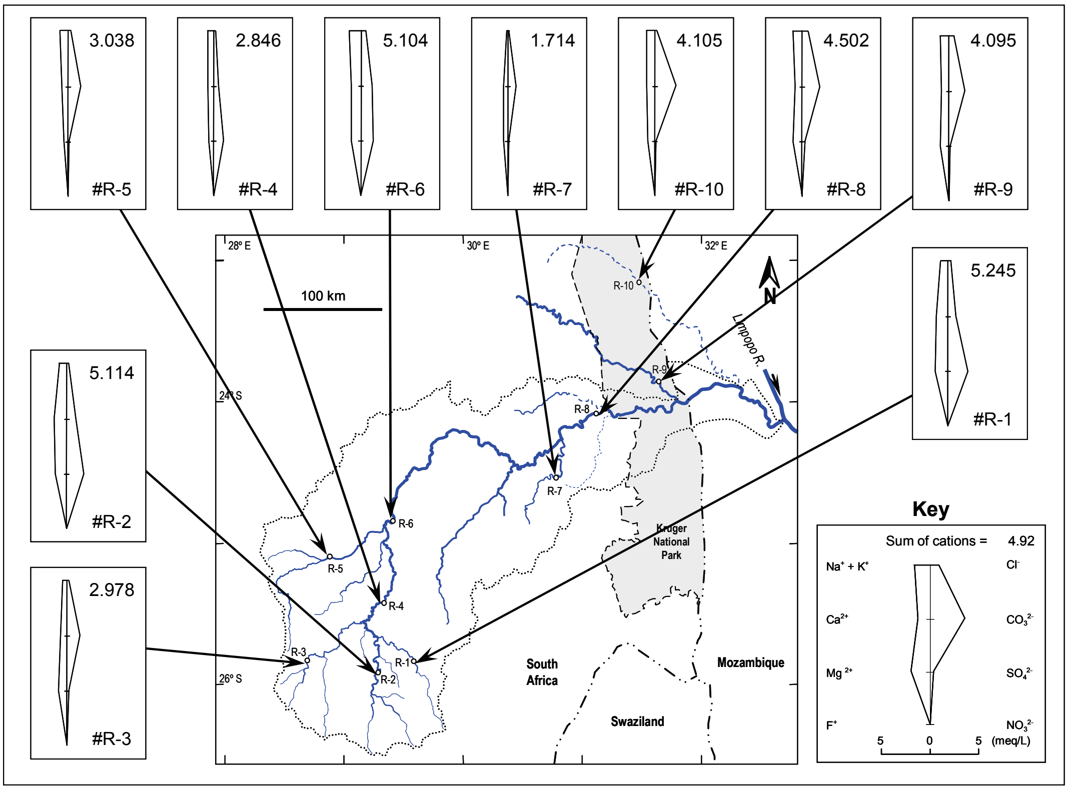

Figure 18. Stiff diagrams of the median concentrations of cations and anions at ten (10) reservoir monitoring sites in the Olifants catchment. The key diagram in the lower left-hand corner illustrates the position of each cation and anion in the Stiff diagram.

3.4 Calculation of water quality indices

Three indicators were calculated from the ionic activity data for each water sample as indices of the fitness-for-use of the water from a particular site and to reveal potential water quality problems at that site. These indices were:

Sulphate to Chloride Ratio (SCR): This is an indicator of the potential extent to which mining and/or industrial contributions and certain other land transformation activities, contribute to changes in water quality (Ashton *et al.*, 2001). The SCR is calculated from the ionic activity data as: (SO_4/Cl). An SCR value greater than 1.0 indicates a strong likelihood that mining and/or industrial activities have had an adverse influence on water quality at the sample site. An SCR value greater than 5.0 provides a definite indication that mining and/or industrial activities have had an adverse influence on water quality. In view of the long history of mining and industrial activities in the Olifants catchment, an SCR value of 5.0 was chosen to represent the equivalent CEV. An SCR value above 5.0 was then regarded as a definite indication of impacts arising from mining and/or industrial activities.

Sodium Adsorption Ratio (SAR): This is an indicator of the suitability of water for irrigation of crops. The SAR is calculated from the ionic activity data as: $Na/[\sqrt{((Ca + Mg)/2)}]$. The interpretation of the SAR values is shown in **Figure 19**. An SAR value below 1.5 with an electrical conductivity value of less than 40 mS/m indicates that the water is suitable for irrigation of all crops. An SAR value above 3.0 with an electrical conductivity value above 100 mS/m indicates that the water is of poor quality for irrigation of most crops and if used for irrigation, soil remediation would be required (DWAF, 1996b). In view of the widespread changes in water quality that have taken place throughout the Olifants catchment, an upper SAR value of 10.0 was selected as the CEV limit for use of water for irrigation. It is important to note that any SAR value above 3.0 is regarded as indicating the water to be of poor quality and therefore unsuitable for irrigation. Therefore, an irrigation CEV of 10.0 is regarded as extremely lenient because the water is not really suitable for irrigation uses.

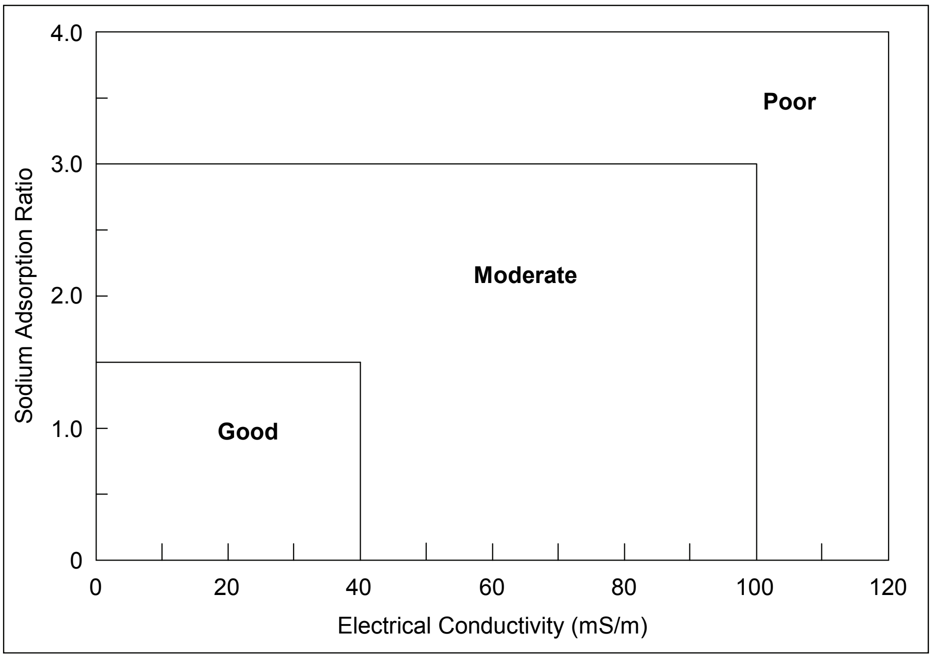

Figure 19. Plot of Sodium Adsorption Ratio (SAR) versus Electrical Conductivity (EC) to illustrate the influence of SAR and EC values on the suitability of water for irrigation.

Corrosion Potential Ratio (CPR): This is an indicator of the likelihood that the water could corrode metal pipes and fittings used to convey and deliver water to users. The CPR is calculated from the ionic activity data as: [(Cl + SO4)/Alkalinity]. A CPR value greater than 0.4 indicates that there is an increasing likelihood that the water will be corrosive (Dabrowski *et al.*, 2010). In view of the long history of water quality deterioration in the Olifants River catchment, an upper CPR value of 1.0 was chosen as the CEV. A CPR value above 1.0 was then regarded as a definite indication of potentially corrosive water – with potential adverse impacts for all water users, especially those such as irrigation agriculture that use extensive pipe and pumps systems to draw water directly from rivers and dams.

3.5 Choice of water quality guidelines to evaluate water quality

The existing water quality in virtually every tributary river the Olifants River catchment is regarded as 'modified' from natural conditions and the management class of most these river sections is regarded as either a "B" (slightly modified) or "C" (markedly modified) (Balance *et al.*, 2001). Therefore, it is not really appropriate to evaluate the existing water quality against the highest (ideal) water quality guidelines (the Target water Quality Range – TWQR). Instead, it is more appropriate from a water resource management and water quality management perspective to evaluate the existing water quality against the Chronic Effect Value (CEV), which indicates whether or not long-term exposure to water of a particular quality will have adverse effects on users. Accordingly, the CEV values for the selected water quality variables measured in DWA routine monitoring programmes was chosen (DWAF, 1996a, b, c). The TWQR and CEV values for the selected water quality variables or constituents and water quality indices are listed for comparison in **Table 3**.

Table 3. Comparison of water quality guideline values for Target Water Quality Range (TWQR) and Chronic Effect Value Range (CEVR) for those water quality constituents measured routinely by DWA – or calculated in this study – and where guidelines are available for aquatic ecosystems (Eco.), domestic use (Dom.) and agricultural use (Agric.). The guideline data were taken from DWAF (1996a, b, c); " – " indicates that no water quality guideline value is available for that constituent and type of use. (Note that aluminium, iron and manganese are measured infrequently).

Constituent	Units	Target Water Quality Range			Chronic Effect Value Range		
		Eco.	Dom.	Agric.	Eco.	Dom.	Agric.
E. C.	mS/cm	< 100	< 70	< 40	100-155	70-110	40-270
TDS	mg/ℓ	< 650	< 455	< 260	650-1000	455-720	–
pH	$-log_{10} [H^+]$	–	> 6-< 9	> 6.5-< 8.4	–	> 6-< 9	> 6.5-< 8.4
Calcium	mg Ca/ℓ	–	< 32	–	–	32-80	–
Magnesium	mg Mg/ℓ	–	< 30	–	–	30-50	–
Sodium	mg Na/ℓ	–	< 100	< 70	–	100-200	70-230
Potassium	mg K/ℓ	–	< 50	–	–	50-100	–
Chloride	mg Cl/ℓ	–	< 100	< 140	–	100-200	140-350
Sulphate	mg SO_4/ℓ	–	< 200	–	–	200-400	–
Alkalinity	mg $CaCO_3$/ℓ	–	< 100	–	–	100-200	–
Aluminium	mg Al/ℓ	< 0.005	< 0.15	< 5	0.005-0.010	0.15-0.5	5-20
Fluoride	mg F/ℓ	< 0.75	< 1.0	< 2.0	0.75-1.5	1.0-1.5	2.0-15.0
Iron	mg Fe/ℓ	–	< 0.1	< 0.2	–	0.1-0.3	0.2-1.5
Manganese	mg Mn/ℓ	< 0.18	< 0.05	< 0.02	0.18-0.37	0.05-1.0	0.2-10.0
Nitrate-N	mg NO_3-N/ℓ	–	< 6.0	< 5.0	–	6.0-10.0	–
Ammonium-N	mg NH_4-N/ℓ	< 0.007	< 1.0	–	0.007-0.015	1.0-2.0	–
Total Inorganic N	Mg N/ℓ	< 0.5	–	< 5	0.5-2.5	–	5-30
Ortho-phosphate	mg PO_4-P/ℓ	< 0.005	–	–	0.005-0.025	–	–
Indices:							
SO_4/Cl ratio	–	–	< 1.0	–	–	1.0-5.0	–
Corrosion potential	–	–	< 0.4	–	–	0.4-1.0	–
S.A.R.	–	–	–	< 2.0	–	–	2.0-8.0

The percentile data for each measured water quality constituent and each calculated water quality index for each river and reservoir sampling site are shown in **Appendix Table A3** and **Appendix Table A4**, respectively. All the percentile values that exceed the respective CEV values for that water quality constituent or water quality index are highlighted in a colour chosen to represent either aquatic ecosystems (green), domestic uses (blue) or irrigated agriculture (yellow). These data are discussed in the three sections of this report that deal with the upper reaches (**Section 4.1**), the middle reaches (**Section 4.2**) and the lower reaches (**Section 4.3**); the extent of these reaches conforms closely to the DWA segmentation of sub-catchments shown in **Figure 2** and the reach outlines shown in **Figure 1**. The contributions from the Great Letaba River and the Shingwidzi River are discussed in **Section 4.3**, which deals with the lower reaches of the Olifants River.

The percentile data that illustrate the longitudinal changes in water quality which occur along the length of the Olifants River, plus the contributions from the tributary rivers, are illustrated and discussed in **Section 4.4** of this report. These longitudinal diagrams include both river sampling sites and reservoir sampling sites. The contribution of total dissolved salts from the major tributary rivers are illustrated and discussed in **Section 4.5** of this report, while **Section 4.6** discusses the influence of the large water storage reservoirs on river water quality in the Olifants River.

4. WATER QUALITY FEATURES OF THE OLIFANTS RIVER CATCHMENT

The extent of the upper, middle and lower reaches of the Olifants River catchment and their major tributary rivers is shown in **Figure 1** while the individual sub-catchments that comprise each reach are shown in **Figure 2**. The descriptions and discussion of water quality in the different reaches of the Olifants River catchment and within the tributary rivers are focussed on the interpretation of DWA routine monitoring data. Where additional data are available from other studies (*e.g.* the occasional data on trace metal concentrations in the rivers draining the upper reach of the Olifants River), then these data are also discussed.

4.1 The upper reaches of the catchment

This segment of the Olifants River catchment comprises the Olifants and Klein Olifants drainages (sub-catchment B1) and the Wilge River drainage (sub-catchment B2). The 13 river sampling sites in the upper reach are sites 1 to 8 in sub-catchment B1 and sites 9 to 13 in sub-catchment B2. The 4 reservoir sampling sites in this reach are R1, R2 and R4 in sub-catchment B1 and R3 in sub-catchment B2 (**Figure 16**).

The time-series graphs for the eight (8) water quality constituents and water quality indices relevant to the river and reservoir sampling sites in this reach are shown in **Appendix A1** (river sites 1 to 13) and **Appendix A2** (reservoir sites R1 to R4), respectively. The percentile water quality data for the river sites and reservoir sites are shown in **Appendix Table A3** and **Appendix Table A4**, respectively.

River Site #1 – Trichardtspruit at Rietfontein (DWA gauge B1H006):

A total of 621 reliable water samples (81.7% of the total data set), collected between 22 November 1982 and 17 June 2008 with an average sampling frequency of 15.1 days, comprised this data set (**Table 2**).

The water in the Trichardtspruit tributary of this reach (**Appendix A1**, **Figures 1A-1H**) is characterized by relatively low TDS concentrations (100 – 200 mg/litre), slightly alkaline pH values (7.0 – 8.5), relatively low sulphate concentrations (20 – 40 mg/litre), and low concentrations of orthophosphate (0.02 – 0.04 mg/litre). The moderately low values for the sulphate : chloride ratio (1.0 – 3.0) and corrosion ratio (0.25 – 0.65) suggest that there has been a relatively minor influence of mining and/or industrial activity on water quality in this tributary. The low values for sodium adsorption ratio (0.4 to 0.9) indicate the water is still suitable for irrigation. The relatively low values for the inorganic N:P ration (< 20) suggest that the water is being enriched with nutrients – either from domestic effluent discharges or from agricultural sources. The occasional high values recorded for orthophosphate (**Appendix Figure A1H**) suggest that this might be associated with individual runoff events from cultivated lands or irrigated pastures where livestock are kept.

The data show some evidence of seasonal cyclical changes in the concentrations of water quality constituents and in the values of water quality indices. However, there is little evidence of any significant trends of change over the length of the data record and the water appears to be fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations exceeded the aquatic ecosystems CEV though this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum recorded values for total alkalinity, sulphate : chloride ratio and corrosion ratio exceeded the CEV for domestic water use. Approximately 50% of the inorganic N:P ratio values were below 10 indicating a likelihood of nutrient enrichment; this is supported by the upper 5% of the orthophosphate concentrations exceeding the CEV for aquatic ecosystems and the occasional high nitrate-N concentrations. However, with the exception of ammonium-N concentrations, the exceedance values represent less than 1% of the total data set for this site and are therefore not a cause for concern.

River Site #2 – Olifants River at Middelkraal (DWA gauge B1H018):

A total of 510 reliable water samples (87.9% of the total data set), collected between 27 May 1991 and 17 June 2008 with an average sampling frequency of 12.2 days, comprised this data set (**Table 2**).

The water in the Olifants River at this site (**Appendix A1**, **Figures 2A** – **2H**) is characterized by slightly higher TDS concentrations (100 – 300 mg/litre), slightly alkaline pH values (7.5 – 9.0), moderate sulphate concentrations (30 – 150 mg/litre, increasing slightly with time) and variable concentrations of orthophosphate (0.01 – 0.08 mg/litre). The initially low values (< 1) for the sulphate : chloride ratio have increased to above 2.0 between 1990 and 2008, while corrosion ratio has also increased from approximately 0.4 to 1.0 in the same period. This suggests that there has been a relatively small influence of mining and/or industrial activities on water quality at this site. The values for the sodium adsorption ratio (0.5 – 2.0) are relatively low but seasonally variable and the water is still suitable for irrigation use. The relatively low values for the inorganic N:P ratio (< 10) plus the slowly increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – either from the discharge of domestic effluents or from agricultural sources. The relative immobility of orthophosphate in soil suggests that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show clear signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. However, while there is evidence of a gradual trend of increase in the concentrations of sulphate and orthophosphate over the length of the data record, the water appears to be suitable for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 25% of the nitrate-N concentrations exceeded the CEV for aquatic ecosystems though, for ammonium-N, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum recorded values for pH, magnesium and the sulphate : chloride ratio exceeded the

CEV for domestic water use, while the upper 5% of the total alkalinity concentrations and corrosion ratio values also exceed the CEV for domestic water use. Approximately 75% of the inorganic N:P ratio values were below 10 indicating a likelihood of nutrient enrichment; this is supported by the upper 25% of the orthophosphate concentrations exceeding the CEV for aquatic ecosystems and the occasional high nitrate-N concentrations. However, these exceedance values represent a very low proportion of the total data set for this site and therefore do not represent a major cause for concern.

River Site #3 – Steenkoolspruit at Middeldrift (DWA gauge B1H021):

A total of 640 reliable water samples (81.7% of the total data set), collected between 2 July 1990 and 17 June 2008 with an average sampling frequency of 10.2 days, comprised this data set (**Table 2**).

The water in the Steenkoolspruit at this site (**Appendix A1**, **Figures 3A – 3H**) is characterized by moderate TDS concentrations (200 – 600 mg/litre), alkaline pH values (7.5 – 9.0), moderate sulphate concentrations (50 – 250 mg/litre) and low but variable concentrations of orthophosphate with occasional high values (0.03 – 0.6 mg/litre). The values for the sulphate : chloride ratio are relatively low (1 – 4) though frequent higher values are recorded, and the corrosion ratio remained relatively constant (0.45 and 1.0), though frequent higher values were also recorded. These data suggest that mining and/or industrial activities have had a relatively low influence on water quality at this site. The values for the sodium adsorption ratio (0.5 – 2.0) are relatively low but seasonally variable and the water is still suitable for irrigation use. The relatively low values for the inorganic N:P ratio (< 10) plus the moderately high – and slowly increasing – orthophosphate concentrations suggest that the water at this site is being enriched by nutrients – either from the discharge of domestic effluents or from agricultural sources. The relative immobility of orthophosphate in soil suggests that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. However, while there is evidence of a gradual trend of increase in the concentrations of TDS, sulphate and orthophosphate over the length of the data record, the water appears to be suitable for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 75% of the nitrate-N concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum recorded ammonium-N concentration (6.94 mg NH_4-N/litre) exceeded the CEV for domestic water use. The minimum and maximum recorded values for pH exceeded the lower and upper CEV limits for domestic water uses. The maximum recorded values for TDS, potassium, calcium, magnesium and sulphate exceeded the CEV for domestic water use, while the upper 5% of the total alkalinity concentrations at this site exceeded the CEV for domestic water use. The upper 50% of the values for the sulphate : chloride ratio and the corrosion ratio exceeded the CEV for domestic water use. Approximately 75% of the inorganic N:P ratio values were below 10 indicating a likelihood of nutrient enrichment; this is supported by the upper 75% of the orthophosphate concentrations exceeding the CEV for aquatic ecosystems and the occasional high nitrate-N concentrations. However, while these exceedance values do reflect the enrichment of the water at this site, the values represent a relatively low proportion of the total data set for this site and are therefore not a major cause for concern.

River Site #4 – Olifants River at Wolwekrans (DWA gauge B1H005):

A total of 784 reliable water samples (95.3% of the total data set), collected between 20 November 1979 and 1 April 2008 with an average sampling frequency of 12.7 days, comprised this data set (**Table 2**).

The water in the Olifants River at this site (**Appendix A1**, **Figures 4A** – **4H**) is characterized by higher TDS concentrations (250 – 1000 mg/litre), slightly alkaline pH values (7.5 – 8.5), high sulphate concentrations (100 – 700 mg/litre, increasing slightly with time) and variable concentrations of orthophosphate (0.01 – 0.06 mg/litre). The initially low values (< 3) for the sulphate : chloride ratio have increased to between 5 and 15 between 1985 and 2008, while corrosion ratio has also increased from approximately 1 to between 3 and 4 in the same period. This suggests that there has been a gradual increase in the influence of mining and/or industrial activities on water quality at this site. The values for the sodium adsorption ratio (0.6 – 1.5) are relatively low but seasonally variable and the water is still suitable for irrigation use. The relatively low values for the inorganic N:P ratio (most values are less than 10) plus the slowly increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – either from the discharge of domestic effluents or from agricultural sources. The relative immobility of orthophosphate in soil suggests that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show clear signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. However, while there is evidence of a gradual trend of increase in the concentrations of sulphate and orthophosphate over the length of the data record, the water appears to be fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 5% of the recorded values for TDS, potassium and sulphate exceeded the CEV for domestic water use, while the maximum recorded values for calcium, magnesium and total alkalinity also exceeded the CEV for domestic water use. The upper 50% of the values for the sulphate : chloride ratio and the upper 75% of the values for the corrosion ratio exceeded the CEV for domestic water use. Approximately 25% of the inorganic N:P ratio values were below 10 indicating a relatively small likelihood of nutrient enrichment. However, the fact that the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, with occasional high nitrate-N concentrations, suggests that nutrient enrichment is definitely occurring at this site. Nevertheless, while the exceedance values reflect the occurrence of nutrient enrichment and the influence of mining and/or industrial activities on the water at this site, the data for this site suggest that the water is still fit for recognized uses and is therefore not a major cause for concern.

River Site #5 – Olifants River downstream of Witbank Dam (DWA gauge B1H010):

A total of 604 reliable water samples (98.4% of the total data set), collected between 26 June 1985 and 6 May 2008 with an average sampling frequency of 13.8 days, comprised this data set (**Table 2**).

The water in the Olifants River at this site downstream of Witbank Dam (**Appendix A1**, **Figures 5A** – **5H**) is characterized by moderate TDS concentrations (200 – 500 mg/litre), slightly alkaline pH values (7.5 – 8.5), moderate sulphate concentrations (100 – 250 mg/litre, though apparently decreasing in recent years) and variable but increasing concentrations of orthophosphate (0.01 – 0.04 mg/litre). The values for the sulphate : chloride ratio reveal a sudden increase from 7 to 17 in 1996, followed by a decrease to between 5 and 10, while the corrosion ratio data show a similar 'spike' in 1996 followed by a decrease to between 1.5 and 3 in the same period. This suggests that – apart from the 1996 increase and subsequent decrease – there has been a more or less constant influence of mining and/or industrial activities on water quality at this site. The values for the sodium adsorption ratio (0.6 – 1.1) are relatively low but seasonally variable and the water is still suitable for irrigation use. The relatively low values for the inorganic N:P ratio (most values are less than 10) plus the gradually increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – possibly upstream of Witbank Dam. The increasing orthophosphate concentrations suggest that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show clear signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. However, while there is evidence of a gradual trend of increase in the concentration of orthophosphate over the length of the data record, there has been a slight decrease in sulphate concentrations in recent years. The water appears to be reasonably fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum recorded pH value exceeded the CEV for domestic water use. The upper 95% of the values for the sulphate : chloride ratio and the corrosion ratio exceeded the CEV for domestic water use, indicating a strong likelihood that mining and/or industrial activities have influenced the water quality at this site. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment and the upper 5% of the orthophosphate concentrations exceeded the CEV for domestic water uses, supporting the suggestion that nutrient enrichment is occurring at this site. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water at this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algal blooms and should be treated before use.

River Site #6 – Spookspruit at Elandspruit (DWA gauge B1H002):

A total of 699 reliable water samples (88.3% of the total data set), collected between 5 May 1979 and 31 March 2008 with an average sampling frequency of 15.1 days, comprised this data set (**Table 2**).

The water in the Spookspruit at this site (**Appendix A1**, **Figures 6A – 6H**) is characterized by high and increasing TDS concentrations (increasing from 200 to over 2500 mg/litre between 1980 and 2008), slightly acidic pH values (5 – 8), high and increasing sulphate concentrations (increasing from around 100 to over 1750 mg/litre between 1980 and 2008) and moderately low but variable concentrations of orthophosphate with occasional high values (0.01 – 0.4 mg/litre). The values for the sulphate : chloride ratio have increased from below 10 in 1980 to over 100 in 2008 and frequent higher values (to above 150) are recorded. The corrosion ratio data show a relatively steady increase from below 5 in 1980 to over 40 in 2008. These data indicate that mining and/or industrial activities have had a strong and increasingly detrimental influence on water quality at this site. The values for the sodium adsorption ratio have gradually declined from approximately 0.7 in 1980 to 0.4 in 2008 – with distinct seasonal variations – and the water appears to be suitable for irrigation use. The moderately high and very variable values for the inorganic N:P ratio (ranging from 5 to 100) plus the moderately low but gradual increase in orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – either from the discharge of domestic effluents or from agricultural sources.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is clear evidence of increasing concentrations of TDS, sulphate and orthophosphate, plus increasing values for the sulphate : chloride ratio and corrosion ratio over the length of the data record, indicating that the water is not fit for all designated uses at all times and would require pre-treatment before use.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 25% of the potassium and calcium concentrations and the upper 50% of the sulphate concentrations exceeded the CEV for domestic water uses, and reflect the influence of mining and/or industrial effluents on water quality at this site. The upper 75% of the values for the sulphate : chloride ratio and the corrosion ratio, plus the upper 25% of the TDS concentrations, exceeded the CEV for domestic water use, indicating a strong likelihood that mining and/or industrial activities have influenced the water quality at this site. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, supporting the suggestion that nutrient enrichment is occurring at this site. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water at this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water should not be used without prior treatment.

River Site #7 – Klein Olifants River downstream of Middelburg Dam (DWA gauge B1H015):

A total of 1100 reliable water samples (97.3% of the total data set), collected between 1 February 1983 and 29 March 2008 with an average sampling frequency of 8.3 days, comprised this data set (**Table 2**).

The water in the Klein Olifants River at this site (**Appendix A1**, **Figures 7A – 7H**) is characterized by moderately high and increasing TDS concentrations (increasing from 200 to over 600 mg/litre between 1985 and 2008), slightly alkaline pH values (7 – 8.5), moderately high and increasing sulphate concentrations (increasing from around 100 to over 350 mg/litre between 1985 and 2008) and relatively low but very variable and slowly increasing concentrations of orthophosphate with occasional high values above 0.05 mg/litre. The concentrations of TDS and sulphate decreased between 1995 and 2001, accompanied by a similar decrease in the sulphate : chloride ratio and corrosion ratio during this period. This would appear to be the result of improved interception and treatment of mining and/or industrial effluents. Overall, the values for the sulphate : chloride ratio have increased from around 5 in 1985 to over 15 in 2008. The corrosion ratio data show a relatively wide range of variability between 2 and 6 in the same period. These data suggest that mining and/or industrial activities have had a moderate and increasingly influence on water quality at this site. The values for the sodium adsorption ratio varied between 0.5 and 0.9 – with distinct seasonal variations – and the water appears to be suitable for irrigation use. The relatively low but variable values for the inorganic N:P ratio (declining from around 80 in 1985 to below 30 in 2008) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – either from the discharge of domestic effluents or from agricultural sources.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is clear evidence of increasing concentrations of TDS, sulphate and orthophosphate over the length of the data record, indicating that the water is not fully fit for all designated uses at all times and would require pre-treatment before use.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations, plus the maximum recorded nitrate-N concentration, exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 5% of the magnesium concentrations and the minimum recorded value for pH exceeded the CEV for domestic water uses. The upper 95% of the values for the sulphate : chloride ratio and the corrosion ratio exceeded the CEV for domestic water use, indicating a strong likelihood that mining and/or industrial activities have influenced the water quality at this site. Approximately 5% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment. The upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, supporting the suggestion that nutrient enrichment is occurring at this site. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water at this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water should not be used without prior treatment.

River Site #8 – Klipspruit at Zaaihoek (DWA gauge B1H004):

A total of 678 reliable water samples (80.6% of the total data set), collected between 17 September 1976 and 31 March 2008 with an average sampling frequency of 17 days, comprised this data set (**Table 2**).

The water in the Klipspruit at this site (**Appendix A1**, **Figures 8A – 8H**) is characterized by moderately high and slowly increasing TDS concentrations (increasing from around 400-500 mg/litre to between 600-800 mg/litre between 1980 and 2008). In 1978-1979, the pH values at this site were extremely acidic (between 3.0 and 4.0) and have slowly increased to between 6.0 and 7.0 by 2008. The abrupt pH changes between 1991-1992 and 1996-1997 appear to have been caused by the implementation of a treatment process for acidic mining effluent. The sulphate concentrations have increased from about 300 mg/litre to about 500 mg/litre during the same period. Orthophosphate concentrations have remained relatively low (< 0.02 mg/litre) with a gradual increase up to 2008, though the data set reveals wide seasonal variations. The values for the sulphate : chloride ratio have increased from around 3-4 in 1978 to between 6 and 8 in 2008. The corrosion ratio data show a relatively wide range of variability, with a marked decline from around 200 in 1980 to approximately 50-60 in 2008. These data suggest that mining and/or industrial activities have had a moderate to high influence on water quality at this site and that some form of treatment of mine effluent has taken place, though this appears not to be working continuously. The values for the sodium adsorption ratio have declined gradually from 3-4 in 1978 to 2-3 in 2008, with distinct seasonal variations, and the water appears to be reasonably suitable for irrigation use based on this statistic alone. The very variable values for the inorganic N:P ratio (declining from around 600-800 in 1978 to below 200 in 2008) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably from the discharge of domestic effluents.

The data show distinct signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is some evidence of increasing concentrations of TDS, sulphate and orthophosphate over the length of the data record, and the relatively high values for TDS and sulphate indicate that the water is not fully fit for all designated uses at all times and would require pre-treatment before use.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations, the upper 5% of the orthophosphate concentrations, and the upper 25% of the recorded nitrate-N concentrations exceeded the CEV for aquatic ecosystems, with the upper 5% of the ammonium-N concentrations exceeding the CEV for domestic water use. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 25% of the magnesium and sulphate concentrations, plus the lower 50% of the pH values, exceeded the CEV for domestic water uses. In addition, the maximum recorded concentrations for chloride, potassium and fluoride also exceeded the CEV for domestic water use. The upper 50% of the values for the sulphate : chloride ratio and all of the values for the corrosion ratio exceeded the CEV for domestic water use, indicating a strong likelihood that mining and/or industrial activities have influenced the water quality at this site, despite whatever treatment may have occurred upstream of this site. Approximately 5% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations, which exceeded the CEV for aquatic ecosystems. The upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, again supporting the suggestion that nutrient enrichment is occurring at this site. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water at this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water should not be used without prior treatment. The upper 25% of the sodium adsorption ratio values are below the chosen limit of 10.0, but still indicate that the water is problematic for irrigation use.

River Site #9 – Koffiespruit at Rietvallei (DWA gauge B2H008):

A total of 445 reliable water samples (87.6% of the total data set), collected between 27 October 1985 and 18 June 2008 with an average sampling frequency of 18.3 days, comprised this data set (**Table 2**).

The water in the Koffiespruit at this site (**Appendix A1**, **Figures 9A – 9H**) is characterized by relatively low and stable TDS concentrations (90-150 mg/litre) over the period of record. In the period 1986 to 1988, pH values were slightly above 7.0 but then rose to between 7.8 and 8.4 where they have stabilized for the remainder of the period of record. The sulphate concentrations were very low (< 10 mg/litre) in 1986 and have increased slightly to about 10 mg/litre between 1986 and 2008. Orthophosphate concentrations have remained relatively low (< 0.02 mg/litre) with a gradual increase up to 2008, though the data set reveals a few instances of higher values up to 0.05 mg/litre. The values for the sulphate : chloride ratio have increased from around 0.5 in 1986 to between 1.0 and 2.0 in 2008. The corrosion ratio data have remained relatively constant between 0.1 and 0.2, with some seasonal variations. These data suggest that mining and/or industrial activities have had a negligible influence on water quality at this site. The values for the sodium adsorption ratio have remained relatively constant between 0.1 and 0.3 for the period of record, though there are distinct seasonal variations within this range, and the water appears to be fully suitable for irrigation use. The very variable values for the inorganic N:P ratio (declining from around 20-30 in 1986 to around 10 in 2008) plus the initially low (< 0.01 mg/litre) but slowly increasing orthophosphate concentrations (0.02 mg/litre in 2008) indicate that the water at this site is receiving small amounts of nutrient enrichment – most probably via runoff from agricultural pastures and irrigated lands.

The data show distinct signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is no firm evidence for any significant increase in TDS concentrations, though there is a slight increase in sulphate concentrations over the length of the data record. This suggests that there may be a very minor contribution from mining and/or industrial activities. The water quality data suggest that the water at this site is fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations, the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, once again, the consistently low ammonium-N concentrations may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum magnesium concentration and the maximum values for the sulphate : chloride ratio and the corrosion ration exceeded the CEV for domestic water use. This again indicates that mining and/or industrial activities have had a very minor influence on water quality at this site during the period of record. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment from agricultural or domestic sources. The upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, again supporting the suggestion that low levels of nutrient enrichment are occurring at this site. In general, the exceedance values at this site suggest that the water at this site can be used without prior treatment for all designated uses.

River Site #10 – Osspruit at Boschkop (DWA gauge B2H004):

A total of 712 reliable water samples (84.9% of the total data set), collected between 27 October 1984 and 21 May 2008 with an average sampling frequency of 12.1 days, comprised this data set (**Table 2**).

The water in the Osspruit at this site (**Appendix A1**, **Figures 10A – 10H**) is characterized by relatively low and stable TDS concentrations (100-150 mg/litre) over the period of record. In the period 1985 to 1988, pH values were slightly above 7.0 but then rose to between 7.8 and 8.4 where they have stabilized for the remainder of the period of record. Most of the sulphate concentrations were very low (< 20 mg/litre) in 1986 and have remained at this concentration for the remainder of the period of record. Orthophosphate concentrations were initially very low (< 0.01 mg/litre in 1984) and slowly increased to around 0.03 mg/litre by 2008, with a few instances of higher values up to 0.1 mg/litre. The values for the sulphate : chloride ratio are generally low (< 2.0) and show no clear trend of change over the period of record. The corrosion ratio data have also remained relatively constant between 0.15 and 0.4, with some seasonal variations. These data suggest that mining and/or industrial activities have had a negligible influence on water quality at this site. The values for the sodium adsorption ratio have remained relatively constant between 0.25 and 0.5 for the period of record, though there are distinct seasonal variations within this range, and the water appears to be fully suitable for irrigation use. The very variable values for the inorganic N:P ratio (declining from around 40-50 in 1985 to below 20 in 2008) plus the initially low (< 0.01 mg/litre) but gradually increasing orthophosphate concentrations (0.03 mg/litre in 2008) indicate that the water at this site is receiving small amounts of nutrient enrichment – most probably via runoff from agricultural pastures and irrigated lands.

The data show distinct signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is no firm evidence for any significant increase in TDS concentrations or sulphate concentrations over the length of the data record. This suggests that there may be a very minor contribution from mining and/or industrial activities. The water quality data suggest that the water at this site is fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations, the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, once again, the consistently low ammonium-N concentrations may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The minimum pH value exceeded the lower

CEV limit for domestic water use while the maximum magnesium concentration and the maximum values for the sulphate : chloride ratio and the corrosion ration exceeded the CEV for domestic water use. This again indicates that mining and/or industrial activities have had a very minor influence on water quality at this site during the period of record. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment from agricultural or domestic sources. The upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, again supporting the suggestion that low levels of nutrient enrichment are occurring at this site. In general, the exceedance values at this site suggest that the water at this site can be used without prior treatment for all designated uses.

River Site #11 – Bronkhorstspruit at Bronkhorstspruit (DWA gauge B2H003):

A total of 505 reliable water samples (86.0% of the total data set), collected between 3 May 1983 and 23 April 2008 with an average sampling frequency of 18 days, comprised this data set (**Table 2**).

The water in the Bronkhorstspruit at this site close to the town of Bronkhorstspruit (**Appendix A1**, **Figures 11A – 11H**) is characterized by relatively low and somewhat variable TDS concentrations (100-200 mg/litre) over the period of record. In the period 1983 to 1986, pH values were slightly above 7.0 but then rose to between 7.8 and 8.6 where they have been more or less stable for the remainder of the period of record. Most of the sulphate concentrations were very low (< 20 mg/litre) in 1986 and have remained at this concentration with minor variations for the remainder of the period of record. Orthophosphate concentrations were initially very low (< 0.01 mg/litre in 1983) and slowly increased to around 0.04 mg/litre by 2008, with a few instances of higher values up to 0.08 mg/litre. The values for the sulphate : chloride ratio are generally low (< 2.0) and show no clear trend of change over the period of record. The corrosion ratio data have also remained relatively constant between 0.2 and 0.5, with some seasonal variations. These data suggest that mining and/or industrial activities have had a negligible influence on water quality at this site. The values for the sodium adsorption ratio have remained relatively constant between 0.25 and 0.6 for the period of record, though there are distinct seasonal variations within this range, and the water appears to be fully suitable for irrigation use. The very variable values for the inorganic N:P ratio (declining from around 30-60 in 1983 to between 5 and 20 in 2008) plus the initially low (< 0.01 mg/litre) but gradually increasing orthophosphate concentrations (0.03-0.05 mg/litre in 2008) indicate that the water at this site is receiving small amounts of nutrient enrichment – most probably via runoff from the town of Bronkhorstspruit or from the discharge of treated sewage effluents.

The data show distinct signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is no firm evidence for any significant increase in TDS concentrations or sulphate concentrations over the length of the data record. This suggests that there may be a very minor contribution from mining and/or industrial activities. The water quality data suggest that the water at this site is fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations, the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, once again, the consistently low ammonium-N concentrations may have been caused by analytical difficulties in measuring low ammonium-N concentrations. None of the values for any of the other water quality constituents or water quality indices exceeded the CEV for any designated use. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment from domestic or agricultural. In general, the few exceedance values recorded for this site suggest that the water at this site can be used without prior treatment for all designated uses.

River Site #12 – Wilge River at Onverwacht (DWA gauge B2H014):

A total of 464 reliable water samples (86.6% of the total data set), collected between 19 January 1991 and 18 June 2008 with an average sampling frequency of 13.7 days, comprised this data set (**Table 2**).

The water in the Wilge River at this site (**Appendix A1**, **Figures 12A – 12H**) is characterized by moderately low but increasing TDS concentrations (increasing from around 100-120 mg/litre to between 150-200 mg/litre between 1991 and 2008). The pH values at this site have remained slightly alkaline (7.4 – 8.4) with a tendency to decrease slightly (to between 7.0 and 8.0) by 2008. The sulphate concentrations have increased from about 10-20 mg/litre to about 50 mg/litre during the same period. Orthophosphate concentrations were relatively low (< 0.01 mg/litre) in 1991 and have gradually increased to between 0.02 and 0.04 mg/litre by 2008, with fairly wide seasonal variations. The values for the sulphate : chloride ratio have remained low (between 1 and 5 for the period of record, with relatively wide seasonal variations. The corrosion ratio data show a relatively wide range of variability, with a gradual increase from around 0.25 in 1991 to about 0.75 in 2008. These data suggest that mining and/or industrial activities have had a low influence on water quality at this site. The values for the sodium adsorption ratio have remained more or less constant between 0.4 and 0.8 during the period of record and the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 2 and 40 during the period of record) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably from the discharge of domestic effluents or runoff from agricultural lands.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence of a slight increase in the concentrations of TDS, sulphate and orthophosphate over the length of the data record, though the relatively low values for TDS and sulphate concentrations indicate that the water is fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations, the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum recorded pH value exceeded the CEV for domestic water use while the upper 5% of the sulphate : chloride ratio and corrosion ratio values also exceeded the CEV for domestic water use. These last two indices suggest that there may be a slight contribution of mining and/or industrial activities to the water quality at this site. Approximately 50% of the inorganic N:P ratio values were below 10, indicating the strong likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from domestic effluent or agricultural runoff. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water at this site is slightly corrosive at times and could require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water can be used for all designated uses.

River Site #13 – Wilge River at Zusterstroom (DWA gauge B2H015):

A total of 396 reliable water samples (86.6% of the total data set), collected between 5 January 1994 and 18 June 2008 with an average sampling frequency of 13.3 days, comprised this data set (**Table 2**).

The water in the Wilge River at this site (**Appendix A1**, **Figures 13A – 13H**) is characterized by low but gradually increasing TDS concentrations (increasing from around 100-150 mg/litre to between 200 mg/litre between 1994 and 2008). The pH values at this site have remained slightly alkaline for the period of record though there has been a slight decrease from around 8 to around 7.4 in this period. The sulphate concentrations remained below 100 mg/litre from 1994 to 2001 and then increased with some variability to about 150 mg/litre by 2008. Orthophosphate concentrations were initially relatively low (0.01- 0.02 mg/litre) and have gradually increased to around 0.03 mg/litre by 2008, with wide seasonal variations. The values for the sulphate : chloride ratio have slowly increased from around 3-4 in 1991 to between 6 and 8 in 2008. The corrosion ratio data show a small wide range of variability, with most values below 2.0 for the period of record. The period 2002 to 2004 was marked by a sudden increase in TDS and sulphate concentrations, as well as in the values for the sulphate : chloride ratio and the corrosion ratio, but declined to approximately their original levels by 2005. This suggest that there may have been a short period where mining and or industrial effluents had a slightly deleterious effect on water quality which has since been remediated. The values for the sodium adsorption ratio have remained approximately constant between 0.4 and 0.6 for the period of record, distinct seasonal variations. The water at this site appears to be suitable for irrigation use based on this statistic alone. The very variable values for the inorganic N:P ratio (increasing from around 3-10 in 1991 to between 10 and 12 in 2008) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably from the discharge of domestic effluents or runoff from agricultural pastures.

The data show distinct signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is some evidence for a slight increase in the concentrations of TDS, sulphate and orthophosphate over the length of the data record, while the relatively low values for TDS and sulphate indicate that the water is fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations, the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum recorded values for potassium and sulphate exceeded the CEV for domestic water uses. The upper 25% of the values for the sulphate : chloride ratio and the upper 50% of the values for the corrosion ratio exceeded the CEV for domestic water use, indicating a strong likelihood that mining and/or industrial activities have had a slight influence on the water quality the water quality at this site. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment; this is supported by the data for the upper 5% of the orthophosphate concentrations, which exceeded the CEV for aquatic ecosystems. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water at this site will require some form of chemical stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water is fit for all designated uses.

Reservoir Site #R1 – Middelburg Dam on the Klein Olifants River (DWA gauge B1R002):

A total of 604 reliable water samples (98.4% of the total data set), collected between 13 November 1978 and 27 March 2008 with an average sampling frequency of 33.5 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Middelburg Dam (**Appendix A2**, **Figures R1A** – **R1H**) the water is characterized by moderately high and increasing TDS concentrations (200 – 600 mg/litre), slightly alkaline pH values (6.5 – 8.2), moderately high and increasing sulphate concentrations (100 – 400 mg/litre) and variable but increasing concentrations of orthophosphate (0.01 – 0.04 mg/litre). The values for the sulphate : chloride ratio reveal a sudden increase from 5 to 13 from 2000 to 2008, while the corrosion ratio data for the corresponding period also show a similar but smaller 'spike' in between 2000 and 2008. This suggests that there has been a slow but steadily increasing influence of mining and/or industrial activities on water quality in this reservoir. The values for the sodium adsorption ratio (0.4 – 0.8) are relatively low with some minor seasonal variations and the water is still suitable for irrigation use. The relatively low values for the inorganic N:P ratio (most values are less than 10) plus the gradually increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – possibly by the discharge of domestic effluents upstream of Middelburg Dam. The increasing orthophosphate concentrations suggest that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show slight signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 1990 has been accompanied by trends of increased concentrations of TDS and sulphate that are particularly evident since 1995. This suggests that the influence of mining and/or industrial effluent has either increased since 1995 or that any treatment of these effluents has become less effective since 1995. Despite these indications of deteriorating water quality in Middelburg Dam, the water appears to be reasonably fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 75% of the values for the sulphate : chloride ratio and all of the corrosion ratio values exceeded the CEV for domestic water use, again indicating a strong likelihood that mining and/or industrial activities have influenced the water quality in this reservoir. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment. The maximum recorded concentrations for potassium, calcium, magnesium and sulphate at this site exceeded the CEV for domestic water use. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water from this reservoir will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment in this reservoir suggests that the water could support the growth of undesirable algal blooms and should be treated before use.

Reservoir Site #R2 – Witbank Dam on the Olifants River (DWA gauge B1R001):

A total of 486 reliable water samples (97.8% of the total data set), collected between 19 March 1975 and 5 March 2008 with an average sampling frequency of 24.8 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Witbank Dam (**Appendix A2**, **Figures R2A** – **R2H**) the water is characterized by moderately high TDS concentrations (increasing from 200 to 500 mg/litre between 1985 and 2002, followed by a decline to around

200 mg/litre by 2008), slightly alkaline pH values (7.0 – 8.4), moderately high sulphate concentrations (increasing from 100 to 250 mg/litre between 1985 and 2002, followed by a decline to around 150 mg/litre by 2008) and variable but increasing concentrations of orthophosphate (0.01 – 0.04 mg/litre). The values for the sulphate : chloride ratio reveal a sudden increase from around 6 to 16 in 1996, followed by an equally sudden decline to previous levels within one year, while the corrosion ratio data for the corresponding period also show a similar but smaller 'spike' of increase and decrease in 1996. This suggests that there has been a slightly variable but noticeable influence of mining and/or industrial activities on water quality in this reservoir. The values for the sodium adsorption ratio (0.6 – 1.0) are relatively low with some minor seasonal variations and the water is still suitable for irrigation use. The values for the inorganic N:P ratio have declined steadily since 1990 to below 10, and the gradually increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – possibly by the discharge of domestic effluents upstream of Witbank Dam. The increasing orthophosphate concentrations suggest that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show slight signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 1990 has been accompanied by trends of increased concentrations of TDS and sulphate despite the subsequent decrease between 2002 and 2008. This suggests that the influence of mining and/or industrial effluent has increased since 1990 with a suggestion that some form of treatment of these effluents has occurred since 2002. Despite these indications of deteriorating water quality in Witbank Dam, the water appears to be reasonably fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. The maximum recorded value for ammonium-N exceeded the CEV for domestic water use. The lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. The upper 75% of the values for the sulphate : chloride ratio and all of the corrosion ratio values exceeded the CEV for domestic water use, again indicating a strong likelihood that mining and/or industrial activities have influenced the water quality in this reservoir. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water from this reservoir will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment in this reservoir suggests that the water could support the growth of undesirable algal blooms and should be treated before use.

Reservoir Site #R3 – Bronkhorstspruit Dam on the Bronkhorstspruit (DWA gauge B2R001):

A total of 336 reliable water samples (89.6% of the total data set), collected between 21 June 1973 and 7 July 2008 with an average sampling frequency of 38.1 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Bronkhorstspruit Dam (**Appendix A2**, **Figures R3A** – **R3H**) the water is characterized by moderately low though variable TDS concentrations (120 to 200 mg/litre), slightly alkaline pH values (7.0 – 8.9), moderately low sulphate concentrations (10 to 35 mg/litre) and variable but increasing concentrations of orthophosphate (0.01 – 0.08 mg/litre). The values for the sulphate : chloride ratio and the corrosion ratio show similar patterns of variability and remain consistently low. This suggests that there has been a negligible influence of mining and/or industrial activities on water quality in this reservoir. The values for the sodium adsorption ratio (0.4 – 0.7) are relatively low with some minor seasonal variations and the water is still suitable for irrigation use. The values for the inorganic N:P ratio have declined steadily since about 1995 to below 10, and the increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – possibly by the discharge of domestic effluents or runoff from agricultural lands and pastures upstream of Bronkhorstspruit Dam. The increasing orthophosphate concentrations suggest that the orthophosphate source is more likely to be the discharge of domestic effluent from a wastewater treatment plant.

The data show slight signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 1995 has been accompanied by trends of slightly increased concentrations of TDS and sulphate suggesting that the small influence of mining and/or industrial effluent may have increased gradually since 1995. Despite these indications, the quality of the water in Bronkhorstspruit Dam appears to be fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. The lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. None of the values for the sulphate : chloride ratio or the corrosion ratio exceeded any CEV limit, emphasizing the likelihood that mining and/or industrial activities have had a negligible effect on water quality in this reservoir. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment. The presence of nutrient enrichment in this reservoir suggests that the water could support the growth of undesirable algal blooms and would need to be treated before use.

Reservoir Site #R4 – Loskop Dam on the Olifants River (DWA gauge B3R002):

A total of 406 reliable water samples (91.2% of the total data set), collected between 12 June 1973 and 27 November 2008 with an average sampling frequency of 32.6 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Loskop Dam (**Appendix A2**, **Figures R4A** – **R4H**) the water is characterized by moderate but gradually increasing TDS concentrations (increasing from about 100 mg/litre in 1975 to over 300 mg/litre by 2008), slightly variable alkaline pH values (changing from about 6.5 – 7.5 in the period 1975 to 1988, to between 7.0 and 8.4 up to 2008) moderately low but gradually increasing sulphate concentrations (increasing from around 30 mg/litre in 1975 to over 140 mg/litre in 2008) and variable but increasing concentrations of orthophosphate (0.01 – 0.05 mg/litre). The values for the sulphate : chloride ratio reveal an almost continuous increase from around 2 in 1975 to over 7 in 2008, while the corrosion ratio data for the same period show a similar steady increase from around 1 in 1975 to over 3 in 2008. These data suggest that there has been a slow but steadily increasing influence of mining and/or industrial activities in the upper catchment on water quality in this reservoir. The values for the sodium adsorption ratio (0.6 – 1.4) are relatively low with some minor seasonal variations and the water in the reservoir is still suitable for irrigation use based on this statistic alone. The relatively low values for the inorganic N:P ratio (most values are below 40) and the gradually increasing orthophosphate concentrations suggest that the water is being enriched with nutrients – possibly by the discharge of domestic effluents in the upper catchment. The increasing orthophosphate concentrations provide no insights into the possible source of the orthophosphate.

The data show slight signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 1990, coupled with the trends of increased concentrations of TDS and sulphate since 1975, suggest that the water quality in the reservoir has had a long history of influence from mining, industrial, agricultural and effluent treatment activities in the catchment. Despite these indications of deteriorating water quality in Loskop Dam, the water appears to be reasonably fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, with the maximum recorded ammonium-N value exceeding the CEV for domestic water use. The low ammonium-N concentrations reported may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 25% of the values for the sulphate : chloride ratio and the upper 75% of the corrosion ratio values exceeded the CEV for domestic water use, again indicating a strong likelihood that mining and/or industrial activities have influenced the water quality in this reservoir. The maximum recorded values for fluoride and pH exceeded the CEV for domestic water use. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water from this reservoir will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment in this reservoir suggests that the water could support the growth of undesirable algal blooms and should be treated before use.

4.2 The middle reaches of the catchment

This segment of the Olifants River catchment comprises the areas drained by the Elands, Moses and Selons rivers (sub-catchment B3) plus the Steelpoort River drainage (sub-catchment B4) and the drainage area between Flag Boshielo Dam and the DWA sampling point at Zeekoegat (sub-catchment B5). The river sampling sites in the middle reach are sites 14 to 17 in sub-catchment B3, site 20 in sub-catchment B4 and sites 18 and 19 in sub-catchment B5. The reservoir sampling sites in this reach are R5 in sub-catchment B3 and R6 in sub-catchment B5 (**Figure 16**).

The time-series graphs for the eight (8) water quality constituents and water quality indices relevant to the river and reservoir sampling sites in this reach are shown in **Appendix A1** (river sites 14 to 20) and **Appendix A2** (reservoir site R5 and R6), respectively.

River Site #14 – Olifants River downstream of Loskop Dam (DWA gauge B3H017):

A total of 421 reliable water samples (97.5% of the total data set), collected between 1 September 1993 and 22 May 2008 with an average sampling frequency of 12.8 days, comprised this data set (**Table 2**).

The water in the Olifants River at this site downstream of Loskop Dam (**Appendix A1**, **Figures 14A** – **14H**) is characterized by moderate TDS concentrations (150 – 300 mg/litre), slightly alkaline pH values (7.2 – 8.3), moderate sulphate concentrations (60 – 160 mg/litre, though apparently decreasing slightly in recent years) and variable but gradually increasing concentrations of orthophosphate (0.01 – 0.04 mg/litre). The values for the sulphate : chloride ratio reveal a sudden increase from 4 to 8 in 1996, followed by a slight decrease to between 5 and 8. The corrosion ratio data do not show a similar 'spike' in 1996 followed by a decrease, but show instead a gradual but steady increase from around 1.5 to 3.5 in the same period. These data suggest that there has been a slow but steady increase in the influence of mining and/or industrial activities on water quality at this site downstream of Loskop Dam. The values for the sodium adsorption ratio (0.5 – 1.1) are relatively low but seasonally variable and the water is still suitable for irrigation use. The moderately low values for the inorganic N:P ratio (most values are less than 40) plus the gradually increasing concentrations of orthophosphate suggest that the water is gradually being enriched with nutrients – probably from sources located upstream of Loskop Dam. The data on orthophosphate concentrations do not indicate what type of source may be responsible for the increased concentrations.

The data show clear signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. However, while there is evidence of a gradual trend of increase in the concentration of orthophosphate over the length of the data record, there has been a slight decrease in sulphate concentrations in recent years. This may reflect an increased deposition and/or transformation of sulphate in Lake Loskop. The water at this site appears to be reasonably fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low concentrations. The upper 75% of the values for the sulphate : chloride ratio and the upper 95% of values for the corrosion ratio exceeded the CEV for domestic water use, indicating a strong likelihood that mining and/or industrial activities have influenced the water quality at this site. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of slight nutrient enrichment arising within Lake Loskop. The exceedance values for the sulphate : chloride ratio and corrosion ratio indicate that the water taken from this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algal blooms and should be treated before use.

River Site #15 – Olifants River at Loskop North (DWA gauge B3H001):

A total of 570 reliable water samples (96.1% of the total data set), collected between 12 October 1976 and 11 April 2008 with an average sampling frequency of 20.2 days, comprised this data set (**Table 2**).

The water in the Olifants River at this site (**Appendix A1**, **Figures 15A – 15H**) is characterized by moderately high and increasing TDS concentrations (increasing from 200 to over 800 mg/litre between 1978 and 2008), slightly alkaline pH values (7 – 8.8), moderately high and increasing sulphate concentrations (increasing from around 50 to over 250 mg/litre between 1978 and 2008) and relatively low but very variable and gradually increasing concentrations of orthophosphate with occasional high values above 0.10 mg/litre. The concentrations of TDS and sulphate increased and displayed greater seasonal variability between 1995 and 2008, accompanied by similar changes in sulphate : chloride ratio and corrosion ratio during this period. The sulphate : chloride ratio increased from around 1 in 1985 to over 6 in 2008. The corrosion ratio data show a relatively wide range of variability between 0.5 and 2.5 in the same period. These data suggest that mining and/or industrial activities have had a moderate and increasingly influence on water quality at this site. The values for the sodium adsorption ratio varied between 1.0 and 3.0 – with distinct seasonal variations – and the water appears to be suitable for irrigation use at most times. The relatively low but variable values for the inorganic N:P ratio (with most values below 80) plus the moderate but apparently more or less constant orthophosphate concentrations indicate that the water at this site is being slightly enriched by nutrients – most likely as a result of agricultural return flows.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is clear evidence of increasing concentrations of TDS and sulphate over the length of the data record, indicating that the water is not fully fit for all designated uses at all times and would require pre-treatment before use.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 25% of the magnesium concentrations and the maximum recorded value for pH exceeded the CEV for domestic water uses. The upper 75% of the values for the corrosion ratio exceeded the CEV for domestic water use, indicating the possibility that mining and/or industrial activities have had a slight influence on water quality at this site. Approximately 5% of the inorganic N:P ratio values were below 10, indicating the strong likelihood of nutrient enrichment. The upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, supporting the suggestion that nutrient enrichment is occurring at this site – most probably derived from agricultural sources. The exceedance values for the corrosion ratio indicate that the water at this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water should not be used without prior treatment.

River Site #16 – Moses River at Mosesriviermond (DWA gauge B3H005):

A total of 132 reliable water samples (92.3% of the total data set), collected between 12 October 1976 and 14 December 1986 with an average sampling frequency of 50.3 days, comprised this data set (**Table 2**). Data after 1986 were unreliable for analysis.

The short span of this data set and its age, make it difficult to draw meaningful conclusions from the data. Nevertheless, the water in the Moses River at this site (**Appendix A1**, **Figures 16A – 16H**) is characterized by moderately high and variable but apparently increasing TDS concentrations (increasing from around 200 mg/litre in 1978 to between around 800 mg/litre in 1987. The pH values at this site have remained slightly alkaline (7.0 – 8.6) with a tendency to increase slightly over the period of record. The sulphate concentrations have increased from about 20-40 mg/litre to over 160 mg/litre during the same period. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre) and do not show a significant trend of increase over the period of record, though some seasonal variations are present. The values for the sulphate : chloride ratio have remained low (between 0.4 and 1.2 for the period of record, with relatively small seasonal variations. The corrosion ratio data show a relatively gradual increase from around 0.5 in 1977 to between 1.0 and 1.5 in 2004. These data suggest that mining and/or industrial activities have had a very low influence on water quality at this site. The values for the sodium adsorption ratio have tended to increase slightly from between 1.0 and 2.0 in 1977 to between 3.0 and 4.0 in 1986, and the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 2 and 600 during the period of record) plus the moderately low orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably from the discharge of runoff or return flows from agricultural lands.

The data show some signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence of a slight increase in the concentrations of TDS and sulphate over the length of the data record, though the more recent (1985-1986) values for TDS and sulphate concentrations indicate that the water is still fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. All of the upper values for the sulphate : chloride ratio indicate the water has not been significantly influenced by mining and/or industrial activities though the upper 25% of the corrosion ratio values exceeded the CEV for domestic water use. This last index suggests that there may be a slight contribution of mining and/or industrial activities to the water quality at this site. Approximately 5% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from domestic effluent or – more likely – from agricultural runoff. The exceedance values for the corrosion ratio indicate that the water at this site is slightly corrosive at times and could require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water can be used for all designated uses.

River Site #17 – Elands River at Scherp Arabie (DWA gauge B3H021):

A total of 292 reliable water samples (100% of the total data set), collected between 6 January 1994 and 3 April 2008 with an average sampling frequency of 17.8 days, comprised this data set (**Table 2**).

The water in the Moses River at this site (**Appendix A1**, **Figures 17A – 17H**) is characterized by moderately high and variable but increasing TDS concentrations (increasing from around 500 mg/litre in 1991 to between around 1000 mg/litre in 2007). The pH values at this site have remained consistently above 8.0 with no apparent tendency to increase over the period of record. The sulphate concentrations have increased from about 100 mg/litre to around 200 mg/litre during the same period. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre in 1991) and have gradually increased to over 0.06 mg/litre by 2007. Definite signs of wide seasonal fluctuations in orthophosphate concentrations are present in the data set. The values for the sulphate : chloride ratio have remained low but slowly increasing from around 0.4 in 1991 to over 0.6 in 2007, again with clear signs of seasonal variations. The corrosion ratio data show a relatively gradual increase from around 1.5 in 1991 to between 2.0 and 3.0 in 2007. These data suggest that mining and/or industrial activities have had a minor influence on water quality at this site. The values for the sodium adsorption ratio have remained more or less constant at around 3, with marked seasonal variations, the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 2 and 60 during the period of record) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably from the discharge of runoff or return flows from agricultural lands.

The data show distinct signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence of a slight increase in the concentrations of TDS, sulphate and orthophosphate over the length of the data record, and while the data suggest that the water is still fit for all designated uses, the increasing TDS and sulphate values indicate that the water may be approaching its limit for domestic use.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 50% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 95% of the corrosion ratio values exceeded the CEV for domestic water use. This last index suggests that there may be a slight contribution of mining and/or industrial activities to the water quality at this site. Approximately 50% of the inorganic

N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 5% of the nitrate-N concentrations and the upper 50% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from domestic effluent or from agricultural runoff. The upper 5% of values for chloride, potassium and calcium exceeded the CEV for domestic water use, while the upper 75% of magnesium and upper 50% for TDS, total alkalinity and fluoride also exceeded the CEV for domestic use. These data suggest that there may be an influence of mining and / or industrial activities on water quality in this sub-catchment. The exceedance values for the corrosion ratio indicate that the water at this site is moderately corrosive at all times and would require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. Overall, the data suggest that a range of different land use activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water would need to be pre-treated to reduce TDS and fluoride for about 25% of the time before the water can be used safely for all designated uses.

River Site #18 – Olifants River downstream of Flag Boshielo Dam (DWA gauge B5H004):

A total of 107 reliable water samples (26.0% of the total data set), collected between 1 September 1993 and 26 December 2007 with an average sampling frequency of 48.8 days, comprised this data set (**Table 2**). The original data set was remarkable for the number of unreliable samples where inadequate adherence to the ionic activity balance required that 74% of the original samples should be rejected and not analyzed.

The relatively few reliable data in this data set make it difficult to draw meaningful conclusions from the data, apart from the conclusion that the unreliable samples were likely to have been caused by some sort of ionic interference in the water samples. Nevertheless, the water at this site in the Olifants River a short distance downstream of Lake Flag Boshielo (**Appendix A1**, **Figures 18A – 18H**) is characterized by moderately high and slightly variable TDS concentrations (300 – 350 mg/litre). The pH values at this site have remained consistently above 8.0 with no apparent tendency to increase over the period of record. The sulphate concentrations have increased from about 60 mg/litre to around 110 mg/litre during the same period. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre in 1993) and have gradually increased to between 0.02 and 0.03 mg/litre by 2007. Definite signs of wide seasonal fluctuations in orthophosphate concentrations are present in the data set. The values for the sulphate : chloride ratio have increased from below 1.0 in 1993 to over 3 in 2006, again with some signs of seasonal variations. The corrosion ratio data show a relatively gradual increase from around 1.2 in 1993 to around 1.6 in 2006. These data suggest that the water released from Lake Flag Boshielo indicates that mining and/or industrial activities have had a minor influence on water quality in the lake. The values for the sodium adsorption ratio have remained more or less constant at between 1.5 and 2, with small seasonal variations, the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 5 and 25 during the period of record) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients in the lake outflow; these are most probably from agricultural sources.

The data show slight signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence to suggest a slight increase in the concentrations of TDS, sulphate and orthophosphate over the length of the data record, and the data suggest that the water is still fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 95% of the corrosion ratio values exceeded the CEV for domestic water use. This last index suggests that there may have been a slight contribution of mining and/or industrial activities to the water quality at this site. Approximately 50% of the inorganic N:P ratio values were below 10, indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 5% of the nitrate-N concentrations and the upper 50% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from Lake Flag Boshielo. The upper 50% of values for magnesium exceeded the CEV for domestic water use. The magnesium data suggest that there may be an influence of water derived from mining and / or industrial activities or from dolomitic sources on water quality in Lake Flag Boshielo. The exceedance values for the corrosion ratio indicate that the water at this site is moderately corrosive at all times and would require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. Overall, the data suggest that a range of different land use activities have had impacts on water quality at this site, reflecting on the status of water quality in Lake Flag Boshielo. In general, the exceedance values at this site suggest that the water could be used for all designated uses though there is a risk of corrosion to metal pipes and fittings that would need to be considered.

River Site #19 – Olifants River at Zeekoegat (DWA gauge B5H002):

A total of 109 reliable water samples (93.2% of the total data set), collected between 26 May 1981 and 9 June 1993 with an average sampling frequency of 40.4 days, comprised this data set (**Table 2**).

The relatively few reliable data in this data set make it difficult to draw meaningful conclusions from the data. The water in the Olifants River at this site (**Appendix A1**, **Figures 19A – 19H**) is characterized by moderately high and variable TDS concentrations (varying between 400 and 1400 mg/litre) over the period of record. The pH values at this site have remained consistently between 7.2 and 8.5 with no apparent tendency to increase over the period of record. The sulphate concentrations remained more or less constant – with wide inter-annual variation – varying between 50 and 200 mg/litre during the same period. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre) though there have been wide inter-annual variations. The values for the sulphate : chloride ratio have remained low but variable, between 0.2 and 0.4 over the period of record, again with clear signs of inter-annual variations. The corrosion ratio data are very variable, ranging from 1 to 5 over the period of record. These data suggest that mining and/or industrial activities have had a minor influence on water quality at this site. The values for the sodium adsorption ratio were quite variable (between 1.5 and 6) with no clear trend discernable. The water appears to be marginally suitable for irrigation use based on this statistic alone, though water with higher SAR values could lead to salinization of soils. The variable values for the inorganic N:P ratio (varying between 1 and 500 during the period of record) plus the moderately low orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably via return flows from agricultural lands.

The data show very few signs of seasonal cyclical changes – but wide inter-annual variations – in the concentrations of all water quality constituents and the values of water quality indices. There is no clear evidence of any increase in the concentrations of TDS, sulphate and orthophosphate over the length of the data record, and while the data suggest that the water is still fit for all designated uses, the increasing TDS and sulphate values indicate that the water may be approaching its limit for domestic use and could compromise vulnerable soils if used for irrigation purposes..

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 75% of the corrosion ratio values exceeded the CEV for domestic water use. This last index suggests that there may be a slight contribution of mining and/or industrial activities to the water quality at this site. Approximately 75% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from domestic effluent or from agricultural runoff. The upper 25% of values for chloride and sulphate, the upper 75% of values for magnesium and the maximum values for calcium, magnesium and potassium exceeded the CEV for domestic water use. These data suggest that there may be an influence of runoff from irrigated agricultural lands on water quality in this sub-catchment. The exceedance values for the corrosion ratio indicate that the water at this site is moderately corrosive at all times and would require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. Overall, the data suggest that a range of different land use activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water would need to be pre-treated to reduce TDS for about 50% of the time before the water can be used safely for all designated uses.

River Site #20 – Steelpoort River at Alverton (DWA gauge B4H001):

A total of 452 reliable water samples (93.4% of the total data set), collected between 2 November 1984 and 28 February 2008 with an average sampling frequency of 16.2 days, comprised this data set (**Table 2**).

The water in the Steelpoort River at this site (**Appendix A1**, **Figures 20A – 20H**) is characterized by seasonally variable TDS concentrations that vary from around 120 mg/litre to around 800 mg/litre without a significant trend of increase with time. The pH values at this site have remained slightly alkaline (7.5 – 8.8) with a few slightly acidic values (6.7 – 6.95) between 1985 and 1990; there is no sign of any tendency for pH values to increase over the period of record. The sulphate concentrations show seasonal variations – similar to those recorded for TDS – varying from around 5 mg/litre to around 100 mg/litre. There is no trend of increasing sulphate concentrations with time during the period of record. Orthophosphate concentrations were relatively low (< 0.01 – 0.02 mg/litre) in the late 1980s and have shown a gradual increase to around 0.05 mg/litre by 2008. Seasonal variations in orthophosphate concentrations are similar to those for sulphate and TDS. The values for the sulphate : chloride ratio remained relatively low (around 0.4) up to 1990 and then increased and became more variable – up to 1.6 – by 2005. These data suggest that mining and/or industrial activities have started to have an influence on water quality at this site, though this influence is still low. The values for the sodium adsorption ratio have remained relatively low (below 4) but seasonally variable, for the entire period of record. The water appears to be suitable for most irrigation uses based on this statistic alone. The initially highly variable values for the inorganic N:P ratio (varying between 2 and 700 up to 1990) have recently decreased to between 2 and 25. This feature, plus the increasing orthophosphate concentrations indicate that the water at this site is being progressively enriched by nutrients – most probably from the discharge of urban runoff or discharges of domestic sewage effluent from the expanding towns in the middle and lower reaches.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is no evidence of any significant increase in the concentrations of TDS and sulphate over the length of the data record, though orthophosphate concentrations are increasing. The data indicate that the water in the Steelpoort River is still fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for the low ammonium-N concentrations, this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The values for the sulphate : chloride ratio indicate that the water has not been significantly influenced by mining and/or industrial activities though the maximum recorded value for the corrosion ratio suggests that the water may have a tendency to be slightly corrosive. Approximately 5% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from domestic effluent or possibly from agricultural return flows. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should be treated before use. In general, the exceedance values at this site suggest that the water can be used for all designated uses.

Reservoir Site #R5 – Rhenosterkop Dam on the Elands River (DWA gauge B3R005):

A total of 328 reliable water samples (94.8% of the total data set), collected between 5 April 1983 and 20 June 2008 with an average sampling frequency of 28.3 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Rhenosterkop Dam on the Elands River (**Appendix A2**, **Figures R5A** – **R5H**) the water is characterized by moderately low though seasonally variable TDS concentrations (80 to 275 mg/litre), that show a clear increasing trend since 1995. The pH values are seasonally variable and remain reasonably constant (7.5 to 8.5) throughout the period of record. The sulphate concentrations are low and variable (3 to 20 mg/litre) while orthophosphate concentrations reveal a gradual but steady increase to around 0.05 mg/litre in 2008. The values for the sulphate : chloride ratio rose from 0.1 in 1988 to around 1.0 in 1996-1997 and have since shown a steady decrease to around 0.2 in 2008. The corrosion ratio values show some seasonal variability but have increased steadily since 1996-1997 to their current levels at around 0.6 in 2008. These data suggest that mining and / or industrial activities have had a negligible influence on water quality in this reservoir, though the water has become increasingly corrosive in recent years. The values for the sodium adsorption ratio (0.5 – 2.5) show a pattern of variability that almost exactly mimics the patterns of change in TDS concentrations, with a steady increase since 1996-1997. The SAR values are still relatively low and the water is still suitable for irrigation use, though this may change if the trend of increase continues. The values for the inorganic N:P ratio have declined steadily since about 1993 to below 10; this, and the gradually increasing concentrations of orthophosphate, suggest that the water is being enriched with nutrients – most probably by increasing quantities of return flows from irrigated agriculture and, possibly, by the discharge of domestic effluents from communities in the catchment.

The data show clear signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 1995 has been accompanied by trends of increased TDS concentrations, indicating that changes in the catchment have had a steadily increasing effect on water quality since 1995-1997. Despite these indications, the quality of the water in Lake Rhenosterkop still appears to be fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. The lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. All of the corrosion ratio values but only the maximum value for the sulphate : chloride ratio exceeded the CEV limit for domestic water use. These results suggest that mining and / or industrial activities have had very little effect on water quality and that agricultural activities and domestic effluent are likely responsible for the decline in water quality. Approximately 50% of the inorganic N:P ratio values were below 10, again indicating the likelihood of nutrient enrichment; the upper 5% of orthophosphate concentrations exceeded the CEV for domestic water use suggesting that domestic effluent is the likely source of this enrichment. The presence of nutrient enrichment in this reservoir and the increasingly corrosive nature of the water indicate that the water would support growths of undesirable algae and would need to be treated before use.

Reservoir Site #R6 – Flag Boshielo Dam on the Olifants River (DWA gauge B5R002):

A total of 192 reliable water samples (99.5% of the total data set), collected between 6 January 1994 and 3 April 2008 with an average sampling frequency of 25.3 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Flag Boshielo Dam (**Appendix A2**, **Figures R6A** – **R6H**) the water is characterized by variable but slowly increasing TDS concentrations (increasing from about 200 mg/litre in 1999 to between 300 and 450 mg/litre by 2008), seasonally variable alkaline pH values (varying between 7.2 and 8.6 up to 2008), moderately sulphate concentrations that have gradually increased from around 60 mg/litre in 2000 to over 120 mg/litre in 2008, and variable but gradually increasing concentrations of orthophosphate (0.01 – 0.05 mg/litre). The values for the sulphate : chloride ratio reveal a steady decline to around 1.0 between 2000 and 2005, followed by a sharp increase to between 3.0 and 4.0 in 2006. The corrosion ratio data for the same period remained almost constant between 1.0 and 2.0, suggesting that there has been a recent increase in the contribution of salts (especially chloride) from agricultural activities upstream, most likely in the Elands and Moses river sub-catchments. The values for the sodium adsorption ratio increased from around 1.0 in 1999 to around 2.5 in 1005, followed by a rapid drop to around 1, with minor seasonal fluctuations. These data indicate that the water in the reservoir is still suitable for irrigation use based on this statistic alone. The relatively low values for the inorganic N:P ratio (most values are less than 20) plus the gradually increasing concentrations of orthophosphate suggest that the water is being enriched with nutrients – possibly by the discharge of agricultural return flows and / or domestic effluents in the upper catchment. The pattern of increasing orthophosphate concentrations provides no insights into the possible source of the orthophosphate.

The data show some signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 2000, coupled with the almost constant concentrations of TDS and sulphate, suggest that the water quality in the reservoir is being increasingly influenced by agricultural activities upstream. Despite these indications of deteriorating water quality in Lake Loskop, the routine DWA monitoring data indicate that water appears to be reasonably fit for most recognized uses for most of the time.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. Once again, the low ammonium-N concentrations reported may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The maximum value for the sulphate : chloride ratio and all of the corrosion ratio values exceeded the CEV for domestic water use. This indicates that there may be some influence of mining and / or industrial activities on water quality in this reservoir, though this is likely to be linked to water released from Lake Loskop further upstream. The maximum recorded values for conductivity, pH, chloride, potassium, calcium total alkalinity and fluoride, plus the upper 25% of the magnesium concentrations, exceeded the CEV for domestic water uses. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the strong likelihood of nutrient enrichment. The exceedance values for the corrosion ratio indicate that the water from this reservoir will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment in this reservoir suggests that the water could support the growth of undesirable algal blooms and should be treated before use.

4.3 The lower reaches of the catchment

This segment of the Olifants River catchment comprises the area drained by Blyde and Ohrigstad rivers (sub-catchment B6), the drainage of the Ga-Selati River plus the seasonal rivers draining towards the northern (left) and southern (right) banks of the Olifants River down to the Mozambique border (sub-catchment B7). In addition, the drainage of the Great Letaba River (sub-catchment B8) and Shingwidzi River (sub-catchment B9) are also included in the description of this reach. The river sampling sites in this reach are sites 22 in sub-catchment B6, and site 21 plus sites 23 to 27 in sub-catchment B7. The reservoir sampling sites in this reach are R7 in sub-catchment B6, R8 in sub-catchment B7, R9 in sub-catchment B8, and R10 in sub-catchment B9 (**Figure 16**).

The time-series graphs for the eight (8) water quality constituents and water quality indices relevant to the river and reservoir sampling sites in this reach are shown in **Appendix A1** (river sites 21 to 27) and **Appendix A2** (reservoir sites R7 to R10), respectively.

River Site #21 – Olifants River at Finale Liverpool (DWA gauge B7H009):

A total of 404 reliable water samples (92.2% of the total data set), collected between 10 May 1979 and 8 October 2007 with an average sampling frequency of 24.8 days, comprised this data set (**Table 2**).

The water at this site in the Olifants River a short distance downstream of the inflows from the Steelpoort River (**Appendix A1**, **Figures 21A – 21H**) is characterized by moderately high and slightly variable TDS concentrations (200 – 400 mg/litre). The pH values at this site have increased from around 7.0 in 1980 to between 8.0 and 9.0, remaining seasonally variable but more or less constant in this range since 1990. The sulphate concentrations have increased from about 20 mg/litre to around 60 mg/litre over the period of record. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre in 1980) and have gradually increased to between 0.04 and 0.05 mg/litre by 2006. Definite signs of wide seasonal fluctuations in orthophosphate concentrations are present in the data set. The values for the sulphate : chloride ratio have increased from below 1.0 in 1980 to around 1.5 by 2007, again with distinct signs of seasonal variations. The corrosion ratio data are seasonally variable and remain within the range 0.4 to 1.0 for the period of record. These data suggest that the water from the middle reaches of the Olifants River shows relatively little influence of mining and / or industrial activities. The values for the sodium adsorption ratio have remained more or less constant at between 1 and 2, with regular, small seasonal variations; the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 5 and 80 during the period of record, declining in recent years) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients, most probably from agricultural return flows.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence to suggest a

slight increase in the concentrations of sulphate and orthophosphate over the length of the data record, and the data suggest that the water is still fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, with the maximum recorded ammonium-N concentration exceeding the CEV for domestic water use. However, the generally low ammonium-N concentrations may have been caused by analytical difficulties in measuring ammonium-N concentrations below 0.02 mg/litre. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 5% of the corrosion ratio values exceeded the CEV for domestic water use. This last index suggests that there may have been a slight contribution of mining and/or industrial activities to the water quality at this site. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 25% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from upstream sources. The upper 25% of values for magnesium and total alkalinity exceeded the CEV for domestic water use, while the maximum recorded values for conductivity, pH, calcium, sulphate and fluoride also exceeded the CEV for domestic water use. The magnesium data suggest that there may be an influence of water derived from mining and / or industrial activities or water derived from dolomitic sources on water quality at this site. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algal blooms and should ideally be treated before use. Overall, the data suggest that a range of different land use activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water could be used for all designated uses though there is a slight risk of occasional corrosion to metal pipes and fittings that would need to be considered.

River Site #22 – Blyde River at Chester (DWA gauge B6H004):

A total of 577 reliable water samples (74.2% of the total data set), collected between 12 April 1978 and 12 March 2008 with an average sampling frequency of 18.3 days, comprised this data set (**Table 2**). The original data set had a number of unreliable samples where inadequate adherence to the ionic activity balance required that 26% of the original samples should be rejected and not analyzed.

The water at this site in the Blyde River a short distance downstream of the Blyderivierspoort Dam (**Appendix A1**, **Figures 22A – 22H**) is characterized by moderately low and seasonally variable TDS concentrations (50 – 150 mg/litre). The pH values at this site have increased from around 7.0 in 1980 to around 8.0 in 2005, with clear signs of seasonal variations. The sulphate concentrations have remained within the range 5 – 20 mg/litre during the period of record. Orthophosphate concentrations were relatively low (0.005 – 0.01 mg/litre in 1980) and have gradually increased to between 0.02 and 0.03 mg/litre by 2006, with some seasonal variations. The values for the sulphate : chloride ratio have remained between 1 and 2 – with seasonal variations – for the period of record. The corrosion ratio data are seasonally variable and remain within the range 0.2 to 0.6 for the period of record, with a suggestion of a slight increase during this period. These data suggest that the water from the Blyde River has not been influenced by mining and / or industrial activities. The values for the sodium adsorption ratio are seasonally variable within the range 0.2 to 0.5; the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 5 and 80 during the period of record, though declining in recent years) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients, most probably from agricultural return flows from irrigated agriculture located downstream of Lake Blyderivierspoort.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence to suggest a slight increase in the orthophosphate concentrations over the length of the data record, suggesting a progressively increasing influence of agricultural activities. Nevertheless, the data suggest that the water is still fit for most designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, the generally low ammonium-N concentrations may have been caused by analytical difficulties in measuring ammonium-N concentrations below 0.02 mg/litre. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from upstream sources. The maximum recorded value for magnesium exceeded the CEV for domestic water use, probably as a result of the inflows of dolomitic water influencing the water chemistry at this site. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algae and should ideally be treated before use. Overall, the data suggest that agricultural activities have influenced the water quality at this site. In general, the exceedance values at this site suggest that the water could be used for all designated uses though there may be a slight risk of occasional corrosion to metal pipes and fittings that would need to be considered.

River Site #23 – Olifants River at Oxford (DWA gauge B7H007):

A total of 666 reliable water samples (88.3% of the total data set), collected between 17 November 1975 and 24 September 2008 with an average sampling frequency of 18.1 days, comprised this data set (**Table 2**).

This site in the Olifants River is located a short distance downstream of the inflows from the Blyde River (**Appendix A1**, **Figures 23A – 23H**) and the water at this site is characterized by moderately high and seasonally variable TDS concentrations (100 – 400 mg/litre). The pH values at this site have increased from around 7.5 in 1980 to between 8.0 and 9.0, remaining seasonally variable but more or less constant in this range since 1990. The sulphate concentrations are still relatively low (10 – 60 mg/litre) though they have increased from about 10 mg/litre to around 60 mg/litre over the period of record. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre in 1980) and have gradually increased to between 0.03 and 0.05 mg/litre by 2006. Definite signs of wide seasonal fluctuations in orthophosphate concentrations are present in the data set. The values for the sulphate : chloride ratio have increased from below 1.0 in 1980 to around 1.5 by 2007, again with distinct signs of seasonal variations. The corrosion ratio data are seasonally variable and remain within the range 0.2 to 1.0 for the period of record. These data suggest that the water from the middle reaches of the Olifants River has experienced relatively little influence of mining and / or industrial activities. The values for the sodium adsorption ratio have remained more or less constant at between 0.5 and 1.5, with regular, moderate seasonal variations; the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 5 and 80 during the period of record, declining in recent years) plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients, most probably from agricultural return flows and discharges of domestic effluent.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence to suggest a

slight increase in the concentrations of sulphate and orthophosphate over the length of the data record, and the data suggest that the water is still fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, the generally low ammonium-N concentrations may have been caused by analytical difficulties in measuring ammonium-N concentrations below 0.02 mg/litre. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the maximum recorded value for the corrosion ratio exceeded the CEV for domestic water use. Approximately 25% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from upstream sources. The upper 5% of values for magnesium and total alkalinity exceeded the CEV for domestic water use, while the maximum recorded values for conductivity, chloride, potassium, calcium, sulphate and fluoride also exceeded the CEV for domestic water use. The magnesium data suggest that there may be an influence of water derived from dolomitic sources on water quality at this site. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algae and should ideally be treated before use. Overall, the data suggest that a range of different land use activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water could be used for all designated uses though there may be a slight risk of occasional corrosion to metal pipes and fittings that would need to be considered.

River Site #24 – Klaserie River at Fleur-de-Lys (DWA gauge B7H004):

A total of 159 reliable water samples (47.7% of the total data set), collected between 20 May 1977 and 6 May 2008 with an average sampling frequency of 71.2 days, comprised this data set (**Table 2**). The original data set was remarkable for the number of unreliable samples where inadequate adherence to the ionic activity balance required that 52% of the original samples should be rejected and not analyzed.

The water at this site in the Klaserie River – a seasonally flowing tributary of the Olifants River – (**Appendix A1**, **Figures 24A – 24H**) is characterized by moderately low and seasonally variable TDS concentrations (40 – 70 mg/litre). The pH values at this site have increased from between 6.0 and 7.0 in the period 1978 – 1989 to between 7.0 and 8.0, remaining seasonally variable but more or less constant in this range since 1990. The sulphate concentrations have remained generally very low (< 10 mg/litre) with wide seasonal variations during the period of record. Orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre in 1980) and have gradually increased to between 0.02 and 0.05 mg/litre by 2006, with wide seasonal fluctuations in concentration. The values for the sulphate : chloride ratio have remained below 1.0 while the corrosion ratio data have also remained in the range 0.3 – 1.2; both indices show clear seasonal fluctuations. These data suggest that the water in the Klaserie River has not been influenced by mining and / or industrial activities. The values for the sodium adsorption ratio have remained more or less constant at between 0.4 and 1.2, with regular, small seasonal variations; the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 2 and 30 during the period of record), plus the moderately low but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients, most probably from agricultural return flows.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence to suggest a

slight increase in the orthophosphate concentration over the length of the data record, and the data suggest that the water is still fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, the generally low ammonium-N concentrations may have been caused by analytical difficulties in measuring ammonium-N concentrations below 0.02 mg/litre. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 5% of the corrosion ratio values exceeded the CEV for domestic water use. Approximately 75% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 5% of the nitrate-N concentrations and the upper 5% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from upstream sources. None of the recorded values for the other water quality constituents exceeded the CEV values for any designated uses. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algae and should ideally be treated before use. Overall, the data suggest that agricultural activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water can be used for all designated uses, though there is a slight risk of occasional corrosion to metal pipes and fittings that would need to be considered.

River Site #25 – Ga-Selati River at Loole (DWA gauge B7H019):

A total of 377 reliable water samples (97.2% of the total data set), collected between 5 January 1989 and 3 July 2008 with an average sampling frequency of 18.7 days, comprised this data set (**Table 2**).

The water in the Ga-Selati River at this site (**Appendix A1**, **Figures 25A – 25H**) is characterized by high and increasing TDS concentrations (100 to over 2000 mg/litre), alkaline pH values (7.9 – 8.9), high (400 – 100 mg/litre) but slowly decreasing sulphate concentrations and moderately low but variable concentrations of orthophosphate with occasional high values (0.01 – 0.7 mg/litre). The values for the sulphate : chloride ratio have decreased from between 3 and 4 in 1990 to between 1 and 2 in 2007, mirroring the decrease in sulphate concentrations. The corrosion ratio data show a relatively steady decrease from between 5 and 7 in 1989 to between 1 and 3 in 2007. These data indicate that mining and/or industrial activities have had a strong detrimental effect on water quality but that this effect appears to be decreasing at this site. The values for the sodium adsorption ratio have gradually increased from around 2.5 to around 3.5 during the period of record, though the water appears to be fit for irrigation use. The initially high and very variable values for the inorganic N:P ratio (ranging from 10 to 85) have declined to well below 1 since 1994. These data plus the moderate but gradually increasing orthophosphate concentrations indicate that the water at this site is being enriched by nutrients – most probably from the discharge of domestic effluents or from effluents containing phosphate derived from the Foskor plant in Phalaborwa.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is clear evidence of decreasing concentrations of sulphate, plus increasing values for the sulphate : chloride ratio and corrosion ratio over the length of the data record, indicating that the water from the Phalaborwa mining and industrial complex is being treated before discharge. The water at this site is often unfit for designated uses and requires pre-treatment before use.

Examination of the percentile water quality data for this site in **Appendix Table A3** revealed that all of the ammonium-N concentrations and the upper 75% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, for ammonium-N this may have been caused by analytical difficulties in measuring low ammonium-N concentrations. The upper 75% of the TDS, calcium, magnesium, sulphate, total alkalinity and fluoride concentrations exceeded the CEV for domestic water uses, and reflect the influence of mining and/or industrial effluents on water quality at this site. The high fluoride concentrations are clearly derived from the fluor-apatite rock that is mined and processed to produce rock phosphate at the Foskor plant. The upper 95% of the values for the corrosion ratio, plus the upper 75% of the TDS concentrations, exceeded the CEV for domestic water use, again indicating a strong likelihood that mining and/or industrial activities have influenced the water quality at this site. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment. The exceedance values for the corrosion ratio indicate that the water at this site will require stabilization before use to prevent corrosion of metal pipes and fittings. The presence of nutrient enrichment at this site suggests that the water could support the growth of undesirable algae and should be treated before use. In general, the exceedance values at this site suggest that the water should not be used without prior treatment.

River Site #26 – Olifants River at Mamba (DWA gauge B7H015):

A total of 592 reliable water samples (96.1% of the total data set), collected between 18 October 1983 and 10 March 2008 with an average sampling frequency of 15 days, comprised this data set (**Table 2**).

This site in the Olifants River is located a short distance downstream of the inflow from the Ga-Selati River, inside the western border of the Kruger National Park (KNP) (**Appendix A1**, **Figures 26A – 26H**) and the water at this site is characterized by moderately high and seasonally variable TDS concentrations (200 – 1500 mg/litre) that have declined to between 200 and 500 mg/litre since 2000. The pH values at this site have increased from around 7.1 in 1984 to between 8.0 and 9.0, remaining seasonally variable but more or less constant in this range since 1990. The sulphate concentrations were initially very variable (80 – 800 mg/litre) but have declined to between 50 and 200 mg/litre since 1995. The orthophosphate concentrations were relatively low (0.01 – 0.04 mg/litre in 1985) and have gradually increased to between 0.03 and 0.10 mg/litre in 2006, whilst becoming more variable. The values for the sulphate : chloride ratio have decreased from around 3.0 in 1992 to around 1.0 in 2006, again with distinct seasonal fluctuations. The corrosion ratio data are also seasonally variable and have declined from around 3.0 in 1990 to below 1.0 in 2006. These data suggest that the water at this site is influenced by water from the middle reaches of the Olifants River as well as water from the Ga-Selati River which is heavily influenced by the mining and industrial activities at Phalaborwa. The values for the sodium adsorption ratio have declined slowly from between 1.5 and 2.5 in 1984 to between 1.0 to 1.5 in 2006, also with regular, moderate seasonal variations; the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio have declined and become less variable in recent years and, taken with the gradually increasing orthophosphate concentrations, indicate that the water at this site is being enriched by nutrients, most probably from a combination of agricultural return flows in the middle reaches of the Olifants River and discharges of mining, industrial and domestic effluent in the Ga-Selati River.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. The slight increase in the orthophosphate over the length of the data record, plus the influence of mining, industrial and domestic effluents, indicate that the water should ideally be pre-treated before use.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, with the maximum recorded ammonium-N concentration exceeding the CEV for domestic water use.

However, the generally low ammonium-N concentrations may have been caused by analytical difficulties in measuring ammonium-N concentrations below 0.02 mg/litre. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 50% of the values for the corrosion ratio exceeded the CEV for domestic water use. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N concentrations and the upper 25% of the orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from upstream sources. The upper 5% of values for calcium, sulphate and fluoride exceeded the CEV for domestic water use, while the upper 25% of the values for TDS, magnesium and total alkalinity also exceeded the CEV for domestic water use. The magnesium data suggest that these values may have been influenced by the mining of vermiculite mica at Phalaborwa or that some water may have been derived from a dolomitic source. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algae and should ideally be treated before use. Overall, the data suggest that a wide range of different land use activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water could be used for all designated uses if the water is pre-treated, though there is a risk of corrosion to metal pipes and fittings that would also need to be considered before the water is used.

River Site #27 – Olifants River at Balule Rest Camp (KNP) (DWA gauge B7H017):

A total of 389 reliable water samples (97.3% of the total data set), collected between 18 October 1983 and 29 May 2008 with an average sampling frequency of 23.1 days, comprised this data set (**Table 2**).

This site in the Olifants River is located close to the Olifants River Gorge near the eastern border of the KNP, and a short distance upstream of the inflow from the Great Letaba River (**Appendix A1**, **Figures 27A – 27H**). The water at this site is characterized by moderately high and seasonally variable TDS concentrations (300 – 1500 mg/litre) that have also tended to decrease and stabilize below 750 mg/litre in recent years. The pH values at this site have increased from around 7.5 in 1985 to between 8.0 and 9.0, remaining seasonally variable but more or less constant in this range since 1990. The sulphate concentrations are moderately high and very variable (40 – 900 mg/litre) though they have decreased from about 250 – 400 mg/litre in 1994 to around 60 – 80 mg/litre since 1996. The orthophosphate concentrations were relatively low (0.01 – 0.02 mg/litre in 1985) and have gradually increased to between 0.03 and 0.05 mg/litre by 2006, with wide seasonal fluctuations. The values for the sulphate : chloride ratio have decreased from around 2.0 in 1985 to around 1.0 by 2006, again with distinct seasonal variations. The corrosion ratio data are seasonally variable and have remained below 2.5 with a tendency to decrease and become more constant around 1.0 by 2006. These data suggest that the water in the lower reaches of the Olifants River is influenced by a wide range of land use activities upstream. The values for the sodium adsorption ratio have remained more or less constant at between 0.5 and 2.5, with regular, moderate seasonal variations; the water appears to be suitable for irrigation use based on this statistic alone. The variable values for the inorganic N:P ratio (varying between 1 and 40 during the period of record, declining in recent years to remain below 20), plus the moderately low but gradually increasing orthophosphate concentrations, indicate that the water at this site is being enriched by nutrients, most probably from agricultural return flows and discharges of domestic effluent.

The data show clear signs of seasonal cyclical changes in the concentrations of all water quality constituents and the values of water quality indices. There is evidence to suggest a slight decrease in the concentrations of sulphate, though orthophosphate concentrations increase, over the length of the data record, and the data suggest that the water is still reasonably fit for all designated uses.

Examination of the percentile water quality data for this site in **Appendix Table A3** once again revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. However, the generally low ammonium-N concentrations may have been caused by analytical difficulties in measuring ammonium-N concentrations below 0.02 mg/litre. The normally low values for the sulphate : chloride ratio suggest that the water has not been significantly influenced by mining and/or industrial activities, though the upper 50% of the values for the corrosion ratio exceeded the CEV for domestic water use. Approximately 50% of the inorganic N:P ratio values were below 10 indicating the likelihood of nutrient enrichment; this is supported by the data for the upper 25% of the nitrate-N and orthophosphate concentrations, which suggest that the water at this site has been enriched with nutrients from upstream sources. The upper 5% of values for calcium, sulphate and fluoride, plus the upper 25% of the values for TDS, magnesium and total alkalinity, exceeded the CEV for domestic water use. The magnesium data suggest that there may be an influence of water derived from dolomitic sources or from the mining and industrial complex at Phalaborwa on water quality at this site. The presence of nutrient enrichment at this site suggests that the water will support the growth of undesirable algae and should ideally be treated before use. Overall, the data suggest that a range of different land use activities have had impacts on water quality at this site. In general, the exceedance values at this site suggest that the water could be used for all designated uses though there is a risk of corrosion to metal pipes and fittings that would need to be considered before the water is used.

Reservoir Site #R7 – Blyderivierspoort Dam on the Blyde River (DWA gauge B6R003):

A total of 188 reliable water samples (70.1% of the total data set), collected between 13 April 1978 and 16 June 2006 with an average sampling frequency of 54.5 days, comprised this data set (**Table 2**).

At this reservoir sampling site located close to the dam wall of the Blyderivierspoort Dam on the scenic Blyde River (**Appendix A2**, **Figures R7A** – **R7H**) the water is characterized by moderately low though seasonally variable TDS concentrations (40 to 120 mg/litre). The pH values are also seasonally variable and have remained reasonably constant (7.5 to 8.3) since 1990. The sulphate concentrations are low and variable (5 to 15 mg/litre) while orthophosphate concentrations reveal a gradual increase to around 0.03 mg/litre in 2006. The values for the sulphate : chloride ratio are very variable but remained within the low range of 1 to 3 during the period of record. The corrosion ratio values show some seasonal variability but have increased steadily from about 0.2 in 1980 to around 0.4 in 2006. These data suggest that mining and / or industrial activities have had a negligible influence on water quality in this reservoir, though the water has become increasingly corrosive in recent years. The values for the sodium adsorption ratio (0.1 – 0.3) show a pattern of variability that almost exactly mimics the patterns of change in TDS concentrations, and have remained more or less constant around 0.2 since 1985. The low SAR values indicate that the water is ideally suited for irrigation use. The values for the inorganic N:P ratio have declined slowly since about 1990 to below 20; this, and the gradually increasing concentrations of orthophosphate, suggest that the water is being enriched with nutrients – most probably by increasing quantities of return flows from irrigated agriculture and, possibly, by the discharge of domestic effluents from communities in the catchment.

The data show clear signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. The trend of increased concentrations of orthophosphate since 1990 has not been accompanied by trends of increased TDS concentrations, suggesting that agricultural return flows are likely responsible for the increasing influence on water quality in this reservoir. Despite these indications, the quality of the water in Lake Blyderivierspoort is fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. The lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. Only the maximum recorded value for the corrosion ratio exceeded the CEV limit for domestic water use. These results suggest that mining and / or industrial activities have had little or no effect on water quality and that agricultural activities and possibly domestic effluent are likely responsible for any decline in water quality. Approximately 25% of the inorganic N:P ratio values were below 10, again indicating the likelihood of nutrient enrichment. The presence of nutrient enrichment in this reservoir indicates that the water would support growths of undesirable algae and should ideally be treated before use.

Reservoir Site #R8 – Phalaborwa Barrage on the Olifants River (DWA gauge B7R002):

A total of 156 reliable water samples (93.4% of the total data set), collected between 17 November 1975 and 31 January 1998 with an average sampling frequency of 54.1 days, comprised this data set (**Table 2**).

This reservoir sampling site is located close to the dam wall of the Phalaborwa Barrage on the Olifants River (**Appendix A2**, **Figures R8A** – **R8H**). The water is characterized by moderately low though seasonally variable TDS concentrations (120 to 350 mg/litre), that have remained more or less stable over the period of record. The pH values are seasonally variable and have slowly increased from around 7.0 in 1976 to around 8.5 in 1996. The sulphate concentrations remained low (10 – 30 mg/litre) from 1976 to 1995, and then increased to between 60 and 80 mg/litre in 1996. The orthophosphate concentration data are very variable (0.005 – 0.03 mg/litre) but do not show signs of any trend of change over time. The values for the sulphate : chloride ratio remained almost constant below 1 between 1976 and 1995 and then rose sharply to around 3.0 in 1996. The corrosion ratio values show some seasonal variability but have increased steadily from around 0.4 in 19976 to around 0.8 in 1996. These data suggest that mining and / or industrial activities have had a very minor influence on water quality in this reservoir, though the water has become slightly more corrosive in recent years. The values for the sodium adsorption ratio (0.5 – 2.0) show a pattern of variability that is similar to the patterns of change in TDS concentrations. The SAR values are still relatively low and the water is still suitable for irrigation use. The values for the inorganic N:P ratio have remained seasonally variable with no trend of increase or decrease over the period of record. This is similar to the seasonal patterns of change in the orthophosphate concentrations, suggesting that the water in this reservoir is being enriched with nutrients though this seems to be more or less constant over the period of record. The data suggest that the source of the nutrient enrichment is likely to be return flows from irrigated agriculture and, possibly, by the discharge of domestic effluents from communities in the catchment.

The data show signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. Apart from the slight increases in sulphate concentrations and the sulphate : chloride ratio, there are no apparent trends of worsening water quality in this reservoir during the period of record. Despite these indications, the quality of the water in the Phalaborwa Barrage appears to be fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 5% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems. The lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. Only the maximum recorded value for the corrosion ratio exceeded the CEV for domestic water use. These results suggest that mining and / or industrial activities have had very little effect on water quality and that agricultural activities and domestic effluent are likely responsible for the decline in water quality. Approximately 25% of the inorganic N:P ratio values were below 10, again indicating the likelihood of nutrient enrichment. This feature, together with the upper 5% of orthophosphate concentrations, suggest that agricultural return flows or domestic effluent are the likely sources of this enrichment. The presence of nutrient enrichment in this reservoir indicates that the water would support growths of undesirable algae and would need to be treated before use.

Reservoir Site #R9 – Engelhard Dam on the Great Letaba River (DWA gauge B8R018):

A total of 142 reliable water samples (93.4% of the total data set), collected between 29 November 1983 and 30 May 2008 with an average sampling frequency of 61.9 days, comprised this data set (**Table 2**).

This reservoir sampling site is located close to the dam wall of the Engelhard Dam on the Great Letaba River (**Appendix A2**, **Figures R9A** – **R9H**). The water is characterized by moderately low and seasonally variable TDS concentrations (150 to 600 mg/litre), that show signs of a slow increase from around 200 mg/litre in 1993 to around 600 mg/litre in 2004, followed by a decrease to around 200 mg/litre in 2006. The pH values were initially (1984-1989) between 7.0 and 8.0 but then increased and have been reasonably stable between 8.0 and 9.0 for the remainder of the record. The sulphate concentrations remained low and variable (5 – 25 mg/litre) from 1984 to 2006, with a slight tendency to remain at the higher values during the latter part of the record. The orthophosphate concentration data are very variable around 0.02 mg/litre and do not show signs of any trend of change over time. The values for the sulphate : chloride ratio were initially low (< 0.2) between 1984 and 1991, then rose to between 0.4 and 0.6 until 1995, followed by a decrease to around 0.2 for the remainder of the record. The corrosion ratio values were low and the patterns of change over the period of record mirrored the patterns of change in the sulphate : chloride ratio. These data suggest that mining and / or industrial activities have had a negligible influence on water quality in this reservoir, though the water has become slightly more corrosive in recent years. The values for the sodium adsorption ratio were between 1.0 and 2.0 from 1983 to 2000 and then increased to between 3.0 and 4.0 until the end of 1994, when the values declined to between 1 and 2. This pattern of change is very similar to the pattern of change in TDS concentrations. The SAR values are still relatively low and the water is still suitable for irrigation use based on this statistic alone. The values for the inorganic N:P ratio have remained low (< 40) and seasonally variable with a short period (1990 – 1995) of increase when the values varied between 60 and 120, followed by a decrease to below 20 for the remainder of the record. These data suggest that the water in this reservoir has received nutrient enrichment from upstream sources or, possibly, from populations of hippopotamus in the lake. The data do not provide any information as to the precise source of the nutrient enrichment.

The data show signs of seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. Apart from the slight increases in sodium adsorption ratio and corrosion ratio, there are no apparent trends of worsening water quality in this reservoir during the period of record. The quality of the water in Lake Engelhard appears to be fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, with the upper 5% of the ammonium-N concentrations exceeding the CEV for domestic water use. Once again, the lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. Only the maximum recorded value for the corrosion ratio exceeded the CEV for domestic water use. The upper 5% of magnesium concentration values and the upper 25% of total alkalinity values exceeded the CEV for domestic water use. Overall, these results suggest that mining and / or industrial activities have had a negligible effect on water quality and that agricultural activities, domestic effluent discharges and quite possibly the presence of hippopotamus populations in the lake are likely responsible for the decline in water quality. Approximately 50% of the inorganic N:P ratio values were below 10, again indicating the occurrence of nutrient enrichment. The presence of nutrient enrichment in this reservoir indicates that the water would support growths of undesirable algae and would need to be treated before use.

Reservoir Site #R10 –Kanniedood Dam on the Shingwidzi River (DWA gauge B9R003):

A total of 200 reliable water samples (92.1 of the total data set), collected between 7 February and 16 December 2007 with an average sampling frequency of 39.7 days, comprised this data set (**Table 2**).

This reservoir sampling site is located close to the dam wall of the Kanniedood Dam on the Shingwidzi River (**Appendix A2**, **Figures R10A** – **R10H**). The water is characterized by initially low and variable TDS concentrations (50 to 250 mg/litre), followed by an almost continual increase in TDS concentrations to between 600 and 1000 mg/litre. The pH values were initially (1984-1989) between 7.0 and 8.0 but then increased and have been reasonably stable between 8.0 and 9.0 for the remainder of the record. The sulphate concentrations have remained low and variable (2 – 20 mg/litre) for most of the period of record, apart from a sudden increase to around 125 mg/litre in 1997, followed by an equally sharp decline to the original low concentrations for the remainder of the record. This sudden 'pulse' of increased sulphate concentrations suggests that mining and / or industrial effluents may have been discharged into the upper reaches of this river system. The orthophosphate concentration data are very variable around 0.05 mg/litre and also showed a sudden increase to around 0.3 mg/litre in 1997 followed by a decline to the original low levels for the remainder of the record. The values for the sulphate : chloride ratio were initially low (0.2 – 0.5) between 1984 and 1991, then rose to between 1.0 and 1.6 until 1996, followed by a decrease to around 0.2 for the remainder of the record. The corrosion ratio values were low (< 0.4) and then rose sharply to around 1.8 in 1997, followed by a decline to below 1.0 for the remainder of the record. The "pulse" of increased values in the corrosion ratio coincided with similar short-duration pulses of increased values in TDS, sulphate, orthophosphate and sodium adsorption ratio. These data suggest that, overall, mining and / or industrial activities have had a negligible influence on water quality in this reservoir, though the sudden increase in water quality indices and water quality constituents in 1997 suggests strongly that mining and / or industrial effluents had been discharged into the upper reaches of this river system, and that this was discontinued within one year. The values for the sodium adsorption ratio were between 0.5 and 2.0 from 1983 to 1996 and then increased to between 5.0 and 6.0 until the end of 1997, when the values declined to between 1 and 2. This was then followed by a similar increase in SAR values during 2000 – 2001, again followed by a decrease to around 2.0 in 2004. This pattern of change is very similar to the pattern of change in TDS concentrations. The SAR values are still relatively low and the water is still suitable for irrigation use based on this statistic alone. The values for the inorganic N:P ratio have tended to remain low (< 20) and seasonally variable with a short period (1991 – 1998) of increase when the values varied between 40 and 70, followed by a decrease to below 10 for the remainder of the record. These data suggest that the water in this reservoir has received nutrient enrichment from domestic effluents or agricultural return flows in the upper catchment or, possibly, from populations of hippopotamus in the lake. The data do not provide any information as to the precise source of the nutrient enrichment.

The data show clear seasonal cyclical changes in the concentrations of water quality constituents and the values of water quality indices. Apart from the coincident increases in TDS, sulphate, orthophosphate, SAR, corrosion ratio and possibly the inorganic N:P ratio in

1997, there are no trends of worsening water quality in this reservoir during the period of record. The quality of the water in Lake Engelhard appears to be fit for all recognized uses.

Examination of the percentile water quality data for this site in **Appendix Table A4** revealed that all of the ammonium-N concentrations and the upper 25% of the orthophosphate concentrations exceeded the CEV for aquatic ecosystems, with the maximum recorded value for ammonium-N concentrations exceeding the CEV for domestic water use. Once again, the lower ammonium-N concentrations in the data set may have been influenced by analytical difficulties in measuring these concentrations. Only the maximum recorded value for the corrosion ratio exceeded the CEV for domestic water use. The upper 5% of TDS and magnesium concentrations and the upper 25% of total alkalinity values exceeded the CEV for domestic water use. Overall, these results suggest that mining and / or industrial activities have had a negligible effect on water quality and that agricultural activities, domestic effluent discharges and quite possibly the presence of hippopotamus populations in the lake are likely responsible for the decline in water quality. Approximately 50% of the inorganic N:P ratio values were below 10, again indicating the occurrence of nutrient enrichment. The presence of nutrient enrichment in this reservoir indicates that the water would support growths of undesirable algae and would need to be treated before use.

4.4 Longitudinal profiles of water quality along the Olifants River

The preceding section of this report described the typical variations and trends in water quality over time for 27 river monitoring sites and 10 reservoir monitoring sites, but did not provide any indication of the longitudinal changes in water quality along the length of the Olifants River. To achieve this, the same four water quality constituents and four water quality indices that were derived from the DWA routine monitoring data for 11 river sites and 4 reservoir sites located along the length of the Olifants River were analyzed to evaluate possible longitudinal trends of change in water quality. **Table 4** lists the river and reservoir sites that were used in this analysis; the location of each site is shown in **Figure 20**.

Table 4. Details of the 11 DWA river monitoring sites and 4 reservoir monitoring sites used to evaluate longitudinal trends in water quality along the length of the Olifants River.

Site Code No.	DWAF Site No.	Site Name
River sites:		
2	B1H018	Middelkraal Weir
4	B1H005	Wolwekrans Weir
5	B1H010	Weir downstream of Lake Witbank
14	B3H017	Weir downstream of Lake Loskop
15	B3H001	Loskop North Weir
18	B5H004	Weir downstream of Lake Flag Boshielo
19	B5H002	Zeekoegat Weir
21	B7H009	Finale Liverpool Weir
23	B7H007	Oxford Weir
26	B7H015	Mamba Weir
27	B7H017	Balule Rest Camp (KNP) Weir
Reservoir sites:		
R2	B1R001	Witbank Dam (Lake Witbank)
R4	B3R002	Loskop Dam (Lake Loskop)
R6	B5R002	Flag Boshielo Dam (Lake Flag Boshielo)
R8	B7R002	Phalaborwa Barrage

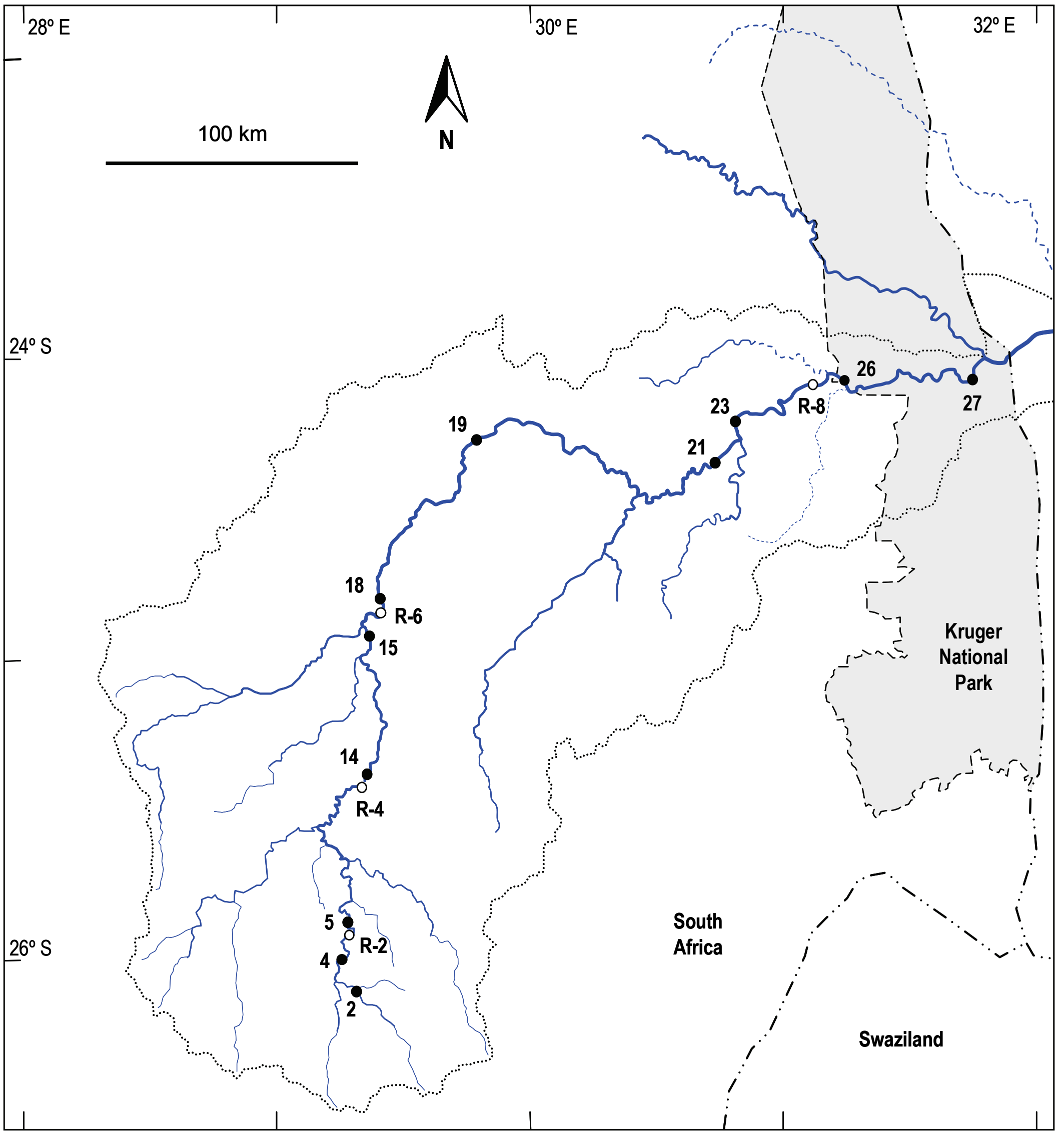

Figure 20. Sketch map showing the locations of the 11 river and 4 reservoir DWA routine monitoring sites where the data were used to evaluate longitudinal trends in water quality.

The percentile water quality data and / or index values for each of these river and reservoir sites were plotted as box and whisker plots, together with their respective CEV values to ascertain the degree to which the water quality index or constituent of interest exceeded the respective CEV values. Each of the 8 constituents or indices is discussed separately below.

4.4.1 Total Dissolved Salts (TDS)

A comparison of the TDS data for the 11 river sites and 4 reservoir sites in **Figure 21** reveals that there are signs of gradually worsening water quality along the length of the Olifants River, with the TDS concentrations in a progressively greater proportion of samples exceeding the CEV for aquatic ecosystems and domestic water uses. Site 2, located close to the source of the Olifants River, had low TDS concentrations for the entire period of record and no values approached the CEV limit. Site 4, located immediately upstream of Lake Witbank, had somewhat higher TDS concentrations with at least 5% of all values exceeding the CEV, most probably due to the seepage of effluent from domestic sources and from active and abandoned mining properties.

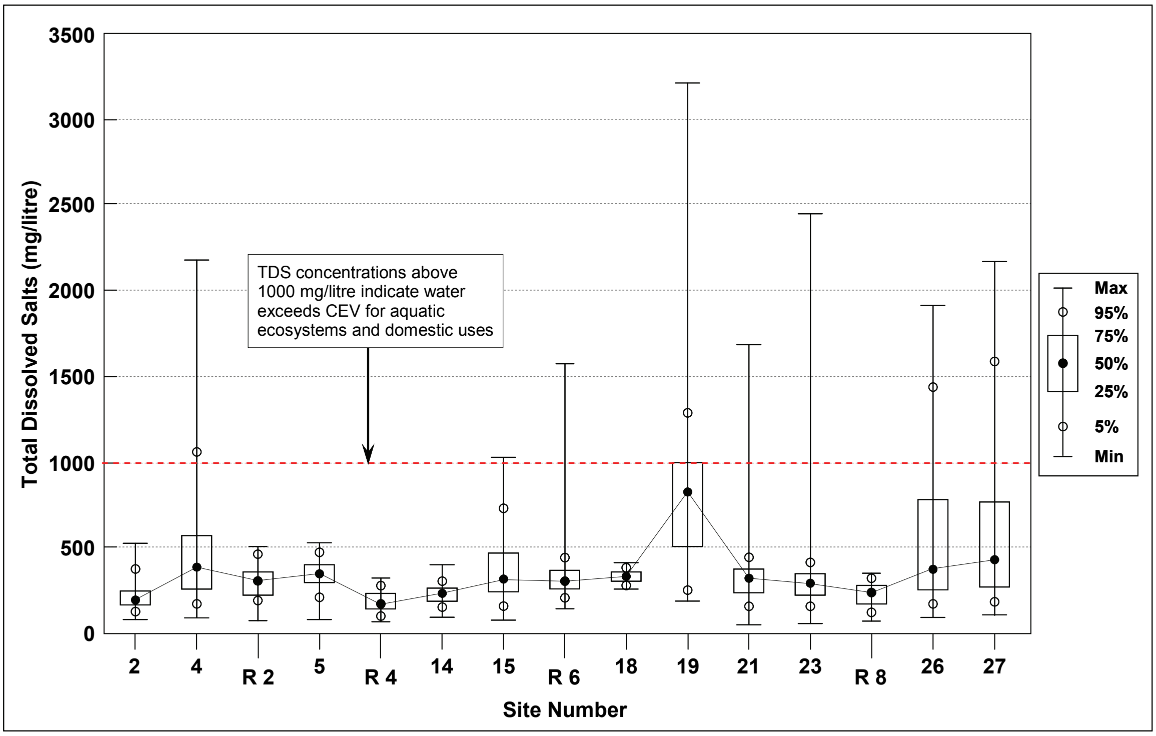

Figure 21. Box and whisker plots of percentile values for total dissolved salt (TDS) concentrations at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses.

The TDS concentrations in Lake Witbank (site R2) were lower and less variable than those recorded for the inflow to the lake (Site 4), while Site 5 downstream of Lake Witbank had slightly higher TDS values. The TDS concentrations in Lake Loskop (Site R4) were lower and less variable than those at Site 5, while the sites located downstream of Lake Loskop showed a progressive increase in median TDS concentrations and greater variability. With a few samples exceeding the CEV limit.

The median TDS concentration in Lake Flag Boshielo (Site R6) was similar to that of the upstream inflow (Site 15) but there was much more variability in the concentrations and some samples exceeded the CEV limit. Site 18, located immediately downstream of Lake Flag Boshielo, had a slightly higher median TDS concentration than that recorded in Lake Flag Boshielo, but a dramatically reduced range of concentrations. Site 19, showed a significant increase in the median TDS concentration, with approximately 25% of all samples exceeding the CEV limit.

The median TDS concentration at Site 21, located downstream of the inflow from the Steelpoort River (**Figure 20**), was approximately half of that for the upstream site (Site 19) and the range of variation was also reduced, though approximately 2% of samples exceeded the CEV limit. The median TDS concentration at Site 23, located a short distance downstream of the inflow from the Blyde River (**Figure 20**), was slightly lower than that of the upstream site. There was also a greater range of variation in the data, and approximately 1% of the samples exceeded the CEV limit.

The median TDS concentration in the Phalaborwa barrage (Site R8) was lower than that of the closest upstream site and the TDS data had a relatively narrow range of variation. None of the TDS values exceeded the CEV limit. At site 26, located a short distance downstream of the Phalaborwa Barrage and downstream of the inflow from the Ga-Selati River (Figure 20), there was an increase in the median TDS concentration and a wide range of variation in the recorded values, with approximately 18% of the TDS values exceeding the CEV limit.

The TDS data for this site reflect the adverse influence of inflows from the Ga-Selati River, which contain significant quantities of effluent from the mining and industrial complex at Phalaborwa. At site 27, located close to the eastern border of the KNP, downstream of inflows from the Klaserie River and upstream of the inflow from the Great Letaba River (**Figure 20**), there was a slight increase in the median TDS concentration and in the range of TDS concentrations recorded, with approximately 18% of the TDS values exceeding the CEV limit. The TDS data at this site indicate that the adverse influence of inflows from the Ga-Selati River have not been dissipated.

4.4.2 pH

A comparison of the pH data for the 11 river sites and 4 reservoir sites in **Figure 22** reveals very little sign of worsening water quality along the length of the Olifants River. Almost all of the pH values were within the upper and lower CEV limits for the pH of water for domestic use, and very few data points exceeded these CEV limits.

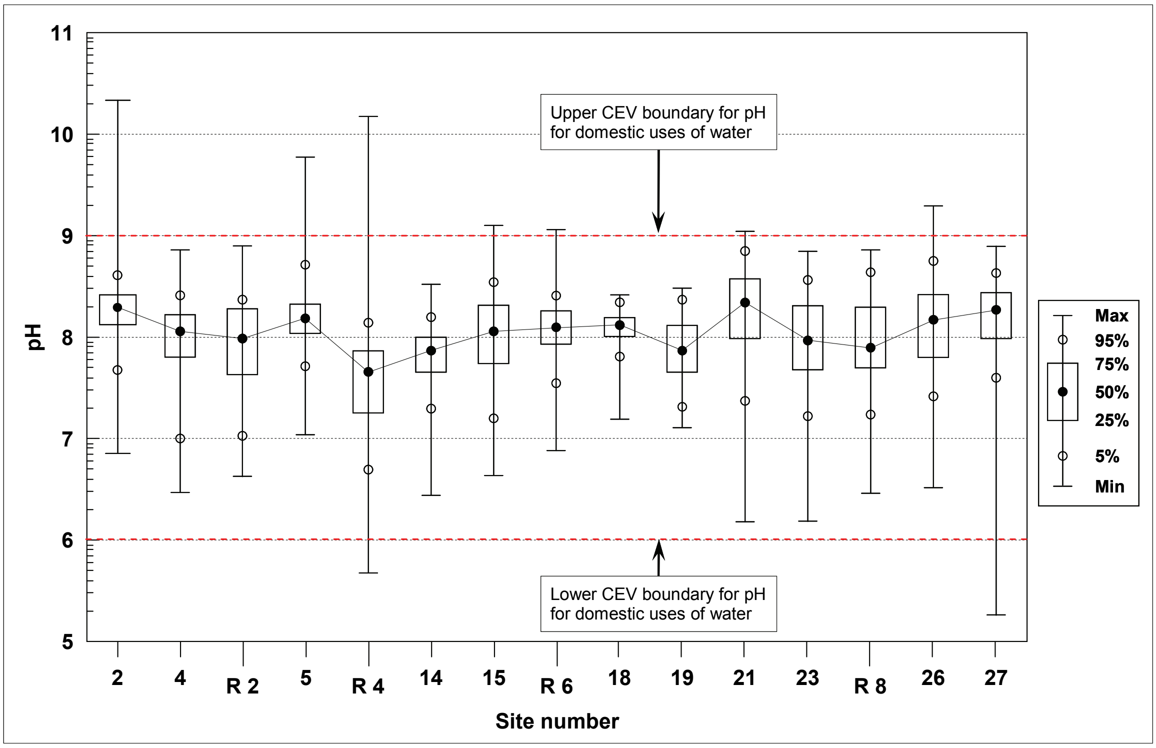

Figure 22. Box and whisker plots of the percentile pH values at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the upper and lower Chronic Effect Value (CEV) limits for domestic water uses.

With the exception of Site R6 (Lake Flag Boshielo), the median pH values in the reservoirs were below the corresponding pH values for their respective inflows. At site R4 (Lake Loskop), the pH values were very variable and the lower and upper values exceeded the respective lower and upper CEV limits for domestic water use. The highest pH values at this site probably reflect the presence of algal blooms in the lake.

4.4.3 Sulphate

A comparison of the sulphate data for the 11 river sites and 4 reservoir sites in **Figure 23** reveals that the water quality in the catchment gradually deteriorates with increasing distance downstream. The sulphate concentrations at the uppermost site (Site 2) were consistently low and no values approached the CEV limit of 400 mg/litre. At Site 4, sulphate concentrations increased markedly, with approximately 12% of the values exceeding the CEV limit for sulphate. These data suggest strongly that the increase in sulphate concentrations is associated with mining activities.

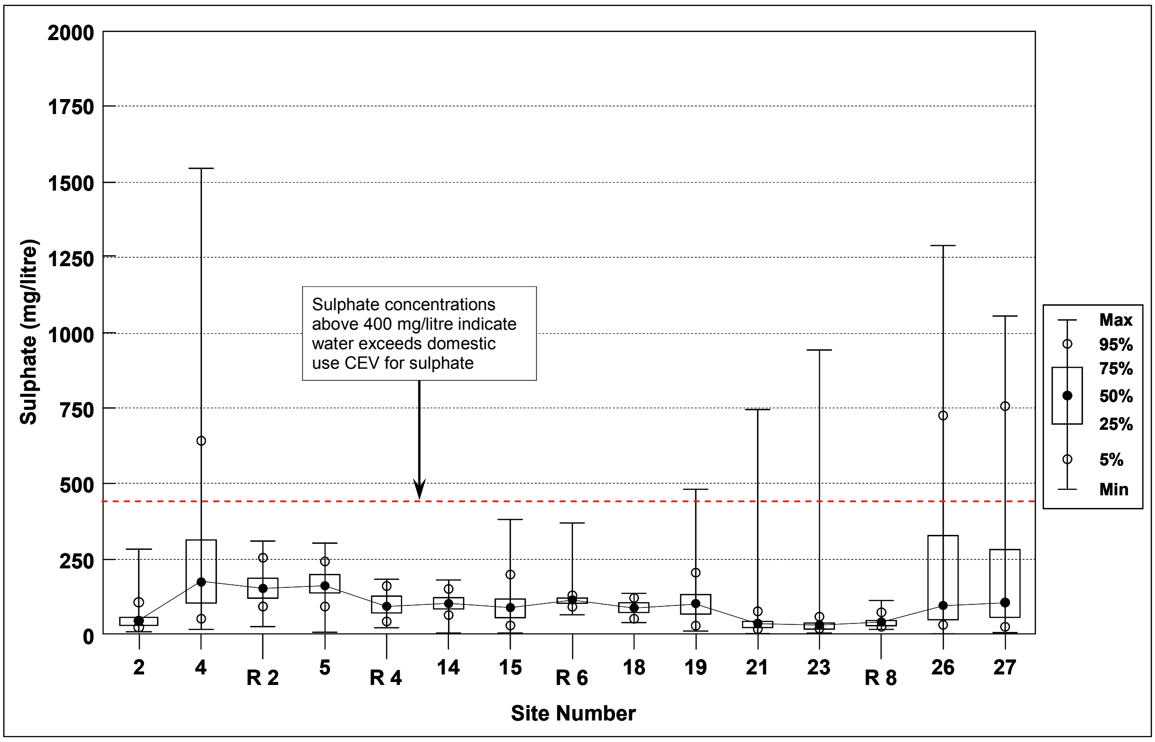

Figure 23. Box and whisker plots of percentile values for sulphate concentrations at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic water uses.

The sulphate concentrations in Lake Witbank (Site R2) were lower and less variable than the values recorded at Site 4, the inflow to the lake. Immediately downstream of Lake Witbank at Site 5, the sulphate concentrations were very similar to those recorded from the lake and reflect the influence of water released from the lake. The median sulphate concentration in Lake Loskop (Site R4) was lower than that recorded downstream of Witbank Dam and sulphate concentrations in the lake were less variable. At Site 14, located immediately downstream of Lake Loskop, the median sulphate concentration and the range of values recorded were very similar to those recorded for Lake Loskop and reflect the influence of water discharged from the lake.

The median sulphate concentration at Site 15, near the inflow into Lake Flag Boshielo, decreased slightly, most probably as a result of inflows from the Moses and Elands rivers that contained lower sulphate concentrations. However, the sulphate concentrations at this site were more variable than the upstream site and the maximum recorded value was only slightly lower than the CEV limit for domestic water use.

In contrast to the TDS data presented in Figure 21, the median sulphate concentration in Lake Flag Boshielo (Site R6) was slightly higher than the upstream site (Site 15), though the range of values recorded was slightly smaller. The median sulphate concentration at Site 18 located immediately downstream of Lake Flag Boshielo was slightly lower than the value recorded within Lake Flag Boshielo and the range of values was also very much reduced. Further downstream at Site 19, the median sulphate concentration increased slightly and the range of values also increased. Approximately 2% of all recorded values exceeded the sulphate CEV limit for domestic water use.

The median sulphate concentration at Site 21, located downstream of the inflow from the Steelpoort River (**Figure 20**), was approximately one-third of that for the upstream site (Site 19) though the range of variation had increased by a factor of approximately three and some 3% of the sulphate concentrations exceeded the CEV limit for domestic water use. The lower median sulphate concentrations recorded at this site reflect the 'diluting' effect of relatively good quality water from the Steelpoort River The median sulphate concentration at Site 23, located a short distance downstream of the inflow from the Blyde River (**Figure 20**), was slightly lower than that of the upstream site (Site 21), once again reflecting the 'diluting' effect of good quality water from the Blyde River. The sulphate concentrations recorded at Site 23 had a greater range of variation than the upstream site and approximately 2% of the samples exceeded the sulphate CEV limit for domestic water use.

The median sulphate concentration in the Phalaborwa barrage (Site R8) was similar to that of the closest upstream site (Site 23) and the sulphate data had a much narrower range of variability. None of the sulphate values exceeded the sulphate CEV limit for domestic water use. At site 26, located a short distance downstream of the Phalaborwa Barrage and downstream of the inflow from the Ga-Selati River (**Figure 20**), there was an increase in the median sulphate concentration and a marked expansion in the range of variation in the recorded values; approximately 16% of the sulphate values exceeded the sulphate CEV limit for domestic water use. The sulphate concentration data for this site reflect the adverse influence of inflows from the Ga-Selati River, which contain significant quantities of effluent from the mining and industrial complex at Phalaborwa. At site 27, located close to the eastern border of the KNP, downstream of inflows from the Klaserie River and upstream of the inflow from the Great Letaba River (**Figure 20**), there was a slight increase in the median sulphate concentration but a slight decline in the range of recorded sulphate concentrations, with approximately 16% of the sulphate values exceeding the sulphate CEV limit for domestic water use. The sulphate data at this site indicate that the adverse influence of inflows from the Ga-Selati River have not been dissipated or reduced by natural processes.

4.4.4 Orthophosphate

A comparison of the orthophosphate data for the 11 river sites and 4 reservoir sites in **Figure 24** reveals that water quality is relatively poor (enriched with nutrients) along the length of the Olifants River. The data show that the maximum orthophosphate concentrations recorded for the upper reaches (Sites 2, 4, 5, R2 and R4) tend to decline slightly downstream of Lake Loskop (Site 14) but then increase again at the inflow to Lake Flag Boshielo (Site 15). Further downstream, the maximum values for orthophosphate concentrations are very variable, with an increase at Site 26, located downstream of the Ga-Selati inflow, probably as a result of the relatively high orthophosphate concentrations in water contributed by the Ga-Selati River. Further downstream at Site 27, orthophosphate concentrations decrease, suggesting that there is little or no additional contribution of orthophosphate to the Olifants River below Site 26.

While the median orthophosphate values at all sites were below the CEV limit for domestic water use, some 20-25% of the orthophosphate values at all sites exceeded the CEV limit for domestic water use. These data indicate that there are numerous sources of orthophosphate entering the Olifants River system and there is no noticeable reduction in orthophosphate concentrations within any of the reservoirs.

In the upper reaches of the catchment, the primary sources of orthophosphate to the river system are likely to be runoff from cultivated lands and intensive livestock rearing areas, plus discharges of treated, partly treated and untreated domestic effluent and urban runoff. In the middle reaches of the catchment, the tributary rivers drain extensive areas of land that support dry-land and irrigated agriculture as well as numerous small towns and rural communities. Agricultural return flows and discharges of domestic effluent are the most likely sources of orthophosphate in this area.

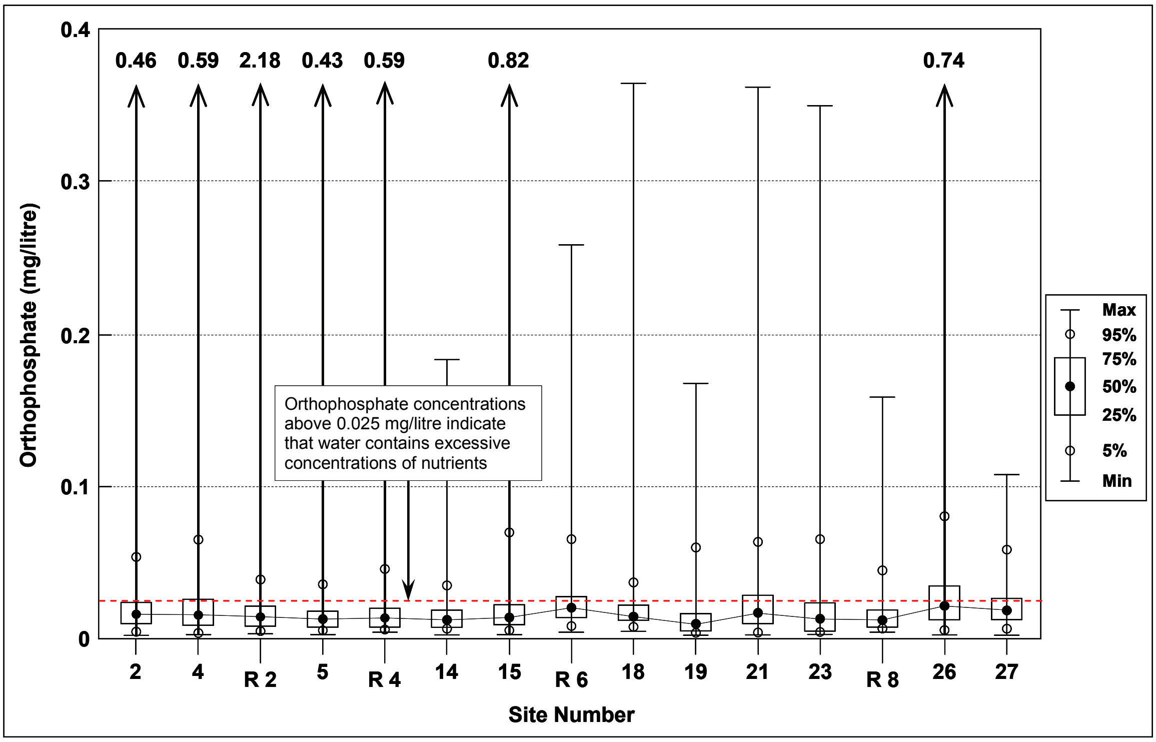

Figure 24. Box and whisker plots of percentile values for orthophosphate concentrations at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic water uses. Arrows indicate maximum recorded values.

In the lower reaches of the catchment, agricultural activities and domestic effluent discharges are likely to be the major contributors of orthophosphate to the river system. Immediately upstream of the western boundary of the KNP, inflows from the Ga-Selati River contain significant quantities of orthophosphate derived from domestic effluent and seepage from the Foskor tailings dams. These sources cause the sharp increase in orthophosphate concentrations downstream of the Phalaborwa Barrage.

4.4.5 Sulphate : Chloride Ratio (SCR)

A comparison of the sulphate : chloride ratio (SCR) data for the 11 river sites and 4 reservoir sites in **Figure 25** reveals that there is poor water quality in the upper reaches of the Olifants River catchment, and that this improves with increasing distance downstream until the inflows from the Ga-Selati River lead to a worsening of water quality.

At Site 2, the SCR data indicate that mining and / or industrial activities have had a minor detrimental effect on water quality, with only 3% of the higher values exceeding the recommended CEV limit for domestic water use. The SCR values at Sites 4, R2, 5, R4 and 14 indicate that mining activities are most likely to have been responsible for the deterioration in water quality, with the majority of values exceeding the recommended CEV limit for domestic water use. There is only slight evidence that lakes Witbank and Loskop have moderated this adverse effect on the SCR values.

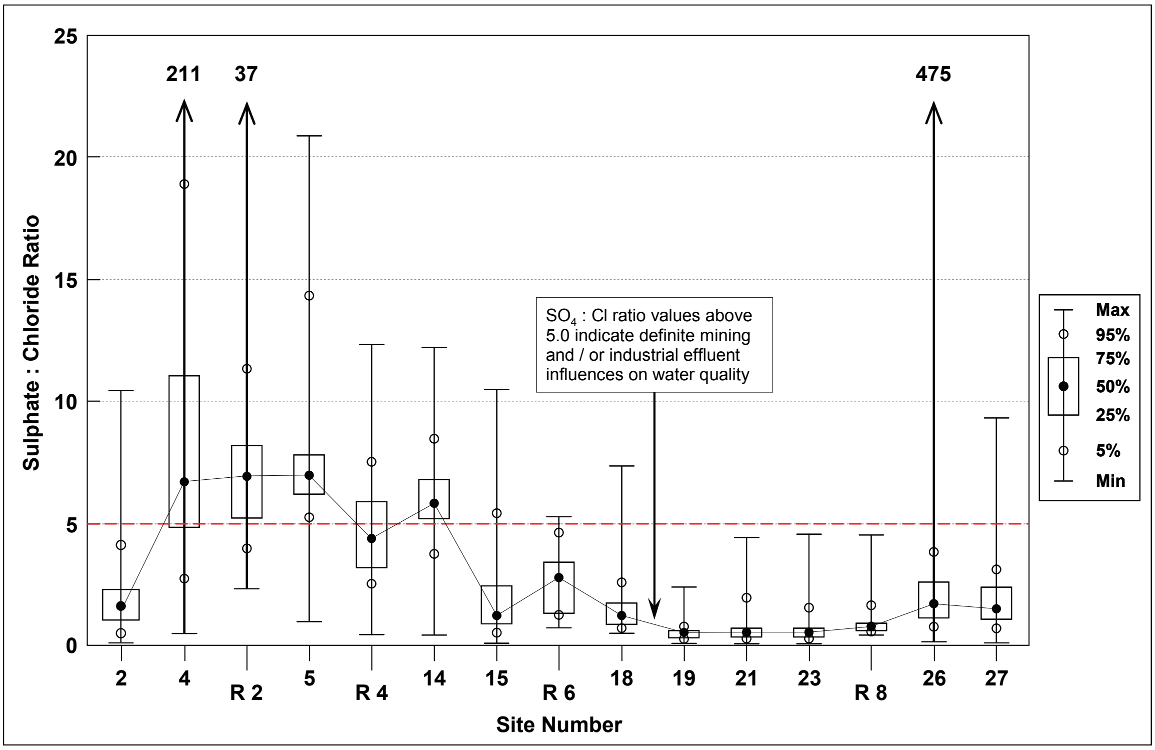

Figure 25. Box and whisker plots of the percentile values for the sulphate : chloride ratio (SCR) at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the recommended Chronic Effect Value (CEV) limit for domestic water uses. Arrows indicate maximum recorded values.

Downstream of Lake Loskop, the median SCR value increases slightly, followed by a rapid improvement further downstream. The median SCR value for Lake Flag Boshielo shows a slight increase, again followed by a sustained decrease further downstream, suggesting that very little adverse influence is exerted on water quality by mining or industrial activities in the middle reaches of the catchment.

The maximum recorded values for the SCR at Site 26 downstream of the Ga-Selati inflow are dramatically higher than the values recorded for the Phalaborwa Barrage (Site R8). Further downstream at Site 27, the declining SCR values indicate that no further mining influence has occurred.

4.4.6 Corrosion Potential Ratio (CPR)

A comparison of the corrosion potential ratio (CPR) data for the 11 river sites and 4 reservoir sites in **Figure 26** reveals that the water is of relatively poor quality along most of the length of the Olifants River, with a modest improvement in quality in the lower reaches of the river. Virtually all of the CPR values exceed the recommended CEV limit above which the water is almost certain to corrode metal pipes and fittings and would require stabilization before use.

The CPR values recorded for the four reservoirs do not show any signs of improvement compared to their corresponding inflows. This is unexpected given the potential of the relatively high nutrient concentrations in the lakes and their inflows to stimulate algal growth and thereby introduce additional alkalinity via photosynthesis into the lake water, which in turn should reduce the corrosion potential of the water.

At Site 2 in the upper reaches of the Olifants River (**Figure 26**), most of the CPR values are relatively low, though the highest values from this site suggest that some acidification has occurred in the uppermost reaches of the catchment. The other sites in the upper (Sites 4, R2, 5 and R4) and middle (Sites 14, 15, R6, 18 and 19) reaches of the catchment reflect clearly that acidification has occurred, most probably as a result of the discharge of mining and / or industrial effluents, while it is also possible that acidic atmospheric deposition has occurred. The CPR values for Lake Flag Boshielo (Site R6) are somewhat unusual in that all of the recorded values exceed the recommended CEV limit for domestic water use. There is a clear need for any water drawn from the Olifants River to be chemically stabilized before it is used.

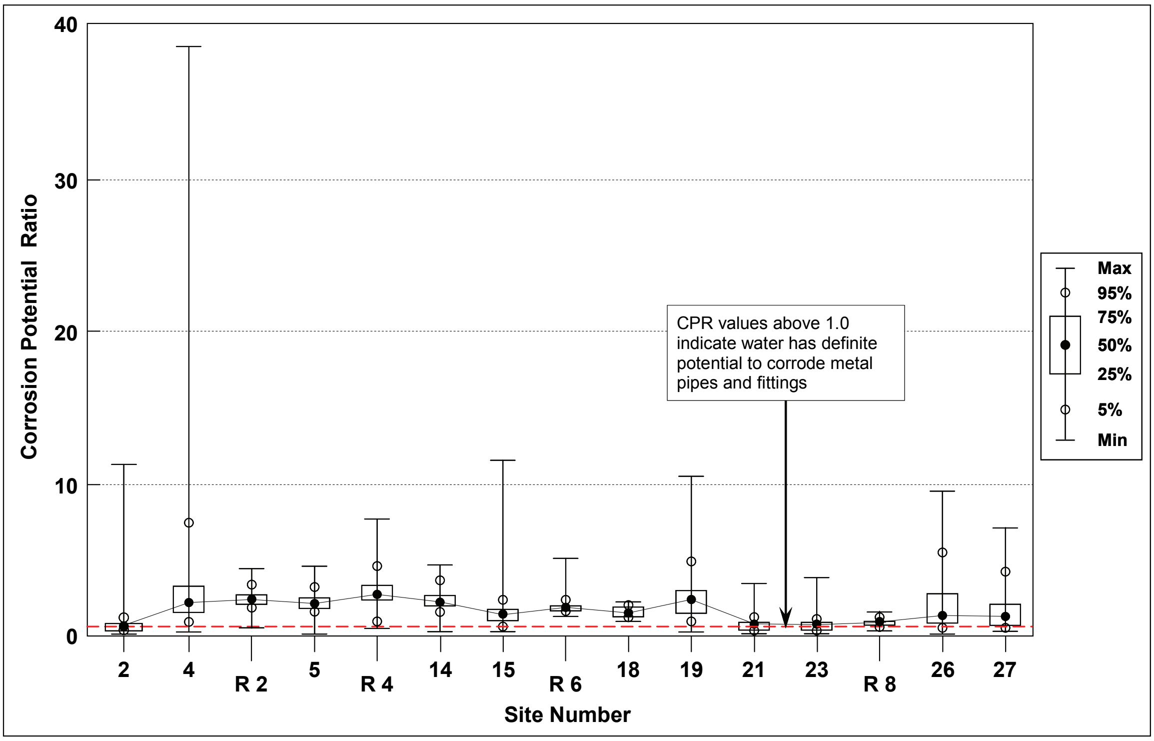

Figure 26. Box and whisker plots of the percentile values for the corrosion potential ratio (CPR) at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the recommended Chronic Effect Value (CEV) limit for domestic water uses.

4.4.7 Sodium Adsorption Ratio (SAR)

A comparison of the sodium adsorption ratio (SAR) data for the 11 river sites and 4 reservoir sites in **Figure 27** reveals that the water in the upper reach of the Olifants River catchment is of relatively good quality for irrigation uses. This situation continues until Site 14 – located downstream of Lake Loskop – and the SAR values increase at Site 15 with approximately 5% of the values exceeding the CEV for irrigation water use. The higher SAR values in the middle and lower reaches of the Olifants River catchment suggest that use of this water to irrigate sensitive crops on vulnerable soils could lead to soil salinization.

There is a slight reduction in the SAR values in Lake Flag Boshielo (Site R6), followed by a slight increase at Site 18 immediately downstream of the lake. At Site 19, there is a sharp rise in SAR values and approximately 73% of all values exceed the CEV for irrigation water use. Further downstream, the SAR values decrease at Sites 21 and 23 most likely as a result of inflows of relatively good quality water from the Steelpoort and Blyde rivers.

There is a slight reduction in the range of SAR values in the Phalaborwa Barrage (Site R8), followed by a slight increase in both the median SAR values and the range of SAR values at Sites 26 and 27. The decline in water quality indicated by the increased SAR values is most likely caused by the inflows of water from the Ga-Selati River, which contains high concentrations of dissolved salts.

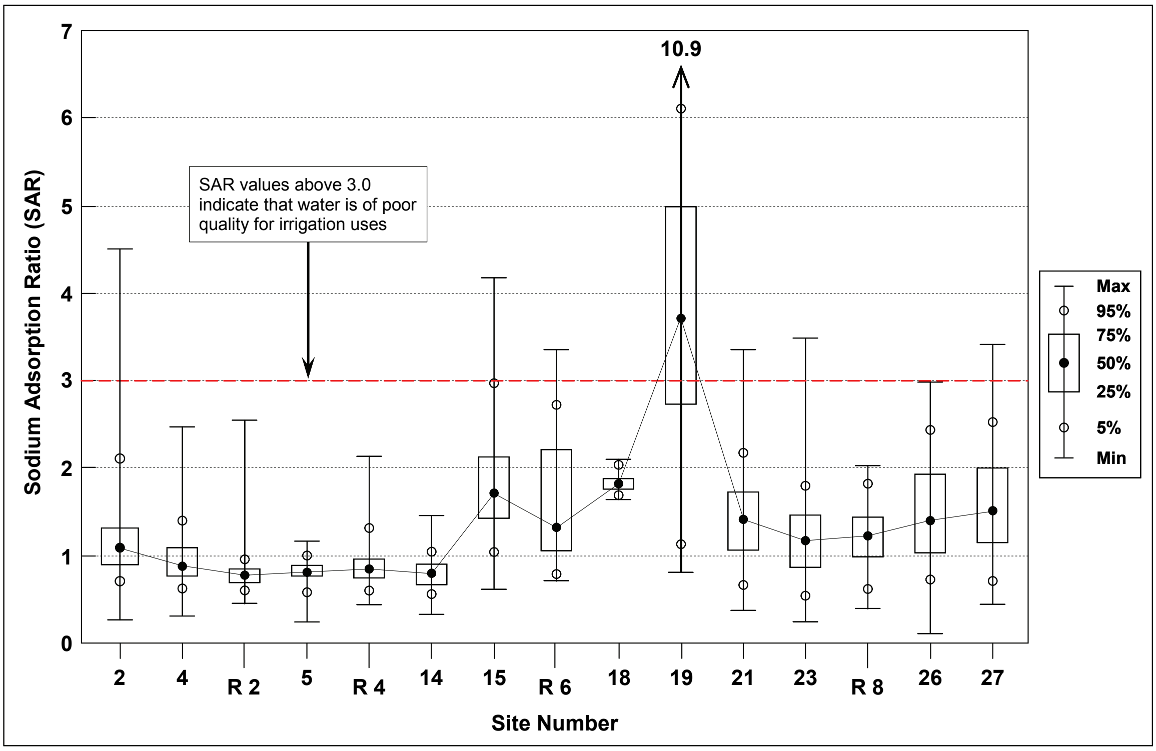

Figure 27. Box and whisker plots of the percentile values for the sodium adsorption ratio (SAR) at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the recommended Chronic Effect Value (CEV) limit for irrigation water use. Arrow indicates maximum recorded value.

4.4.8 Inorganic N:P Ratio (INPR)

A comparison of the inorganic N:P ratio (INPR) data for the 11 river sites and 4 reservoir sites in **Figure 28** reveals that the water throughout the length of the Olifants River is considered to be eutrophic for at least part of the time, with INPR values below 10. However, it is important always to evaluate the INPR data in conjunction with the orthophosphate data because, on its own, the INPR can produce misleading results.

Given this caveat, a comparison of the INPR data with the orthophosphate data for each of the sites along the Olifants River (**Figure 24**) confirms that all of the river and reservoir monitoring sites along the length of the Olifants River display eutrophic – and occasionally hypertrophic – characteristics. These features would be reflected in increased growth of nuisance benthic algae in the rivers and planktonic algae in the reservoirs. In both cases, the INPR values and the orthophosphate data suggest that cyanobacteria (blue-green algae) would be likely to dominate the algal populations.

There is no clear pattern to the changes in the INPR values along the length of the Olifants River, though there is some evidence to suggest that each of the four reservoirs located along the Olifants River do reduce the INPR values. However, despite these in-reservoir reductions in the INPR values, the values increase again immediately downstream of each reservoir.

The noticeable increase in INPR values at Site 19 appears to be due to either agricultural return flows containing nitrogenous fertilizer or the discharge of incompletely treated domestic effluent in the area immediately upstream of this site. The slight increase in the median and range of INPR values at Site 23 (downstream of the Blyde River inflow) also appear to have been caused by agricultural return flows from the important irrigation area downstream of the Blyderivierspoort Dam. The relatively large increase in INPR values at Site 26 located downstream of the Phalaborwa Barrage appear to have been caused by inflows from the Ga-Selati River, which contain domestic effluent in addition to effluent from the mining and industrial complex at Phalaborwa.

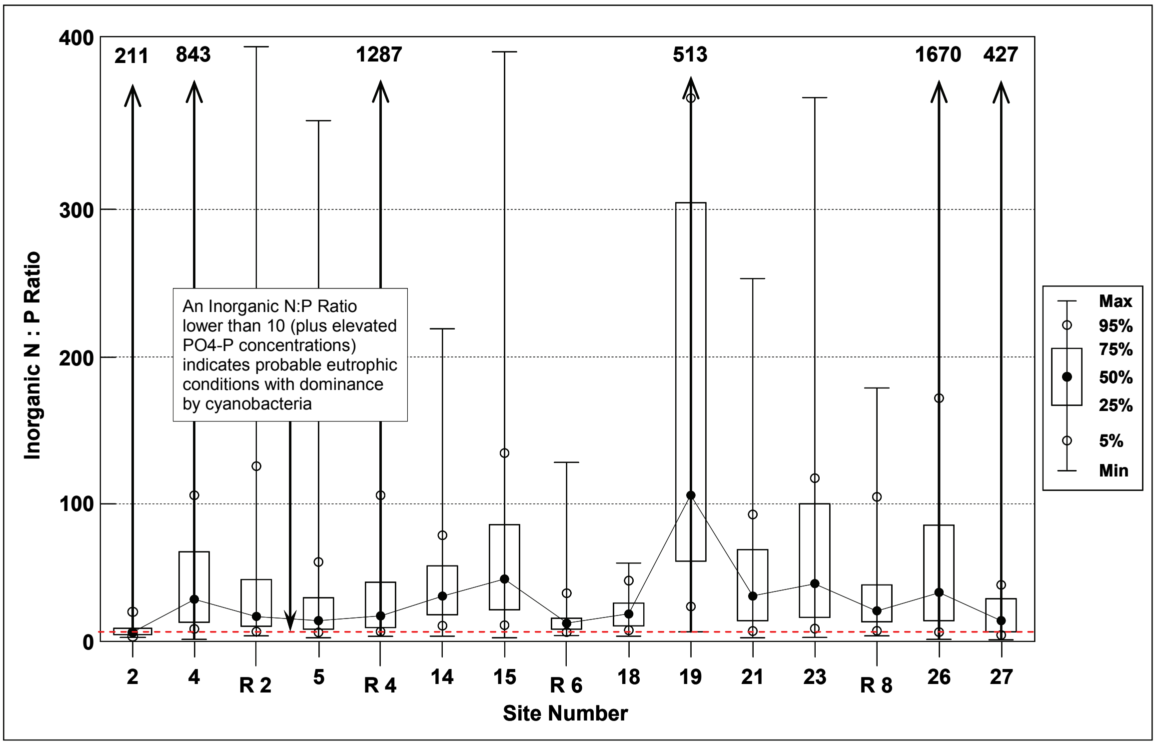

Figure 28. Box and whisker plots of the percentile values for the inorganic N:P ratio (INPR) at 11 river and 4 reservoir monitoring sites along the length of the Olifants River, compared with the recommended limit below which water is considered to be increasingly eutrophic. Arrows indicate maximum recorded values.

4.5 Contributions from major tributary rivers

The preceding descriptions and discussions have highlighted the importance of salts and nutrients contributed by the different tributary rivers along the length of the Olifants River and the apparent impacts that inflows from these tributaries have on water quality in the main channel of the Olifants River. Therefore, to evaluate the contributions of salts and nutrients contributed by the tributary rivers, the same four water quality constituents and four water quality indices that were derived from the DWA routine monitoring data for 16 river sites and 2 reservoir sites located on important tributaries were analyzed. **Table 5** lists the river and reservoir sites that were used in this analysis; the location of each site is shown in **Figure 29**.

The first 5 sites (Sites 1, 3, 6, 7 and 8) form part of the upper reaches of the main Olifants River while the second set of five sites (Sites 9, 10, 11, 12 and 13) are part of the Wilge River system, which joins the Olifants River immediately upstream of Lake Loskop (**Figure 16**). The remaining six river sampling sites (Sites 16, 17, 20, 22, 24 and 25) are the lowest representative sites on the Moses, Elands, Steelpoort, Blyde, Klaserie and Ga-Selati rivers.

Table 5. Details of the 16 DWA river monitoring sites and 2 reservoir monitoring sites used to evaluate the contributions of tributary rivers to water quality along the length of the Olifants River.

Site Code No.	DWAF Site No.	Site Name
River sites:		
1	B1H006	Trichardtspruit at Rietfontein Weir
3	B1H021	Steenkoolspruit at Middeldrift Weir
6	B1H002	Spookspruit at Elandspruit Weir
7	B1H015	Klein Olifants River downstream of Middelburg Dam
8	B1H004	Klipspruit at Zaaihoek Weir
9	B2H008	Koffiespruit at Rietvallei Weir
10	B2H004	Osspruit at Boschkop Weir
11	B2H003	Bronkhorstspruit River at Bronkhorstspruit Weir
12	B2H014	Wilge River at Onverwacht Weir
13	B2H015	Wilge River at Zusterstroom Weir
16	B3H005	Moses River at Mosesriviermond Weir
17	B3H021	Elands River at Scherp Arabie Weir
20	B4H011	Steelpoort River at Alverton Weir
22	B6H004	Blyde River at Chester Weir
24	B7H004	Klaserie River at Fleur-de-Lys Weir
25	B7H019	Ga-Selati River at Loole Weir
Reservoir sites:		
R9	B1R001	Engelhard Dam on the Great Letaba River
R10	B3R002	Kanniedood Dam on the Shingwidzi River

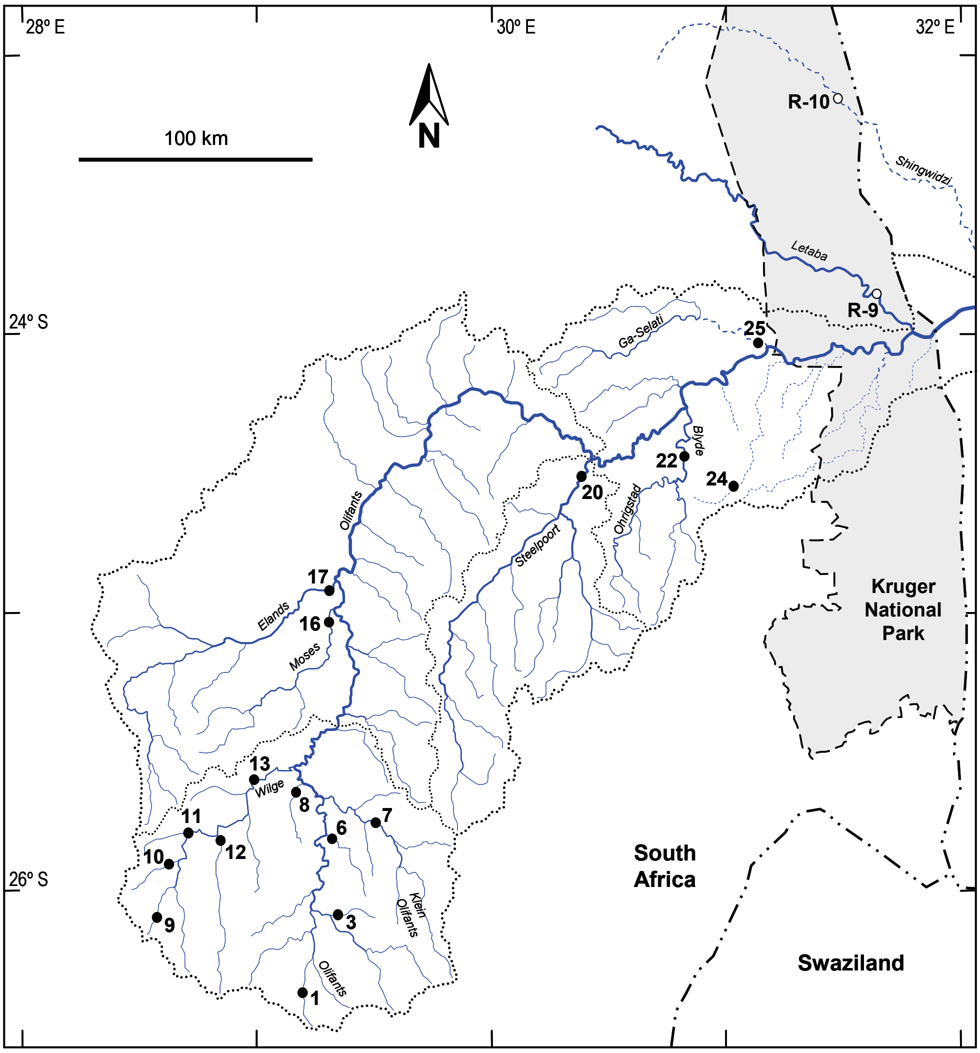

Figure 29. Sketch map showing the locations of the 16 river and 2 reservoir DWA routine monitoring sites where the data were used to evaluate contributions of tributary rivers to water quality.

4.5.1 Total Dissolved Salts (TDS)

A comparison of the TDS data for the 16 river sites and 2 reservoir sites in **Figure 30** reveals clearly that there are large differences in the TDS content contributed by the different tributary rivers. Sites 6 (Spookspruit), 8 (Klipspruit), 17 (Elands River) and 25 (Ga-Selati River) contribute the highest concentrations of TDS to the Olifants River, with many of the TDS concentrations measured at these sites exceeding the CEV limit for domestic water use. Approximately 85% of the recorded TDS concentrations contributed by the Ga-Selati River exceed the CEV limit for domestic water use. At this site, almost all of the TDS concentrations measured at this site fall within a relatively narrow range (1400 – 2000 mg/litre) indicating that the source of these salts is almost certain to be a single composite source.

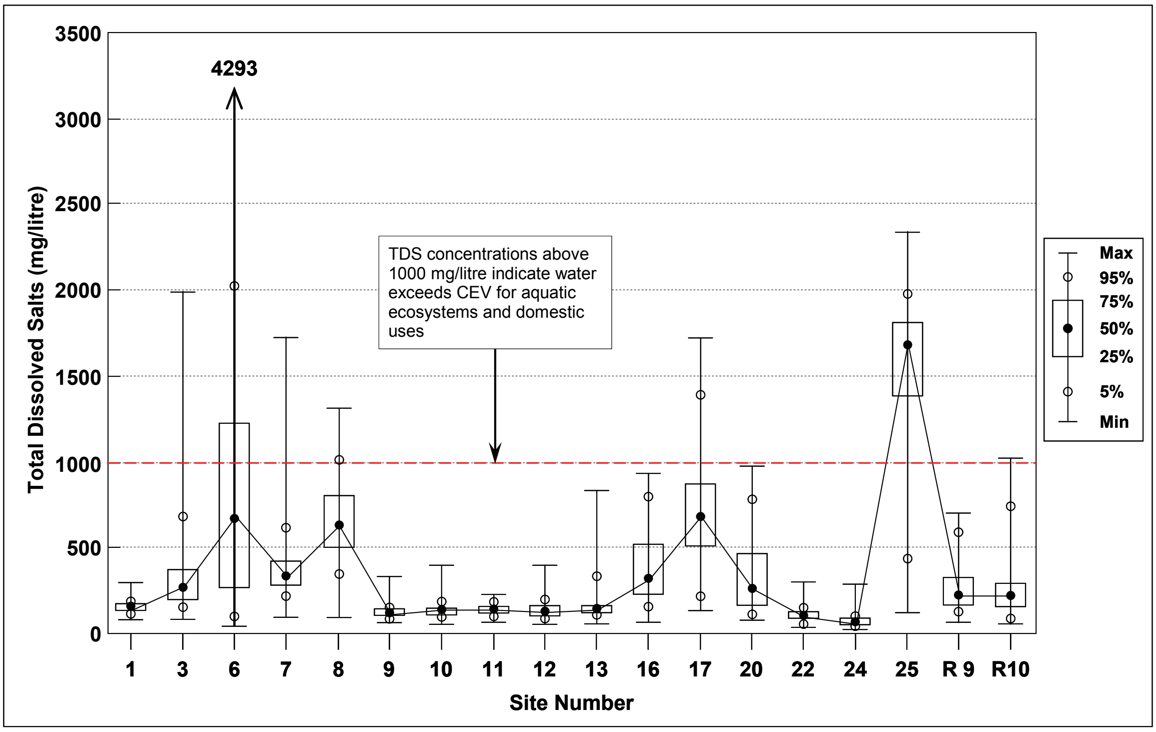

Figure 30. Box and whisker plots of percentile values for total dissolved salt (TDS) concentrations at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses. Arrow indicates maximum recorded value.

In the upper reaches of the catchment, the tributary rivers and stream that flow into the Olifants and Klein Olifants rivers (Sites 1, 3, 6, 7 and 8) contain the highest TDS concentrations, while those rivers that flow into the Wilge River (Sites 9, 10, 11, 12 and 13) contain the lowest TDS concentrations (**Figure 30**). Site 7 (Klein Olifants River) has a slightly lower median TDS concentration than those recorded for the Spookspruit (Site 6) and Klipspruit (Site 8). The TDS concentrations at Sites 3, 6, 7 and 8 suggest that mining activities may be responsible for at least some of the salts present. The very high TDS concentrations recorded at Site 6 (Spookspruit), in particular, indicate that mining and industrial sources are the main sources of salts in this tributary.

The Moses River (Site 16) and especially the Elands River (Site 17) contribute relatively high TDS concentrations, while the TDS concentrations in the Steelpoort River (Site 20) are still reasonably low (**Figure 30**). It is likely that the TDS concentrations recorded from these three sites reflect a mixed contribution from mining and agricultural sources in the respective catchments.. The TDS concentrations in the Blyde River (Site 22) and Klaserie River (Site 24) are both low, while the TDS concentrations in the Ga-Selati River (Site 25) are very high.

The majority of the TDS concentrations in the Ga-Selati River exceed the CEV for domestic water use, reflecting the dominance of mining and industrial effluent that comprises the flow in this river (**Figure 30**).

The TDS concentrations in the Great Letaba River (Site R 9) and Shingwidzi River (Site R 10) are both relatively low, though there are a small percentage of TDS concentrations in the Shingwidzi River that approach the CEV for domestic water use (**Figure 30**).

4.5.2 pH

A comparison of the pH data for the 16 river sites and 2 reservoir sites in **Figure 31** reveals the highly variable contribution of acidity from the different tributary rivers. A few low pH values were recorded from the sites in the upper Olifants – Klein Olifants sub-catchment (Sites 1, 3, 6, 7 and 8), with Site 6 (Spookspruit) and Site 8 (Klipspruit) showing the lowest pH values. Most of the pH values recorded in the Klipspruit (Site 8) in particular exceed the lower CEV limit for domestic water use.

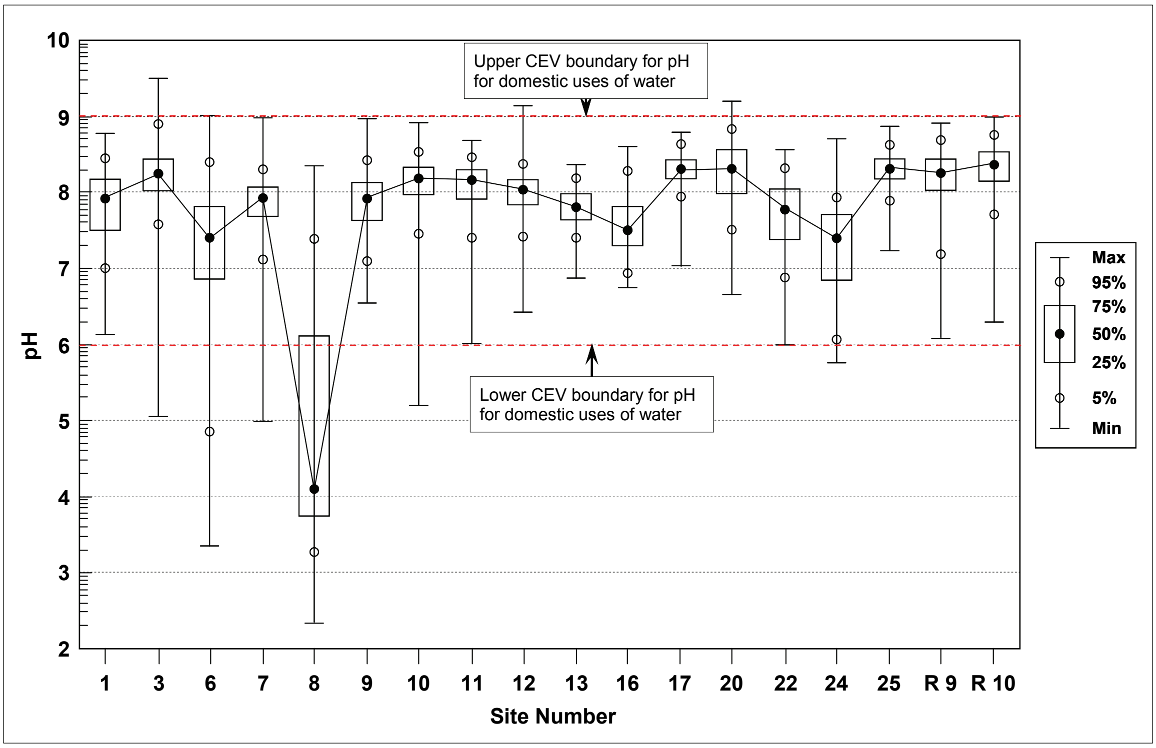

Figure 31. Box and whisker plots of the percentile pH values at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses.

Most of the pH values recorded for sites in the Wilge River sub-catchment (Sites 9, 10, 11, 12 and 13) fall within the CEV limits for domestic water use (**Figure 31**), though the occasional low pH values recorded at Site 10 (Osspruit) suggest that there is a small contribution from mining activities and / or abandoned mines in this small sub-catchment.

The pH values recorded for the Moses (Site 16), Elands (Site 17) and Steelpoort (Site 20) and Blyde (Site 22) tributaries are all within the CEV limits for domestic water supplies (**Figure 31**). A few low pH values were recorded for the Klaserie River (Site 24) though it is likely that these are the result of naturally low pH waters from the headwater streams upstream of this site. All of the pH values recorded for the Ga-Selati River (Site 25) are alkaline and reflect the fact that the alkaline rocks of the local ore bodies contain sufficient alkalinity to neutralize any acidity generated during the mining and metal refining processes. All of the pH values recorded for the Great Letaba River (Site R 9) and Shingwidzi River (Site R 10) (**Figure 31**) fall within the CEV limits for domestic water use and suggest that there has been very little influence of mining and / or industrial activities on the acidity of these two rivers.

4.5.3 Sulphate

A comparison of the sulphate concentration data for the 16 river sites and 2 reservoir sites in **Figure 32** reveals the highly variable contribution of acidity from the different tributary rivers. High to very high sulphate concentrations were recorded from four of the five sites located in the upper Olifants – Klein Olifants sub-catchment (Sites 3, 6, 7 and 8 all exceeded the sulphate CEV for domestic water use), with the concentrations in the Spookspruit (Site 6) and Klipspruit (Site 8) being noticeably higher than the other tributary rivers in this portion of the catchment.

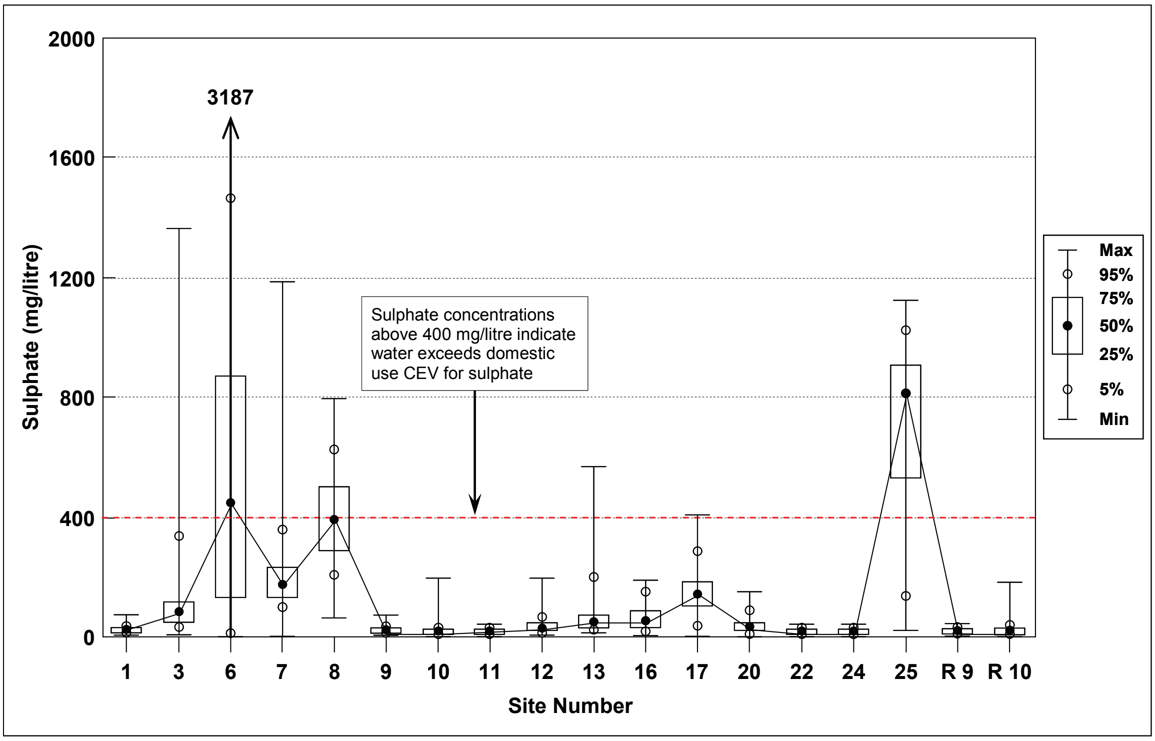

Figure 32. Box and whisker plots of the percentile values for sulphate concentrations at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses. Arrow indicates maximum recorded value.

Low sulphate concentrations were recorded from all of the tributary rivers in the Wilge sub-catchment, though some higher concentrations were recorded at Site 13, possibly reflecting some contribution from mining and/or industrial activities close to the town of Bronkhorstspruit (**Figure 32**). Some of the sulphate concentrations at Site 17 (Elands River) exceeded the sulphate CEV for domestic water use. With the exception of the Ga-Selati River (Site 25), the sulphate concentrations recorded for all of the other tributary rivers were within the sulphate CEV limits for domestic water use. Approximately 80% of all sulphate concentrations recorded for the Ga-Selati River (Site 25) exceeded the sulphate CEV limit for domestic water use.

4.5.4 Orthophosphate

The orthophosphate concentration data for the 16 river sites and 2 reservoir sites in **Figure 33** reveals the enormous variation in the contributions from the different tributary rivers, with all rivers having at least some values above the CEV limit for domestic water use. Site 3 (Steenkoolspruit – most likely caused by discharges of untreated or poorly treated domestic effluent) and Site 25 (Ga-Selati River – most likely containing orthophosphate from the Foskor workings) have the highest median orthophosphate concentrations. The Elands River (Site 17) also displays slightly elevated orthophosphate concentrations, most likely as a result of the discharge of poorly treated domestic effluent.

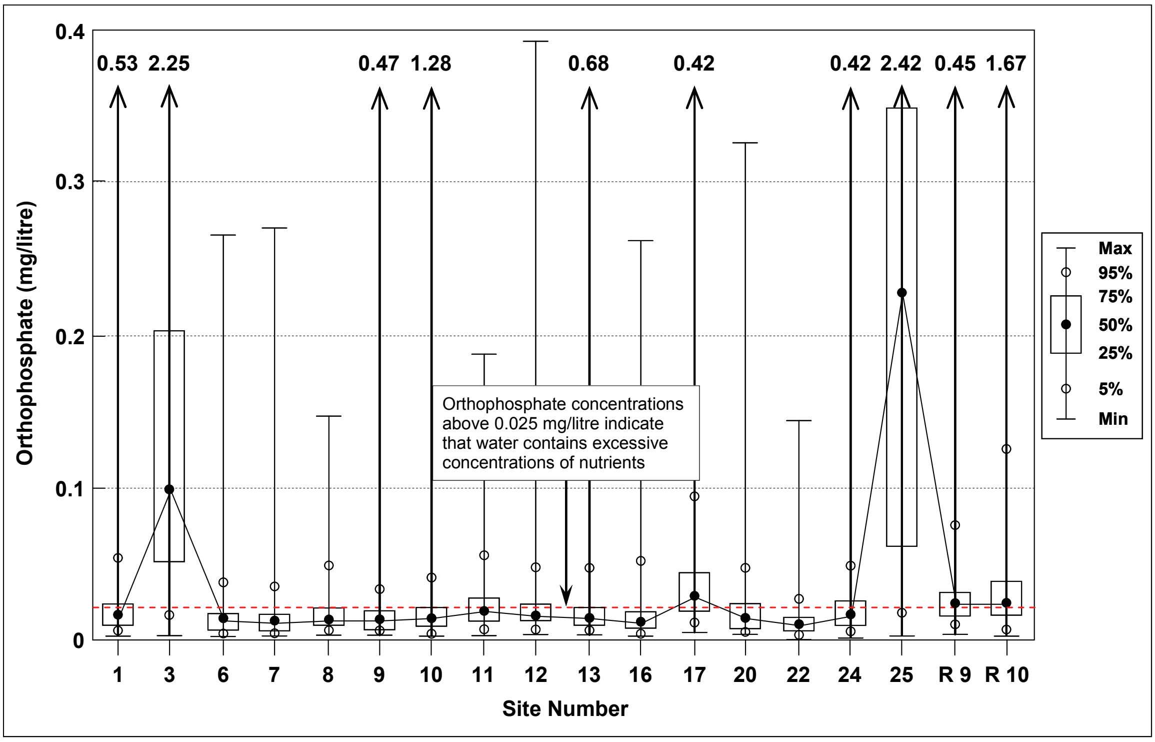

Figure 33. Box and whisker plots of the percentile values for orthophosphate concentrations at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses. Arrows indicate maximum recorded values.

The presence of high orthophosphate concentrations in all of the tributary rivers (**Figure 33**) suggests very strongly that all of the rivers receive discharges of domestic effluent that has not been properly treated before discharge. The median orthophosphate concentrations from the Great Letaba River (Site R 9) and the Shingwidzi River (Site R 10) exceed the CEV for domestic water use, but these higher values could also be a result of the relatively large populations of hippopotamus that are present at these sites (Joubert, 2007).

4.5.5 Sulphate : Chloride Ratio (SCR)

A comparison of the SCR data for the 16 river sites and 2 reservoir sites in **Figure 34** reveals the highly variable contribution of acidity from the different tributary rivers. Four of the sites in the upper Olifants – Klein Olifants sub-catchment (Sites 3, 6, 7 and 8) had very high SCR values indicating important contributions of acidity from mining and / or industrial activities, with Sites 6, 7 and 8 exceeding the CEV limits for domestic water use. Site 1 (Trichardtspruit) had much lower SCR values, with less than 2% of values exceeding the CEV limit for domestic water use, indicating that mining and / or industrial activities had had a very low impact on water quality in this tributary.

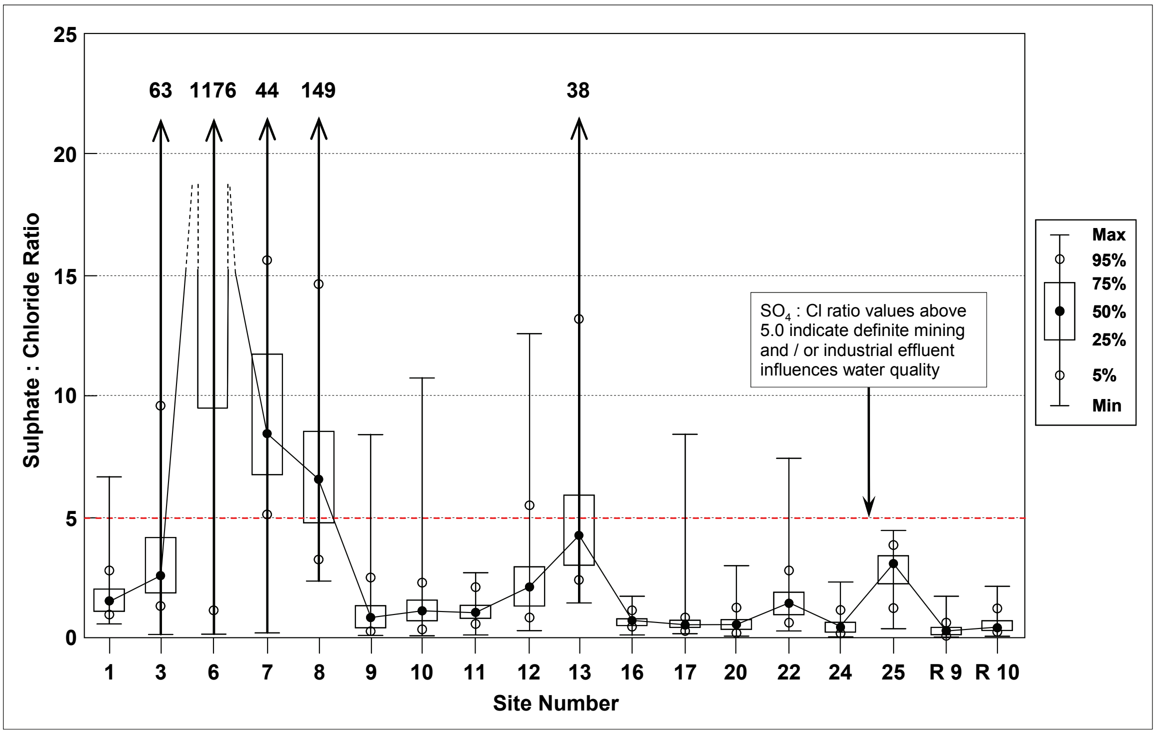

Figure 34. Box and whisker plots of the percentile values for the sulphate : chloride ratio at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the suggested Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses. Arrows indicate maximum recorded values.

The sites located in the Wilge River sub-catchment (Sites 9 to 13) showed steadily increasing SCR values with increasing distance downstream – indicating gradually increasing influence of mining and / or industrial activities – (**Figure 34**), with Site 13 (Zusterstroom) having a median SCR value close to the CEV limit for domestic water use.

The various tributary rivers entering the Olifants River downstream of Lake Loskop had relatively low SCR values, though Site 25 (Ga-Selati River) had slightly elevated SCR values (**Figure 34**). This reflects the relatively low contribution of acidity from the Ga-Selati River, caused by the alkaline nature of the country rock around the Phalaborwa mining and industrial complex. Sites R 9 (Great Letaba River) and R 10 (Shingwidzi River) had consistently low SCR values, indicating very little contribution to water quality from mining and / or industrial activities.

4.5.6 Corrosion Potential Ratio (CPR)

A comparison of the CPR data for the 16 river sites and 2 reservoir sites in **Figure 35** reveals the highly variable contribution of water with a corrosion potential from the different tributary rivers. Once again, four of the sites in the upper Olifants – Klein Olifants sub-catchment (Sites 3, 6, 7 and 8) had very high CPR values indicating important contributions of acidity from mining and / or industrial activities, with each of these sites exceeding the CEV limits for domestic water use. Site 1 (Trichardtspruit) had much lower CPR values, though some 27% of the values exceeded the CEV limit for domestic water use, indicating that mining and / or industrial activities had had a moderately low impact on water quality in this tributary.

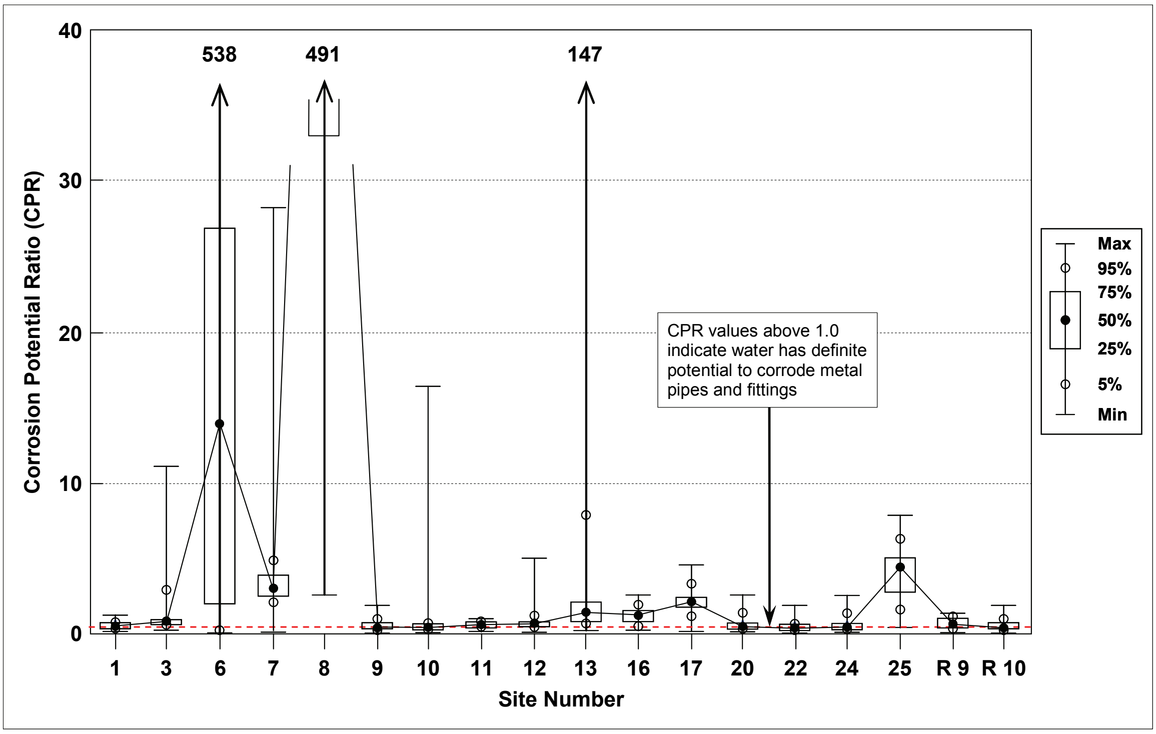

Figure 35. Box and whisker plots of the percentile values for the corrosion potent ratio at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the suggested Chronic Effect Value (CEV) limit for domestic and aquatic ecosystem water uses. Arrows indicate maximum recorded values.

The sites located in the Wilge River sub-catchment (Sites 9 to 13) showed increasing CPR values with increasing distance downstream – indicating gradually increasing influence of mining and / or industrial activities – (**Figure 35**), with Site 10 (Osspruit) and Site 13 (Zusterstroom) having median CPR value above the CEV limit for domestic water use.

Inflows from the Moses (Site 16) and Elands (Site 17) rivers had median CPR values above the CEV limit for domestic water use, while Sites 20, 22 and 24 had relatively low CPR values. Most of the CPR values for the Ga-Selati River (Site 25) exceeded the CEV limit for domestic water use indicating that while the available alkalinity had effectively neutralized the acidity present in the water, the absence of any excess alkalinity rendered the water corrosive (**Figure 34**). Sites R 9 (Great Letaba River) and R 10 (Shingwidzi River) had consistently low CPR values, indicating very little contribution to water quality from mining and / or industrial activities.

4.5.7 Sodium Adsorption Ratio (SAR)

A comparison of the SAR data for the 16 river sites and 2 reservoir sites in **Figure 36** reveals the highly variable contribution of water and salts from the different tributary rivers. Two of the sites in the upper Olifants – Klein Olifants sub-catchment (Sites 3 and 8) had high CPR values indicating important contributions of salts – probably from domestic effluent and from mining and / or industrial activities, though only 28% of the SAR values at Site 8 exceeded the CEV limit for irrigation use. Site 1 (Trichardtspruit), Site 6 (Spookspruit) and Site 7 (Klein Olifants River) had much lower CPR values that were within the CEV limit for domestic water use, indicating that the water in these tributaries was still suitable for irrigation use.

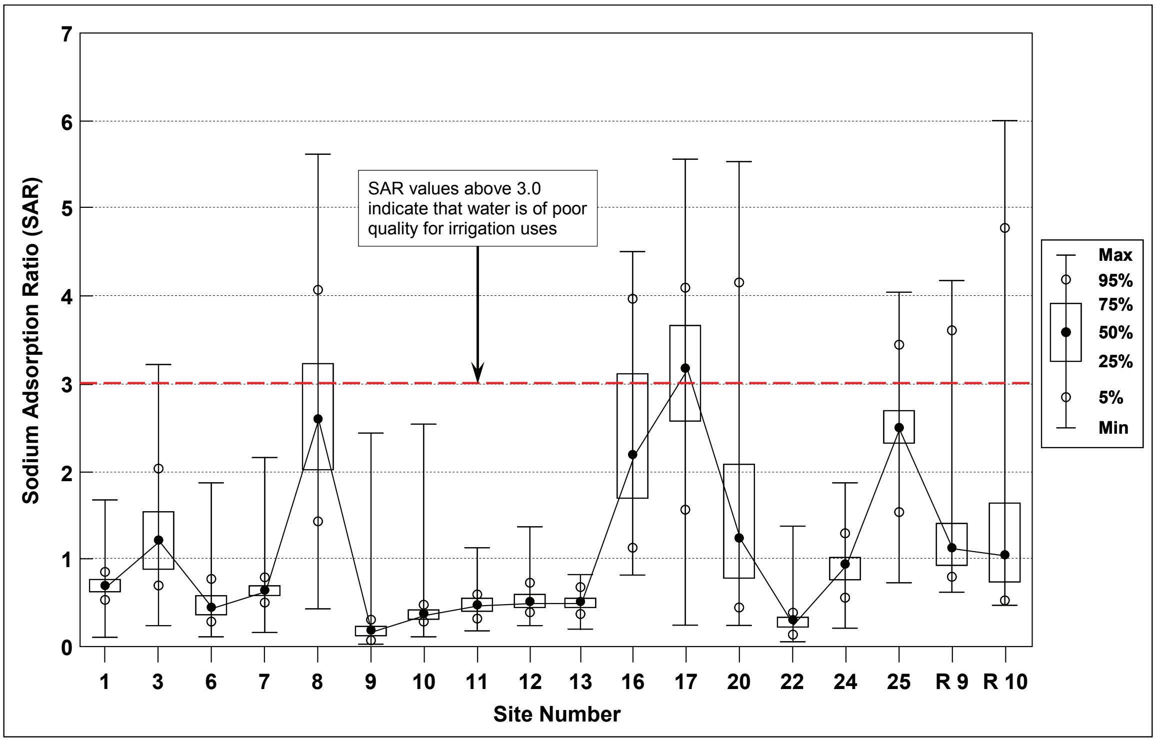

Figure 36. Box and whisker plots of the percentile values for the sodium adsorption ratio at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the suggested Chronic Effect Value (CEV) limit for irrigation water use.

All of the sites located in the Wilge River sub-catchment had low SAR values indicating that the water was still suitable for irrigation use (**Figure 36**). However, the SAR values recorded for Site 16 (Moses River), Site 17 (Elands River) and Site 20 (Steelpoort River) exceeded the CEV for irrigation water use. Sites 22 (Blyde River) and 24 (Klaserie River) had low SAR values, but many of the SAR values recorded for the Ga-Selati River (Site 25), Great Letaba River (Site R 9) and Shingwidzi River (Site R 10) exceeded the CEV limit for irrigation use (**Figure 36**). These last three sites indicated that the three tributary rivers contributed relatively large quantities of salts to the main stem of the Olifants River.

4.5.8 Inorganic N:P Ratio (INPR)

A comparison of the INPR data for the 16 river sites and 2 reservoir sites in **Figure 37** reveals the highly variable nutrient status of the different tributary rivers, where an INPR value below 10, plus high orthophosphate concentrations (**Figure 33**), is taken to indicate the presence of eutrophic conditions caused by human activities. Where the INPR values are very high (above 30), and orthophosphate concentrations are also high, this is usually an indication of contamination by poorly treated sewage effluent. A complicating factor in the interpretation of INPR values is that where acidic conditions are present, for example at a site influenced by acidic mine drainage, then the orthophosphate is often bound to the iron present in the water and precipitates out of solution. This is evident at Site 8 (Klipspruit) where the very high INPR values indicate enrichment, but the relatively low orthophosphate concentrations indicate that phosphorus has been lost from the water.
In summary, the INPR values and orthophosphate concentrations for the tributary rivers indicate that all of the rivers are nutrient enriched, most likely through a combination of agricultural return flows containing nitrogen fertilizers and poorly treated sewage effluent from towns and small communities in the catchments.

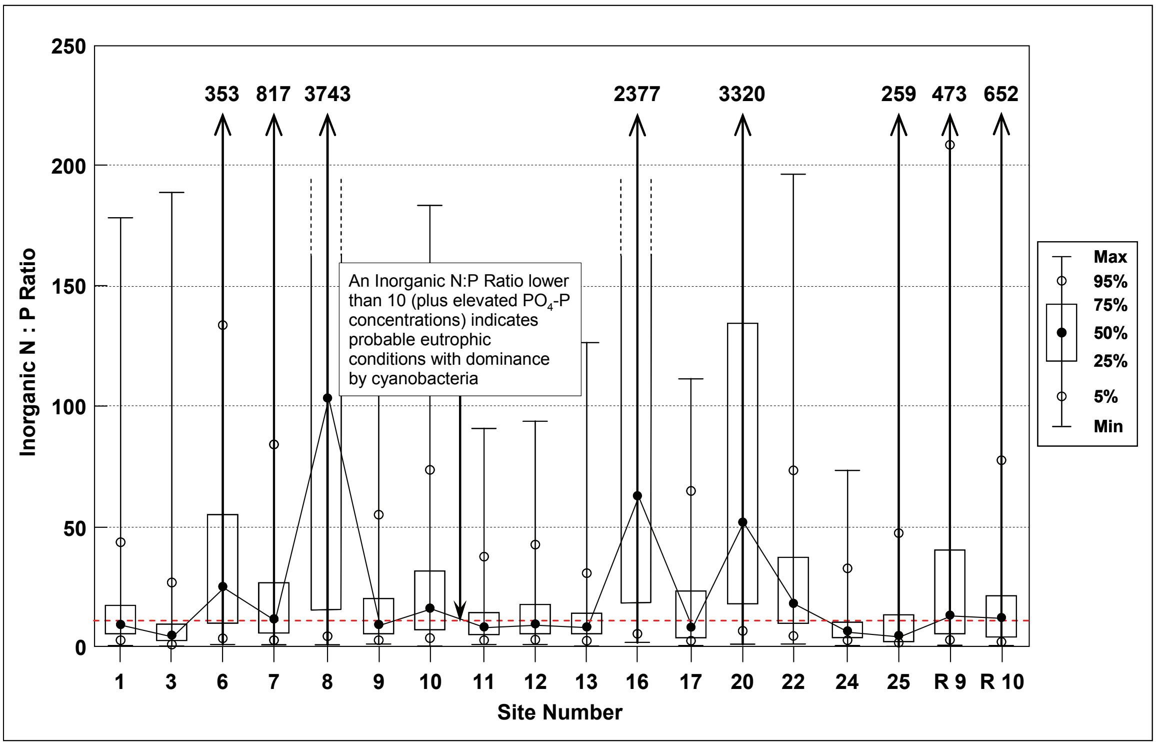

Figure 37. Box and whisker plots of the percentile values for the inorganic N:P ratio at 16 river and 2 reservoir monitoring sites on tributary rivers that flow into the Olifants River, compared with the recommended limit below which water is considered to be increasingly eutrophic. Arrows indicate maximum recorded values.

4.6 Overall chemical character of rivers and reservoirs

Against the background provided by the detailed review of the chemical features of each of the river and reservoir sampling sites in the Olifants River catchment, it is instructive to compare the overall chemical nature of the waters at these sites. The chemical features are summarized in piper diagrams for the 27 river sampling sites in **Figure 38**, while the chemical features of the 10 reservoir sites are summarized in **Figure 39**.

In **Figure 38**, the river sampling sites in the Wilge River sub-catchment show that there is a progressive change (sites 9, 10, 11, 12 and 13) from an anionic dominance of carbonate-bicarbonate in the headwaters, to an increase dominance by sulphate and chloride that is typical of increasing influence of acidic mine drainage. These data indicate that the major influences on water chemistry in the headwater regions of this sub-catchment are agricultural sources, with increasing influence exerted by domestic effluent and effluent or seepage from current or abandoned mining activities further downstream.

In contrast, the river sampling sites in the upper Olifants River catchment show a wide spread of chemical characteristics (**Figure 38**). The water quality at sites 1, 2 and 3 shows that these sites receive a combination of influences from agriculture and a growing contribution from mining sources with increasing distance downstream, with site 4 (inflow to Lake Witbank) being clearly influenced by mining sources. Site 5 (immediately downstream of Lake Witbank) as well as sites 6, 7 and 8, all display anionic dominance by sulphate and chloride that indicate the dominance of mining influences on water quality.

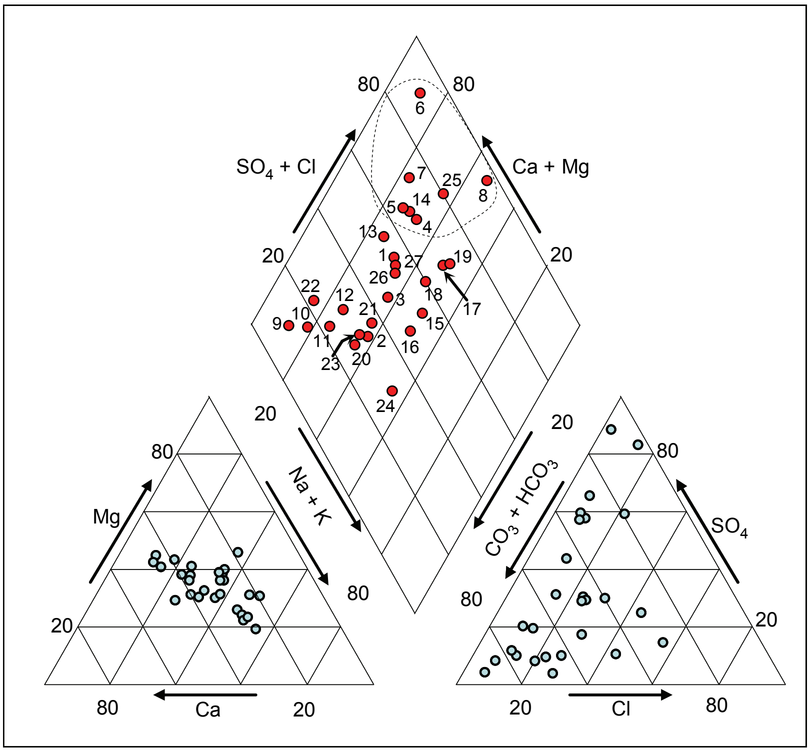

Figure 38. Piper diagram showing the plotting positions of the median values for the macro-ion chemical constituents recorded from the 27 DWA river sampling sites evaluated in this study as listed in **Table 2**. The river sites that display characteristics typical of an influence from treated and untreated acidic mine drainage are circled by a dashed line.

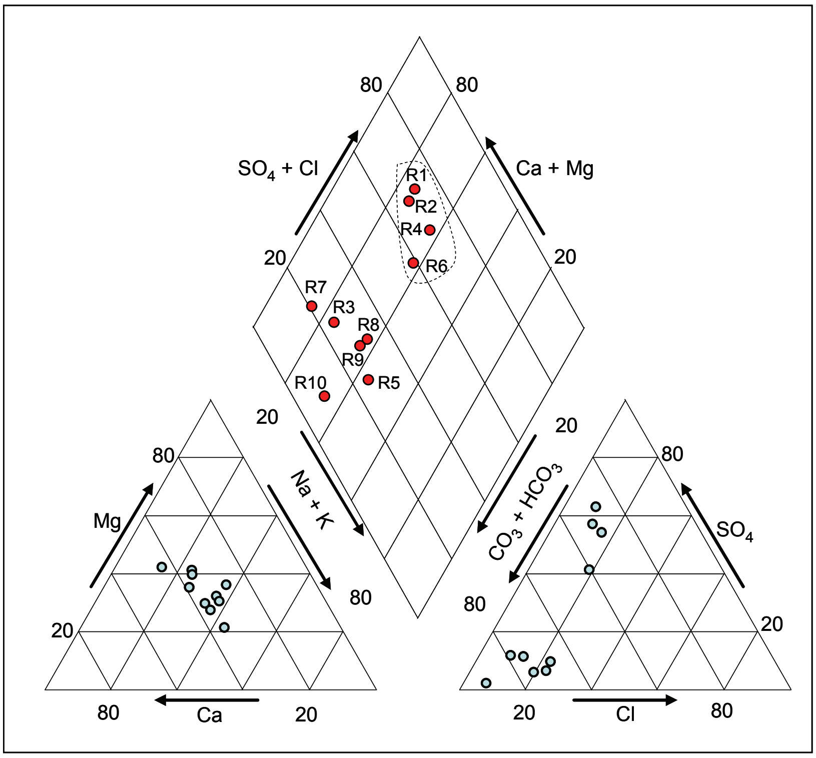

Figure 39. Piper diagram showing the plotting positions of the median values for the macro-ion chemical constituents recorded from the 10 DWA reservoir sampling sites evaluated in this study as listed in **Table 2**. The reservoir sites that display characteristics typical of an influence from treated and untreated acidic mine drainage are circled by a dashed line.

Site 14 (downstream of Lake Loskop) again displays an anionic dominance of sulphate and chloride (**Figure 38**), while sites 16 and 17 (on the Moses and Elands rivers, respectively) show intermediate features indicating that the water quality in both rivers has been influenced by agricultural and mining sources.

Site 15 (the inflow to Lake Flag Boshielo) and site 18 (located immediately downstream of Lake Flag Boshielo) also show intermediate features that indicate water quality at these sites has been influenced by both agricultural and mining sources. The position of site 19 (Olifants River at Zeekoegat, **Figure 38**) is unusual in that its chemical character is showing an increased influence of mining activities through the increased dominance of sulphate and chloride in the anions. Interestingly, the cation dominance order for sites 15, 16, 17, 18 and 19 shown in **Figure 38** reveals that sodium and potassium have increased in importance at these sites while calcium and magnesium have become slightly less important.

In the lower part of the Olifants River catchment, sites 20 (Steelpoort River), 21 (Olifants River at Finale Liverpool), site 22 (Blyde River), site 23 (Olifants River at Oxford) all show that the increased dominance of sulphate and chloride typical of sites located further upstream in the Olifants River has been modified to an increased dominance of carbonate and bicarbonate (**Figure 38**). A large part of this change is likely to be caused by inflows of good quality water from the Steelpoort and Blyde rivers. The Klaserie River (site 24) has a relatively distinct water quality with sodium and potassium dominating the cations and carbonate and bicarbonate dominating the anions (**Figure 38**).

Despite is neutral to slightly alkaline pH values, site 25 (the Ga-Selati River at Loole) plots in the same group as those river sites that are clearly influenced by acidic mine drainage (**Figure 38**). The ionic dominance characteristics of this site indicate very clearly that water quality is influenced almost completely by mining activities, though with a slightly lower level of mining influence than shown by site 6 (Steenkoolspruit) and site 8 (Klipspruit).

The ionic composition data for sites 26 and 27 along the lower reaches of the Olifants River show that the influence of the Ga-Selati River inflows remains visible in the chemical composition of the river water at these sites (**Figure 38**). The water quality at the lowest river site (site 27, Balule Rest Camp in the KNP) is a reflection of the likely quality of the water that enters Lake Massingir in Mozambique.

In **Figure 39**, there is a clear separation of the four reservoirs whose waters are heavily influenced by acidic mine drainage, from the six other reservoirs where the chemical quality of the inflowing waters are dominated by agricultural activities and domestic effluents. The chemical characteristics of lakes Witbank, Middelburg, Loskop and Flag Boshielo reveal that the ionic dominance in these lakes is heavily controlled by calcium and magnesium plus sulphate and chloride. In contrast, the other six lakes are all grouped in a portion of the diagram showing the dominance of calcium and magnesium plus carbonate and bicarbonate (**Figure 39**). The earlier discussion of reservoir water quality also indicated that these reservoirs displayed characteristics indicating that their inflowing waters had been influenced primarily by agricultural activities and domestic effluents.

4.7 Evidence for the presence of trace metals

The routine water quality monitoring programmes carried out by the Department of Water Affairs (DWA) seldom include any trace metals – apart from boron – amongst the list of constituents that are analyzed. The few analyses that are reported (usually iron and manganese, occasionally aluminium) represent scattered, single samples that were analyzed in response to a particular query or investigation (Grobler *et al.*, 1994). Systematic sampling and analysis for trace metals is confined to those programmes that monitor particular effluent discharge streams; these analytical data are normally not available to the general public.

The CSIR's Natural Resources and the Environment business unit has collected a range of water samples from the river and reservoir sites in the upper Olifants River catchment (upstream of Lake Loskop) as part of a large, three-year project funded by COALTECH (Dabrowski *et al.*, 2010). However, the number of samples collected and the frequency of sample collection is relatively low and it is difficult to discern clear evidence of specific seasonal patterns of trace metal contamination in this portion of the catchment. Despite this shortcoming, the few data available indicate that several of the tributary rivers in the catchment upstream of Lake Loskop contain high concentrations of aluminium, iron and manganese, with occasional high concentrations of zinc and copper. All of these appear to be associated with acidic effluent from active or abandoned mines in the upper catchment (Bullock *et al.*, 1997; Geldenhuis and Bell, 1998). The highest recorded concentrations of aluminium (64 mg/litre), iron (42 mg/litre), manganese (27 mg/litre), vanadium (7.02 mg/litre) and zinc (1.65 mg/litre) were recorded from the Brugspruit, a small tributary of the Klipspruit, a short distance downstream of the town of Witbank. Water from the Klipspruit flows into the Olifants River and causes a distinct discolouration of the water in the receiving river. All measured concentrations of these trace metals exceeded the CEV and AEV limits for domestic use and aquatic ecosystems (Dabrowski *et al.*, 2010).

Other short-term studies have been carried out by the University of the North on Lake Flag Boshielo and by CSIR on Lake Loskop. Once again, relatively few samples have been collected and it is difficult to draw firm conclusions as to seasonal trends of change from these studies. The few data available indicate that aluminium, iron and manganese concentrations can reach relatively high levels in the water column and in the lake sediments and that these could pose potential health risks to humans and livestock who might drink water from the lake. Again, these high concentrations of trace metals appear to be associated with inflows of water from active and abandoned mines.

These researchers found that the 95%ile values for arsenic, copper and zinc – plus aluminium in the Moses River sites – exceeded the CEV at all sampling sites, and the concentrations of boron, aluminium, manganese and iron were elevated at all sampling sites (Bollmohr *et al.*, 2008). However, no speciation analyses were carried out so it is difficult to determine whether or not any of the particularly toxic forms of different trace metals posed a real risk to humans or livestock that might use the water directly (Kempster *et al.*, 2007). In overview, the results indicated that the presence of high arsenic concentrations at all sites posed the greatest potential health threat to human water users. Important findings from this study were that the existing water quality guidelines do not include many of the important trace metals that are found in aquatic systems, that guidelines for these trace metals should be developed, and that much more systematic (routine) monitoring of trace metals was needed in aquatic systems throughout South Africa.

A short dataset on the concentrations of trace metals and hemi-metals present in the sediments at two sites in Lake Flag Boshielo was made available to the project team by Dr Willimien Luus-Powell of the University of Limpopo. These data were derived from sediment samples collected during January 2010 (**Table 7**).

With the exception of arsenic, boron and cadmium, the concentrations of all trace metals and hemi-metals (*e.g.* arsenic, silicon) present in the sediment samples declined from the lake inflow to the dam wall sampling site. These data suggest that at least a proportion of the remaining trace metals were attached to or associated with suspended sediments or particulate matter that settled out or precipitated shortly after entering the slower-flowing waters of Lake Flag Boshielo. The presence of appreciable quantities of trace metals in sediments located close to the dam wall at Lake Flag Boshielo also indicates that sediments within this lake may be slowly transported from the inflow to the deepest portion of the lake at the dam wall.

Table 6. The 95th percentile concentrations of 18 trace metals present in water samples collected bi-monthly from two sites in the Moses River and three sites in the Olifants River between August 2007 and May 2008. Shaded cells indicate that 95th percentile values exceed the CEV for the constituents concerned. (Data taken from Bollmohr *et al.*, 2008).

Constituent	Detection limit (mg/ℓ)	Moses River		Olifants River		
		M1	M2	O1	O2	O3
Aluminium (Al)	0.002	1.300	3.372	0.129	0.016	0.020
Arsenic (As)	0.004	0.025	0.058	0.035	0.055	0.049
Barium (Ba)	0.001	0.099	0.103	0.074	0.086	0.103
Beryllium (Be)	0.001	BD	BD	BD	BD	BD
Boron (B)	0.018	0.026	0.106	0.044	0.053	0.074
Cadmium (Cd)	0.001	0.002	BD	0.002	0.003	BD
Chromium (Cr)	0.001	0.005	0.004	0.003	0.003	0.004
Cobalt (Co)	0.001	BD	BD	BD	BD	BD
Copper (Cu)	0.001	0.008	0.006	0.006	0.008	0.009
Iron (Fe)	0.012	0.971	1.568	0.069	0.046	0.081
Lead (Pb)	0.004	BD	BD	BD	BD	BD
Manganese (Mn)	0.001	0.002	0.008	0.003	0.004	0.003
Molybdenum (Mo)	0.003	0.006	0.012	0.008	0.013	0.013
Nickel (Ni)	0.012	BD	BD	BD	BD	BD
Strontium (Sr)	0.001	0.092	0.354	0.250	0.259	0.381
Titanium (Ti)	0.001	BD	BD	BD	BD	BD
Vanadium (V)	0.001	BD	BD	BD	BD	BD
Zinc (Zn)	0.001	0.014	0.058	0.022	0.018	0.013

The sediment data from Lake Flag Boshielo (**Table 7**) show that aluminium, iron, titanium, manganese, silver and barium were present in highest concentrations in the sediments, while bismuth and selenium were not detected. Notably, the high arsenic concentrations in water samples found in the Moses River and the Olifants River downstream of Lake Loskop (**Table 6**; Bollmohr *et al.*, 2008) are not reflected as correspondingly high arsenic concentrations in the sediments of Lake Flag Boshielo. All of the trace metals detected in the sediment samples can be linked to mining and industrial activities in the upper catchment (see section 2.6 and **Figure 10** for the distribution of mines in the Olifants catchment).

In the absence of analytical data from sediment samples for Lake Loskop, it is not possible to draw conclusions as to the likelihood that the metals may have originated in the upper reaches of the catchment, upstream of Lake Loskop. Nevertheless, given the well-known ability of reservoirs to trap and retain sediments, nutrients and salts, it is likely that the trace metals present in the sediments from Lake Flag Boshielo originated from mining activities in the portion of the catchment between Lakes Loskop and Flag Boshielo. Examination of **Figure 10** reveals that this portion of the catchment contains numerous mines that extract the same metals that are found in the sediments of Lake Flag Boshielo. The data on trace metal concentrations in the waters of the Moses River and the Olifants River downstream of Lake Loskop also indicate that this portion of the catchment is contributing trace metals to the main stem of the Olifants River.

A single set of water analyses from eleven sites along the length of the Steelpoort River and lower Olifants River as far as the outflow from Phalaborwa Barrage are contained in a baseline water quality report for the new De Hoop Dam (Dabrowski *et al.*, 2008). The analytical data for trace elements show that aluminium and iron are present at moderate concentrations (Al = 0.097 to 0.238 mg/litre; iron = 0.195 to 0.605 mg/litre;, *i.e.* not exceeding the CEV for domestic use) in both the Steelpoort River and the lower reaches of the Olifants River. Low concentrations of chrome (< 0.002 mg/litre) in the lower reaches of the Steelpoort River and Olifants River were most likely derived from effluents discharged by the Tubatse

Ferrochrome plant at the town of Steelpoort. Similarly, low concentrations of vanadium in the Steelpoort River are most likely a consequence of effluent discharged from vanadium mines in the upper reaches of this sub-catchment (Dabrowski *et al*., 2008).

Table 7. Concentrations of 5 macro-elements and 27 trace metals detected in sediment samples collected from two sites in Lake Flag Boshielo during January 2010. (All data expressed as milligrammes of constituent per kilogramme of sediment; sediment samples analyzed by ICP-AES; data provided courtesy of Dr Willimien Luus-Powell, University of Limpopo).

Constituent	Sampling Site	
	Lake Inflow	Dam Wall
Macro-elements		
Calcium (Ca)	7,098	6,567
Magnesium (Mg)	6,284	2,402
Potassium (K)	7,119	2,306
Sodium (Na)	1,275	1,096
Phosphorus (P)	1,643	1,728
Trace metals		
Aluminium (Al)	105,880	25,300
Antimony (Sb)	2	2
Arsenic (As)	0	9
Barium (Ba)	337	129
Beryllium (Be)	5	2
Bismuth (Bi)	0	0
Boron (B)	119	129
Cadmium (Cd)	2	2
Chromium (Cr)	179	102
Cobalt (Co)	34	20
Copper (Cu)	79	25
Iron (Fe)	67,175	40,675
Lead (Pb)	50	21
Lithium (Li)	55	12
Manganese (Mn)	1667	649
Molybdenum (Mo)	1	0
Nickel (Ni)	90	29
Selenium (Se)	0	0
Silicon (Si)	60	50
Silver (Ag)	554	338
Strontium (Sr)	45	24
Tin (St)	4	2
Titanium (Ti)	2,398	1,649
Vanadium (V)	122	83
Wolfram (W)	1	1
Zinc (Zn)	152	69
Zirconium (Zr)	38	16

Other trace metal data are contained in a series of papers on the accumulation of trace metals in various fish species collected at different points along the Olifants River (Du Preez and Steyn, 1992; Seymore *et al.*, 1995, 1996a, 1996b; Claassen, 1996; Du Preez *et al.*, 1997; Kotzè, 1997; Robinson and Avenant-Oldewage, 1997; Marx and Avenant-Oldewage, 1998; Heath and Claassen, 1999; Kotzè *et al.*, 1999; Nussey *et al.*, 1999, 2002; Van Vuuren *et al.*, 1999; Avenant-Oldewage and Marx, 2000; Barnhoorn and Van Vuuren, 2001; Coetzee *et al.*, 2002). These studies were carried out by staff and studies at the (then) Rand Afrikaans University (now re-named as the University of Johannesburg) as part of a comprehensive series of studies on the bioaccumulation of trace metals. In summary, these studies showed clearly that several fish species were accumulating trace metals to harmful concentrations that posed health risks to anyone who might eat these fish. The fact that these fish bio-accumulated trace metals in the Olifants River indicates that the trace metals must have been present in the water and sediment at appreciable concentrations for a prolonged period of time (Heath *et al.*, 2004).

No reliable routine monitoring data are available for the presence of trace metals in the Great Letaba and Shingwidzi rivers. However, a broad-scale survey undertaken to assess whether or not mercury is present in key South African rivers (Somerset *et al.*, 2010) noted that low concentrations of mercury were present in both of these rivers. It is thought that this mercury may be the result of illegal artisan gold miners using mercury amalgamation processes to extract gold in the respective catchments. While the recorded mercury concentrations were very low, there is a need to undertake more detailed monitoring for trace metals in these catchments.

4.8 Evidence for the presence of agricultural pesticides

The different types of agricultural land uses in the Olifants River catchment all make use of a variety of different pesticides to eliminate weeds and to control crop pests and animal diseases. Several different methods of application are used for the different pesticide formulations (spot treatment hand sprays, soil fumigation, mechanical sprayers, aerial applications), and the rates of application can vary widely during a calendar year. The different application techniques and rates of application sometimes result in portions of the pesticides being washed into the rivers and streams that drain the treated agricultural lands. Many agricultural pesticides have chronic and acute effects on humans, livestock and aquatic biota. The presence of pesticides in aquatic systems is taken to indicate that the water quality of the particular system has been compromised and poses potential health risks to humans, livestock and aquatic biota.

The routine water quality monitoring programmes carried out by the Department of Water Affairs (DWA) do not include pesticides amongst the list of constituents that are analyzed. Pesticide analyses are confined to specific sampling campaigns or to investigations of the reasons for unusual events such as a fish kill in a water storage reservoir. Efforts to resolve the problem of determining what concentration of a pesticide may be considered harmful is made more difficult by the absence of guideline values for many of the pesticides.

The most useful set of analytical data on pesticides in the Olifants River catchment are those that were collected during an eight-month investigation of 53 pesticides in the Olifants and Moses rivers downstream of Lake Loskop (Bollmohr *et al.*, 2008). This investigation reported on the presence of 8 aromatic hydrocarbons, 6 pthalates, 18 organochlorine pesticides, 13 organophosphorus pesticides, 2 carbamates, 3 pyrethroids and 3 triazines. The analytical results recorded by these workers revealed that several of the pesticides could not be detected at particular sites because their concentrations were below their respective analytical detection limits. However, many of the analytical results also revealed that several commonly-used pesticides were present at concentrations that posed potential health risks to humans, livestock and aquatic biota.

Given the apparent extent of pesticide use and the variety of compounds used – especially in commercial agricultural operations – it can be expected that pesticides will be present in most of the tributary rivers and also in the main stem of the Olifants River and its reservoirs. The shortage of reliable analytical data on the presence of pesticides makes it impossible to develop conclusive recommendations that might alleviate the problem. Instead, it is clear that more analytical data are needed to substantiate the variety of pesticides present in the river system and the likely implications of these substances for humans, livestock and aquatic biota.

4.9 Evidence for the presence of microbial contaminants

The routine water quality monitoring programmes carried out by the Department of Water Affairs (DWA) seldom include the analysis of microbial contaminants and pathogens. Most often, the microbial analyses that are reported (usually faecal coliform bacteria and, sometimes, *E. coli* counts), represent scattered, single samples that were analyzed in response to a particular query or investigation (Grobler *et al.*, 1994). Systematic sampling and analysis for microbial contaminants has been planned as part of the National Microbiological Monitoring Programme but it is not clear if actual monitoring has started.

The COALTECH-funded study carried out by CSIR's Natural Resources and the Environment business unit collected a range of water samples for microbiological examination from the river sites in the upper Olifants River catchment (Dabrowski *et al.*, 2010). While the relatively low number of samples collected and the low frequency of sample collection makes it difficult to discern seasonal patterns of microbial contamination, the data do provide clear evidence of microbial contamination in this portion of the catchment. In addition, laboratory tests carried out as part of this study revealed the presence of widespread resistance to common antibiotics amongst the different bacterial strains (Dabrowski *et al.*, 2010). The study revealed the presence of high numbers of *E. coli* at all of the study sites, with the highest numbers recorded from sites located close to the towns of Middelburg and Witbank. The Brugspruit sampling site consistently had the highest *E. coli* counts during the study (Dabrowski *et al.*, 2010). These results confirm visual observations of raw and partly treated sewage flowing into the rivers from nearby wastewater treatment works. In addition, water samples collected at two sites located downstream of cattle feedlot operations in the upper reaches of the Klein Olifants River also had high *E. coli* counts.

The CSIR team also conducted laboratory tests for three bacterial pathogens (*Salmonella* sp., *Vibrio cholerae* and *Shigella* sp.), two protozoan parasites (*Giardia* sp. and *Cryptosporidium* sp.) and two enteric viruses (Enterovirus and Norovirus) in every water sample collected from each of the sampling sites. Data from the site on the Klein Olifants River downstream of Middelburg indicated that this site was the most heavily contaminated with bacterial pathogens (*Salmonella*, *Shigella* and non-toxigenic strains of *Vibrio cholerae*) of all the sampling sites. The two protozoan parasites (*Giardia* and *Cryptosporidium*) were routinely detected at sampling sites located downstream of cattle feedlots, indicating that these feedlots were most probably the sources for these organisms (Dabrowski *et al.*, 2010). Other reports (*e.g.* Dungeni and Momba, 2009) indicate that *Giardia* and *Cryptosporidium* are regularly detected in the effluents discharged from improperly operated domestic wastewater treatment plants. Given the evidence that many wastewater treatment plants in the Olifants River catchment are not properly functioning, it can be expected that both *Giardia* and *Cryptosporidium* are likely to be present at several localities in the catchment.

A single set of microbiological analyses were carried out on water samples collected along the length of the Steelpoort River and lower Olifants river as far as the outflow from Phalaborwa Barrage (Dabrowski *et al.*, 2008). The study revealed relatively low numbers (18-57 cells/100 millilitres) of faecal coliform bacteria and *E. coli* in the upper reaches of the Steelpoort River, with very high numbers (2,400-8,500 cells/100 millilitres) of both organisms immediately downstream of the town of Steelpoort, followed by intermediate, but still high (93-1,600 cells/100 millilitres) bacterial numbers in the lower reaches of the Olifants River. These results indicate clearly that the Steelpoort River and the lower Olifants River receive untreated or improperly treated domestic sewage from upstream communities, and the rivers possibly also receive animal wastes from upstream farms (Dabrowski *et al.*, 2008).

No routine monitoring data are available for the presence of microbial contaminants in the Great Letaba and Shingwidzi rivers. However, given the presence of numerous small and large communities – often with very low levels of sanitation services provided – in these catchments, there is a strong likelihood that microbial contaminants are present in these two river systems.

Given the widespread prevalence of municipal wastewater treatment plants that are not functioning effectively (DWA, 2010), it is likely that the occurrence of microbial contamination in the Olifants River catchment is far more widespread and probably occurs in all of the tributary rivers that have urban settlements in their drainage areas.

4.10 Evidence for the presence of new or emerging pollutants

In recent years, increasing attention has been paid to the presence of new or emerging pollutants in river and reservoir systems with a particular focus on endocrine disrupting compounds (EDCs). These are compounds whose presence in water has the potential to interfere with human and animal endocrine systems which provide the key communication and control links between the nervous system and bodily functions (WHO, 2003). While the endocrine system in humans differs from those found in mammals, birds, fish and invertebrates, the presence of EDCs in water elicits broadly similar responses in all these organisms (WHO, 2003).

No routine monitoring data are available for the presence of EDCs in the river and reservoir systems of the Olifants River catchment. However, the COALTECH-funded study conducted by the CSIR carried out a set of tests for EDCs on water samples from the upper portions of the catchment. This study used two different tests, namely the Recombinant Yeast Estrogen Screen (YES) test and the T47D-KBluc Reporter Gene Assay (T47-KBluc) – to illustrate the presence or absence of EDCs (Dabrowski *et al.*, 2010).

The YES test results revealed the presence of oestrogenic activity in water samples from five of the nine sites that were tested, with highest values obtained for the Brugspruit site. In contrast, the T47-KBluc test results revealed the presence of oestrogenic activity at all nine sites, with highest values recorded for the Brugspruit site and the Klein Olifants River site immediately downstream of Middelburg. While these results indicate that EDCs are present in all of the tributary streams in the upper portion of the Olifants River catchment and suggest that the source of these EDCs might be incompletely treated domestic effluent, the findings should only be regarded as preliminary. More detailed sampling and analysis will be required to demonstrate unequivocally that EDCs are present in the tributary rivers and possibly water storage reservoirs. In turn, this will help to understand the extent and severity of the problem and the implications for the health of water users (humans and animals) as well as the implications for raw water treatment processes that produce potable water.

No analytical data are available for the presence of new or emerging pollutants in the Great Letaba and Shingwidzi rivers.

4.11 Evidence for poor quality rainwater contributions

A few studies were carried out in the late 1970s and 1980s to assess the possibility that atmospheric emission from power plants and industries on the Highveld were contributing to poor quality – in particular acidic rainfall – rainfall in the area (Zunckel *et al.*, 2000). These studies were undertaken because it was thought that the relatively high sulphur content of the coal used to fire iron and steel furnaces and to generate electricity was responsible for acidifying the local rainfall. This is a reasonable assumption given that some 110 million tonnes of coal are used each year by the power plants to generate electricity (Dabrowski *et al.*, 2009) and these power plants are not fitted with flue gas desulphurization systems. In summary, the findings suggested that the relatively large amounts of sulphur and nitrogen oxides emitted by the power stations could cause acidic rainfall and that this rainfall could have deleterious effects on crops, soils and aquatic systems in areas receiving this rainfall (Zunckel *et al.*, 2000).

Acidic rainfall is able to mobilize metal ions from soil (Dise *et al.*, 2001) and also to contribute low pH water and airborne pollutants (*e.g.* sulphate and trace metals) directly into surface waters (Gorham, 1976). There are several important industrial activities (*e.g.* power generation, chemical industries and metal smelters) in the upper Olifants catchment and the air quality of the area is generally poor, with high levels of SO_2 present in the atmosphere (Zunckel *et al.*, 2000).

A first year of data collected during a three-year duration COALTECH-funded study coordinated by the CSIR study (Dabrowski *et al.*, 2010) showed that almost two thirds (59%) of the rain water samples tested from the upper Olifants River catchment could be classified as acidic, with the pH values of rain water samples often below 5 and sometimes even as low as 3.7. At these low pH values, it is possible for acid rain to dissolve heavy metals from soil and rocks. In 67% of the rain water samples that were analyzed, ammonium nitrogen concentrations were higher than the recommended guideline values for aquatic ecosystems and domestic use. Vanadium, manganese, zinc, aluminium, cadmium, iron and fluoride were also detected in rain water samples from some of the sites, with the trace metals, aluminium, fluoride, manganese and zinc often exceeding the recommended guideline values for aquatic ecosystems, domestic use and irrigation. Aluminium, fluoride, manganese, zinc and chloride concentrations in almost all of the rainwater samples collected during the period March to May 2010 were higher than their respective recommended guideline values.

The CSIR results (Dabrowski *et al.*, 2010) indicated that rain water is likely to be a major contributor to contamination of aquatic ecosystems in the upper Olifants River catchment. However, it is also clear that more in-depth studies on air movements and precipitation events, including additional sampling sites and the use of satellite technology and computer modelling, are needed to establish the origins of the different types of contamination derived from rainfall. This should also be supplemented by direct measurements of atmospheric emissions at specific sites (e.g. thermal power plants, iron and steel refineries and cement manufacturing plants) that are known to emit atmospheric discharges.

4.12 Evidence for the presence of suspended sediments in watercourses

The presence of suspended sediments in South African river and reservoir systems has long been recognized as a widespread water quality problem in many parts of the country (Rooseboom *et al.*, 1992; DWAF, 2008). In general, the processes involved in sediment production and the choice of suitable management practices to control sediment production are well understood and documented (*e.g.* Rooseboom *et al.*, 1992). However, despite this understanding, suspended sediments remain a persistent water quality problem in many river systems. In particular, the lower reaches of the Olifants River system are well-known for the large volumes of suspended sediments that are transported each year (Moolman *et al.*, 1999), and which have been shown to have adverse effects on aquatic ecosystems and their biota along the river reaches within the KNP (Buerman *et al.*, 1995; Swanepoel, 1999). More recently, excessively high concentrations of suspended sediments in the lower reaches of the Olifants River have also been implicated in the deaths of fish and, possibly, Nile crocodiles (Van Vuuren, 2009; Heath *et al.*, 2010).

Some data are available on the concentrations of suspended sediments in river samples from the middle and lower reaches of the Olifants River, the Steelpoort River and the Blyde River (Moolman *et al.*, 1999). However, the low number of samples analyzed at these sites and the episodic nature of sediment transport events makes it difficult to discern clear seasonal or inter-annual patterns of change (Moolman *et al.*, 1999). The few data available (Moolman *et al.*, 1999) show that the lower reaches of the Olifants River – approximately from the junction with the Steelpoort River – consistently had suspended sediment concentrations above 100 mg/litre, the water quality guideline for aquatic ecosystems (DWAF, 1996c).

The scarcity of reliable data on suspended sediment concentrations in the Olifants River prompted the Department of Water Affairs and Forestry (DWAF) to develop a GIS-based modelling approach to estimating where the sediments were derived from (Moolman *et al.*, 1999). This study revealed the presence of large areas of vulnerable soils in the middle reaches of the Olifants River catchment, coupled with high population densities and intensive overgrazing in areas previously forming part of Apartheid "homelands", steep slopes with rapid rates of runoff, and high erosivity levels of summer rainfalls.

The net result of the DWAF investigation revealed that almost all of the suspended sediments present in the Olifants River were derived from the area located between the towns of Lebowakgomo and Phalaborwa (see map in **Figure 1**). However, despite this information, it appears that no remedial actions have been undertaken to reduce or minimize the loss of sediments from this area. The lower reaches of the Olifants River still carry high concentrations of suspended sediments (see **Figure 9c** for a view of the Olifants River close to the Abel Erasmus Pass) and a large proportion of the suspended sediment load settles out and is retained within the Phalaborwa Barrage. Periodic attempts to flush out the accumulated sediments result in a dramatic increase in the concentration of suspended sediment in the Olifants River downstream of the Phalaborwa Barrage. Two measurements of suspended sediment concentrations in samples collected in 1992, immediately downstream of the Phalaborwa Barrage when the scour gates on this reservoir were opened in an attempt to remove some of the accumulated sediments, had values of 55,000 mg/litre and 62,000 mg/litre (Ashton *et al.*, 1992). These exceptionally high suspended sediment concentrations resulted in the death of large numbers of fish within the KNP at that time (Dr Andrew Deacon, KNP, personal communication).

In 2007, the wall of the Massingir Dam in Mozambique (see **Figure 13**) was raised by seven metres; when the reservoir filled up to its new full supply level, this flooded reaches of the inflowing Olifants River into the Olifants River Gorge within the KNP. This transformation of a rapidly-flowing gorge section of the river to a slow-flowing lacustrine system stimulated the deposition of large quantities of suspended sediments – released from the Phalaborwa Barrage – in the upper portions of the flooded Olifants River Gorge (Dr Danie Pienaar, KNP – personal communication). However, no numerical data are available on the concentrations of suspended sediments or rates of sediment deposition at this site.

Shortly after these sediment deposits were first noticed, fish kills were also noticed in the Olifants River, followed by the deaths of large numbers (> 170) of Nile crocodiles in 2009. All of the Nile crocodiles appeared to have contracted pansteatitis – a form of lipid autoxidation – apparently as a result of eating fish that had contracted the disease (Van Vuuren, 2009). As yet, the precise chain of events and cause-effect relationships are still under investigation. Nevertheless, there is increasing speculation that the recent accumulation of sediment deposits and their associated load of adsorbed ionic and organic constituents in the Olifants River Gorge are likely to be a primary driver of the events that occurred (Dr Danny Govender, KNP, and Professor Jan Myburgh, Onderstepoort Veterinary Faculty – personal communications). Ultimately, though, it is very likely that a combination of factors – including the presence of inorganic and organic contaminants in the water draining the entire Olifants River catchment and high suspended sediment concentrations – all contribute to the final expression of pollution in the deaths of fish and Nile crocodiles.

Taken as a whole, the few data that are available for suspended sediment concentrations provide very little substantive evidence for the seasonal and inter-annual variations in suspended sediment concentrations in the Olifants River catchment. The fact that high (> 1,000 mg/litre) and very high (> 20,000 mg/litre) suspended sediment concentrations have been recorded from the lower reaches of the Olifants River system suggests that a far more systematic approach to monitoring suspended sediments is required urgently.

4.13 Influence of water storage reservoirs on river water quality

Earlier studies on the water quality in Lake Loskop (Gieskes, 1960; Dabrowski *et al.*, 2010; Oberholster *et al.*, 2010) and in water storage reservoirs elsewhere in South Africa (*e.g.* Allanson, 1961; NIWR, 1985; Chutter, 1989; O'Keeffe *et al.*, 1989) have all shown that reservoirs are able to trap and retain significant proportions of their inflowing sediment and nutrient loads. In most water storage reservoirs, the accumulation of sediments results in a gradual reduction in the water storage capacity of the reservoir over time. At the Phalaborwa barrage, approximately 70% of the reservoir's water storage capacity has been lost because of accumulated sediments (Ashton and Murray, 1992). Periodic attempts to scour out some of the sediments and 'regain' some of the water storage capacity seldom have more than a short-term positive effect, while the scoured-out sediment results in very high suspended sediment concentrations downstream. Given that a relatively large proportion of trace metal ions is often associated with suspended sediments, the ability of a water storage reservoir to trap inflowing sediments will also help to reduce the concentrations of trace metals in water.

In some hypertrophic reservoirs (*e.g.* Lake Hartbeespoort), the reservoir traps approximately 50-60% of the inflowing orthophosphate load and 40-60% of the inflowing inorganic nitrogen load. Within the reservoir, the trapped orthophosphate is retained within the lake sediments (Twinch, 1987) while a large proportion (>40%) of the trapped inorganic nitrogen is lost from the aquatic system to the atmosphere via denitrification (Ashton, 1981). This ability of reservoirs to 'trap' some of the nutrients present in inflowing rivers helps to improve the quality of the water released from the reservoir to downstream systems. The available nutrient concentration data for the reservoirs located on the main stem of the Olifants River (**Figures 24 and 28**; **Appendices A1 and A2**) indicate that lakes Witbank, Loskop and Flag Boshielo, and the Phalaborwa Barrage also account for a reduction in the concentration of nutrient at downstream sampling sites. In recent years, Lake Loskop has become progressively more heavily enriched with nutrients and is now regarded as being hypertrophic (Oberholster *et al.*, 2010; **Figure 40**).

Another feature of water storage reservoirs that is seldom noted in the literature is the fact that these reservoirs are also able to trap salts, especially sulphate. This feature is visible in **Figures 21 and 23** and **Appendices A1 and A2**. However, these salts are not lost permanently from the aquatic system but are gradually accumulated within the settled out sediments. Localized changes in water quality at the inflow of Lake Loskop (Oberholster *et al.*, 2010) indicate that the chemical changes that occur within the water column need to be examined in greater detail.

The combined ability of reservoirs to trap sediments and associated metal ions, nutrients and dissolved salts results in an improvement in the quality of water released to rivers downstream of the reservoirs, compared to the quality of the original inflow to the reservoir.

Figure 40. Aerial view of a portion of Lake Loskop close to the inflow of the Olifants River, showing the development of an extensive bloom of *Microcystis aeruginosa*. (Photograph taken by Ms Jackie Brown in February 2011).

However, the accumulation of sediments, metal ions, nutrients and salts within the reservoir also results in a rapid degradation of water quality within the reservoir, which then compromises the quality of water available for users that rely on water drawn from the reservoir (Van Rooyen and Versveld, 2010). An additional feature of reservoirs that have accumulated quantities of nutrients is that they become progressively more eutrophic (nutrient-enriched) and, if nutrient loads continue to increase, then become hypertrophic, with phytoplankton populations that are dominated by potentially toxic cyanobacteria (*e.g.* NIWR, 1985; Wicks and Thiel, 1990; Correll, 1998; Owuor *et al.*, 2007). The greater rate of loss of nitrogen relative to phosphorus within a reservoir (Ashton, 1981) results in a relatively rapid decline in the inorganic nitrogen to phosphorus ratio with the result that the increased concentrations of orthophosphate relative to inorganic nitrogen provide cyanobacteria with a competitive advantage over other algal species (NIWR, 1985; Harper, 1992; Correll, 1998). This situation has been recorded for Lake Loskop (Driescher, 2008; Oberholster *et al.*, 2010) and has also been linked to the decline in the Nile crocodile population of this reservoir (Jacobsen, 1984; Botha, 2006, 2010; Driescher, 2008; Ashton, 2010; Dabrowski *et al.*, 2010; Oberholster *et al.*, 2010).

An important feature of all water storage reservoirs in South Africa is their patterns of thermal and chemical stratification (Walmsley and Butty, 1979; NIWR, 1985; Allanson *et al.*, 1990; Kalff, 2002). In the case of Lake Loskop, earlier studies (*e.g.* Gieskes, 1960; Butty *et al.*, 1979; Twinch, 1987; Ashton and Van Vliet, 1997) have shown that Lake Loskop can be classified as a warm monomictic reservoir, with a single period of continuous vertical mixing during winter and clearly defined thermal stratification during the warmer summer months.

During the period of summer stratification, the deeper, colder hypolimnetic waters become anaerobic and high concentrations of reduced metal ions and nutrients are present. Though the upper, warmer epilimnetic waters contain lower concentrations of metal ions and nutrients, the nutrient concentrations are still high enough to promote the growth of dense phytoplankton blooms (Butty *et al.*, 1979; Allanson *et al.*, 1990). The depth of the epilimnion is controlled by the strength of the thermal and chemical stratification patterns – the resistance to wind mixing – and the strength, duration and orientation of the prevailing winds (Allanson *et al.*, 1990). Periods of low wind speeds result in a relatively shallow epilimnion while periods of strong winds deepen the epilimnion (Butty *et al.*, 1979; Allanson *et al.*, 1990). With the progressive increase in nutrient concentrations in Lake Loskop, the phytoplankton blooms that occur mainly during the summer months are dominated by *Microcystis aeruginosa*, a potentially toxic cyanobacterium (Oberholster *et al.*, 2010).

At overturn, when the cooling surface waters are mixed down into the hypolimnion, the resulting mixture of metal ions and nutrients raises their concentrations in the entire water column to levels that pose potential risks to aquatic life and to water users at this time (Butty *et al.*, 1979). In addition, the accumulated organic material in the hypolimnion exerts a sudden increase in the biochemical oxygen demand within the reservoir and can result in deoxygenation of the water and fish kills (NIWR, 1985).

This pattern of summer stratification and winter mixing is shared by all the other water storage reservoirs in the Olifants River catchment (Allanson *et al.*, 1990). As a consequence, the periods marking the onset and end of summer stratification are characterized by sudden changes in water quality within each reservoir and this, in turn, influences the quality of waters released for downstream users (Allanson *et al.*, 1990).

4.14 Relationship between salt loads and river flows

Several studies have demonstrated that the TDS concentrations that are present at a particular time in a river system are inversely related to the river flow at that time (*e.g.* Walmsley and Butty, 1979; Allanson *et al.*, 1990; NIWR, 1985). This results in a repetitive, cyclical sequence where salt concentrations increase during the low-flow winter months and decrease during the higher-flow summer months. This pattern is visible in the TDS graphs for all of the DWA river sampling sites in the Olifants River catchment (**Appendix 1**, **Figures A1-1 to A1-27**, with those rivers that contain the highest TDS concentrations showing the widest seasonal fluctuations. The same patterns of seasonal change in TDS concentrations are also present, but less easily visible, in the water storage reservoirs (**Appendix 2**, **Figures A2-R1 to A2-R10**).

This pattern allows preliminary calculations to be made as to the relative size and importance of the loads of total dissolved salts carried by each river system. However, the shortage of reliable TDS data for the river systems made it difficult to calculate accurate values for the total monthly and annual loads of dissolved salts. As a first estimate, therefore, monthly loads of dissolved salts were calculated from total monthly flows and representative (middle of the month) values for TDS concentrations for selected river sampling sites. The results for six river sampling sites are shown in **Figure 41**.

The six graphs in **Figure 41** all reveal the negative relationship between monthly flow and representative TDS concentrations for each month. The data for the Ga-Selati River (**Figure 41E**) are unusual because they indicate that there is a fairly constant source of dissolved salts probably emanating from a single source or a set of sources located in close proximity to each other. This would support the suggestion that seepage from the series of tailings dams close to Phalaborwa are responsible for the majority of the salts in the Ga-Selati River (Ashton and Murray, 1992; Ashton *et al.*, 1992). The data for the other five river sampling sites shown in **Figure 41** suggest that these rivers receive dissolved salts from a number of sources.

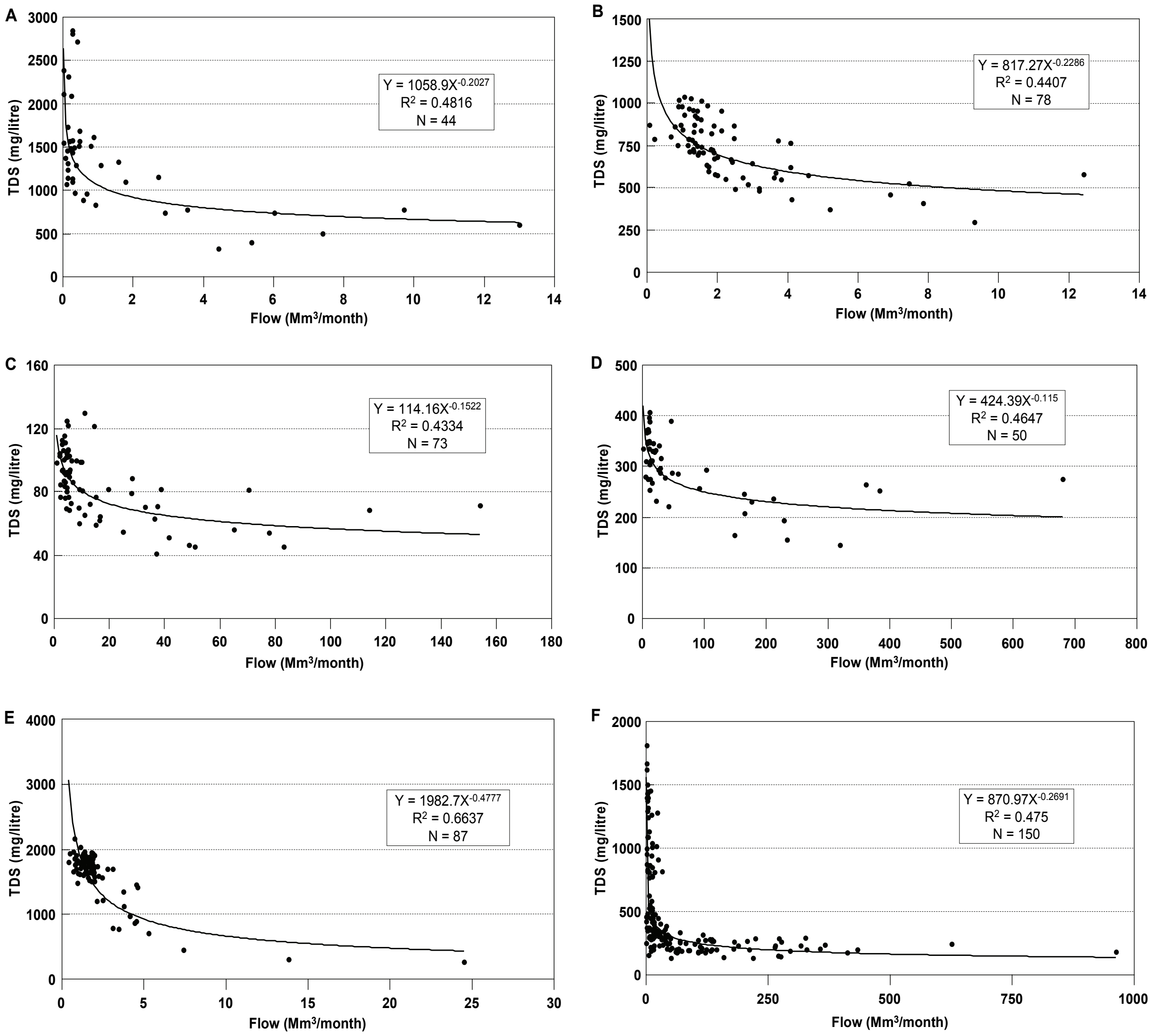

Figure 41. Plots of the relationships between Total Dissolved Salt (TDS) concentrations (mg/litre) and monthly flows (Mm^3/month) for six DWA sampling sites in the Olifants River catchment. (A = B1H002 – Spookspruit at Elandspruit; B = B1H004 – Klipspruit at Zaaihoek; C = B6H004 – Blyde River at Chester; D = B7H007 – Olifants River at Oxford; E = B7H019 – Ga-Selati River at Loole; F = B7H015 – Olifants River at Mamba). (Note that the vertical and horizontal scales are different in each figure; the inset boxes in each figure show the formula for the best-fit line, the R^2 value for the equation, and the number of data points used).

While the data for the Klipspruit (**Figure 41B**) show that this river contains relatively high TDS concentrations, though somewhat lower than the TDS concentrations contained in the Spookspruit, Ga-Selati and lower Olifants rivers (**Figures 41A, E F**), the data reveal nothing about the relative ionic composition of these salts. A portion of the water in the Klipspruit consists of neutralized acid mine drainage with the result that calcium sulphate concentrations are close to saturation levels. A comparison of the visual appearance of waters in an area receiving three different sets of acid mine drainage and the Klipspruit water (**Figures 42A and 42B**) shows the visual differences clearly. The water at sites close to sources of acid mine drainage in reddish or orange in colour (**Figure 42A**). At the point where the Klipspruit flows into the Olifants River, chemical interactions between the high concentrations of dissolved calcium sulphate and the salts already present in the Olifants River water result in the calcium sulphate (plus some associated metal ions) precipitating out of solution as micro-crystals. The refraction of sunlight on these suspended micro-crystals gives the water a distinct aquamarine colour which persists for several kilometres downstream (**Figures 42B and 42C**).

The accurate calculation of loads of salts and nutrients in a particular river system allows water resource managers to understand the relative size and importance of the contributions made by each tributary. When this knowledge is supplemented by a clear understanding of the chemical composition of these loads, water resource managers are able to select and implement appropriate remedial strategies to control unwanted salts and nutrients in prioritized rivers. However, a carefully designed and reliably operated monitoring programme is needed to achieve an acceptable level of accuracy when calculating salt and nutrient loads.

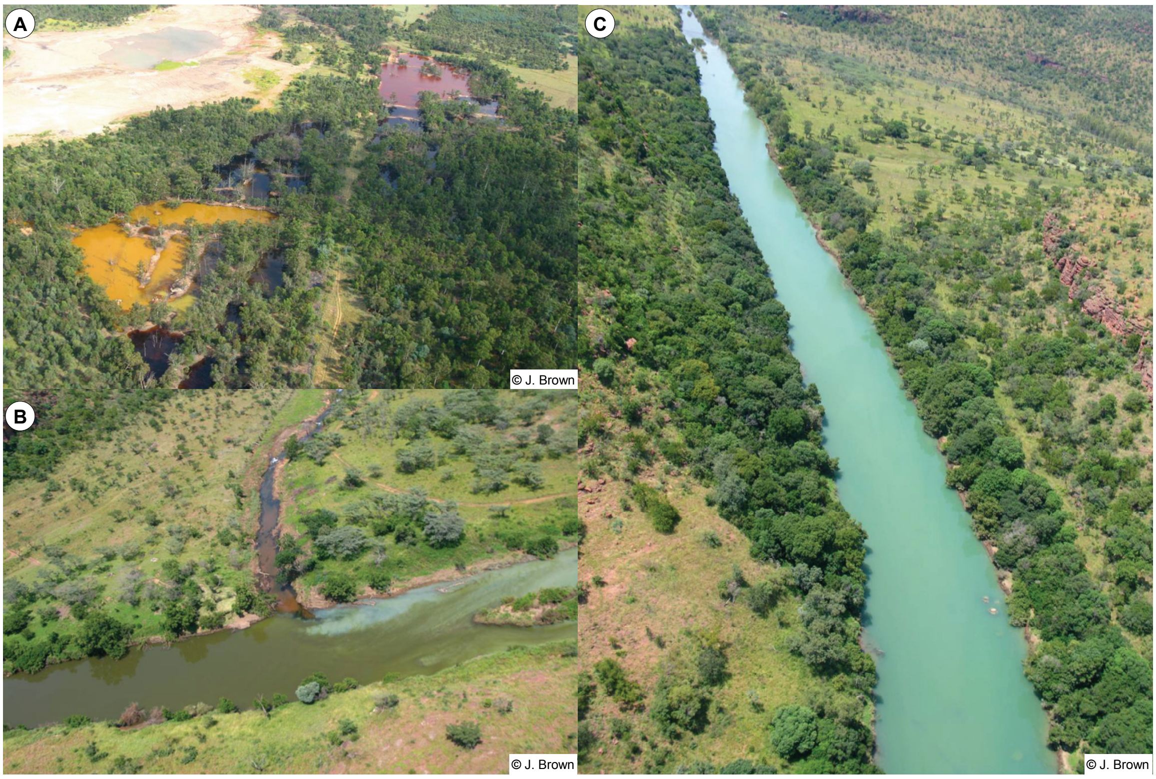

Figure 42. Aerial photographs showing: (A) pools collecting three different types of acid mine drainage water in the upper reaches of the Brugspruit; (B) the junction of the Klipspruit with the Olifants River showing the onset of calcium sulphate precipitation; and (C) a view of the Olifants River downstream of the Klipspruit inflow showing the entire reach coloured blue as a result of refracted daylight interacting with suspended micro-crystals of calcium sulphate. (All photographs taken by Ms Jackie Brown in February 2011).

The different tributary rivers and streams that contribute flows to the main stem of the Olifants River also contribute nutrient and salt loads to the main stem of the river. In an attempt to determine the relative size and importance of the salt loads contributed by the major tributary rivers, TDS loads were calculated for these rivers using total monthly flow volumes and representative (middle of the month) TDS concentrations. The results are shown as a set of eight time-series graphs of flows and TDS loads in **Figure 43**, arranged in order from the tributaries located in the uppermost portion of the catchment down to the lowermost portion of the catchment, with the final figure (**Figure 41H**) being for Mamba Weir on the lower Olifants River. Note that the length of time and the TDS loads covered by each of the graphs in **Figure 43** are different.

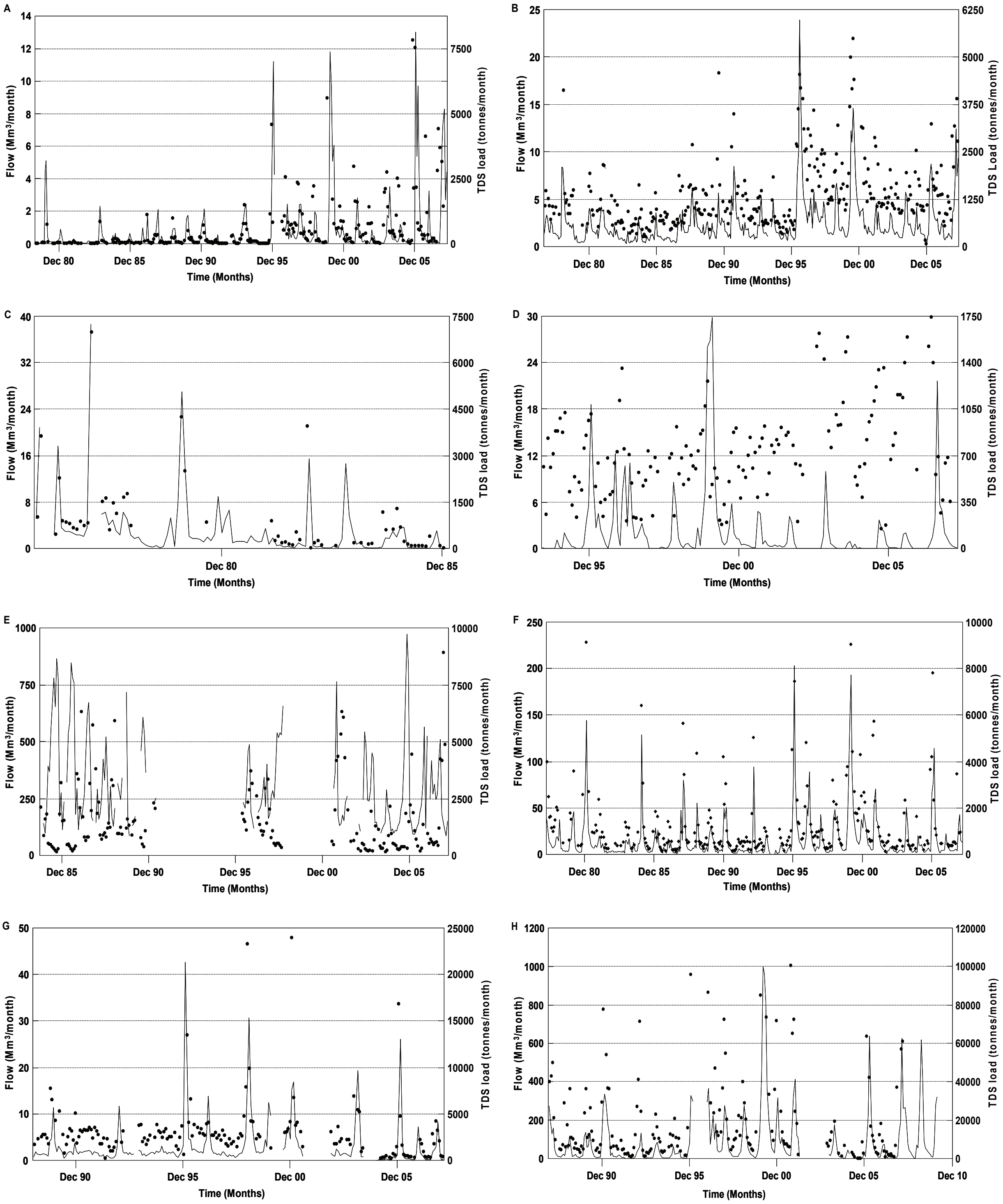

Figure 43. Monthly time series plots of total monthly flow (Mm^3/month) and TDS loads (tonnes/month) for eight DWA river sampling sites. (A = B1H002 – Spookspruit at Elandspruit; B = B1H004 – Klipspruit at Zaaihoek; C = B3H005 – Moses River at Mosesriviermond; D = B3H021 – Elands River at Scherp Arabie; E = B4H011 – Steelpoort River at Alverton; F = B6H004 – Blyde River at Chester; G = B7H019 – Ga-Selati River at Loole; H = B7H015 – Olifants River at Mamba). (Note that the left- and right-hand vertical scales for flows (LH) and TDS loads (RH) are different in each graph).

The TDS loads in all of the river sites shown in **Figure 43** vary widely during each calendar year. Higher TDS loads are associated with high summer flow events while low TDS loads are linked to the low-flow winter months, though there seems to be no clear correlation between the absolute volume of flow and the associated TDS load. The load data for three of the tributaries (Spookspruit, Klipspruit and Elands River, **Figures 43A, B and D**, respectively) appear to be increasing in recent years, while the other tributaries and the main stem of the Olifants River do not show a pattern of increasing TDS loads. The TDS loads present in the Ga-Selati River during the winter months appear to have decreased since 2003 (**Figure 43G**). Overall, the TDS load data are not sufficiently accurate for firm estimates to be made as to the relative contributions of salts made by each tributary river.

Despite the inherent inaccuracies in using monthly data for total flows and TDS, these data allowed a preliminary evaluation to be made of the annual volume of flow and annual load of TDS contributed by the different tributary rivers (**Figure 44**). The flow and TDS load estimations shown in **Figure 44** indicate the relative contributions made by each tributary river to the Olifants River and also highlight some important anomalies.

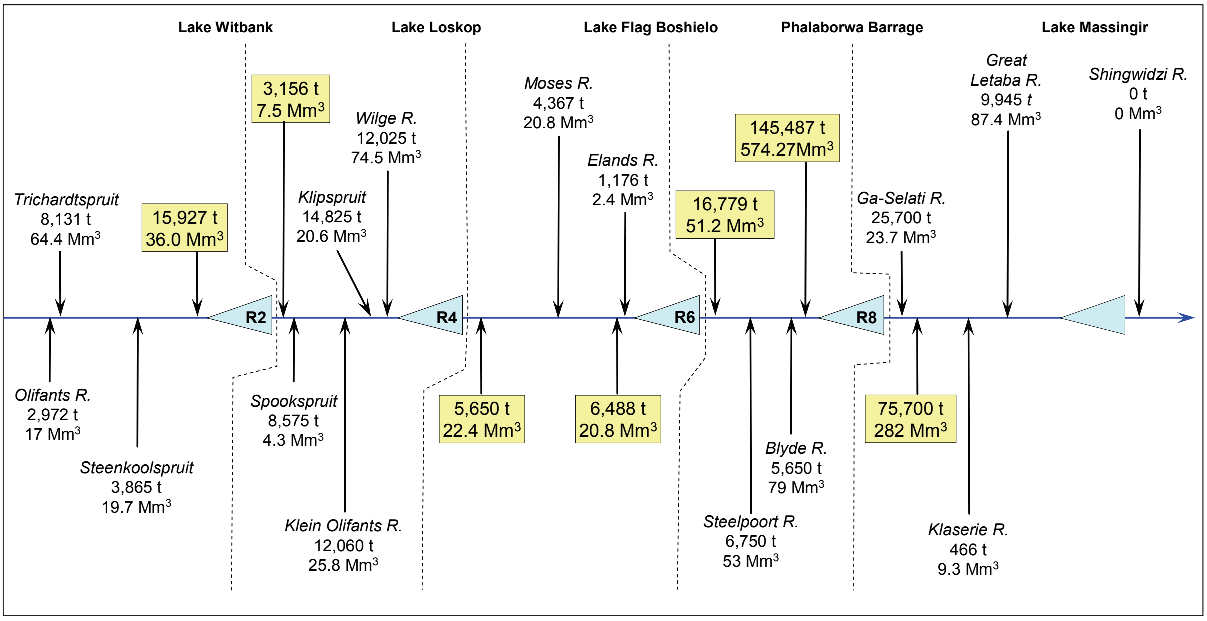

Figure 44. Schematic diagram showing the annual volume of flow and annual TDS load carried by the main stem of the Olifants River and its tributaries for the 2004-2005 hydrological year (October 2004 to September 2005). The numbers in yellow-shaded boxes represent the flows and loads in the main stem of the Olifants River. (Annual TDS loads are in metric tonnes (t), while annual flows are in millions of cubic metres (Mm^3)).

The difference between the TDS loads entering and leaving the four reservoirs on the main stem of the Olifants River provide reasonably strong supporting evidence for the ability of some reservoirs to retain a significant proportion of the inflowing TDS load. In the case of lakes Witbank and Loskop, it appears that these two reservoirs retained 80% and 88%, respectively, of their inflowing TDS loads. This feature appears to be quite different in Lake Flag Boshielo, where the outflowing TDS load is approximately 30% greater than the inflowing TDS load for the same period. There is also a relatively large difference of approximately 838 tonnes between the TDS load immediately downstream of Lake Loskop (5,650 tonnes) and the TDS load upstream of Lake Flag Boshielo (which includes TDS contributions from the Moses River but not the Elands River). These data suggest that some of the TDS load downstream of Lake Loskop may be retained within sediments that have accumulated in the main channel of this slow-flowing portion of the Olifants River.

Here, it is important to recognize that large volumes of water are contributed from Lake Loskop via two canals to the irrigated area controlled by the Groblersdal Irrigation Board downstream of Lake Loskop. No data are available for either the volumes of water or their TDS content and it is clear that the TDS loads in these water contributions will reduce the apparent retention of TDS within Lake Loskop.

The combination of the TDS load in the Olifants River immediately downstream of Lake Flag Boshielo with the TDS loads contributed by the Steelpoort and Blyde rivers is also well below the TDS load for the Olifants River at Oxford. In this case, it seems that there is another source or group of sources that contribute TDS – probably located between Lebowakgomo and Oxford. This region contains many mines (see **Figure 10**) and also corresponds to the portion of the catchment that has been shown to contribute the largest quantities of suspended sediments (Moolman *et al.*, 1999). It is therefore likely that the TDS loads which appear to enter the Olifants River in this region may be associated either with mining and quarrying activities, or with dispersed subsistence agriculture activities on the vulnerable soils in this area (Moolman *et al.*, 1999; Fey, 2010).

A comparison of the TDS load in the Olifants River at Oxford with the TDS load at Mamba downstream of the Phalaborwa Barrage (**Figure 44**) reveals what appear to be important discrepancies. The contribution of TDS via the Ga-Selati River is equivalent to approximately 34% of the TDS load at Mamba. Given that the TDS load calculated at Oxford amounts to approximately 145,000 tonnes, this suggests that the Phalaborwa Barrage may retain as much as 66% of the inflowing TDS load. Nevertheless, the periodic opening of the radial gates at the Phalaborwa Barrage results in the scouring out of large quantities of accumulated sediments and their associated salt loads. No systematic measurements are available for the TDS content (or the sediment content) of water in these periodic releases, thereby preventing more accurate estimates to be made of the salt load retained within the Phalaborwa Barrage. Further downstream, the Great Letaba River contributes approximately 9,945 tonnes of TDS to the lower Olifants River, thereby increasing the salt load that enters Lake Massingir in Mozambique.

The TDS load estimates shown in **Figure 44** indicate clearly that the Klipspruit, plus the Wilge and Klein Olifants rivers in the upper reaches of the Olifants River catchment are responsible for contributing relatively high salt loads to the main stem of the Olifants River upstream of Lake Loskop. In the middle reach of the catchment, the Moses River also contributes a moderately large TDS load (higher than the contribution received from the Elands River), but again a proportion of this salt load is likely to be trapped within the sediments of Lake Flag Boshielo.

Importantly, however, there is no evidence available to indicate the relative permanency of salt retention within the reservoirs. Indeed, it is very likely that periodic flood inflows and their discharge from the reservoirs will re-suspend some of the accumulated lake sediments and their associated salt loads and deliver these to downstream portions of the river system.

When compared with their salt (TDS) loads, the flows contributed by the different tributary rivers in the Olifants catchment reveal several discrepancies (**Figure 44**). For example, the sum of the flows contributed by the upper Olifants River plus the flows from the Trichardtspruit and Steenkoolspruit (101.1 Mm^3) should be approximately equal to the total inflow into Lake Witbank (36 Mm^3). However, the inflow to Lake Witbank is approximately one-third of this, suggesting that large volumes of water have been abstracted from these tributary rivers before the combined flow of the Olifants River enters Lake Witbank. This decrease in the volume of water available in this portion of the river system implies that less water is available to dilute the relatively high salt loads that enter the river system. The volume of water contributed by the Wilge River is equivalent to approximately three times the volume contributed by the Klein Olifants River, which in turn is approximately equal to the volume of flow contributed by the Klipspruit (**Figure 44**).

Downstream of Lake Loskop, the volumes of flow contributed by the Moses and Elands rivers, plus the outflow from Lake Loskop, exceed the volume of water that enters Lake Flag Boshielo (**Figure 44**). In this area, it is likely that direct abstraction of water from the river plus return flows from irrigated agriculture may be responsible for these discrepancies.

A similar situation exists for the section of the Olifants River between Lake Flag Boshielo and the Phalaborwa Barrage (**Figure 44**). The available data suggest that large volumes of water enter the Olifants River between these two reservoirs and are likely to be associated with the dramatic increase in salt loads recorded for this river segment. Downstream of the Phalaborwa Barrage, the data suggest that the Great Letaba River contributes approximately 23% of the total flow that enters Lake Massingir, while the much smaller Klaserie River contributes a mere 2.5% to this flow. During the 2004-2005 hydrological year, the available data indicate that the Shingwidzi River did not contribute measurable flows to the lower Olifants River.

4.15 Implications of poor water quality for neighbouring countries

The Olifants River is an important tributary of the Limpopo River, which is shared by four countries (Botswana, Mozambique, South Africa and Zimbabwe), and one of six river basins that South Africa shares with its neighbours (Turton and Ashton, 2008; Kistin *et al.*, 2009). As has happened elsewhere, the shared or transboundary river and aquifer systems in southern Africa have increasingly been the subject of formal bi-lateral and multi-lateral agreements and treaties between the states whose territory comprises the respective river basins. In broad terms, these agreements and treaties acknowledge and build upon the provisions of international water law and the provisions of the revised Southern African Development Community (SADC) Protocol on Shared Watercourse (SADC, 2000; Kisten *et al.*, 2009). Essentially, the revised SADC Water Protocol requires each sovereign state in the SADC region to co-operate closely with its neighbours to ensure the judicious and co-ordinated utilization of shared water systems (Kistin *et al.*, 2009). Ultimately, this co-operation and collaboration is anticipated to minimize the risks of disputes or conflicts over water, underpin peace, security and welfare in the region, and promote sustainable socio-economic development (SADC, 2000; Turton *et al.*, 2005).

An earlier study revealed that a total of 101 international agreements and treaties relating to water had been signed by successive South African governments since 1910 (Ashton *et al.*, 2006). Two additional treaties have since been added to bring the total up to 103 (Kistin *et al.*, 2009). Of these 103 treaties and agreements, the majority deal with small-scale issues of collaboration and co-operation or joint funding and operation of specific projects, while 25 pertain specifically to shared / transboundary river systems. Of these, only five relate to the broader Limpopo River basin, with only one treaty dealing specifically with the Olifants River through the conditions around the construction of the Massingir Dam (Ashton *et al.*, 2006; Kistin *et al.*, 2009). No treaties contain provisions that deal with the specific issues of water quantity or water quality in the Olifants River. In fact, the treaty that deals with the construction of the Massingir Dam enables both South Africa and Mozambique to conduct whatever water development projects they wish to carry out within their specific portions of the catchment, only requiring each country to notify the other of their intentions (SADC, 2000; Ashton *et al.*, 2006; Kistin *et al.*, 2008).

The absence of specific provisions that deal with water quality in the Olifants River has been the subject of considerable debate (*e.g.* Couzens and Dent, 2006), especially when the construction of the controversial De Hoop Dam on the Steelpoort River tributary was evaluated (ACER-CSIR, 2004). At this time, many individuals who were engaged in the public participation process made strident calls for a thorough review and revision of the treaty (Couzens and Dent, 2006). Subsequently, the raising of the Massingir Dam wall by 7 metres – resulting in the back-flooding of the Olifants River Gorge within the KNP – appears to have had a profound effect on water quality in the Olifants River Gorge section of the river and also within Lake Massingir (Mussagy, 2008). Again, there are no international treaty provisions that can be relied upon to resolve this problem. In summary, therefore, none of the international treaties or agreements between Mozambique and South Africa contain specific requirements that stipulate water shares for each Party or that require either Party to regulate or control water quantity or water quality in the Olifants River (Ashton *et al.*, 2006).

Importantly, South Africa's landmark National Water Act (RSA, 1998) contains specific provisions for the recognition of international obligations (for both water quantity and water quality) in shared / transboundary river systems. This formal recognition of international obligations with regarded to a shared water resource appears to be sufficient to ensure that South African water resource managers must consult their Mozambique counterparts when a change to river flows or river water quality could result from a proposed development project (Basson *et al.*, 1997). In theory at least, this would also require both Parties to reach agreement on an equitable share of the waters within a shared catchment and also to agree on particular water quality management goals. An equally important South African statute, the Water Services Act (RSA, 1997) recognizes the formal right of all individuals to receive appropriate levels of water services and (by implication) sanitation services. These two important pieces of legislation are widely recognized for their world-class, cutting-edge content and full alignment with key clauses in South Africa's Constitution (RSA, 1996). However, the widespread failure to fully implement the specific provisions within these Acts that relate to water quality management (particularly through the strict control of effluent quality prior to discharge into river systems) has meant that – on the ground – individuals, communities and organizations – both rich and poor, urban and rural – have been systematically disadvantaged by the progressive deterioration in water quality along the length of the Olifants River in South Africa. Worryingly, while this situation is not unique to the Olifants River catchment, it does mean that there has been no improvement over time in the quality of the Olifants River water that enters Mozambique.

The few water quality data that are available for Lake Massingir (Mussagy, 2008) reveal that this lake contains high nutrient concentrations and high but variable concentrations of several problematic trace metals that are known to occur in the South African portion of the Olifants River. In the absence of any significant industrial development around Lake Massingir, these metals could only have entered the lake via inflowing waters from South Africa. The recent deaths of numerous Nile crocodiles in the Olifants River Gorge (Van Vuuren, 2009) located immediately upstream of Lake Massingir suggests that whatever compound or mixture of compounds – either or both inorganic or organic – that may be implicated in the crocodile deaths has also entered Lake Massingir from South Africa. Given that the communities living along the shoreline of Lake Massingir are heavily dependent on fish from the lake for their daily food and livelihoods (Leira and McNabb, 2003), plus the use of water released from Lake Massingir to irrigate crops at the Chokwe Irrigation Scheme located at the junction of the Olifants and Limpopo rivers, it is apparent that these communities are exposed to health risks that are, as yet, unquantified. Any further deterioration in water quality of the Olifants River that might originate within the South African portion of the catchment will worsen this precarious situation.

5. CONCLUSIONS AND RECOMMENDATIONS

This investigation into the water quality status of the Olifants River catchment has focussed on the surface waters – rivers and reservoirs – and has not dealt explicitly with the quality of ground water systems. We recognize that the ground water systems in the Olifants River catchment are important sources – and in some cases, the only source – of water for large numbers of individuals and homesteads, as well as small and large communities in the previous Apartheid 'homeland' areas, and also provide some water for use in irrigated agriculture and for stock watering. Equally, it is important to remember that the visible surface water flows in streams and rivers during the dry winter months are comprised almost entirely of ground water base flow contributions. In effect, therefore, the quality characteristics of the river flows that are present towards the end of the dry season represent a 'snapshot' of the quality of ground water contributions to that stream or river.

By focussing on the quality characteristics of the surface waters present in the catchment, this study has provided a wealth of detail on the seasonal and inter-annual variations in water quality and the trends of change in water quality. There are clear indications that there has been a progressive decline in water quality along the main stem of the Olifants River – and in several important tributary rivers – over the last twenty years. In most instances, the water quality data and water quality indices provide clear indications as to the type of land-use activity that has contributed to this poor water quality. However, the available DWA monitoring data are not sufficient in terms of their spatial coverage, frequency of sampling or the variety of variables analyzed to allow a precise determination to be made as to the specific source of a particular contaminant. As a consequence of this, it is important to understand the implications of the wording in the ***Caveat*** presented below.

CAVEAT

It is necessary to stress an important ***Caveat*** to readers of this report in relation to the interpretation of general statements that attribute the causes of poor water quality to past and / or current mining activities in the different sub-catchments. The numerous mines in the Olifants catchment range from large to small operations – of different ages – and employ a range of different mining techniques, while their respective operating companies have widely differing economic resources at their disposal. Many of the older mines – particularly coal mines in the upper portion of the Olifants catchment – have been worked out and abandoned; custodial responsibility for these mines now rests with the National Government. All mines that are still operating with valid mining permits and water use licences are responsible for controlling their water use and for the quality of any effluent that may seep out of or be discharged from their properties. Several mines are known to operate highly effective pollution control systems and it is likely that these mines would contribute very little in the way of "problematic" water quality constituents. In contrast, some other mines - including abandoned mines - appear not to have effective pollution control measures in place. Therefore, while it is definitely possible to link instances of certain water quality variables (*e.g.* low pH values or high concentrations of sulphate, total dissolved salts and some metal ions) to the broad category of causes that are labelled "mining activities", we do not have the fine-scale, more detailed data that would allow us to indicate which specific mines or mining operations are responsible for specific cases of water quality problems in particular rivers. This issue can only be resolved by obtaining a much more detailed data set from those rivers where mining activities appear to be responsible for water quality problems. These data would allow a clear distinction to be made between the mines and mining operations that are effectively managed from those where additional or more stringent management efforts and interventions are required.

It is equally important to stress that the broad-scale of the analysis conducted in this study could not provide information at a sufficiently fine scale of resolution that would allow definition of the specific industries, wastewater treatment works or areas and types of farming operations that are responsible for specific water quality constituents or for specific water quality problems. This finer level of detail will require more detailed studies in specific sub-catchments to determine which specific land-use activities are responsible for particular types of water quality problems. This information can then be used to design customized solutions to each specific problem.

These conclusions and recommendations that have arisen from this study are grouped into four sections that address the primary issue of concern identified in this study.

5.1 Water quality data collection and interpretation

Our evaluation of the water quality data collected by the DWA routine water quality monitoring programme for the Olifants River system revealed several short-comings of this programme. In particular, evaluation of the ionic activity balance characteristics for the data set for each sampling site used revealed that less than 90% of the analyses for samples from 13 of the 27 river monitoring sites and 2 of the 10 reservoir monitoring sites were reliable and could be analyzed further. The relatively high proportion of unreliable samples from these sites – with one site have 74% of unreliable samples – is unfortunate because it represents a significant waste of scarce time, money and human resources.

A similarly unfortunate aspect of the DWA water quality monitoring programme data was the relatively long time interval between reliable samples (*i.e.* after exclusion of the unreliable samples). Eighteen (18) of the 27 river sampling sites and all 10 of the reservoir sampling sites had a sampling interval of greater than 14 days, with some sites having an average sampling interval of over 50 days. Where there are long intervals between samples, it is unlikely that the data for the site in question will provide a sufficiently good reflection of the water quality at that site. Another implication of long periods between the dates when samples are collected has adverse implications for the interpretation of unacceptable water quality. For example, in many water quality management approaches, a particular water quality variable may be allowed to exceed a specific limit for a maximum 5% of the time, usually expressed as one in every twenty samples may exceed the allowable limit. However, if samples are only collected every 30 days, then this equates to once in twenty months, or a period equivalent to approximately 60 days. Clearly, this should not be an accepted approach to managing water quality.

A sampling interval of up to 14 days provides the most reliable way of routinely monitoring water quality in a river system (Appelo and Postma, 2007). Counter arguments that samples collected at intervals of up to 14 days will reveal auto-correlation, conveniently ignore the original purpose of collecting the samples to reflect the catchment characteristics and discern unusual events – *e.g.* an effluent spill – that might occur within the catchment. Sequential samples <u>should</u> share several chemical characteristics because they reflect the same catchment influences over time. Differences are to be expected when climatic features change, land use is altered, or accidents occur. Long time intervals between the collection of samples make it difficult if not impossible to discern unusual events that require remedial management action.

The DWA routine water quality monitoring programme has been structured to provide a balance between effective evaluation of water quality and the costs of collecting, analyzing and processing the data (DWAF, 1996a, b, c). However, the relatively few water quality variables that are analyzed are not sufficient to provide an overview of the full range of water quality problems that are encountered in river and reservoir systems. In particular, the absence of routine analyses of suspended sediments, trace metals, pesticides and microbiological indicators prevent proper evaluation of the potential health risks associated with water quality in the Olifants River catchment.

A closely related problem is the common practice in many water quality reports of only reporting mean values – or very occasionally median values – as a measure of the water quality in a particular river or reservoir. On their own, these values are meaningless because it is the high values – and the period of time that these may persist, or the time of year that they occur – which results in unacceptable health risks to humans, livestock, crops and aquatic biota. All water quality monitoring reports should include the percentile analysis of the data and a comparison of the percentile data with specific limits for each water quality variable. In addition, time series analyses should be presented to illustrate trends of change and times of the year when water quality worsens.

Every local authority, industry, institution or commercial farming operation that has been granted a water use licence and an effluent discharge licence by the Department of Water Affairs (DWA) is required to submit regular reports to DWA on the quantity of water used and quantity and quality of effluent discharged. These reports and their associated monitoring and audit data are often privately commissioned and their contents and data are considered to be 'confidential' or 'commercial in confidence'; the contents and data in these reports are not available to the general public for examination. As a result, none of these data were available for evaluation in this study. This is unfortunate because these data would have allowed a clearer picture to be produced of the precise quantities and sources of many contaminants that enter the Olifants River system. In future, these reports and data need to be thoroughly scrutinized so that specific effluent dischargers can be identified and prioritized for actions designed to improve the treatment of their effluents.

Independent academic studies and short-term sampling campaigns have revealed that extremely high concentrations of certain trace metals have been present for prolonged periods of time in some of the tributary rivers (*e.g.* the Spookspruit, Steenkoolspruit and Klipspruit, as well as the Moses, Elands and Ga-Selati rivers). The sources of these trace metals must be determined precisely and appropriate management actions taken to improve water quality and prevent a recurrence or continuation of the problem.

The short-term sampling campaign to evaluate trace metals and pesticides in the rivers and canals immediately downstream of Lake Loskop revealed that a wide variety of these organic compounds and trace metals were present in the water (Bollmohr *et al.*, 2008). While the concentrations of some compounds and trace metals were often above limits regarded as safe or acceptable, no water quality guidelines are available to judge the acceptability or otherwise of several of the potentially harmful organic compounds. The Department of Water Affairs needs to address this issue effectively by revising and expanding the current sets of water quality guidelines for South Africa.

The primary source area for a large proportion of the suspended sediments that enter the Olifants River has been known for several years (Moolman *et al.*, 1999), yet no corrective actions have been taken to date. Given the high probability that the suspended sediments are closely linked to fish kills and crocodile deaths in the lower Olifants River, it is essential that suitable actions are taken to reduce the entry of these sediments into the river system.

The COALTECH-funded study of the river and reservoir systems upstream of Lake Loskop similarly revealed the presence of unacceptably high numbers of microbiological contaminants and pathogenic organisms in several rivers. These organisms reflect the presence of faecal contamination (from both humans and livestock) and indicate that few of the wastewater treatment works in the upper catchment are operating efficiently or effectively. The presence of *Giardia* and *Cryptosporidium* in some streams in the upper catchment (Dabrowski *et al.*, 2010) poses a significant health risk to humans and livestock (Traub, 2008). Rural communities and single households that may draw their water directly from the river seldom have access to sufficient resources to allow them to treat the water before use (Ashton *et al.*, 2008), and are therefore at greatest risk from these contaminants. The Department of Water Affairs needs urgently to work with the local authorities and institutions that are responsible for operating wastewater treatment works and bring all these works back to full operational efficiency.

The few data available on the chemistry of rainwater samples collected in the upper Olifants catchment (Dabrowski et al., 2010) reveal that most rainwater samples are sufficiently acidic to be classed as 'acid rain'. This acidic rainfall has the definite potential to acidify soils and also to influence the productivity of croplands in areas where this rain falls (Wren and Stephenson, 1991; Zunckel *et al.*, 2000; Rodhe *et al.*, 2002). There is an urgent need to understand the full extent and implications of the acidic deposition across the upper Olifants catchment and to work with the institutions responsible for the source emissions to find cost-effective ways to reduce these emissions. In addition, there is also an urgent need for the Department of Agriculture and the Department of Water Affairs to work closely with commercial and subsistence farmers to devise and apply the most cost-effective solutions to counter increased soil acidity.

The available water quality data indicate very clearly that significant acidic mine drainage with its associated low pH values and elevated concentrations of sulphate and other dissolved salts and metal ions has been present in some tributary streams and rivers in the upper reaches of the Olifants catchment for at least the last 25 years. In some instances (*e.g.* Spookspruit, Klipspruit, Klein Olifants River), there are clear indications that the situation has become progressively worse in recent years. Urgent remedial management attention should be directed to identifying the specific sources of the contaminants that enter these rivers and then working with the operators of these mining activities and associated industries to rectify the problems. In addition, the presence of elevated concentrations of aluminium in several tributary streams and in Lake Loskop (Dabrowski *et al.*, 2010; Oberholster *et al.*, 2010) suggests that there is an urgent need to understand the speciation chemistry of aluminium in river and reservoir waters that receive acidic mine drainage so that a fuller assessment can be made of the potential health risks of this aluminium to humans, aquatic biota and livestock, as well as the implications for the design and operation of water and wastewater treatment works (Driscoll, 1985; Gray, 1988; Stohs and Bagchi, 1995; Soucek *et al.*, 2001; Ward *et al.*, 2001; Soucek, 2006).

The precise sources of the elevated nutrient (N and P) concentrations recorded for most of the streams and rivers in the Olifants catchment are not easy to identify. While there is clear evidence that significant proportions of these nutrients are derived from non-functional or improperly operated wastewater treatment works, return flows from irrigated agriculture also contribute nutrients to the river system. In addition, to sewage, domestic wastewater treatment works also receive large quantities of phosphorus that originate from the use of detergents (Quayle *et al.*, 2010). There is good evidence that the imposition of phosphorus-free detergents would help to reduce phosphorus loads to wastewater treatment works by up to 40% – helping to improve the efficiency of phosphorus removal and improve the quality of discharged effluents (Quayle *et al.*, 2010).

Like many other catchments in South Africa and elsewhere in the world, sewage effluents seem to be the principal source of phosphorus (Jarvie *et al.*, 2006). In those areas where the catchment soils have a high clay content, phosphorus is relatively immobile and return flows comprise mainly forms of nitrogen (Hart *et al.*, 2004). In areas where more sandy soils predominate, less phosphorus is retained by the soils and agricultural return flows contain both nitrogen and phosphorus. The combination of nutrients from wastewater treatment works and agricultural sources has resulted in high to very high nutrient concentrations in every tributary river in the Olifants catchment. This has led to the progressive accumulation of nutrients in reservoirs such as Lake Loskop and has resulted in the development of extensive blooms of potentially toxic cyanobacteria. The toxins produced by these organisms are known to persist in water for relatively long periods of time (NIWR, 1985; Wicks and Thiel, 1990; Watanabe *et al.*, 1992) and are not removed or eliminated in conventional secondary water treatment processes (Lahti *et al.*, 1997). This situation cannot be allowed to continue and the Department of Water Affairs must urgently work with local authorities and agricultural organizations to prevent further eutrophication of the rivers in the catchment, and enforce the existing policies and statutes to ensure that the current situation can be reversed.

The issues highlighted in preceding comments and by other authors (e.g. De Villiers and Mkwelo, 2009; Heath *et al.*, 2010) indicate that perhaps the most worrying issue related to the water quality data for the Olifants catchment is the apparent absence of effective management actions to deal with easily identifiable situations where water quality has been compromised. This suggests that the officials and water resource managers who are responsible for water quality management have not received the information, or if they have received the information it is in such a form that it does not indicate that water quality has been compromised. If either of these two options is true then it indicates a breakdown of the monitoring process, which includes every aspect from sample collection, analysis and interpretation to management response. Another possible alternative – that the information has been received in the correct format but the responsible individuals have been unable to react appropriately – also indicates that the water quality monitoring programme has failed to achieve its purpose. This situation will require a complete review of the ways in which water resource managers interpret water quality data and information, and – if necessary – a change to the processes used to initiate management responses to poor water quality. It is not appropriate simply to accept statements from operators of wastewater treatment works that they are unable operate the works effectively and thereby maintain the *status quo*.

Overall, therefore, while the DWA routine water quality monitoring does provide some useful information it does not cover all of the variables of concern nor does there appear to be an effective translation of the evidence for poor water quality into decisive management actions to improve the situation. If the predicted consequences of global climatic changes do indeed occur, including more intense rainfall events and warmer air temperatures, these will greatly accentuate the existing situation of poor water quality across the entire catchment (De Wit and Stankiewicz, 2006)

5.2 Temporal and spatial trends of change in water quality

The preceding section of this report pointed out that the available data show clear indications of seasonal variations in water quality in every tributary river in the Olifants catchment. In general, water quality improves slightly (concentrations of contaminants decline) during the summer months when the river flows increase, and gradually worsen during the dry winter months as surface runoff declines. The cycle is then repeated when the input of increased surface runoff during the following rainy season once again helps to dilute the water quality constituents present in the river. The same type of annual cycle is visible in each of the reservoir systems though the amplitude of the seasonal variation for each water quality constituent is far smaller.

The data analyzed in this study also reveal that water quality in some tributary rivers has progressively worsened due to the entry of acidic mine drainage into these systems. In the case of the Spookspruit and Klein Olifants River, this deterioration has continued unabated since at least 1990. Despite some management attention having been directed towards the Klipspruit in the form of treating a portion of the acidic seepage in this river, the quality of the water in the Klipspruit has continued to decline.

Similar trends of worsening water quality are visible for Lakes Witbank and Loskop; in the case of Lake Loskop, the deterioration in water quality has continued unabated since at least the start of the DWA water quality monitoring programme in 1975. Given that the water storage reservoirs tend to accumulate a proportion of their inflowing loads of salts, nutrients and sediments, the water quality of the reservoirs in the Olifants catchment will continue to deteriorate if there is no improvement to the water quality of their inflowing rivers. However, it is important to remember that even if the inflowing water quality is dramatically improved, it will take a period of time equal to approximately 5-7 times the water residence time in the lake for the lake to reach a new equilibrium and for the full benefits of the improvement to be visible (Walmsley and Butty, 1979).

Another important consideration is that while water quality deteriorates during the drier winter months, the coincidence of this worsening water quality with low water temperatures accentuates the adverse effects on aquatic organisms at this time (Cairns *et al.*, 1975).

The available data on temporal trends in water quality do not appear to have prompted sufficient meaningful and effective management responses to remedy any of these issues. Small-scale efforts such as localized treatment of some acid mine drainage in the Brugspruit near Witbank, while praiseworthy, are simply not sufficient to deal with the scale of the problems in the catchment. Early attempts to derive water quality guidelines for the rivers flowing through the Kruger National Park (Moore *et al.*, 1991) have not resulted in any meaningful improvements to water quality in any of these rivers (DWA, 2009).

Examination of the other water quality variables reveals that many of the characteristics of poor water quality are present to varying degrees along the entire length of the Olifants River. This unfortunate situation also occurs in numerous other rivers across South Africa (De Villiers and Thiart, 2007). While there is a tendency for a gradual improvement in water quality with increasing distance down the Olifants River, tributary inputs of untreated or incompletely treated domestic effluent, as well as industrial and mining effluents, plus return flows from irrigated lands ensure that the water quality remains poor. In the lower reaches of the Olifants River, the contribution of the Ga-Selati River, which contains poor quality seepage and effluent from the Phalaborwa mining and industrial complex, maintains poor water quality in the lower reaches of the Olifants River (Ashton *et al.*, 1992).

The COALTECH-funded study conducted by CSIR has revealed the presence of unacceptably high numbers of microbial contaminants and pathogenic organisms in water samples collected from the upper reaches of the Olifants catchment. From the identity of the organisms concerned, there is clear evidence that wastewater treatment works in the upper reaches are either not operating effectively or large volumes of sewage effluent are leaking / being discharged directly into the rivers. Conversations with local residents indicate that the Brugspruit tributary of the Klipspruit, for example, has received raw (untreated) sewage for at least 18 months, and has received acidic mine drainage for at least 15 years (Bell *et al.*, 2002). The resulting "cocktail" of contaminants accentuates the poor water quality already present in the Klipspruit, and eventually contributes to the progressively worsening water quality in Lake Loskop. In some tributary rivers, the presence of endocrine disrupting compounds (EDCs) and both pharmaceutical and veterinary antibiotics (Dabrowski *et al.*, 2010) poses health risks to all users and is likely to lead to the development of antibiotic resistance in certain microorganisms (Kummerer, 2003).

The extensive (and expanding) areas of low-cost, high-density housing close to the towns of Middelburg and Witbank appear to lack uniformly effective sanitation services and garbage removal services. As a result, surface runoff from these settlements will contain high concentrations of nutrients and other pollutants (Ashton (1988). The entry of this runoff in combination with untreated or poorly treated domestic effluent from other urban areas accentuates an already poor situation (Carpenter *et al.*, 1998).

The ability of water storage reservoirs to trap portions of their inflowing loads of salts, nutrients and sediments results in an improvement to the water quality that is discharged from each reservoir to downstream sections of rivers. However, this improvement is short-lived because additional inflows of nutrients, salts and sediments continue to enter the river system. Lake Massingir, the largest water storage reservoir in the Olifants catchment, receives inflows that contain relatively high concentrations of salts, nutrients and sediments. The occasional scouring out of accumulated sediments from the Phalaborwa Barrage periodically increases the sediment loads that enter Lake Massingir (Ashton *et al.*, 1992).

An overview of the changes in water quality along the length of the Olifants River shows that while some of the sampling sites in the lower reaches of the Olifants River had relatively good water quality (compared to upstream sites), these sites also experienced periodic worsening of water quality. The water quality of the Great Letaba and Shingwidzi rivers appear to contribute relatively few salts, nutrients and metal ions to the lower reaches of the

Olifants River. The periodic cessation of flow in both of these rivers also reduces the size and importance of their contributions to water quality in the lower Olifants River.

The spatial trends in water quality across the Olifants catchment reveal that numerous sources of different contaminants are contributing to the overall water quality situation. The apparent absence of any meaningful or sustained improvements in water quality across the catchment suggests that whatever management actions may have been taken to date have not been effective.

The Department of Water Affairs is in the process of completing the compilation and implementation of an integrated water resource management plan for the upper and middle reaches of the Olifants River catchment (DWA, 2009). While this is a welcome development, it will need to be fully embraced by all stakeholders in the catchment if it is to succeed. The last evaluation of the quality of drinking water supplies – the so-called "Blue Drop Report" – indicates that very few local authorities within the Olifants catchment have been able to demonstrate competence in water treatment or compliance with water use licences, and several have failed to meet water quality targets (DWAF, 2009).

5.3 International implications of poor water quality

The continued inflow of poor quality water from the South African portion of the Olifants River into Mozambique would appear to contravene some of the provisions in the revised SADC Water Protocol (SADC, 2000). While this Protocol does not deal specifically with water quality issues, it requires all signatory Parties to ensure that their water use in a shared river basin does not cause appreciable harm to a neighbouring country. In effect, the provisions of the SADC Water Protocol are regarded as carrying greater weight than, and thereby over-riding, the provisions of earlier bilateral agreements and treaties between countries.

An argument can be made that the Treaty between Mozambique and South Africa that deals with the construction of the Massingir Dam can be interpreted to mean that both Parties may do whatever suits them best in this catchment without regard for the other Party, for as long as both may wish to do so. However, such an argument would be contrary to the content and intent of the revised SADC Water Protocol and would therefore be likely to have no effect.

In summary, therefore, the continued flow into Mozambique of poor quality water, which continues to deteriorate further over time, is considered to be contrary to the content and intent of the revised SADC Water Protocol and could give rise in future to claims for compensation from Mozambique. While it is clear that this situation should be halted and reversed as quickly as possible, this will require a far greater emphasis on effective water quality management across the entire Olifants River catchment. In turn, this will require a far closer association with and continuous co-operation between water resource managers, local authorities, industries and land-owners at all levels. All stakeholders will need to be involved in the process and everyone will need to contribute to solving the many problems linked to or caused by the catchment's poor water quality.

5.4 Additional research needs

This study has exposed several areas where the available data and information are not sufficient to provide a clear and unambiguous assessment of many of the causes of poor water quality in the Olifants River catchment. A summary of the most important research needs to resolve these problems include investigations aimed at defining the extent and exact sources of critical pollutants and contaminants, followed by their control or remediation. The suggested research topics include:

- Evaluate the effluent quality data that are currently considered to be 'confidential' or 'commercial in confidence' to determine which industries, institutions, local authorities or landowners need to be prioritized in terms of urgent remedial treatment of their effluents.
- Review and revise the current DWA water quality monitoring programmes so that they include trace metals, bacteria and other microbial organisms, organic compounds and suspended sediment evaluations.
- Develop and enforce effective resource quality objectives (RQOs) for each river reach in the Olifants River catchment;
- Find ways to strengthen and enhance the abilities of water user groups such as the Olifants River Forum (ORF) so that their efforts to improve the water quality situation in the catchment are more likely to succeed;
- Develop and refine ways to streamline some of the management approaches (such as the resource classification system which is presently cumbersome to use and often deters potential applications) so that water quality management approaches can be less time-consuming and more cost-effective;
- Review and if necessary revise the chemical composition conditions of all effluent discharge licences issued to effluent dischargers in the Olifants River catchment;
- Determine the longevity in natural aquatic systems of the microbial contaminants indicative of domestic sewage pollution and the implications of this for water users located downstream of points where these organisms originate;
- Define the types, extent, exact sources and implications of endocrine disrupting compounds (EDCs, including pharmaceutical and veterinary antibiotics) and other new and emerging pollutants such as nano-sized particles;
- Pin-point the sources, followed by determination of their character and extent, of acidic drainage from operating and abandoned mines and devise or compile suitable options to control and minimize these;
- Define the exact sources of pathogenic organisms (especially *Cryptosporidium* and *Giardia*) and the most suitable treatment or preventative processes to stop the input of these organisms to the aquatic systems;
- Accurately quantify the extent to which water storage reservoirs are retaining salts, nutrients and sediments, the conditions under which this happens, the factors that control the rates of retention and transfer between sediments and water, and the implications of the retained loads for water quality in these reservoirs;
- Accurately quantify the extent to which coal-fired power plants and heavy industries are contributing atmospheric emissions that contain potentially acidic materials to the catchment and identify the most appropriate treatment and preventative processes to minimize the impacts of these substances on aquatic systems and cultivated areas;
- Identify which trace metals originate from which type of mining or industrial activity and specify how best to prevent the entry of these trace metals into the aquatic systems;
- Evaluate alternative mining methods for coal mines in the upper catchment that would allow proper exploitation of the available reserves whilst minimizing the generation of acid mine drainage from their associated pyrite deposits;
- Implement a monitoring system to conduct routine evaluations of the presence and toxicity of cyanobacteria in reservoirs and selected river sites in the catchment;
- Evaluate simple water treatment systems for small communities and possibly also for single households that would allow individuals to obtain reliable supplies of wholesome water for domestic use and reduce their health risks;
- Gauge the extent to which "Payments for Ecosystem Services" (PES) approaches could be used as a mechanism to improve water quality across the Olifants River catchment and, if found to be economically feasible, how best to implement such approaches;
- Confirm and quantify the exact origins of the suspended sediments present in the Olifants River and determine when and where these sediments are transported and settled out;
- Quantify the extent to which trace metals and other contaminants are associated with suspended sediments and evaluate their implications for water quality, aquatic biota and water treatment processes;

- Review the existing water treaties and agreements between Mozambique and South Africa to determine if there are mechanisms that can be incorporated to strengthen their applicability to water quality management for the benefit of both countries;
- Investigate the most cost-effective technical solution for treating water that contains cyanobacterial toxins so that the water is both affordable to consumers and safe for use;
- Determine those aspects of the speciation chemistry of aluminium associated with waters that receive acidic mine drainage and the implications of this for aquatic biota, human health and the design and operation of water treatment systems;
- Evaluate the full implications of introducing phosphorus-free detergents for domestic use on the effectiveness and efficiency of wastewater treatment works, and the resulting reduction in phosphorus loads entering rivers in the Olifants catchment;
- Determine what remedial techniques and technologies could be deployed to successfully improve water quality in water storage reservoirs;
- Compile a comprehensive water quality management plan for the Olifants River catchment to complement the DWA integrated water resource management plan for the catchment;
- Assess the extent to which passive water treatment systems such as natural and man-made wetland systems could be used to improve water quality, and evaluate the implications of seasonal changes in climatic factors and inflowing loads on the functioning of these systems;
- Determine the extent to which nutrients derived from livestock are influencing water quality in the Olifants catchment and derive effective land management options to prevent this source of nutrients from entering the river systems;
- Determine the exact water quality conditions and components that are implicated in the pansteatitis incidents amongst fish and crocodiles;
- Determine the most appropriate options for treating acidic mine drainage to a state where it can safely be used over the long-term for alternative uses such as irrigation;
- Develop and implement suitable operating procedures for the Phalaborwa Barrage and other water storage reservoirs to reduce the quantity of sediments released to downstream river sections; and
- Review and revise the existing sets of water quality guidelines, expanding these to include inorganic and organic substances where no guideline exists.

This long listing of research needs reflects the extent to which our collective knowledge and understanding of the Olifants River system and its water quality are deficient. It is clear that the required research cannot be carried out over-night and that it may take several years before all of the pressing water quality issues can be dealt with effectively. Nevertheless, it will be essential to initiate a process whereby research funding institutions, academic institutions, local authorities, industries, water user organizations and water quality researchers can jointly examine and prioritize the research needs. This will allow a carefully structured approach that will help to provide the information that is required to successfully restore the water quality in the Olifants catchment to acceptable levels.

In addition, this process will require improvements to be made to the effectiveness of several institutional structures and organizations that share responsibility for managing water resources and water quality in the Olifants River catchment.

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Appendix 1

Monthly Time Series Plots of Eight Water Quality Characteristics at Twenty-Seven Department of Water Affairs (DWA) River Sampling Sites in the Olifants River Catchment

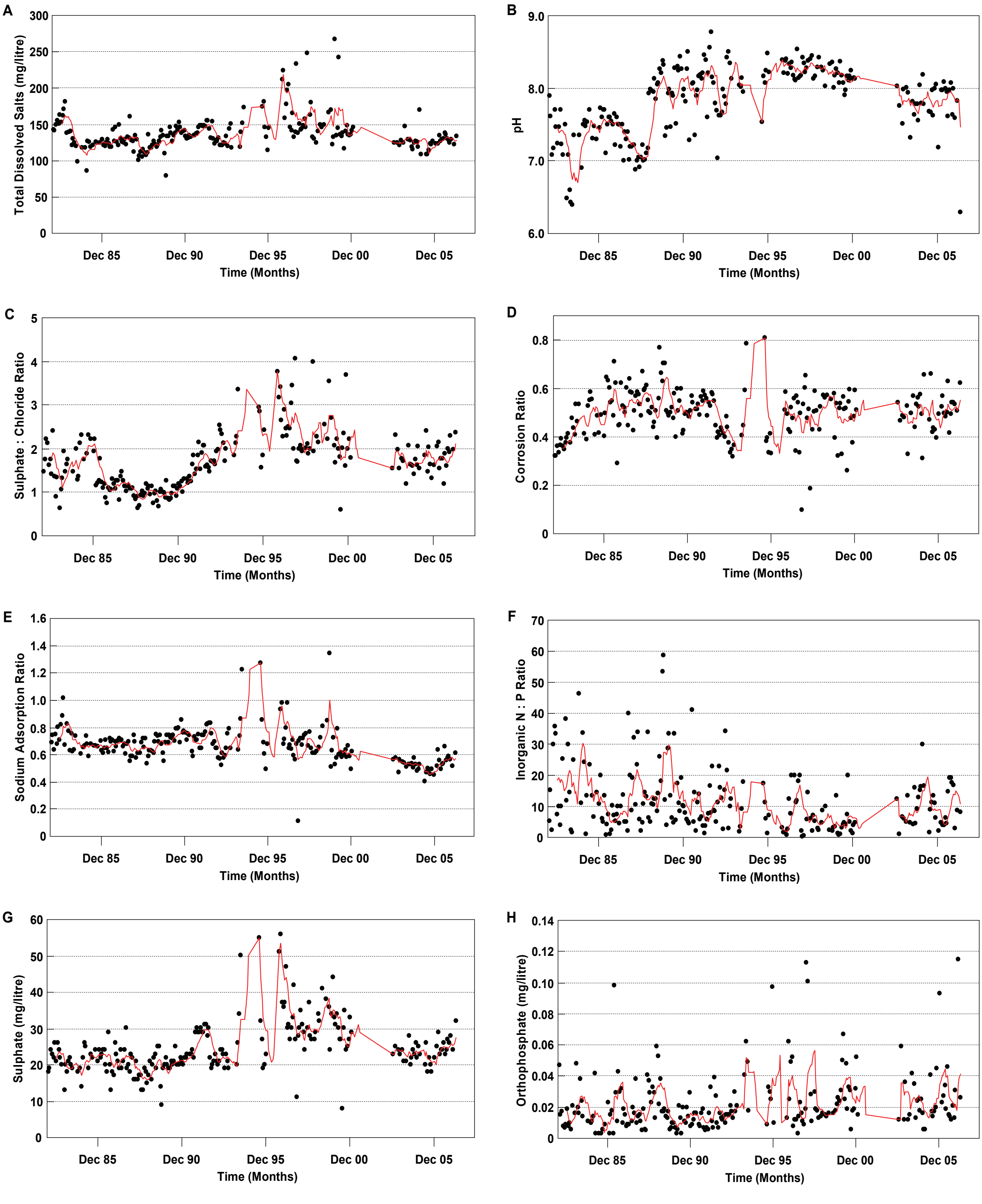

Figure A1 - 1A – H: Trichardtspruit at Rietfontein – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 1 (DWA gauge B1H006) for the period November 1982 to June 2008. (Solid line = seven-point moving average).

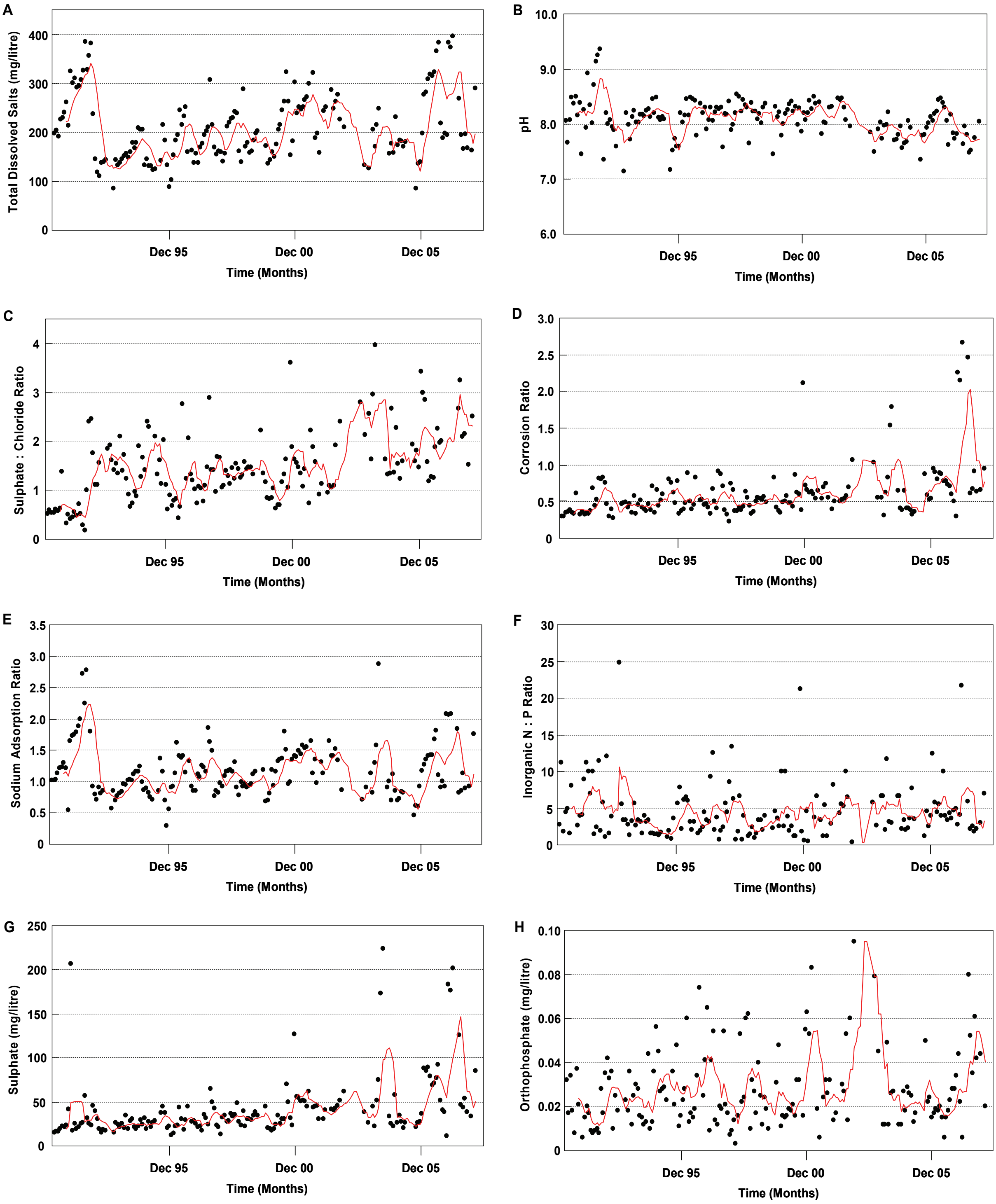

Figure A1 - 2A – H: Olifants River at Middelkraal – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 2 (DWA gauge B1H018) for the period May 1991 to June 2008. (Solid line = seven-point moving average).

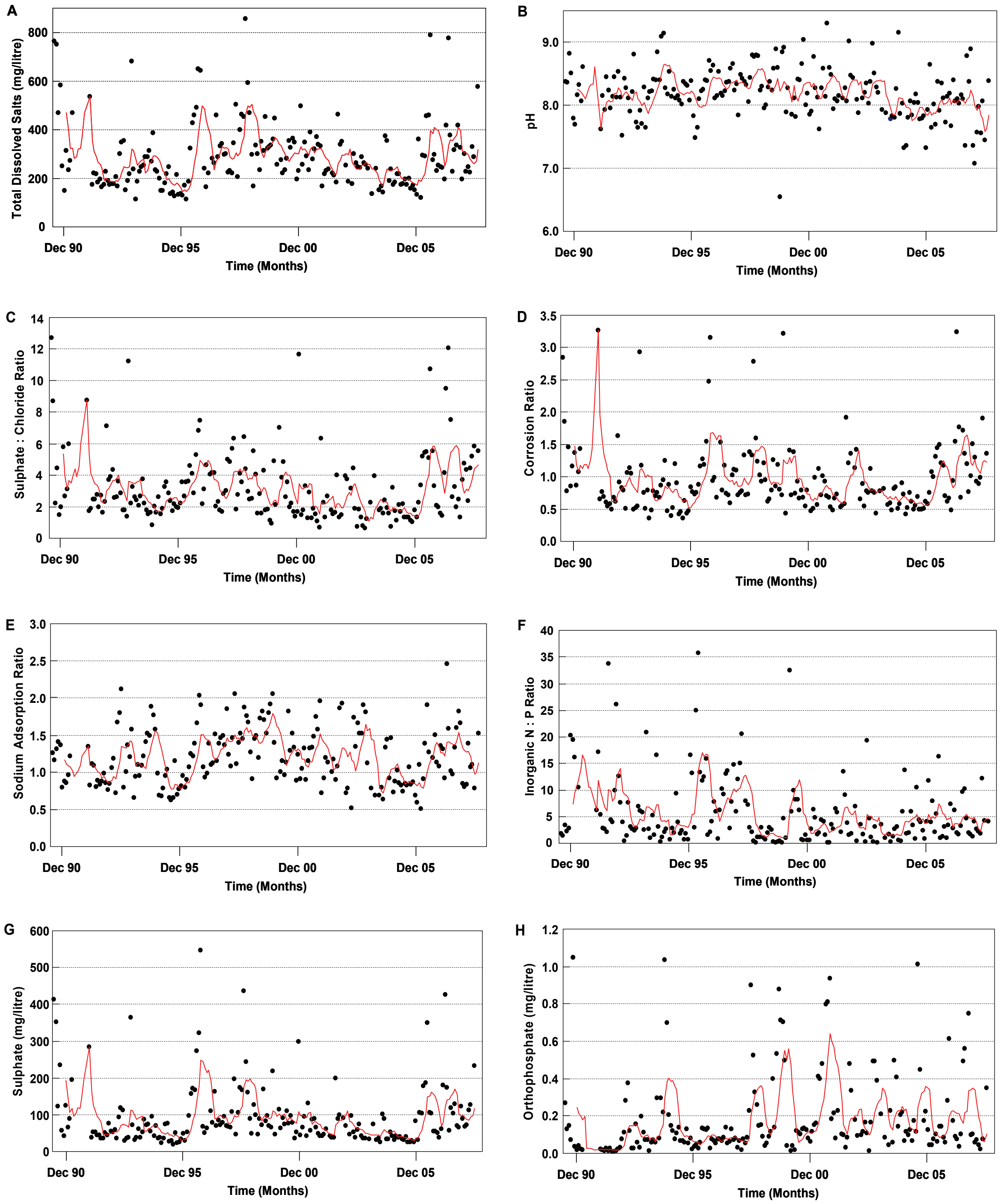

Figure A1 - 3A – H: Steenkoolspruit at Middeldrift – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 3 (DWA gauge B1H021) for the period July 1990 to June 2008. (Solid line = seven-point moving average).

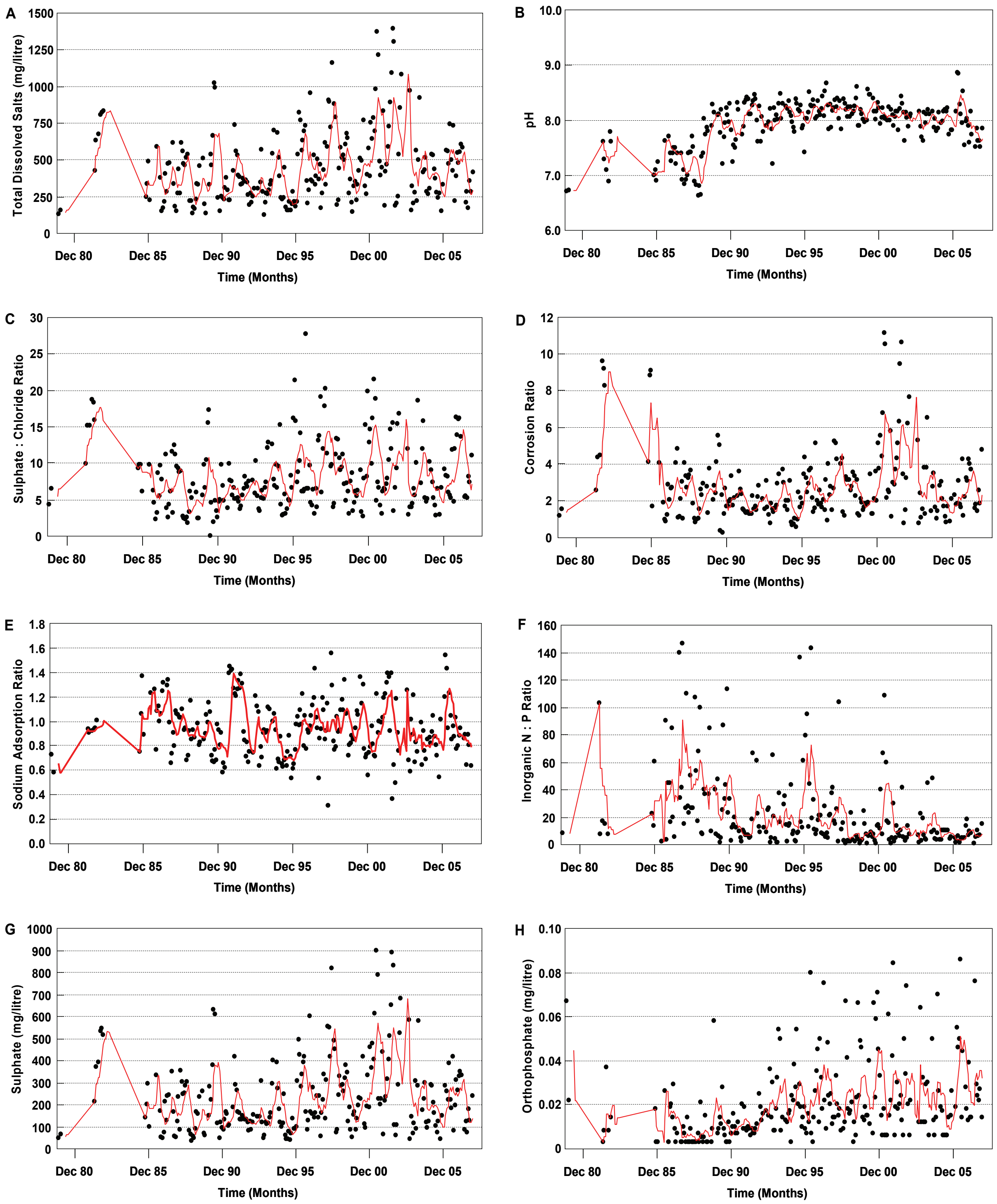

Figure A1 - 4A – H: Olifants River at Wolwekrans – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 4 (DWA gauge B1H005) for the period November 1979 to April 2008. (Solid line = seven-point moving average).

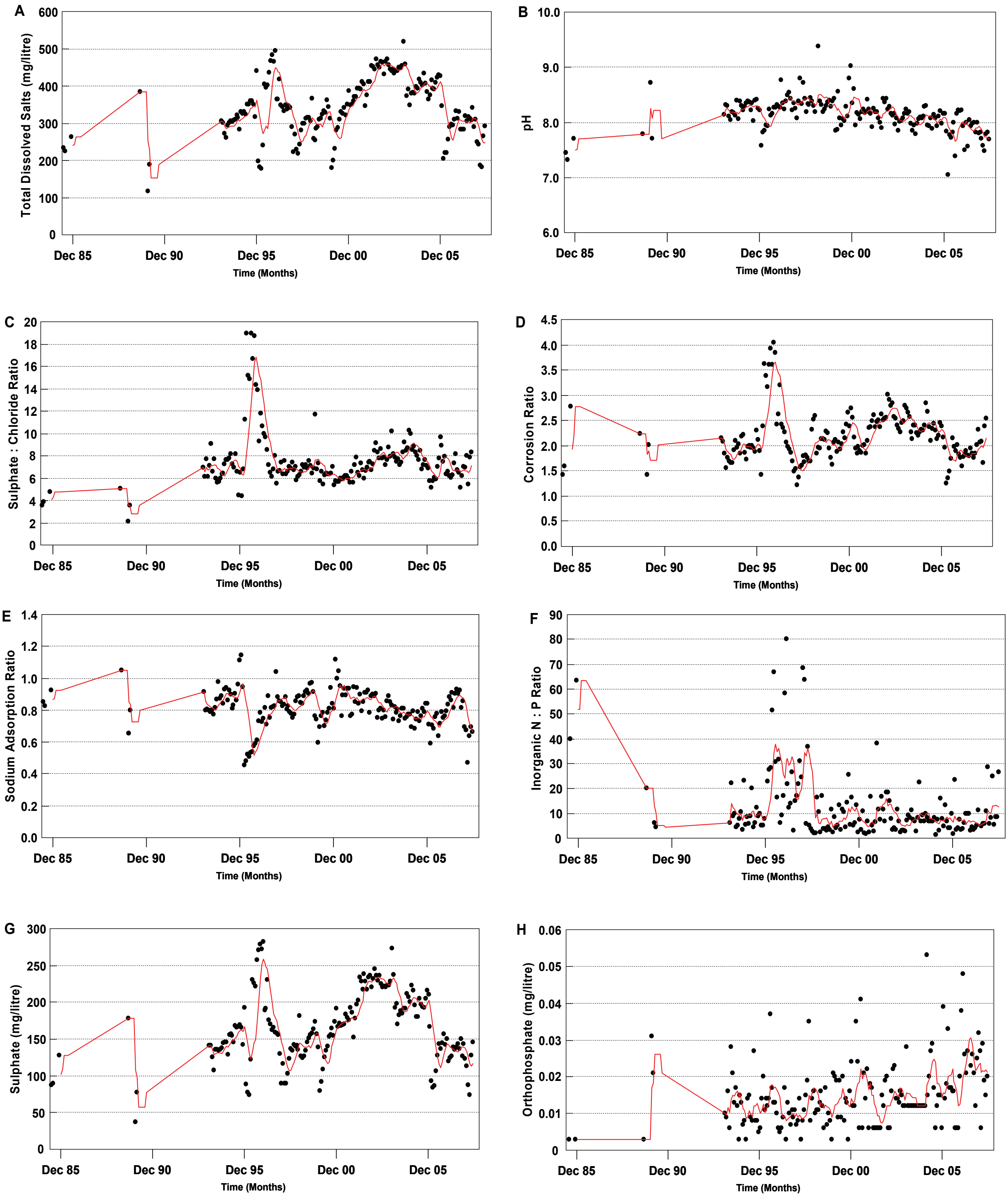

Figure A1 - 5A – H: Olifants River downstream of Witbank Dam – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 5 (DWA gauge B1H010) for the period June 1985 to May 2008. (Solid line = seven-point moving average).

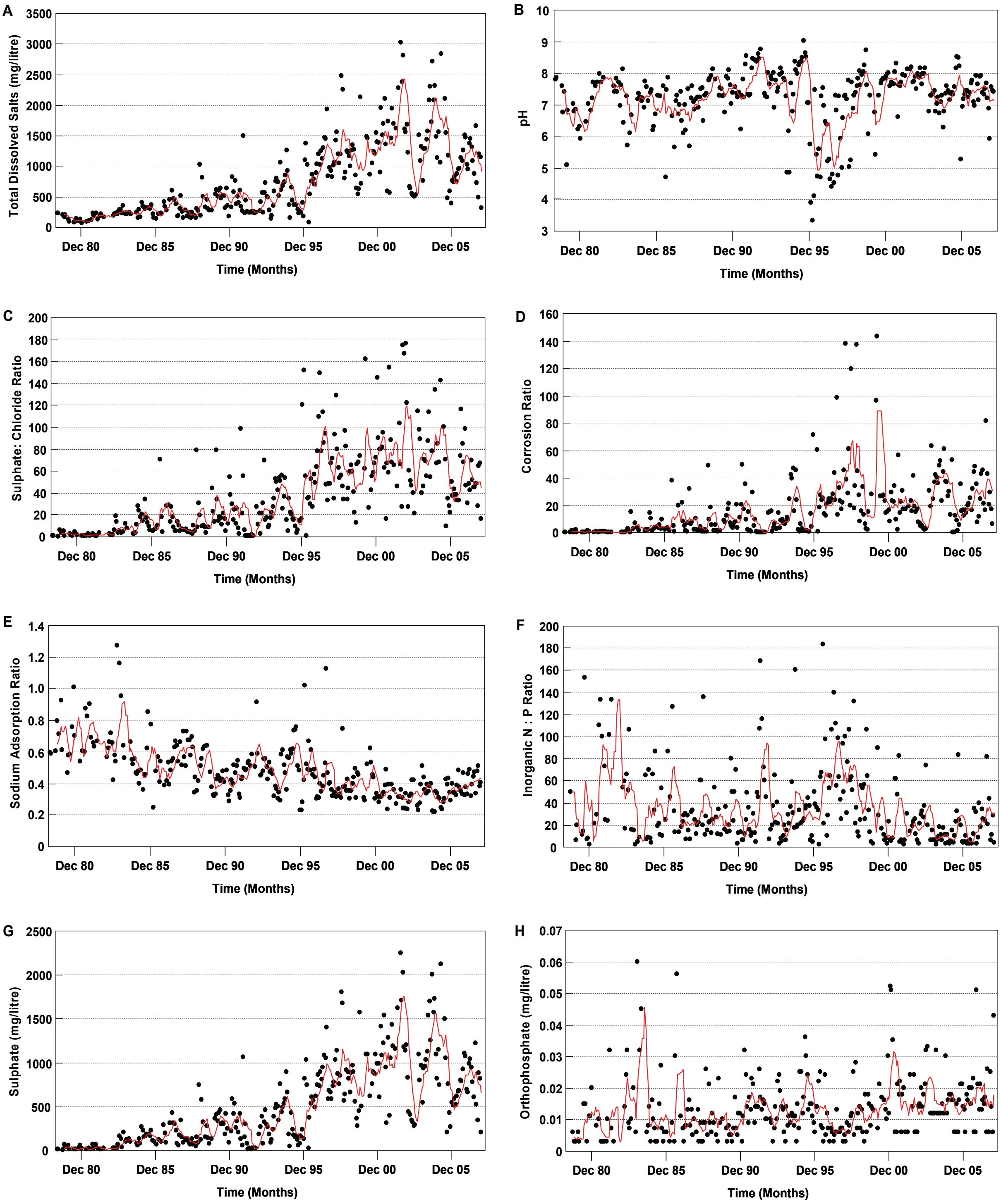

Figure A1 - 6A – H: Spookspruit at Elandspruit – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 6 (DWA gauge B1H002) for the period May 1979 to March 2008. (Solid line = seven-point moving average).

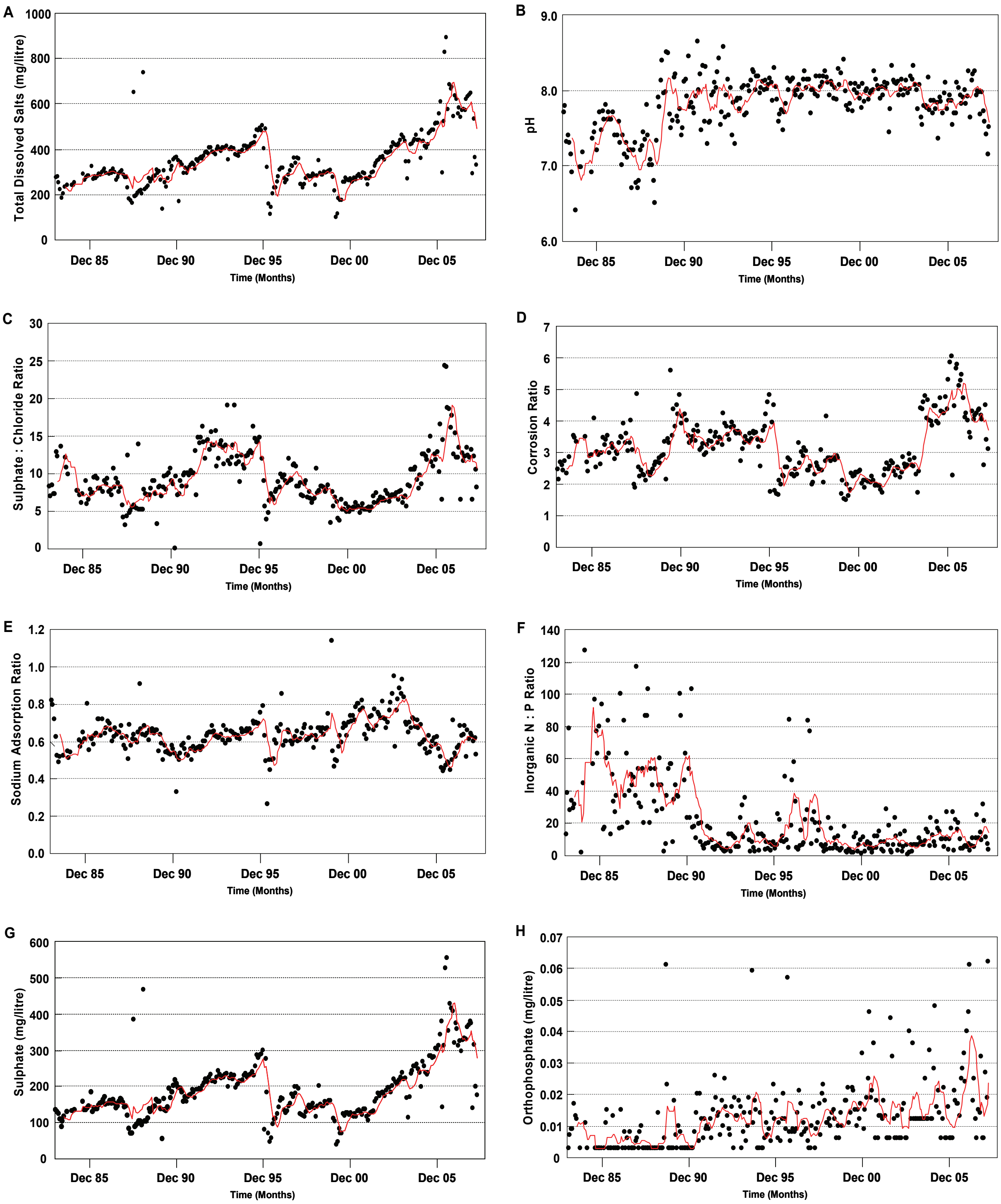

Figure A1 - 7A – H: Klein Olifants River downstream of Middelburg Dam – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 7 (DWA gauge B1H015) for the period February 1983 to March 2008. (Solid line = seven-point moving average).

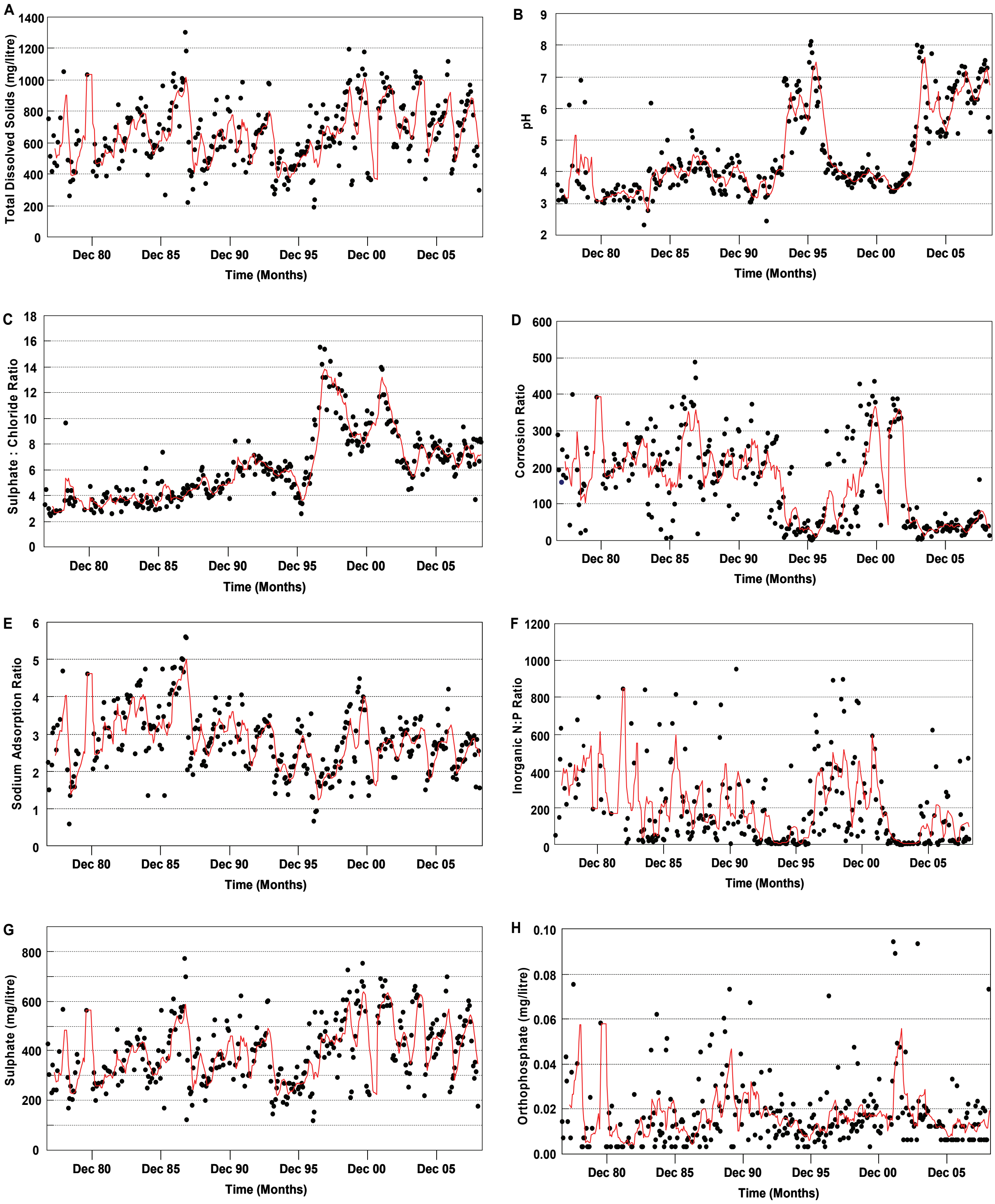

Figure A1 - 8A – H: Klipspruit at Zaaihoek – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 8 (DWA gauge B1H004) for the period September 1976 to March 2008. (Solid line = seven-point moving average).

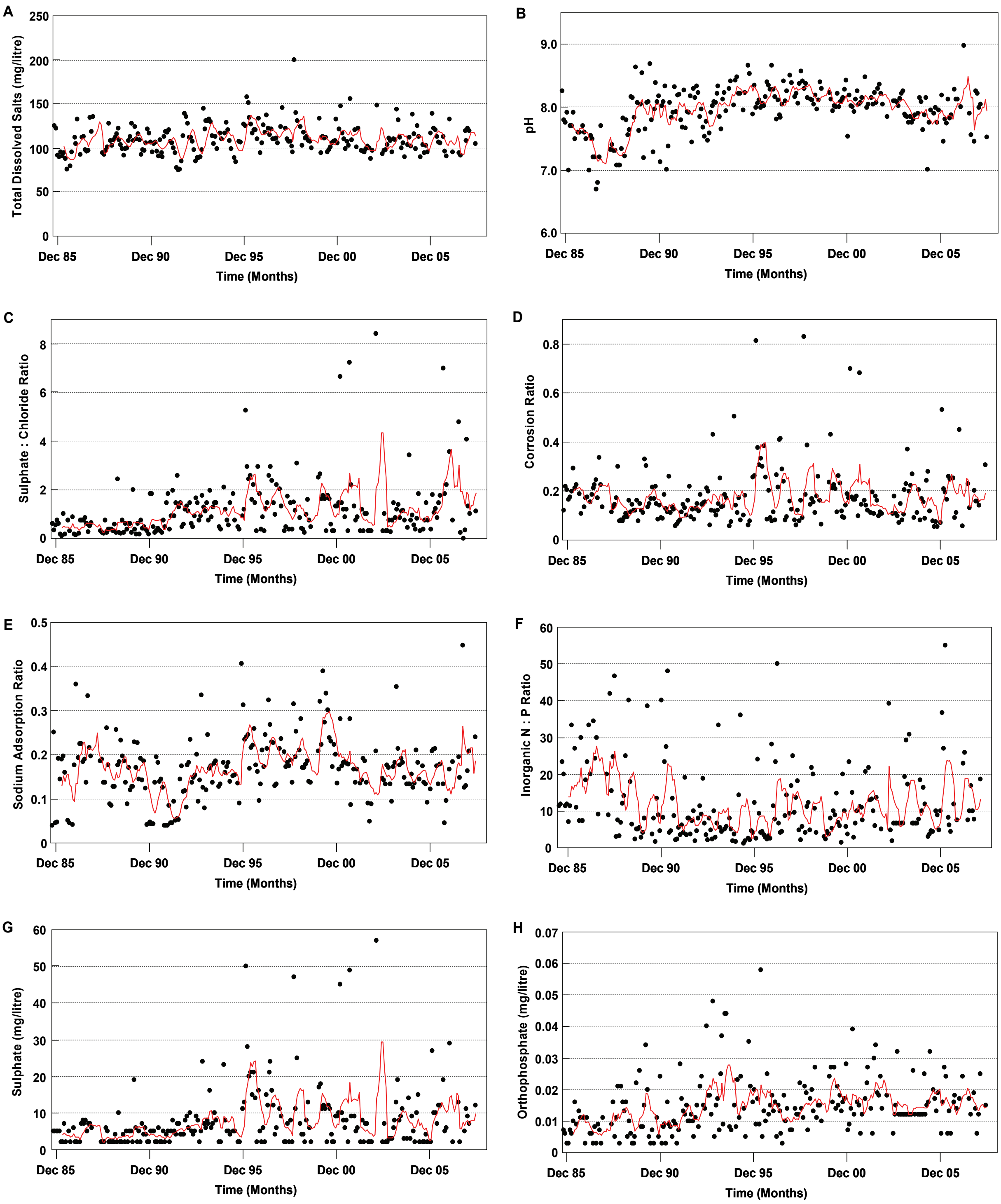

Figure A1 - 9A – H: Koffiespruit at Rietvallei – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 9 (DWA gauge B2H008) for the period October 1985 to June 2008. (Solid line = seven-point moving average).

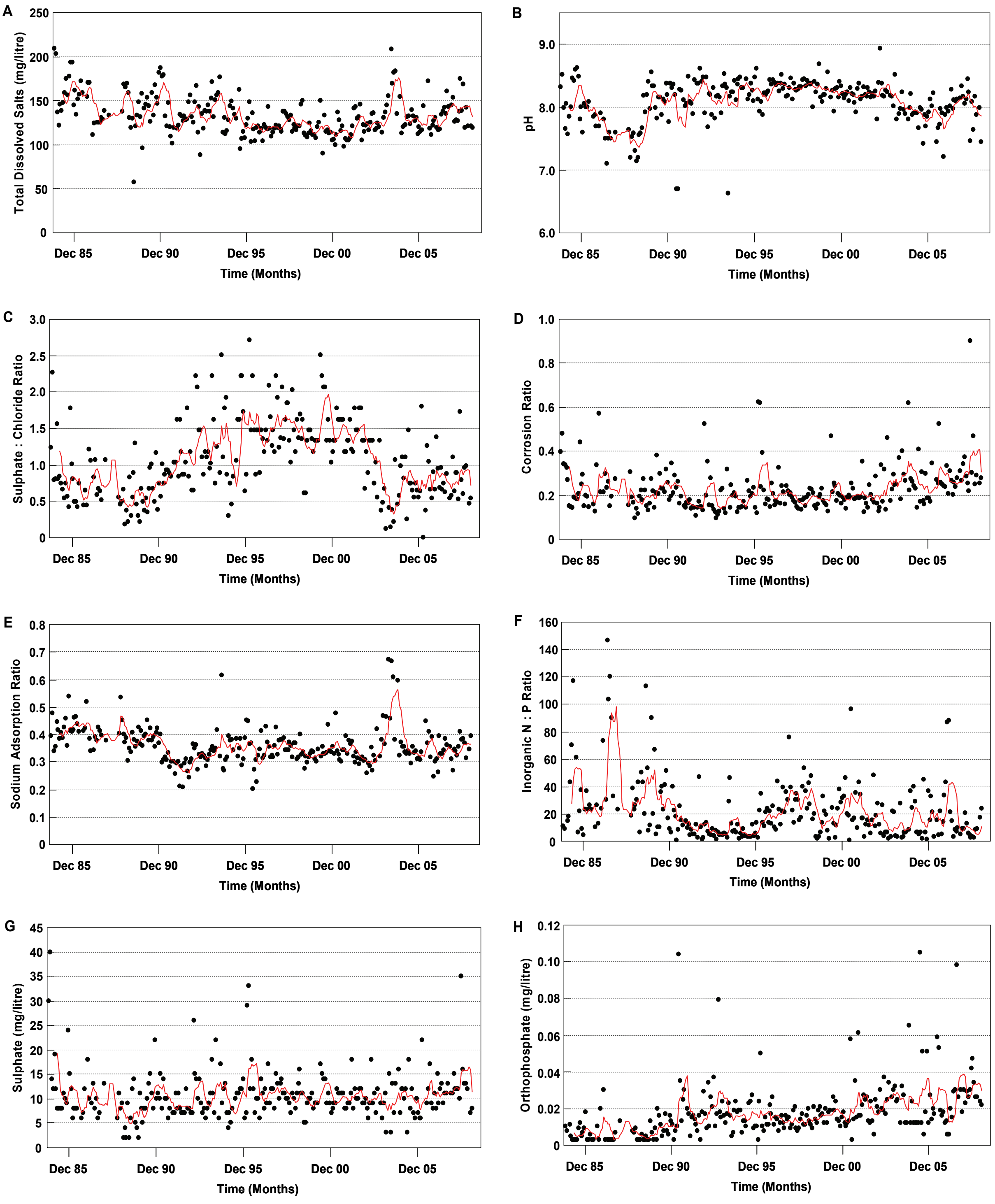

Figure A1 - 10A – H: Osspruit at Boschkop – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 10 (DWA gauge B2H004) for the period October 1984 to May 2008. (Solid line = seven-point moving average).

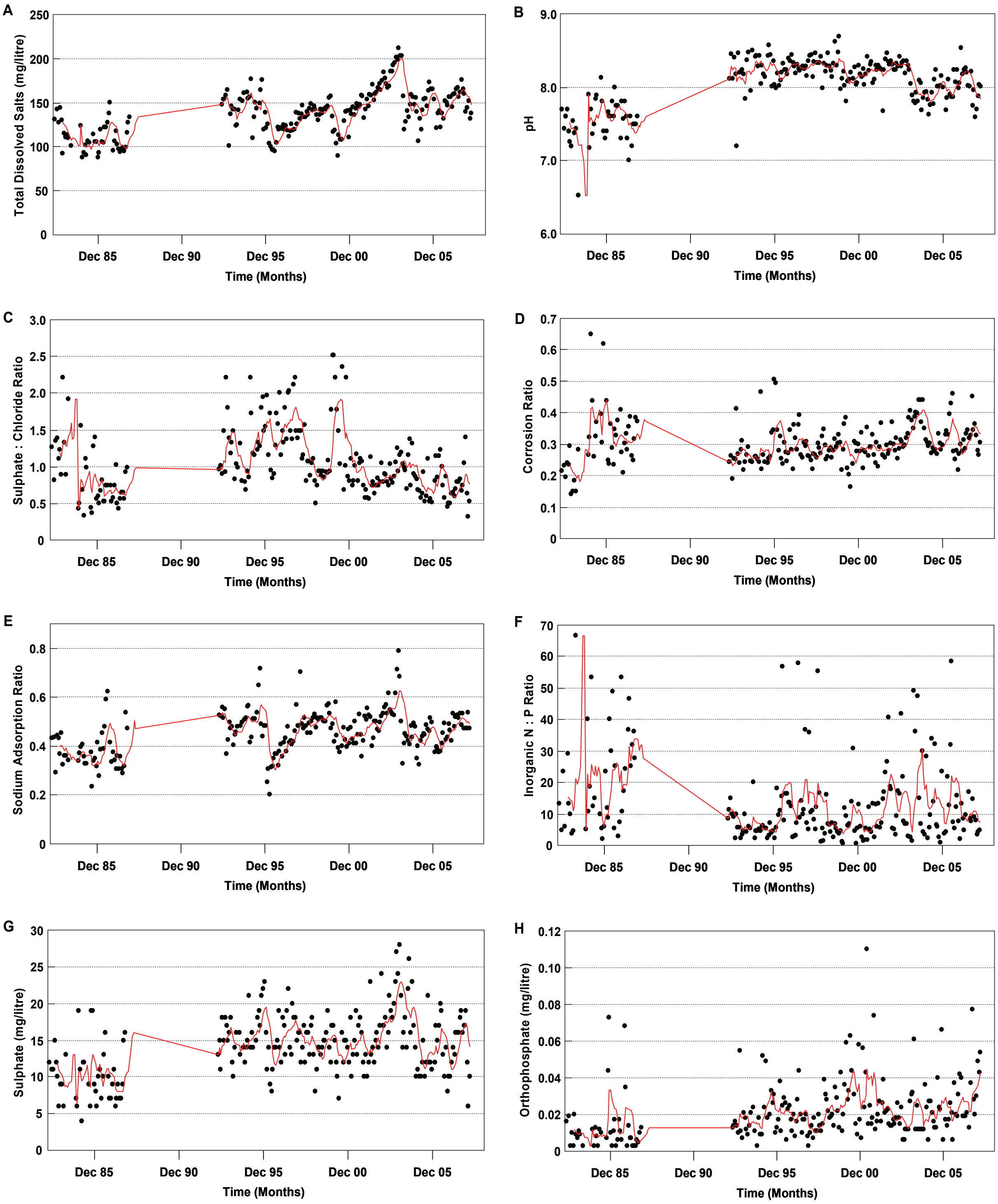

Figure A1 - 11A – H: Bronkhorstspruit River at Bronkhorstspruit – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 11 (DWA gauge B2H003) for the period May 1983 to April 2008. (Solid line = seven-point moving average).

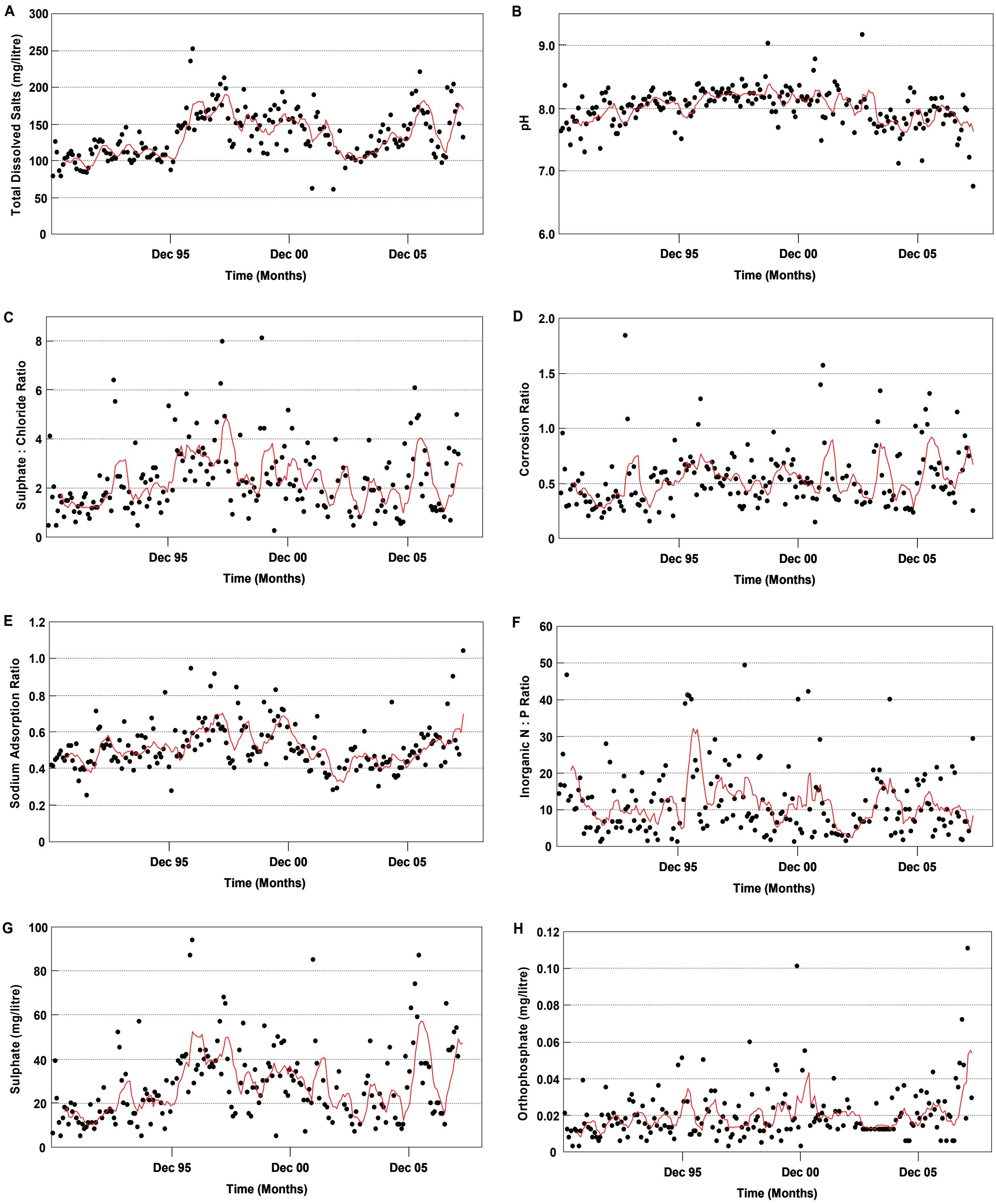

Figure A1 - 12A – H: Wilge River at Onverwacht – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 12 (DWA gauge B2H014) for the period January1991 to June 2008. (Solid line = seven-point moving average).

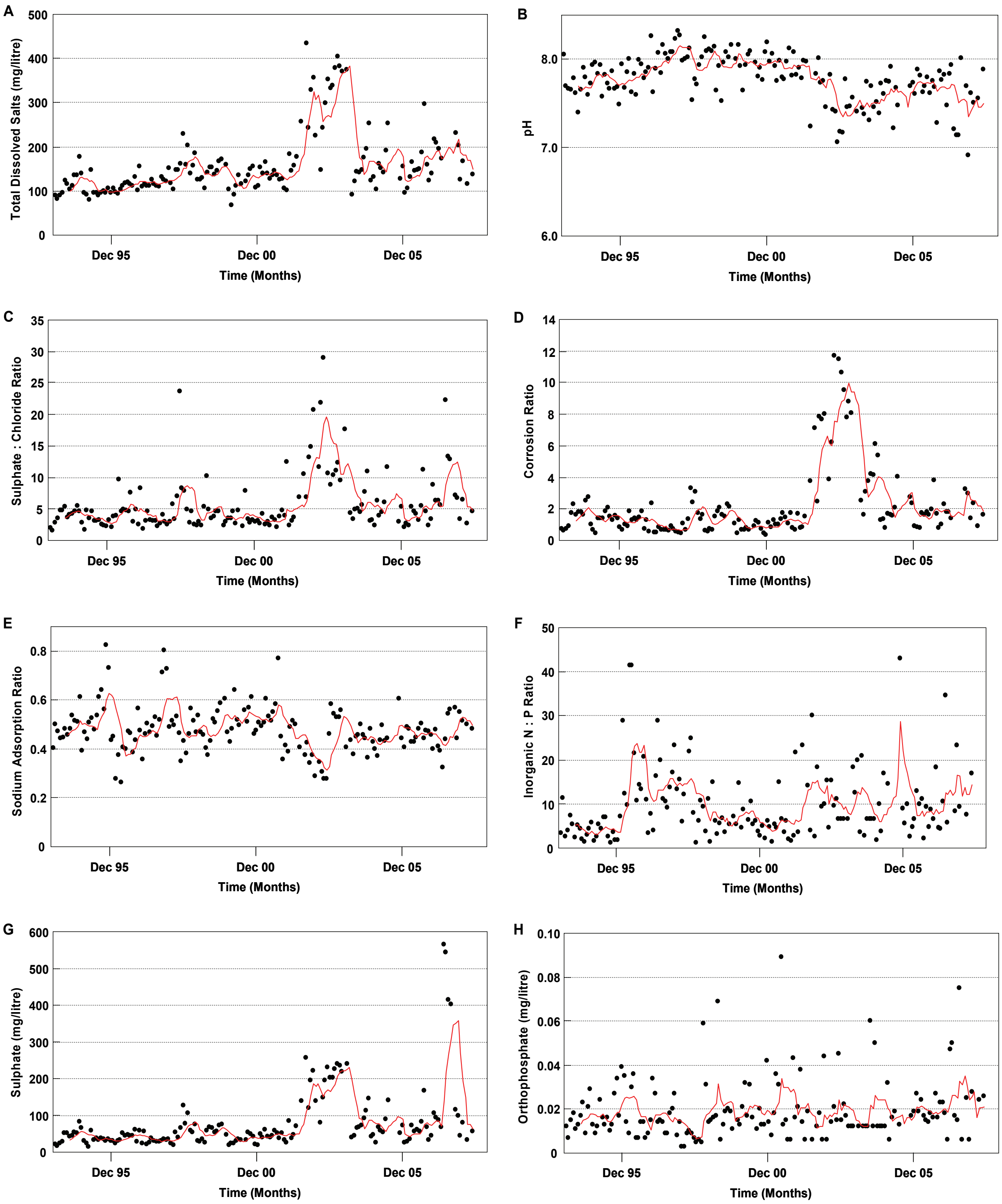

Figure A1 - 13A – H: Wilge River at Zusterstroom – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 13 (DWA gauge B2H015) for the period January 1994 to June 2008. (Solid line = seven-point moving average).

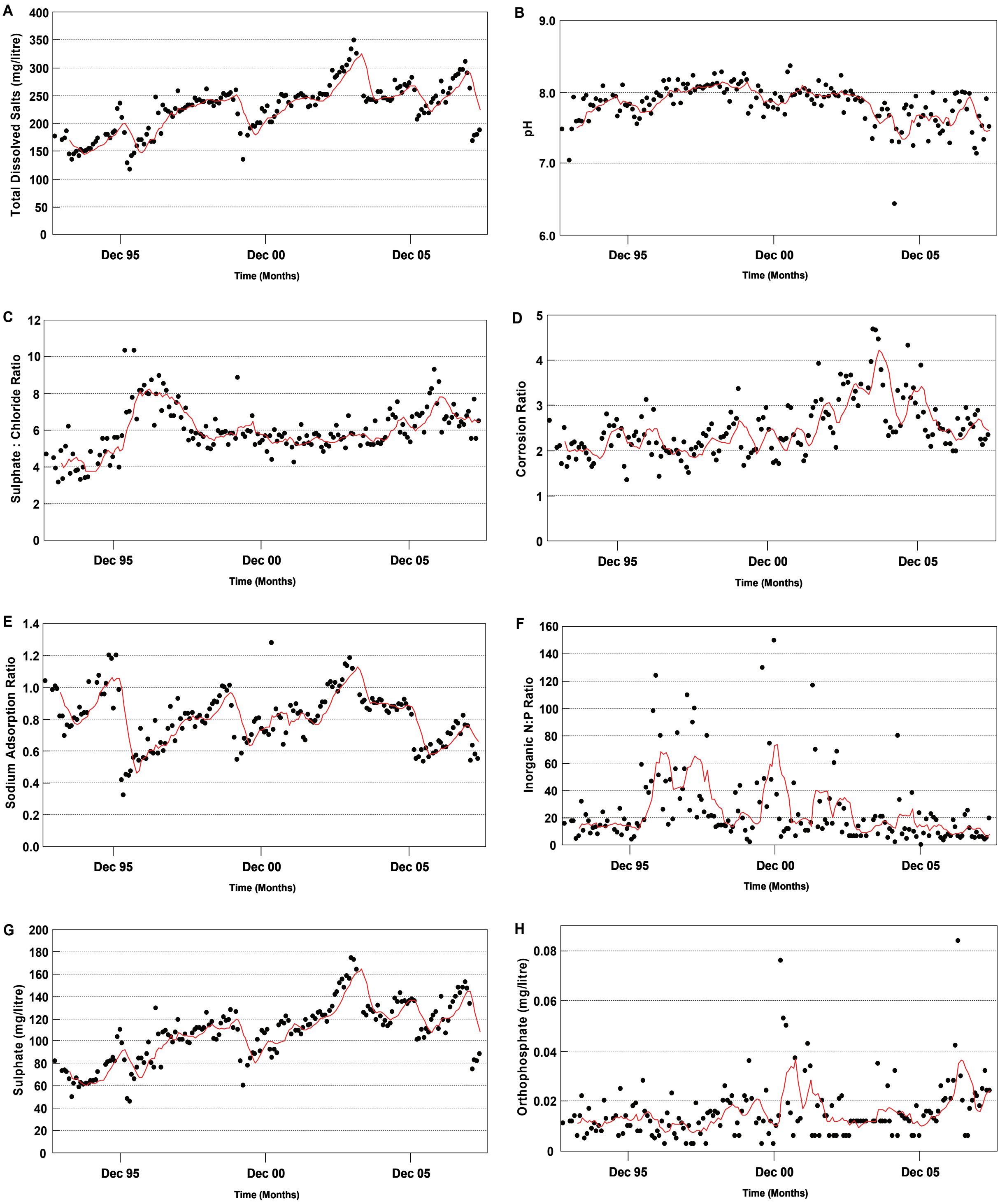

Figure A1 - 14A – H: Olifants River downstream of Loskop Dam – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 14 (DWA gauge B3H017) for the period September 1993 to May 2008. (Solid line = seven-point moving average).

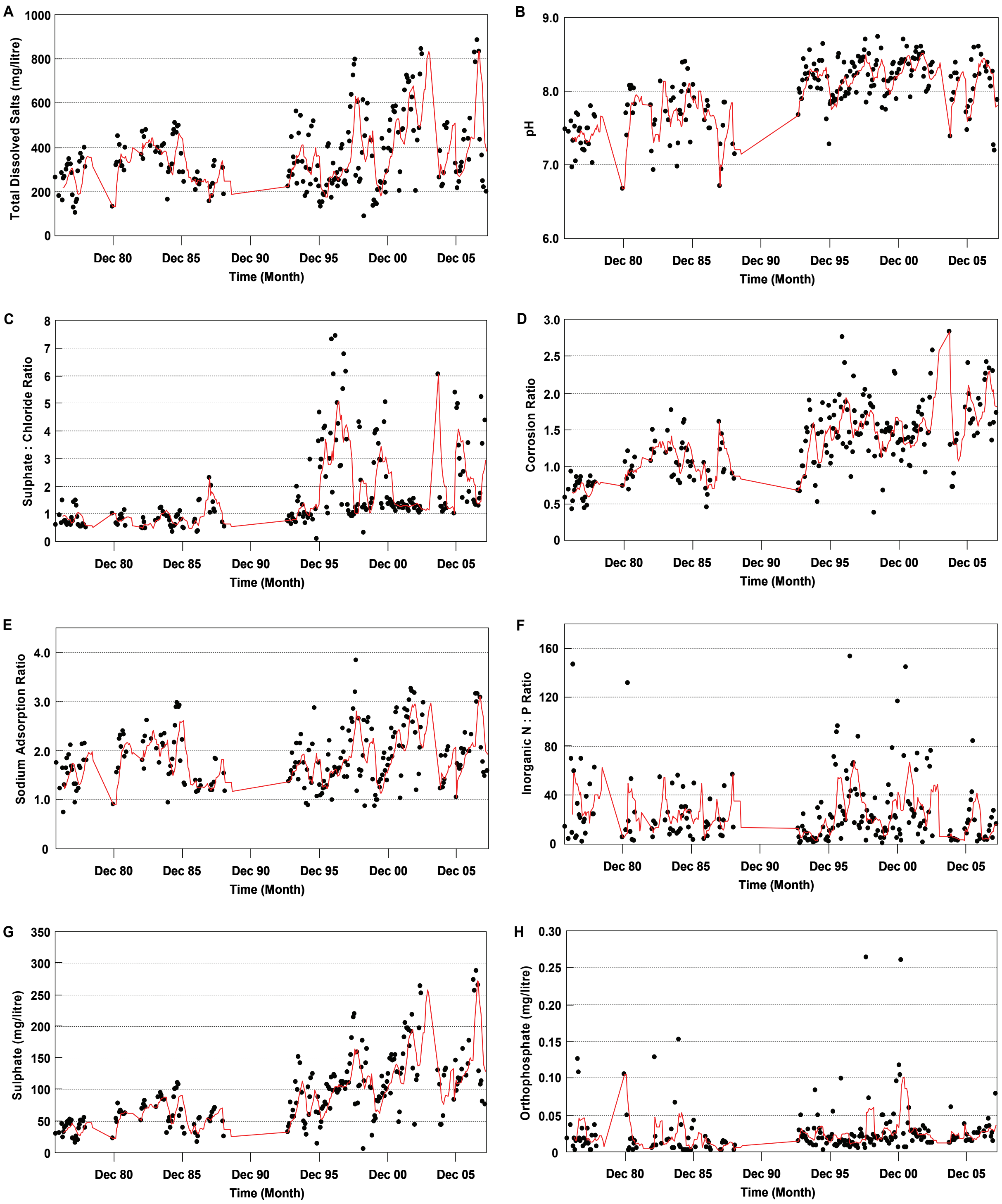

Figure A1 - 15A – H: Olifants River at Loskop North – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 15 (DWA gauge B3H001) for the period October 1976 to April 2008. (Solid line = seven-point moving average).

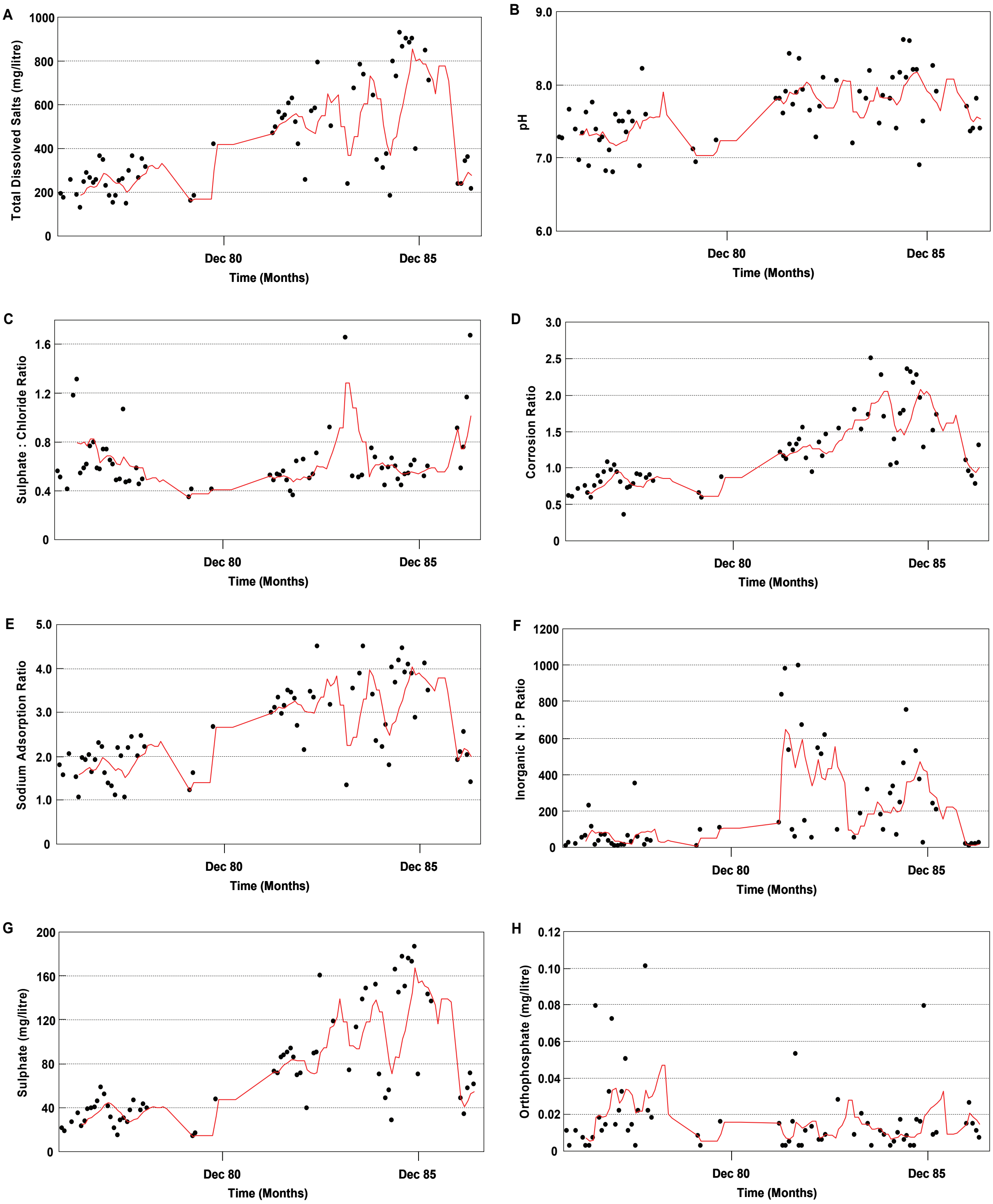

Figure A1 - 16A – H: Moses River at Mosesriviermond – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 16 (DWA gauge B3H005) for the period October 1976 to April 1987. (Solid line = seven-point moving average).

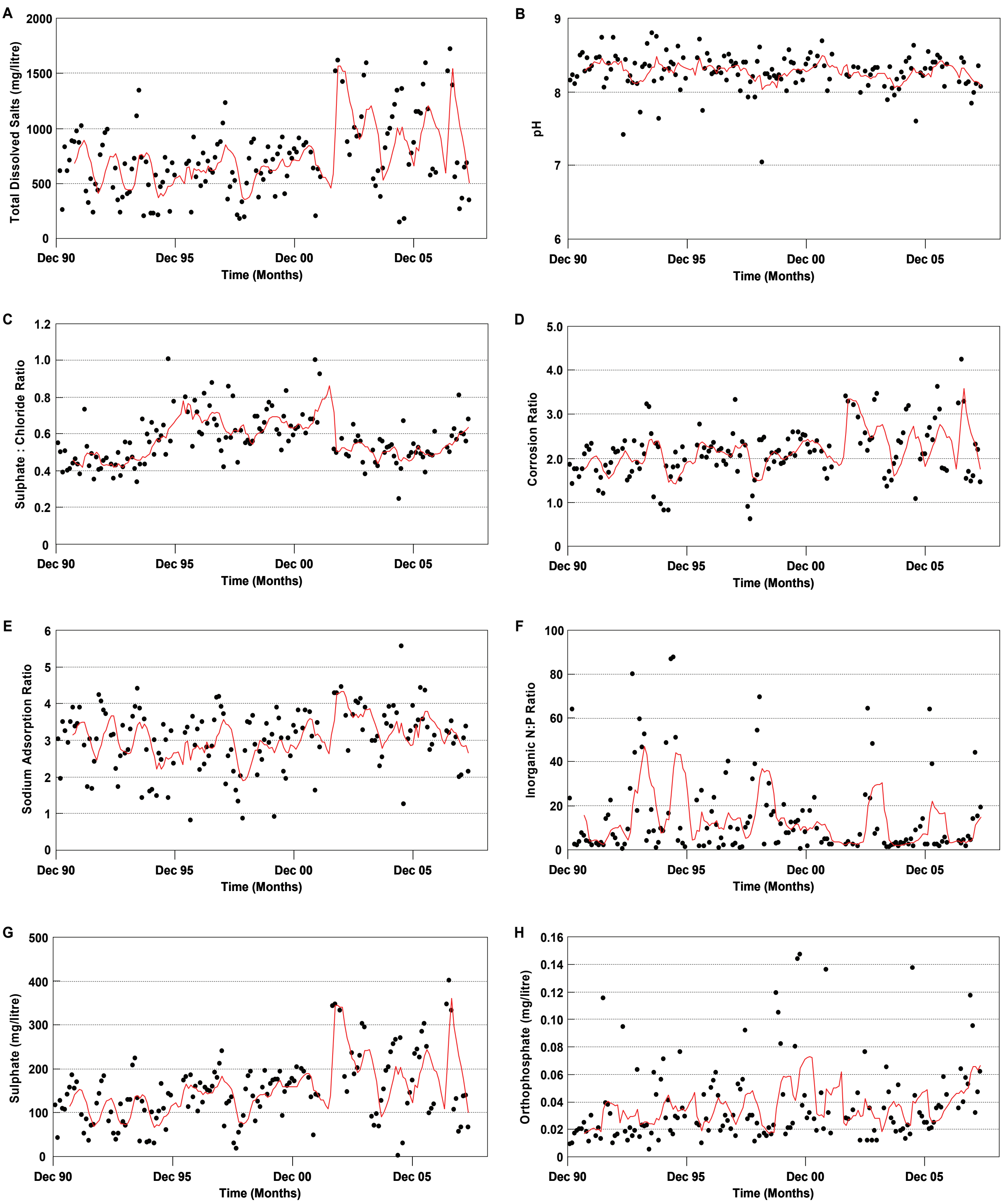

Figure A1 - 17A – H: Elands River at Scherp Arabie – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 17 (DWA gauge B3H021) for the period January 1994 to April 2008. (Solid line = seven-point moving average).

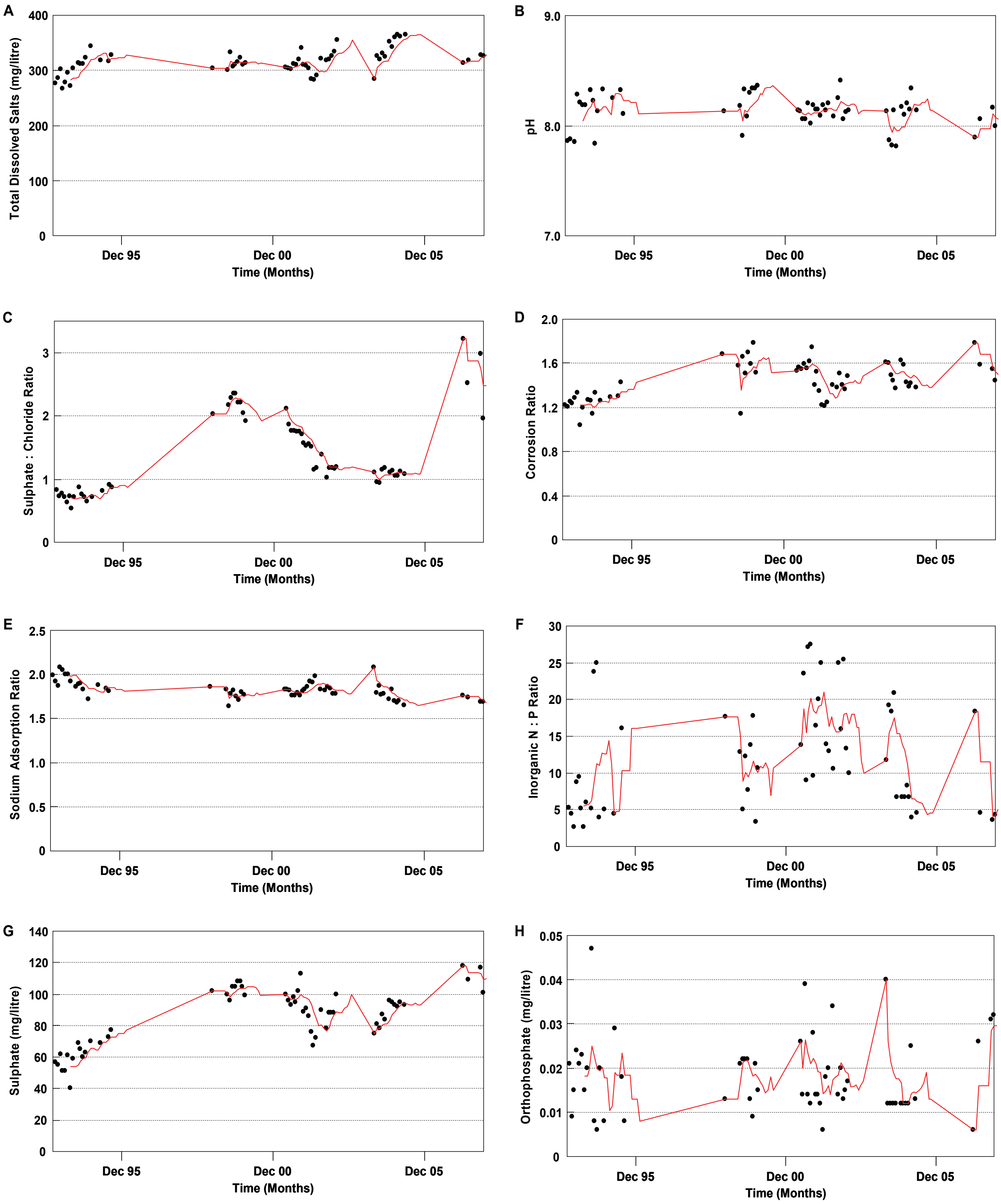

Figure A1 - 18A – H: Olifants River downstream of Flag Boshielo Dam – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 18 (DWA gauge B5H004) for the period September 1993 to December 2007. (Solid line = seven-point moving average).

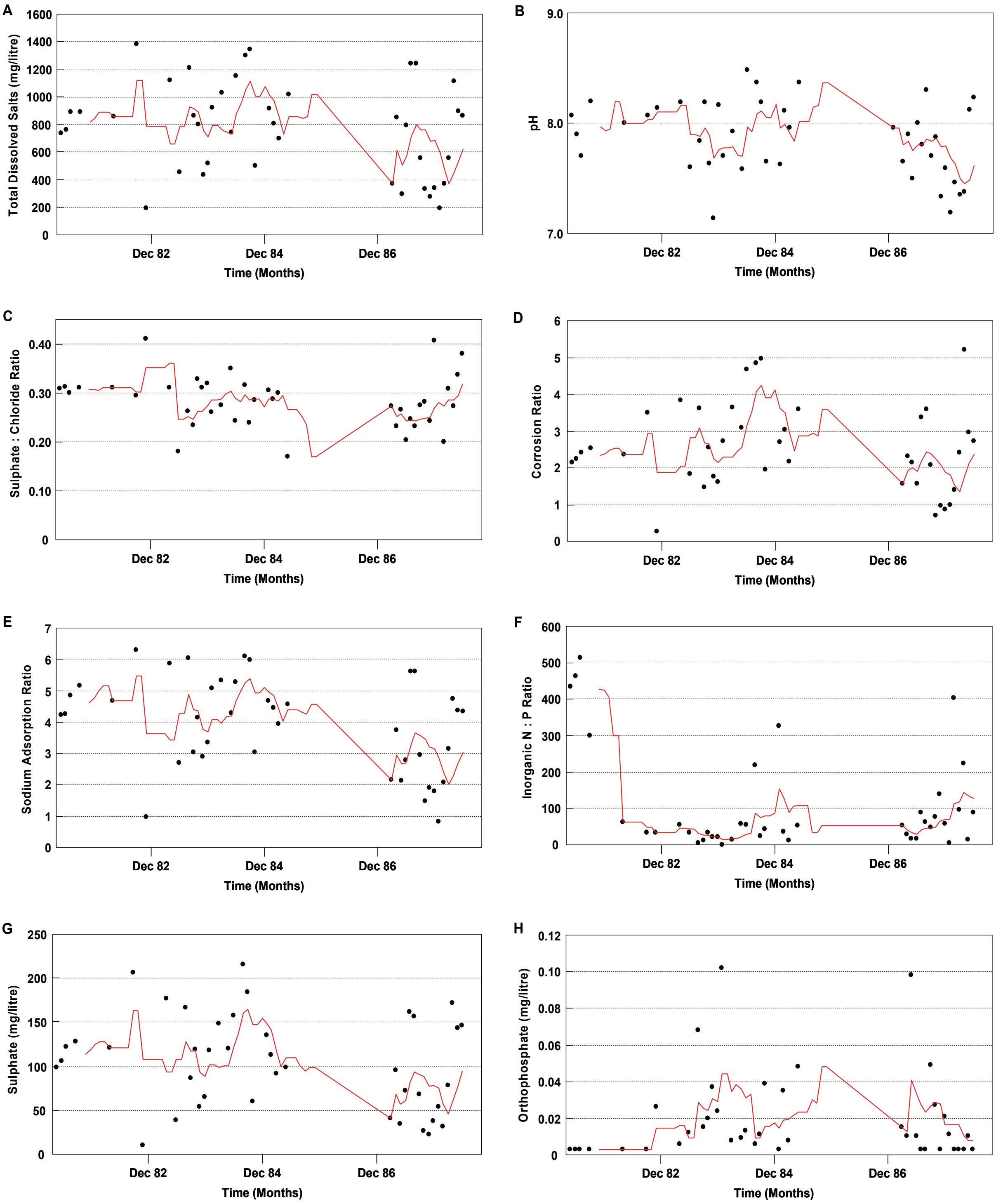

Figure A1 - 19A – H: Olifants River at Zeekoegat – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 19 (DWA gauge B5H002) for the period May 1981 to June 1988. (Solid line = seven-point moving average).

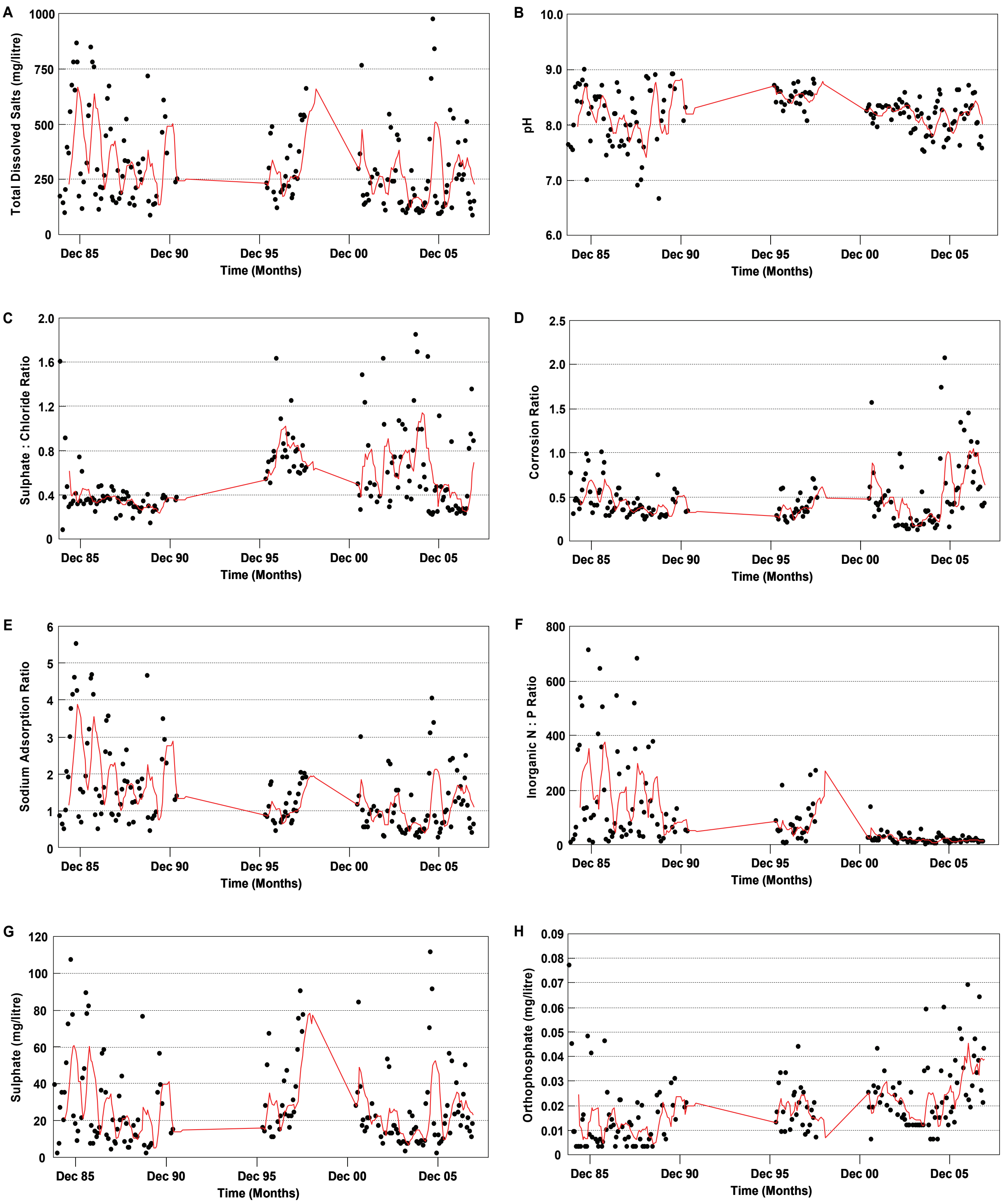

Figure A1 - 20A – H: Steelpoort River at Alverton – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 20 (DWA gauge B4H011) for the period November 1984 to February 2008. (Solid line = seven-point moving average).

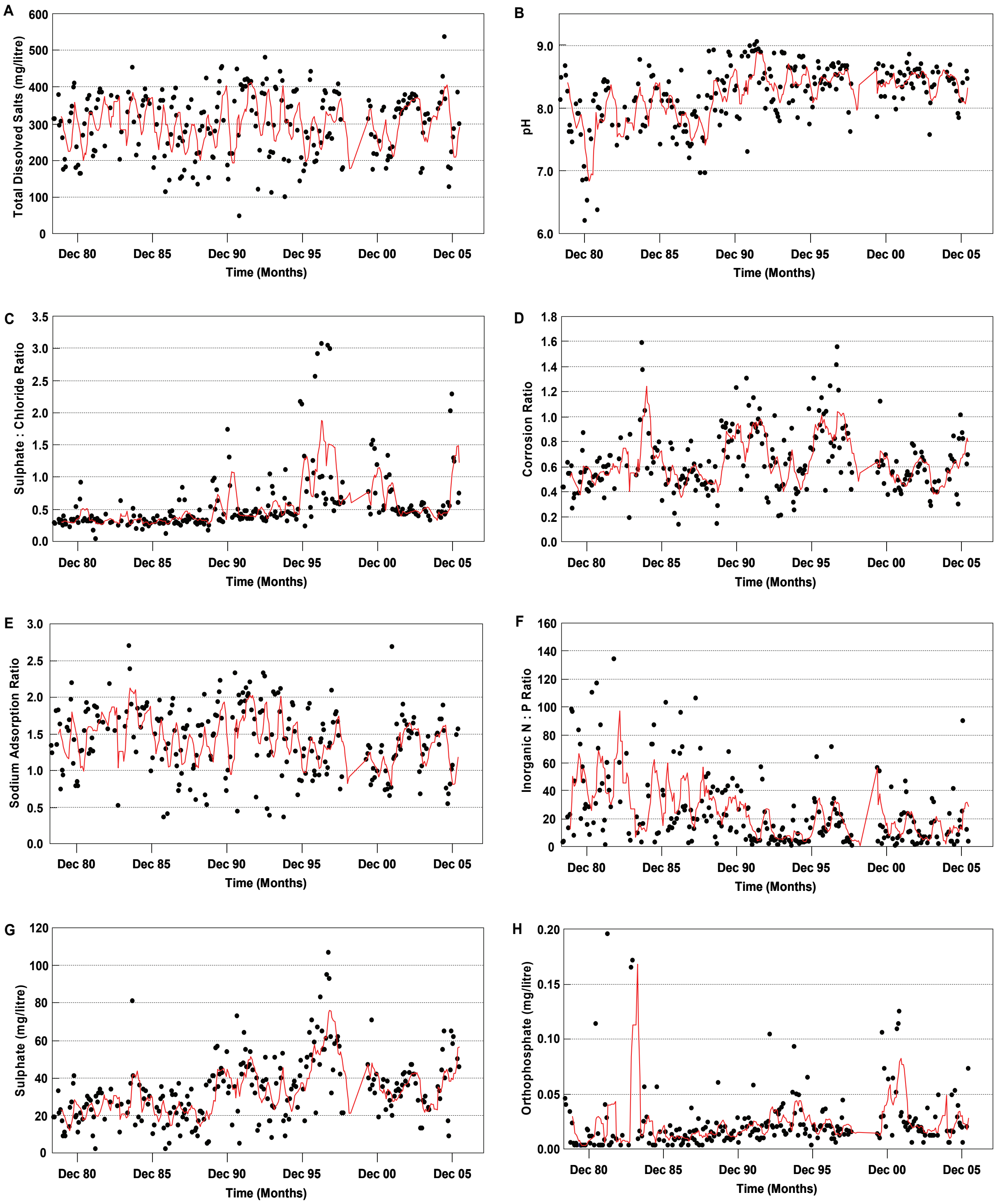

Figure A1 - 21A – H: Olifants River at Finale Liverpool – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 21 (DWA gauge B7H009) for the period May 1979 to October 2007. (Solid line = seven-point moving average).

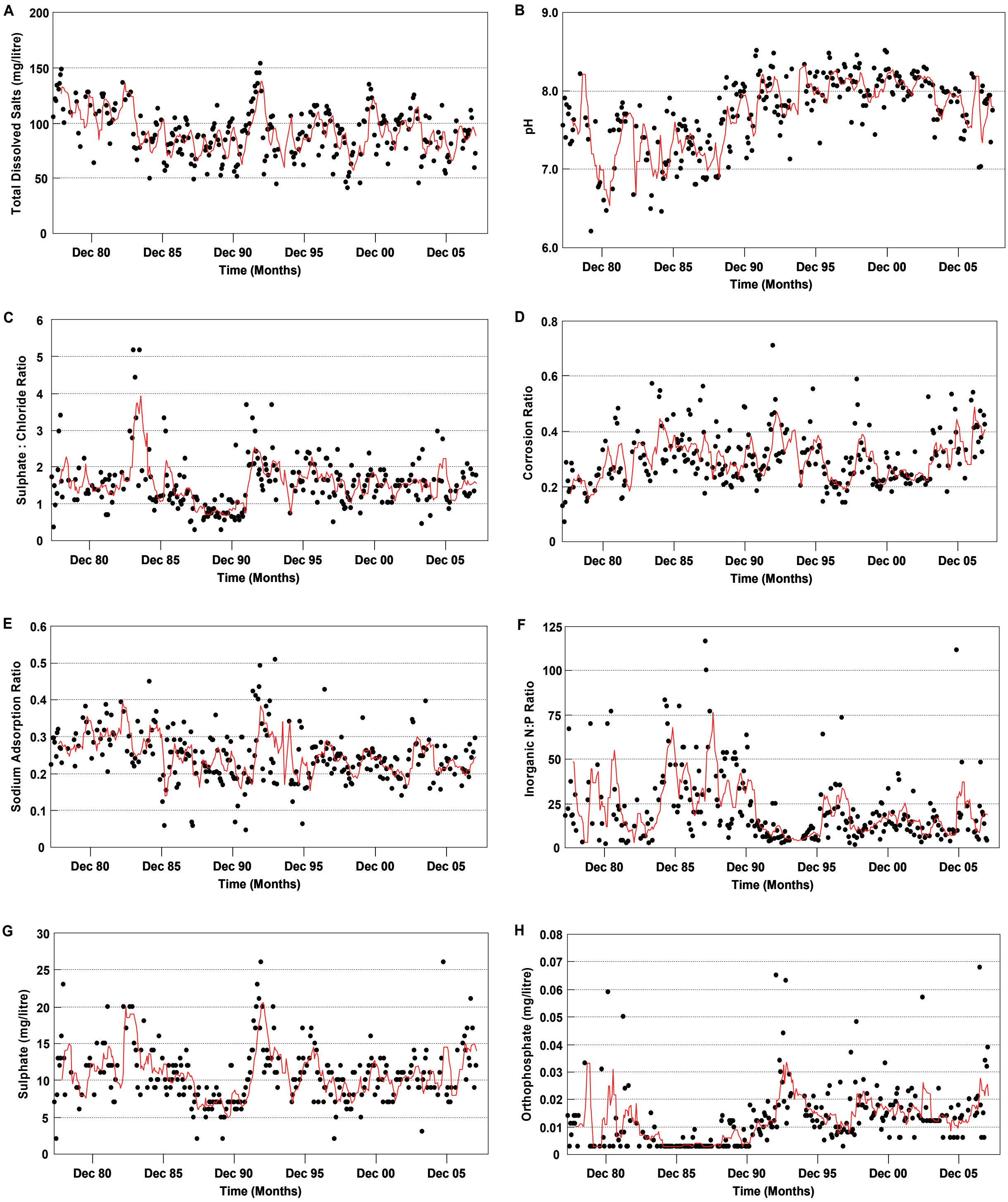

Figure A1 - 22A – H: Blyde River at Chester – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 22 (DWA gauge B6H004) for the period April 1978 to March 2008. (Solid line = seven-point moving average).

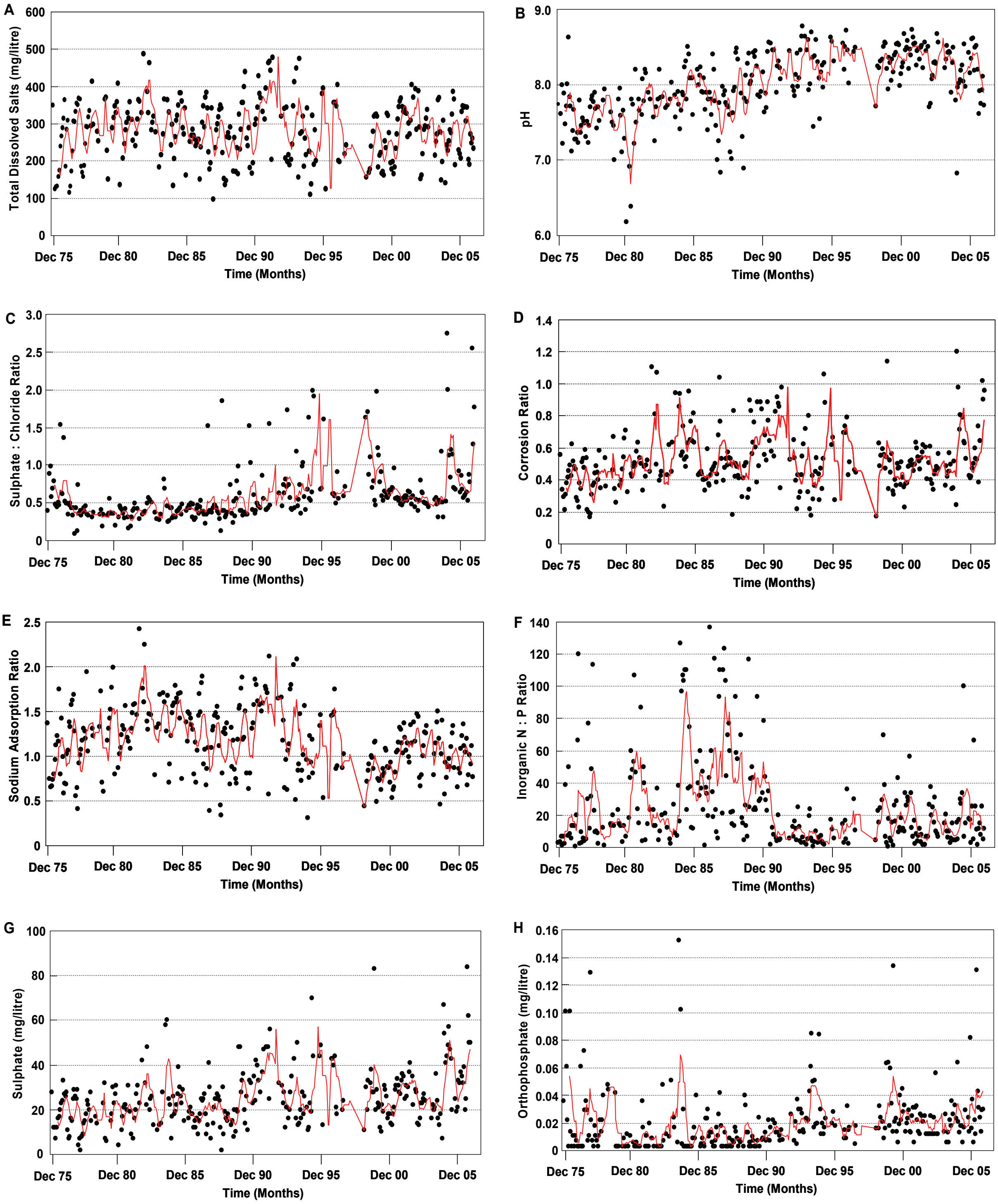

Figure A1 - 23A – H: Olifants River at Oxford – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 23 (DWA gauge B7H007) for the period November 1975 to September 2008. (Solid line = seven-point moving average).

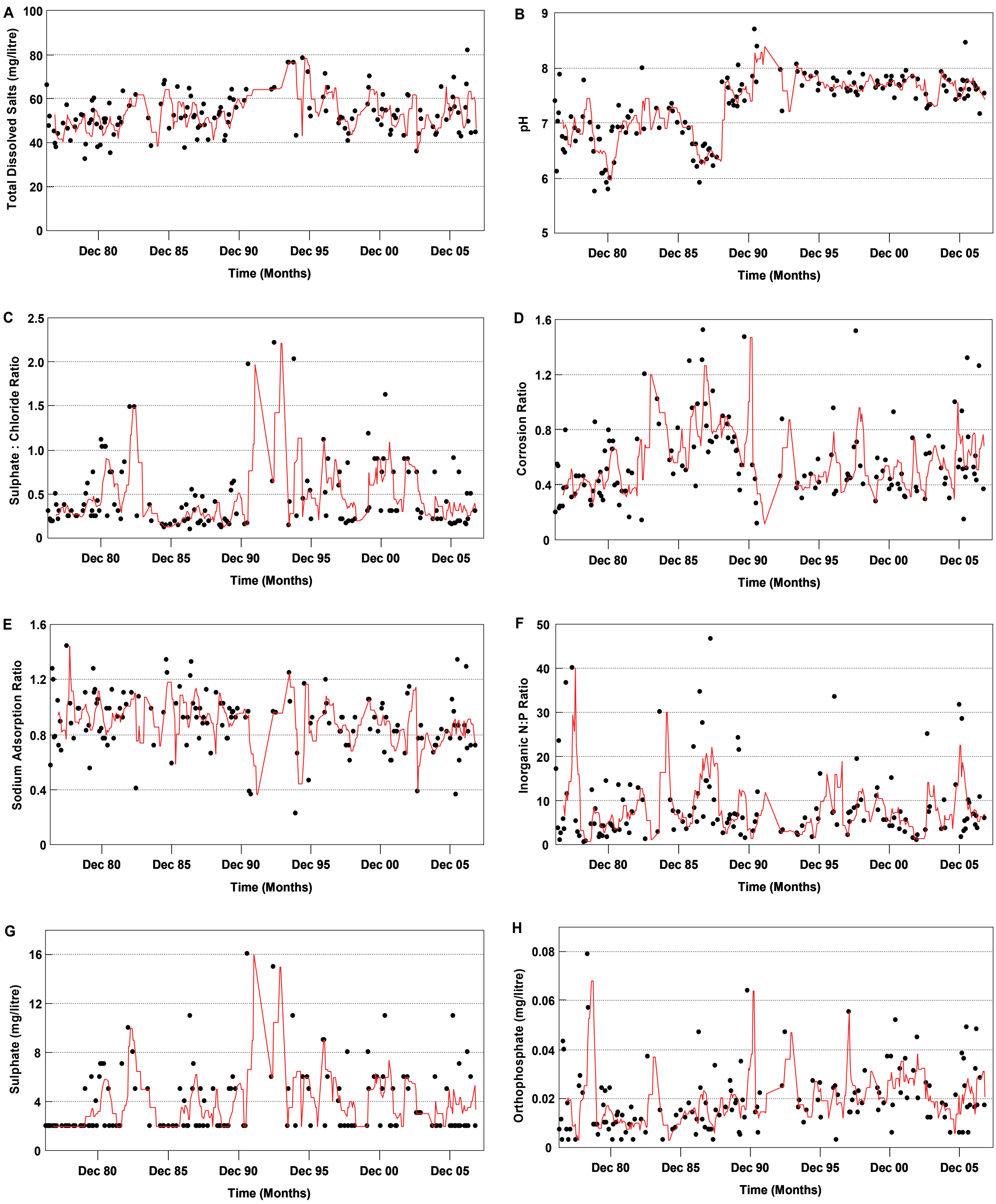

Figure A1 - 24A – H: Klaserie River at Fleur-de-Lys – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 24 (DWA gauge B7H004) for the period May 1977 to May 2008. (Solid line = seven-point moving average).

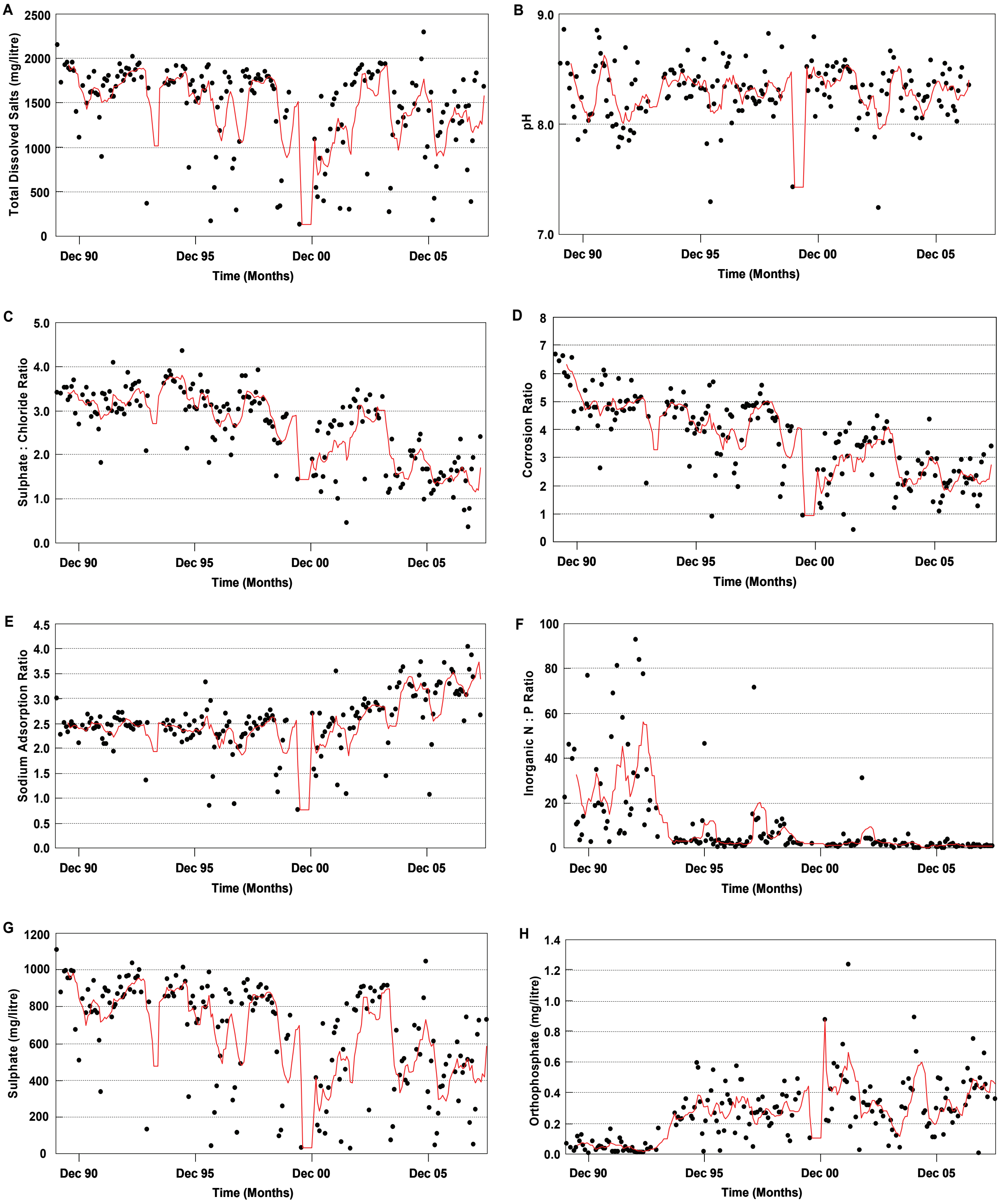

Figure A1 - 25A – H: Ga-Selati River at Loole – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 25 (DWA gauge B7H019) for the period January 1989 to July 2008. (Solid line = seven-point moving average).

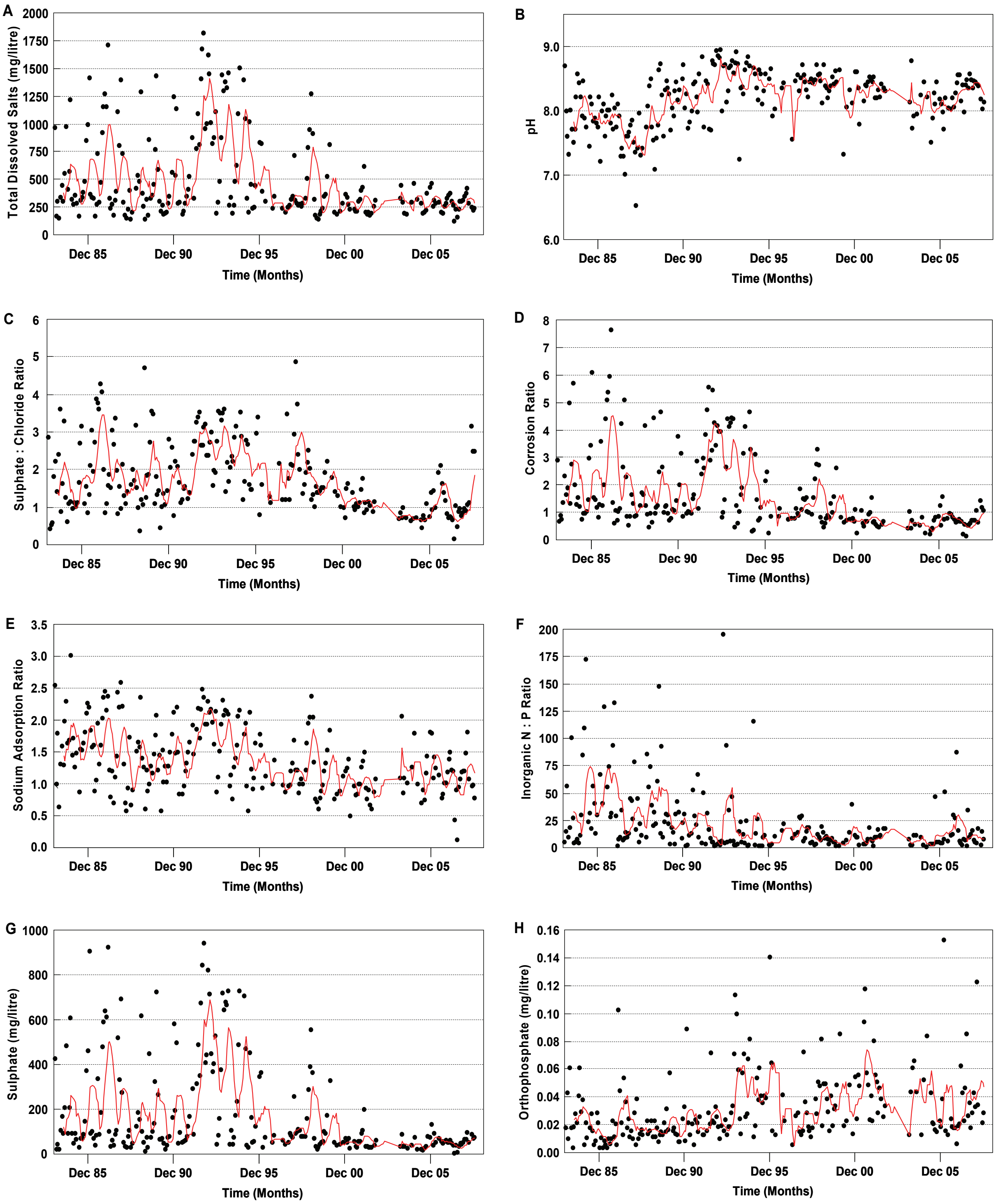

Figure A1 - 26A – H: Olifants River at Mamba – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 26 (DWA gauge B7H015) for the period October 1983 to March 2008. (Solid line = seven-point moving average).

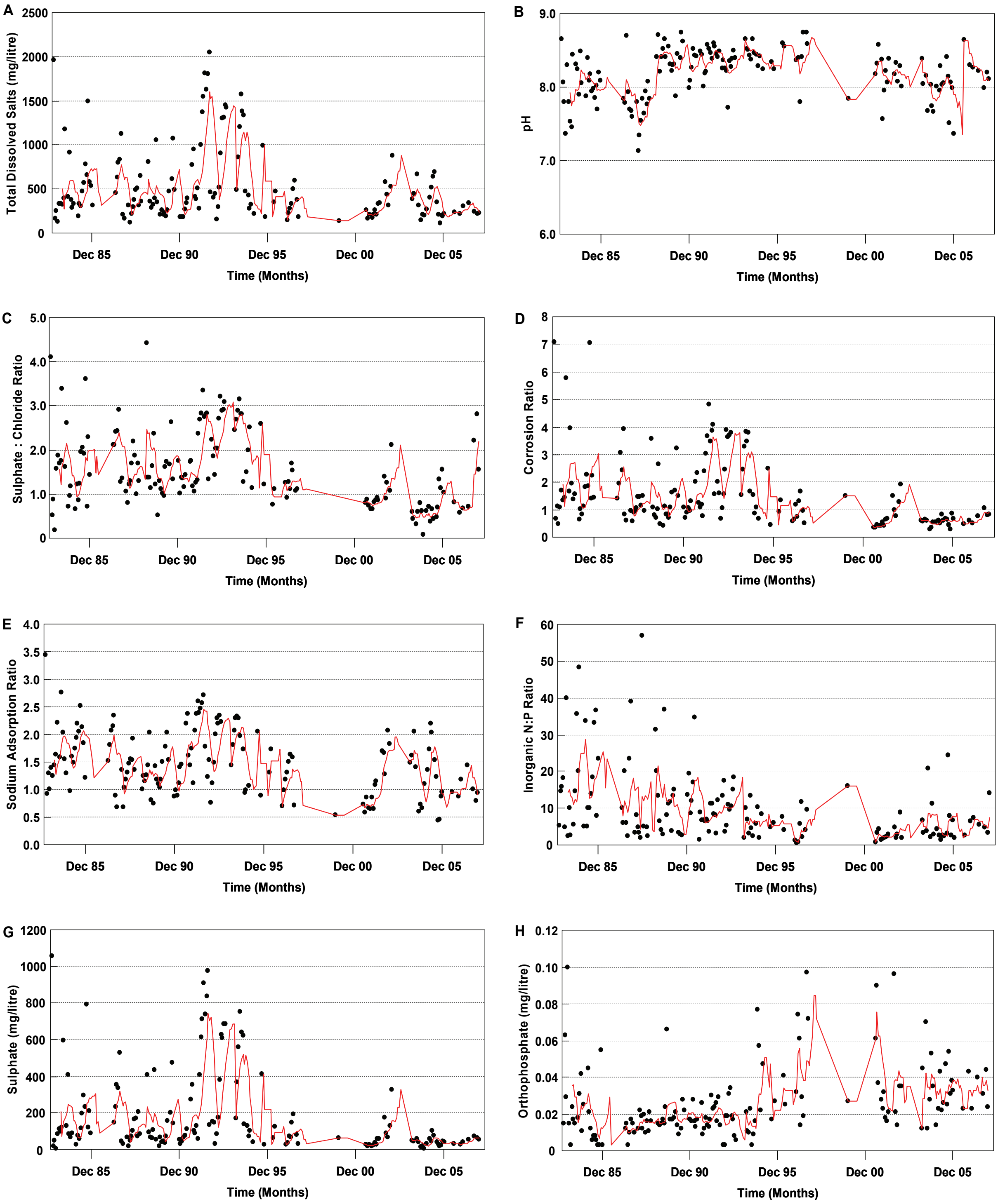

Figure A1 - 27A – H: Olifants River at Balule Rest Camp, KNP – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at Site 27 (DWA gauge B7H017) for the period October 1983 to May 2008. (Solid line = seven-point moving average).

Appendix 2

Monthly Time Series Plots of Eight Water Quality Characteristics at Ten Department of Water Affairs (DWA) Reservoir Sampling Sites in the Olifants River Catchment

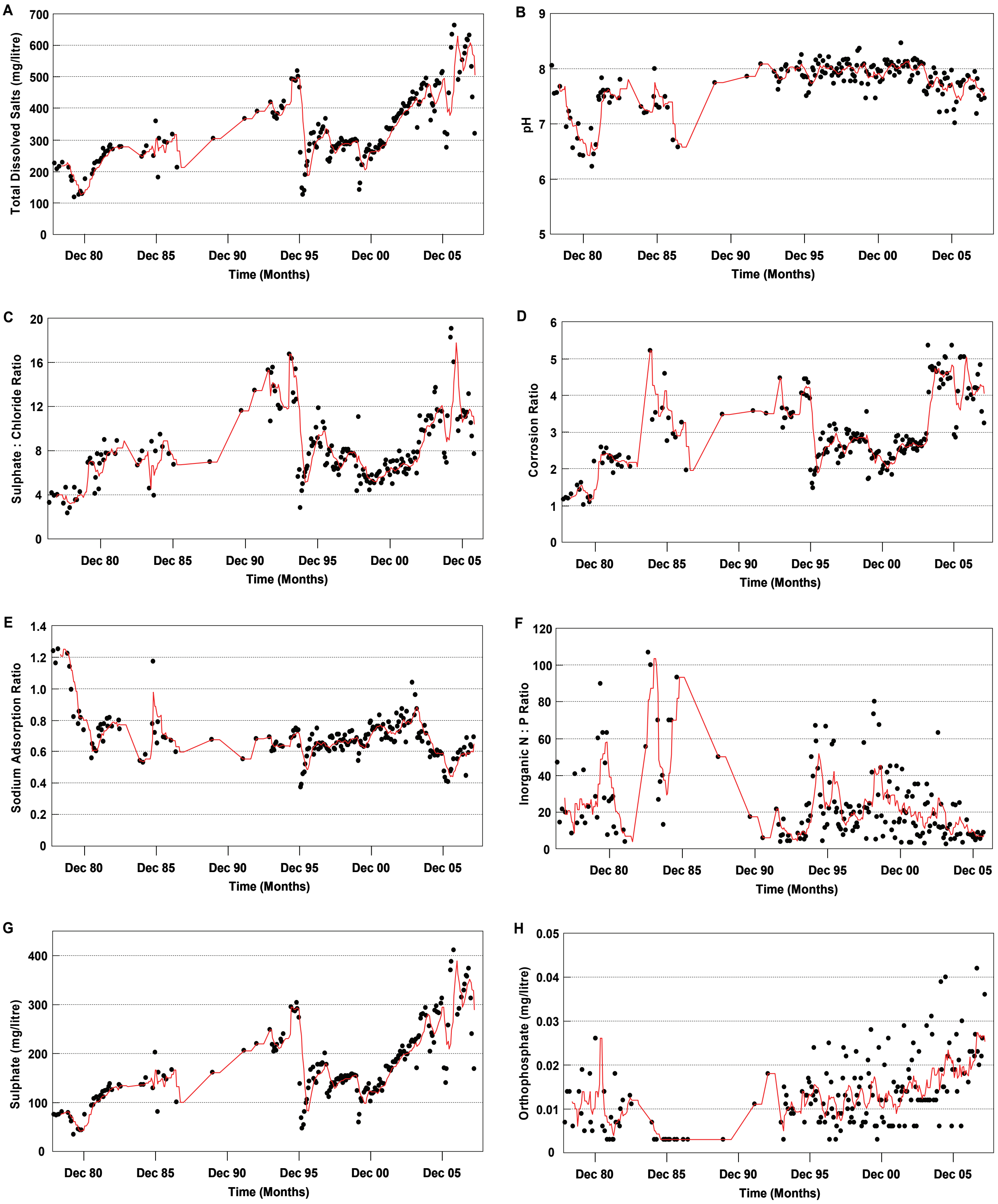

Figure A2 - R1A – H: Middelburg Dam on the Klein Olifants River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R1: DWA gauge B1R002 for the period November 1978 to March 2008. (Solid line = seven-point moving average).

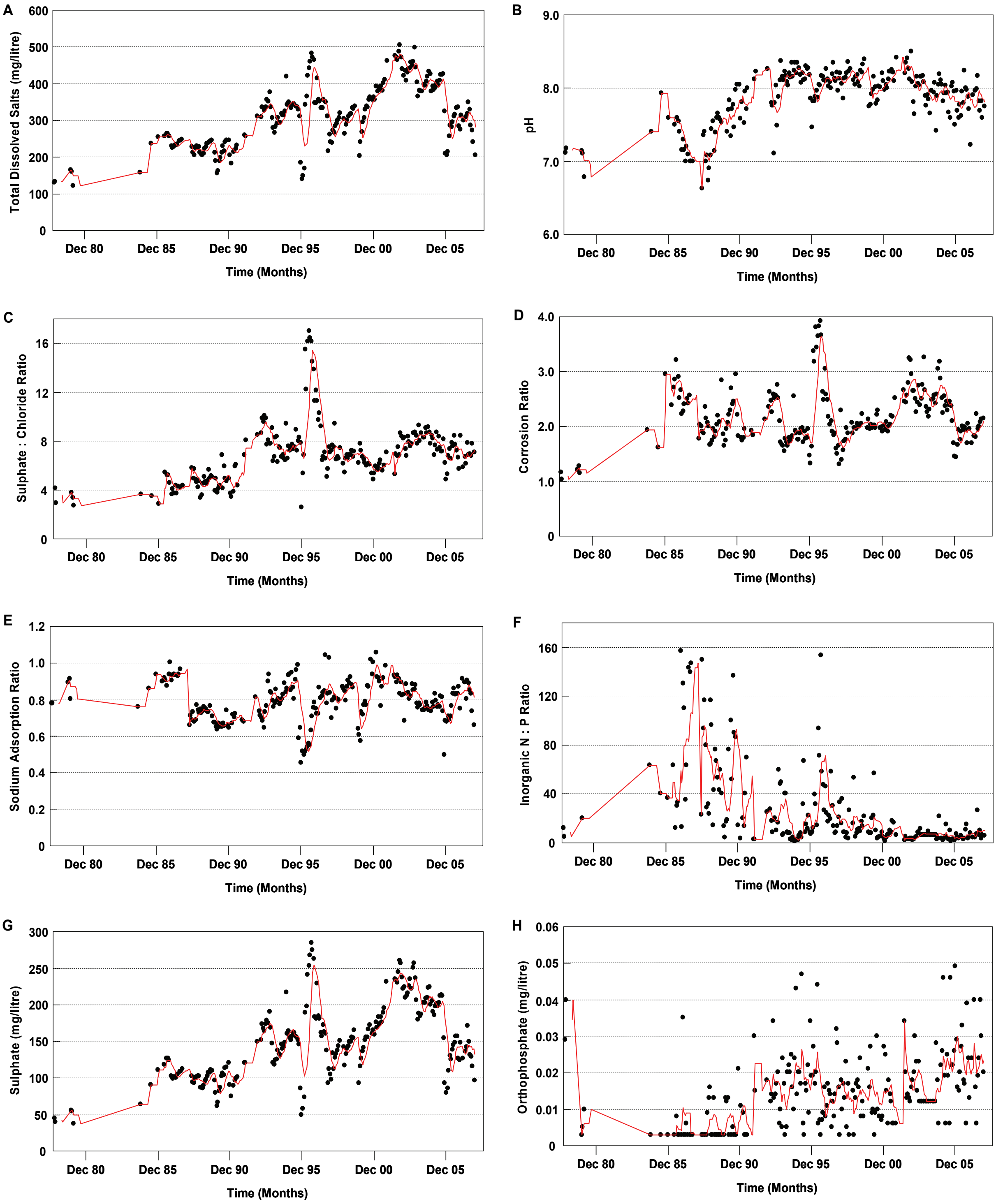

Figure A2 - R2A – H: Witbank Dam on the Olifants River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R2: DWA gauge B1R001 for the period March 1975 to March 2008. (Solid line = seven-point moving average).

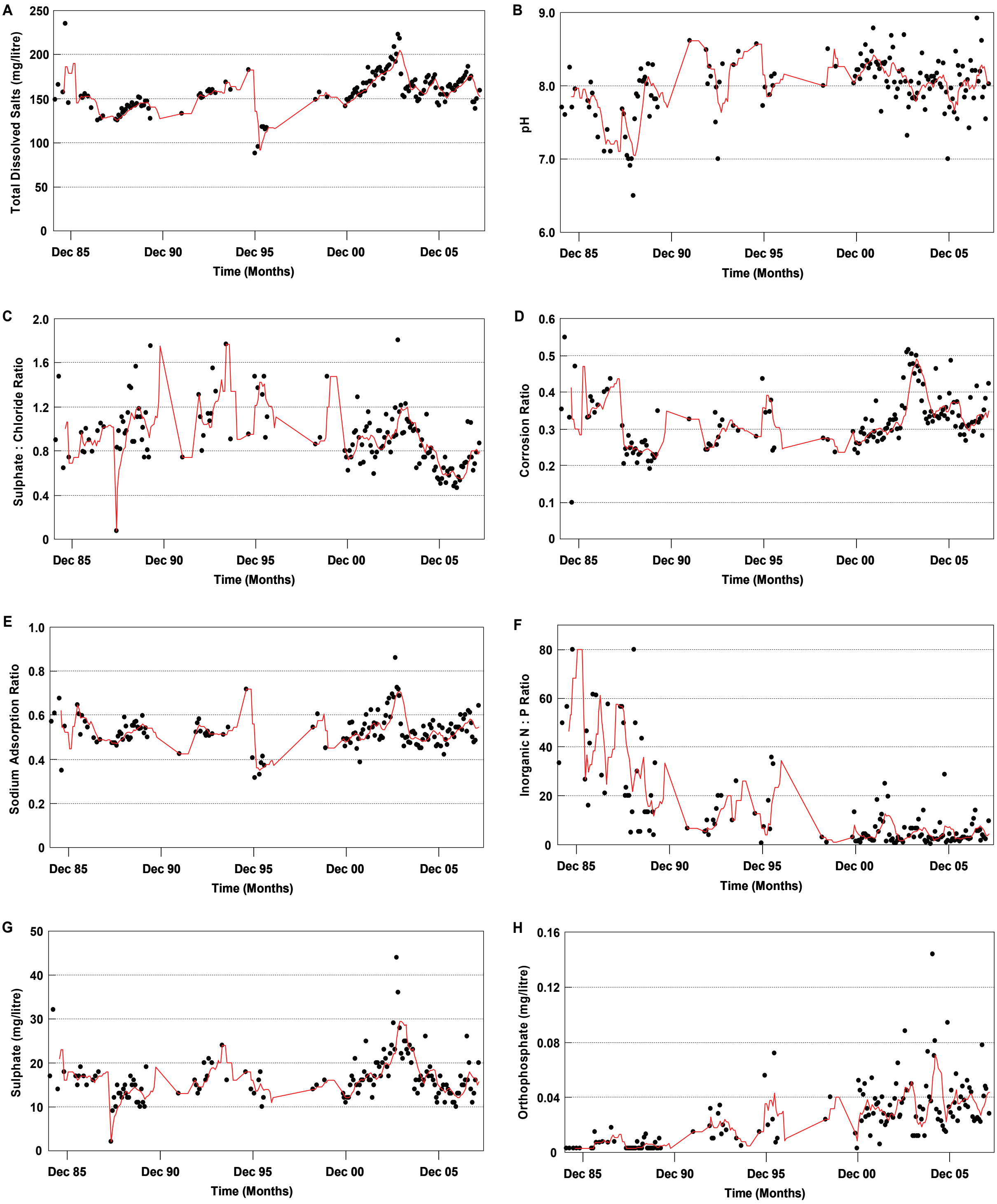

Figure A2 - R3A – H: Bronkhorstspruit Dam on the Bronkhorstspruit River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R3: DWA gauge B2R001 for the period February 1985 to July 2008. (Solid line = seven-point moving average).

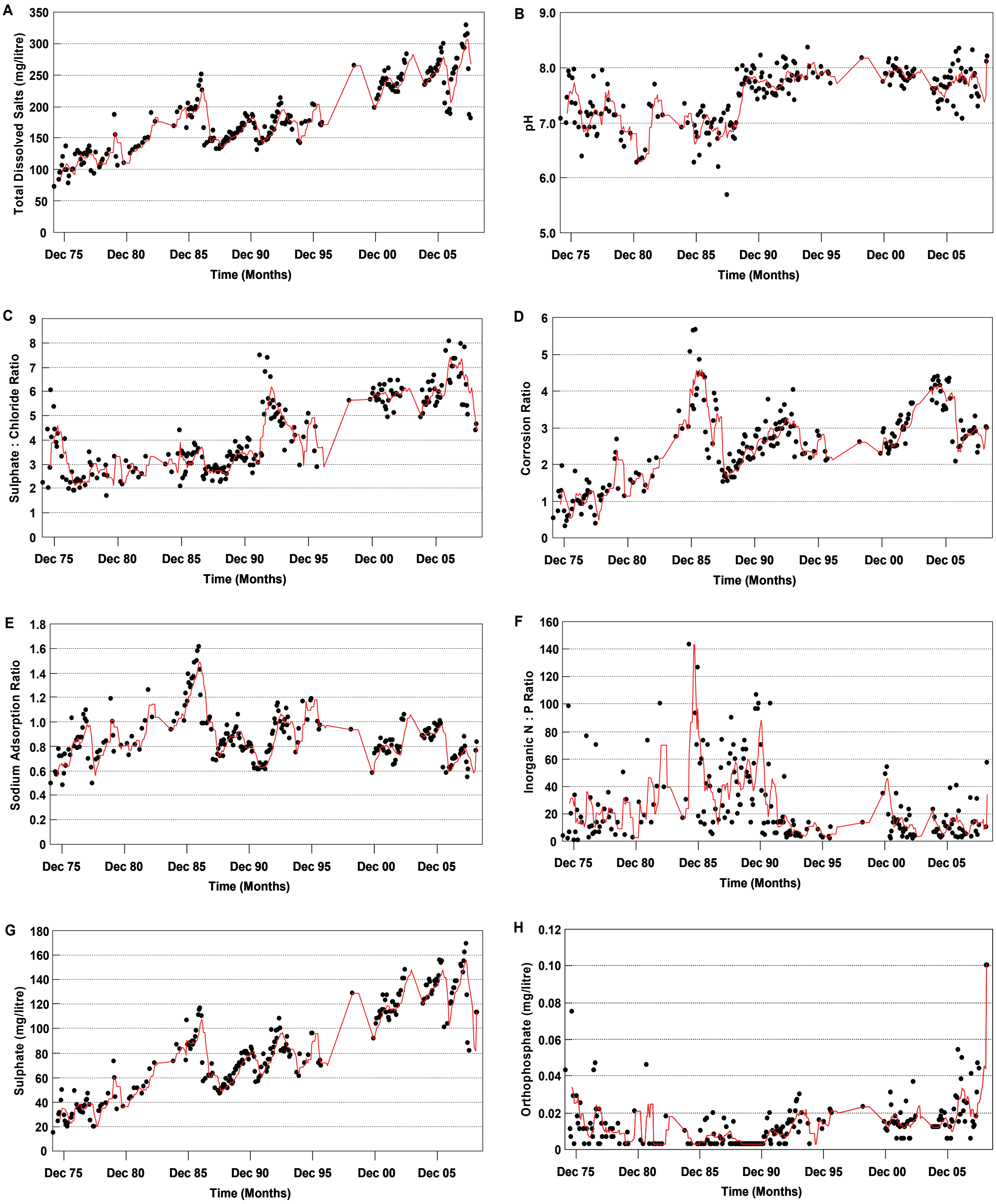

Figure A2 - R4A – H: Loskop Dam on the Olifants River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R4: DWA gauge B3R002 for the period June 1973 to November 1988. (Solid line = seven-point moving average).

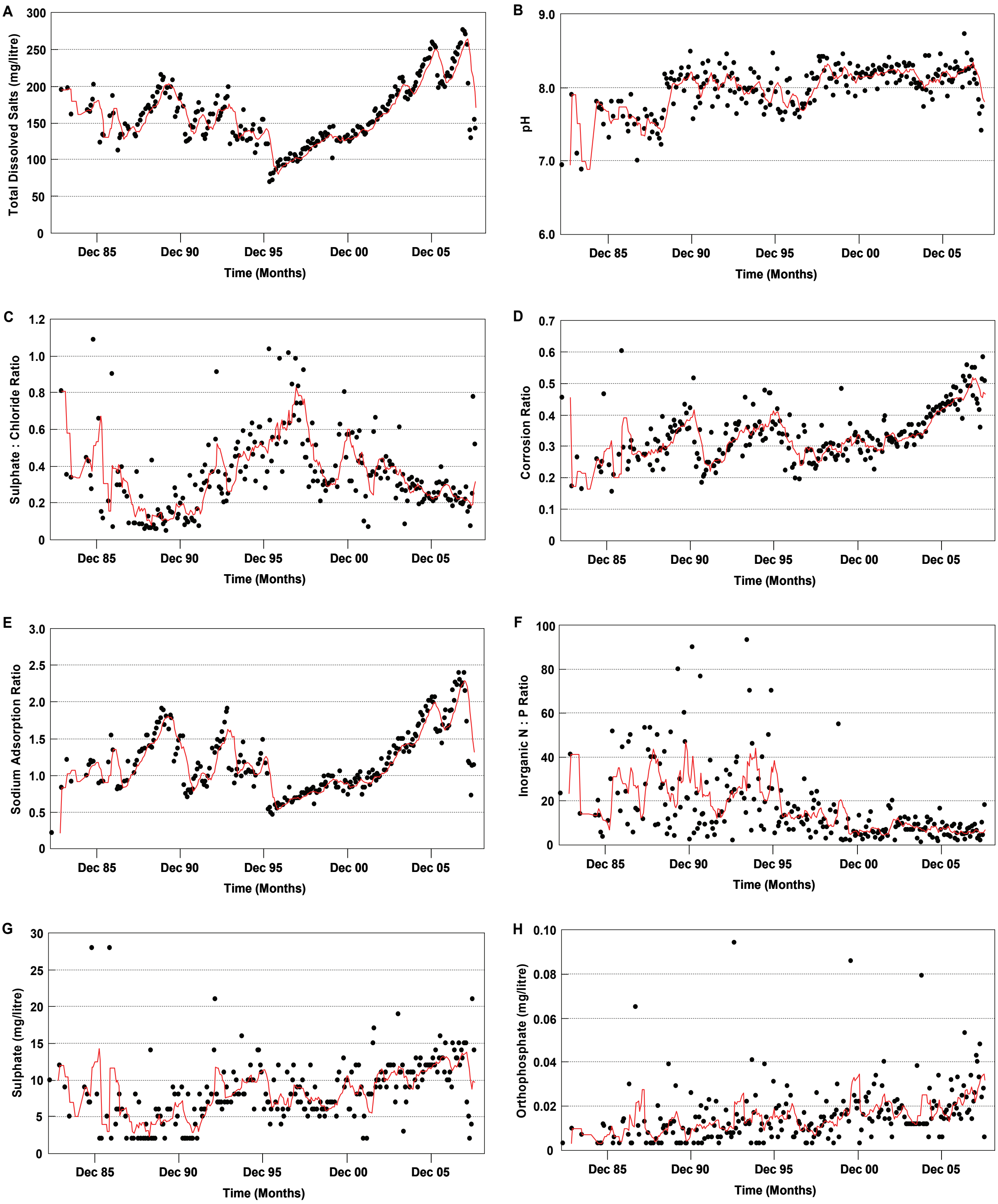

Figure A2 - R5A – H: Rhenosterkop Dam on the Elands River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R5: DWA gauge B3R005 or the period April 1983 to June 2008. (Solid line = seven-point moving average).

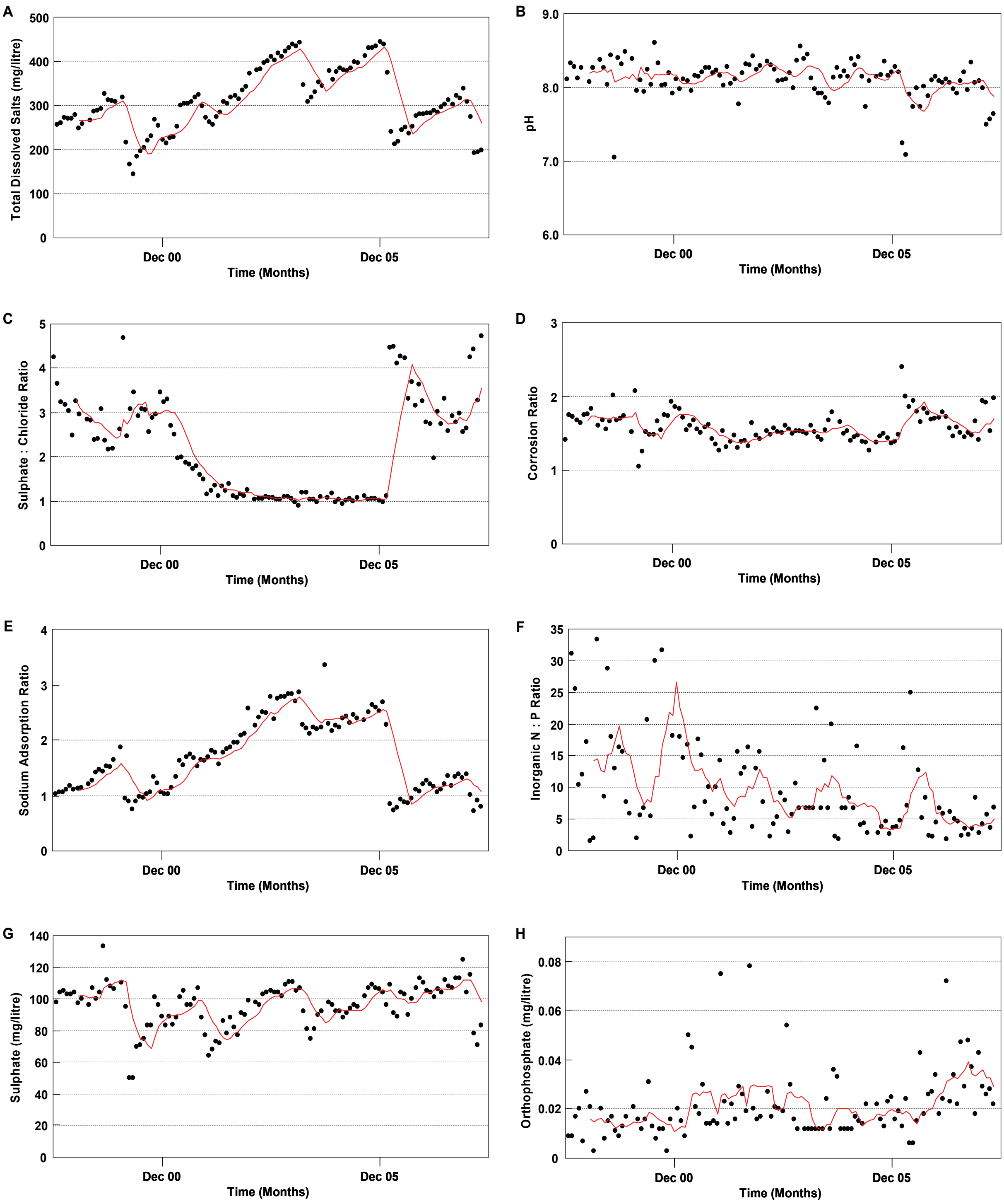

Figure A2 - R6A – H: Flag Boshielo Dam on the Olifants River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R6: DWA gauge B5R002 for the period July 1998 to April 2008. (Solid line = seven-point moving average).

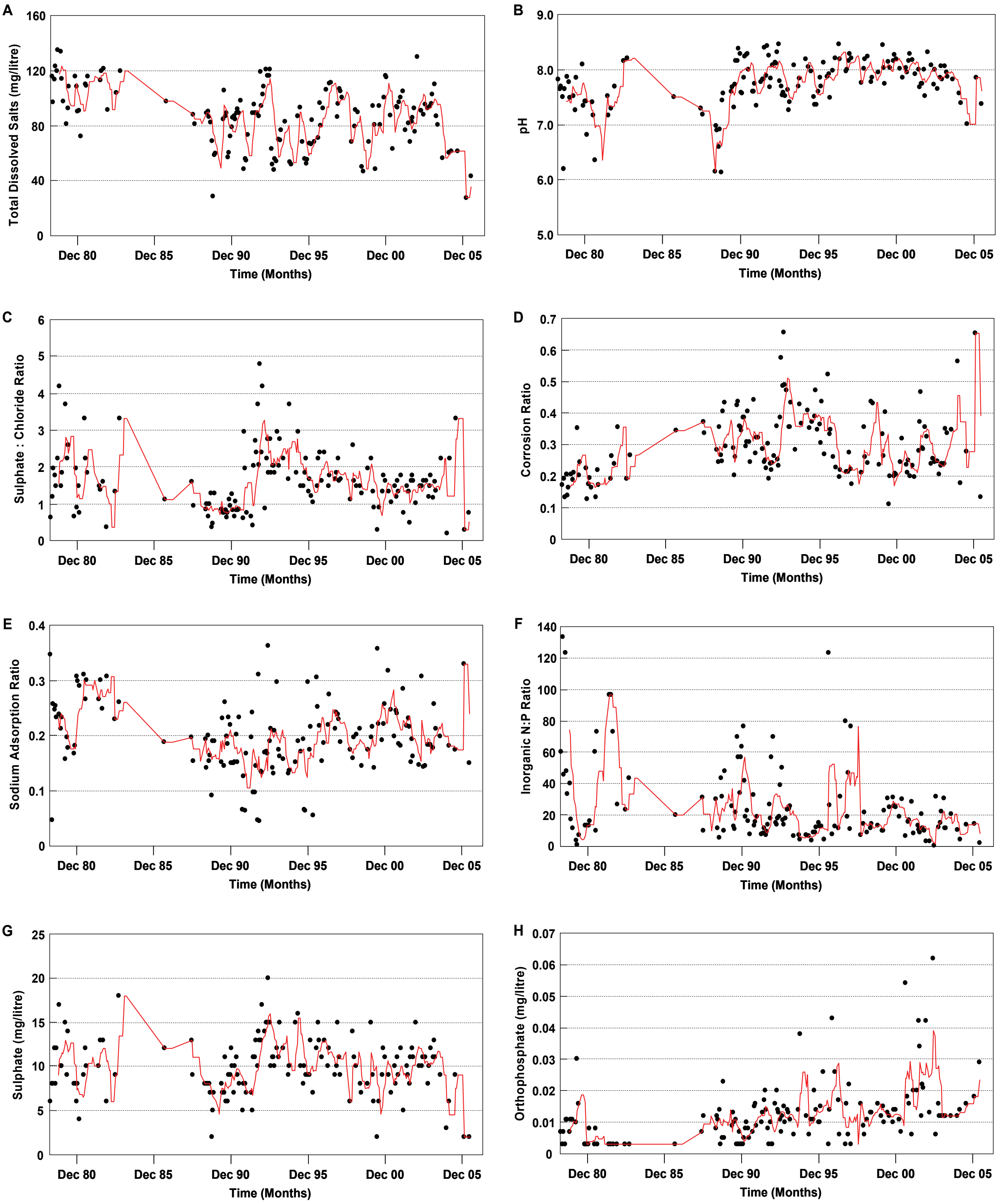

Figure A2 - R7A – H: Blyderivierspoort Dam on the Blyde River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R7: DWA gauge B6R003 for the period April 1978 to June 2006. (Solid line = seven-point moving average).

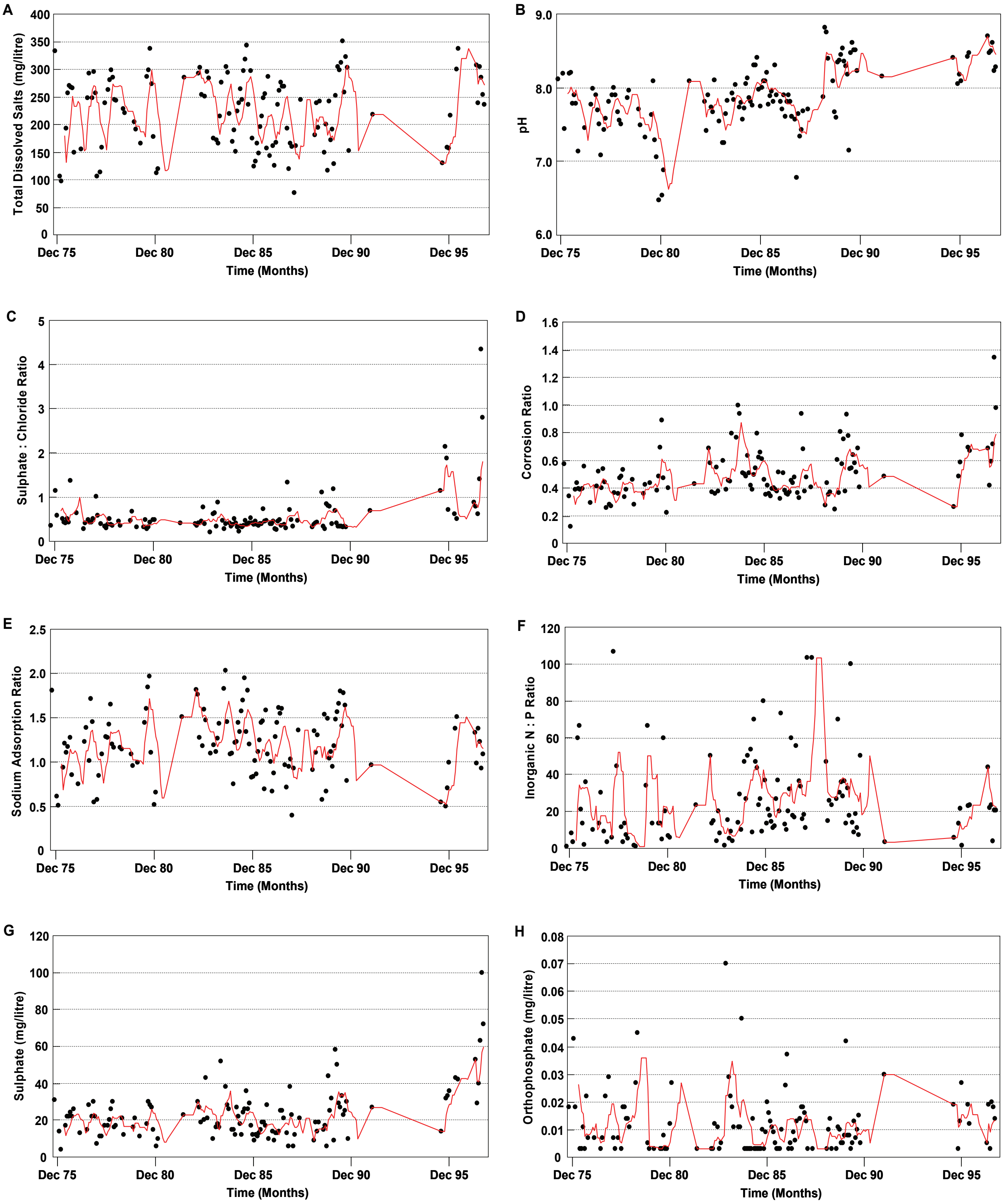

Figure A2 - R8A – H: Phalaborwa Barrage on the Olifants River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R8: DWA gauge B7R002 for the period November 1975 to January 1998. (Solid line = seven-point moving average).

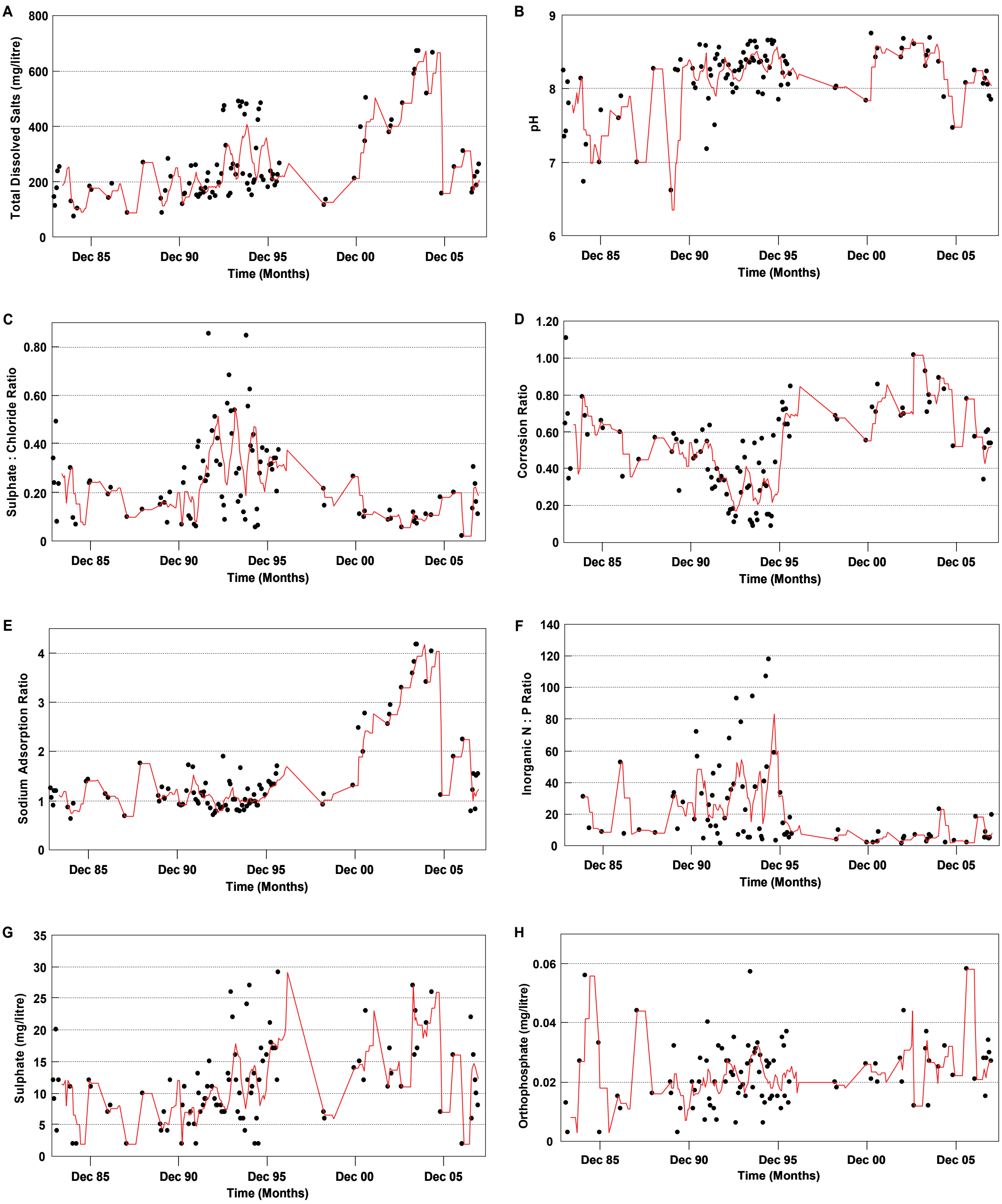

Figure A2 - R9A – H: Engelhard Dam on the Great Letaba River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R9: DWA gauge B8R018 for the period November 1983 to May 2008. (Solid line = seven-point moving average).

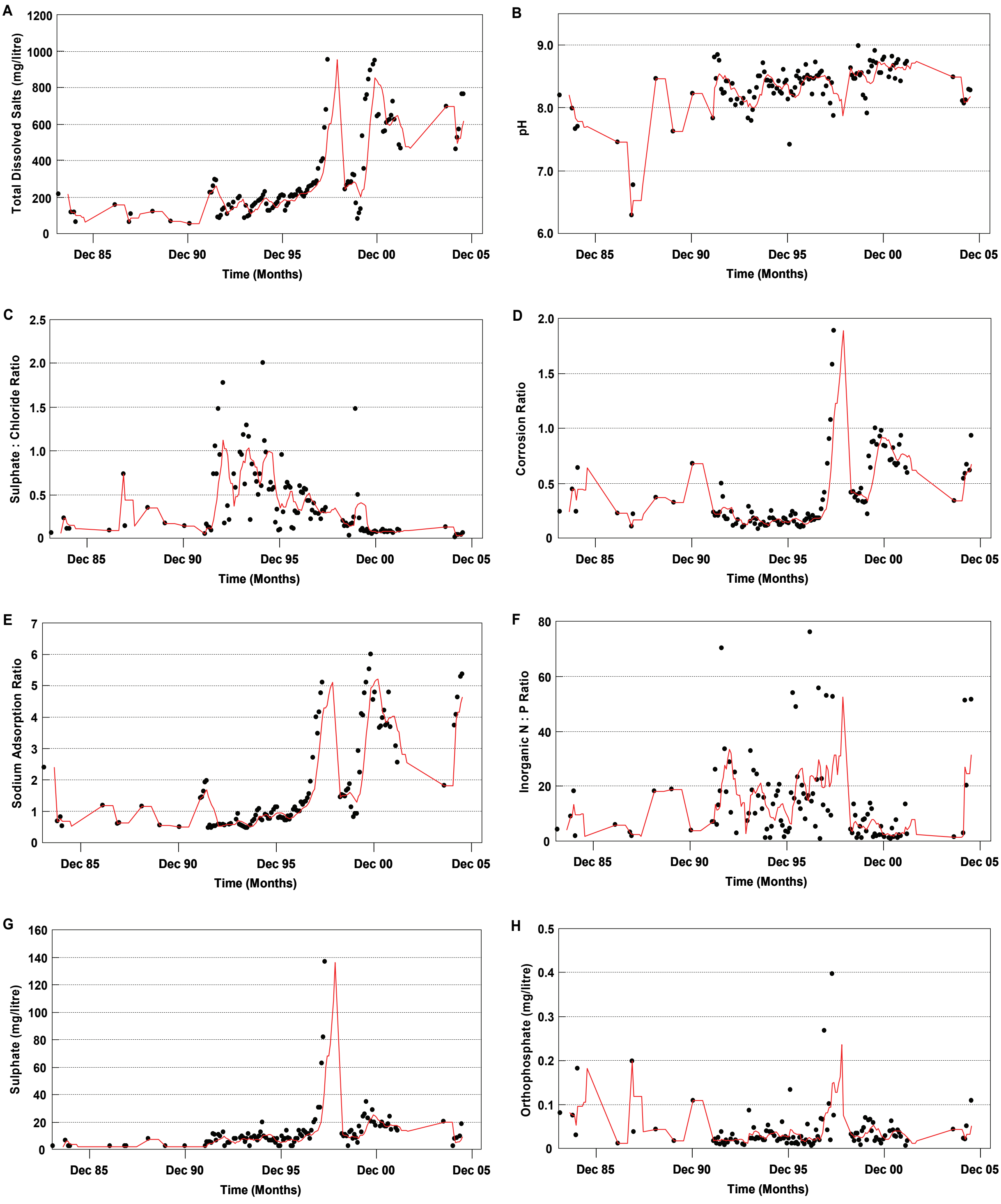

Figure A2 - R10A – H: Kanniedood Dam on the Shingwidzi River – Monthly time-series plots of eight water quality characteristics (A = Total dissolved salts; B = pH; C = Sulphate : chloride ratio; D = Corrosion ratio; E = Sodium adsorption ratio; F = Inorganic N : P ratio; G = Sulphate; H = Orthophosphate) at site R10: DWA gauge B9R003 for the period February 1984 to December 2007. (Solid line = seven-point moving average).

Appendix 3

Percentile Statistics for Fourteen Measured Water Quality Variables and Six Calculated Water Quality Indices for Twenty-seven DWA River Monitoring Sites in the Olifants River catchment

Table A3. Percentile statistics for fourteen (14) measured water quality variables and six (6) calculated water quality indices for data from twenty-seven (27) DWA river monitoring sites in the Olifants River catchment. Details of each monitoring site are given in **Table 2**. (Units: E.C. = mS/m; Cl, Na, K, Ca, Mg, SO_4, F, PO_4-P, NH_4-N, NO_3-N, Si, TDS = mg/litre; Tot. Alk. = mg $CaCO_3$/litre; Sum of Cations = milliequivalents/litre; Inorganic N:P ratio, SO_4/Cl ratio, Corrosion ratio, and SAR are dimensionless; Colour shading indicates values exceed Chronic Effect Value (CEV) guidelines: green = aquatic ecosystem, blue = domestic, yellow = agriculture).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#1 - B1H006 - Trichardtspruit at Rietfontein																			
n	621	621	621	621	621	621	621	621	621	621	621	621	621	621	621	621	621	621	621	621
Min	13.8	6.13	2	3	0.5	6	6	8	32	0.1	0.003	0.020	0.020	0.2	76	0.2	0.59	0.10	0.111	1.313
5%	22	7.00	7	11	2.8	14	9	16	63.0	0.2	0.003	0.020	0.020	0.5	108	1.6	0.84	0.35	0.511	2.043
25%	24.3	7.50	9	13	3.2	16	10	20	75	0.2	0.010	0.020	0.020	1.3	123	4.7	1.09	0.44	0.615	2.302
50%	25.9	7.93	12	15	3.4	17	11	22	81	0.3	0.015	0.040	0.090	2.2	132	9.0	1.48	0.51	0.676	2.456
75%	28.2	8.18	14	16	3.7	18	12	27	88	0.3	0.024	0.060	0.170	3.5	144	16.9	1.99	0.56	0.736	2.701
95%	32.2	8.44	17	20	4.1	21	15	34	110	0.4	0.053	0.120	0.370	5.2	169	42.5	2.71	0.67	0.857	3.125
Max.	51.6	8.77	26	39	9.9	36	30	72	223	1.2	0.532	0.870	0.820	7.7	286	178.0	6.64	1.02	1.668	5.450
	#2 - B1H018 - Olifants River at Middelkraal																			
n	510	510	510	510	510	510	510	510	510	510	510	510	510	510	510	510	510	510	510	510
Min.	12.6	6.80	5	2.8	7	4	4	11	20	0.2	0.003	0.020	0.020	0.2	77	0.3	0.10	0.22	0.294	1.239
5%	22.2	7.60	14	3.8	13	8	10	16	68.5	0.3	0.008	0.020	0.020	1	126	1	0.46	0.32	0.706	2.135
25%	29.6	8.02	20	4.6	18	11	13	23	95	0.3	0.015	0.020	0.020	2.7	161	2.1	0.90	0.40	0.909	2.860
50%	36.9	8.19	27	5.3	22	14	19	29	119	0.4	0.021	0.020	0.040	3.9	197	3.5	1.24	0.50	1.128	3.594
75%	46	8.32	37	6.1	27	18	26	40	149.8	0.5	0.032	0.050	0.070	5.3	249	6.3	1.66	0.65	1.382	4.573
95%	64.3	8.50	62	7.8	33	25	43	85	212	0.8	0.064	0.090	0.200	6.8	367	14.2	3.38	1.05	2.079	6.566
Max.	90.5	10.16	125	15	64	33	117	271	275	1.6	0.457	0.920	6.820	10.5	511	451.3	10.6	11.77	4.608	8.544
	#3 - B1H021 - Steenkoolspruit at Middeldrift																			
n	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640
Min.	17.2	5.05	4	1.3	9	6	2	5	47	0.1	0.003	0.020	0.020	0.2	85	0.0	0.08	0.31	0.235	1.384
5%	27.1	7.57	16.0	4.2	17	11.0	9	28	75	0.3	0.015	0.020	0.020	0.2	148	0.3	1.26	0.46	0.684	2.569
25%	36.6	8.03	24	5.2	24	14	14	46	101	0.3	0.051	0.020	0.080	1	201	1.6	1.84	0.63	0.901	3.628
50%	48.3	8.24	36	6	30	19	21	74	127	0.4	0.098	0.050	0.310	3.4	275	3.6	2.49	0.82	1.197	4.828
75%	63.1	8.45	52.3	6.9	40	26	30	113	164	0.5	0.203	0.100	0.833	4.7	367	8.6	4.11	1.17	1.529	6.622
95%	98.4	8.88	77	8.8	73	49.1	44	333.8	204.1	0.6	0.812	0.401	2.000	6.3	683	26.1	9.50	2.76	2.017	11.493
Max.	246	9.50	135	12.5	244	193	58	1363	265	0.8	2.252	6.940	7.140	10.7	1993	188.3	62.88	11.08	3.212	31.978
	#4 - B1H005 - Olifants River at Wolwekrans																			
n	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	784	783
Min.	21.3	6.47	9	1.8	10	7	3	16	22	0.1	0.003	0.020	0.020	0.2	97	0.4	0.45	0.34	0.299	1.653
5%	29.8	7.00	16	4.3	20	12	9.2	48.2	54	0.3	0.003	0.020	0.020	0.2	163	1.8	2.66	0.88	0.627	2.839
25%	44.4	7.81	24	5.5	32	18	14	103	79.8	0.4	0.009	0.020	0.040	1.5	253	5.7	4.78	1.51	0.770	4.230
50%	64.2	8.06	36	6.2	48	29	19.5	177	99	0.5	0.015	0.020	0.145	3.2	383	12	6.77	2.24	0.928	6.439
75%	88	8.22	47	7	75	44	25	317	116	0.5	0.027	0.070	0.330	4.4	568	27.2	11.1	3.45	1.114	9.516
95%	142.7	8.42	64	8.8	142.4	78	35.8	639.6	136.9	0.7	0.064	0.138	0.858	5.8	1049	96.4	18.84	7.37	1.390	16.691
Max.	230	8.86	115	13.1	373	178	88	1549	205	1.2	0.593	0.560	4.650	57.9	2173	843.3	211.59	38.7	2.476	34.689

Table A3. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#5 - B1H010 - Olifants River downstream Witbank Dam																			
n	604	604	604	604	604	604	604	604	604	604	604	604	604	604	604	604	604	604	604	604
Min.	13.3	7.04	4	0.9	9	7	3	5	40	0.1	0.003	0.020	0.020	0.2	76	0.3	0.92	0.15	0.234	1.304
5%	35.4	7.71	18	4.7	27	14	10	87	60.2	0.4	0.005	0.020	0.020	0.6	210	2.2	5.23	1.52	0.572	3.495
25%	49.8	8.04	25	5.7	37	22	14	135.8	81	0.4	0.008	0.020	0.020	1.2	298	4.4	6.25	1.84	0.762	4.938
50%	56.4	8.19	28	6.3	43	26	16	159	90	0.5	0.013	0.020	0.050	1.9	338	7.1	6.97	2.08	0.817	5.662
75%	65.5	8.33	31	6.9	52	32	20	199	100	0.5	0.018	0.050	0.100	2.9	400	14	7.87	2.44	0.889	6.635
95%	74.8	8.72	36	7.7	61.9	38	24	239	112	0.6	0.035	0.109	0.420	4.8	469	51.2	14.24	3.19	1.000	7.760
Max.	82.2	9.78	46	10.6	71	43	32	300	126	0.7	0.428	0.640	2.050	59.4	518	345	20.89	4.59	1.144	8.584
	#6 - B1H002 - Spookspruit at Elandspruit																			
n	699	699	699	699	699	699	699	699	699	699	699	699	699	699	699	699	699	699	699	699
Min.	8.4	3.34	4	0.8	4	3	2	2	2	0.1	0.003	0.020	0.020	0.2	46	0.7	0.16	0.07	0.106	1.102
5%	20.3	4.84	11	2	13	8	5	10	12	0.2	0.003	0.020	0.020	2.4	106	3.3	1.03	0.18	0.278	2.678
25%	47.6	6.85	17	4.3	37	26.8	7	132	27	0.4	0.006	0.020	0.080	3.6	277	10.0	9.47	1.97	0.343	5.340
50%	98.8	7.39	22	6.9	97	60	10	443.5	44	0.4	0.012	0.050	0.210	5.2	676	24.6	33.14	13.89	0.434	11.797
75%	160.3	7.83	26	9.2	159	119	12	871.3	77.3	0.5	0.017	0.080	0.400	7.9	1217	54.0	67.36	26.72	0.565	19.613
95%	243	8.40	36	14.2	249	222.5	18	1464.8	181	0.8	0.038	0.279	0.944	15.6	2027	133.3	125.14	65.94	0.770	32.415
Max.	439	9.02	91	27	430	569	89	3187	209	1.4	0.264	0.980	2.330	22.5	4293	353.3	1176.19	538.14	1.865	70.242
	#7 - B1H015 - Klein Olifants River downstream of Middelburg Dam																			
n	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
Min.	16.1	4.98	4	3	1	9	6	2	9	0.1	0.003	0.020	0.020	0.2	89	0.4	0.18	0.08	0.154	1.585
5%	37.1	7.10	10	15	5.5	26	16	94	48	0.3	0.003	0.020	0.020	0.2	206	2.3	5.05	1.96	0.493	3.501
25%	46.7	7.68	13	19	6.3	34	22	136	59	0.3	0.006	0.020	0.020	0.7	276	5.6	6.70	2.45	0.577	4.569
50%	52.4	7.93	15	21	7.3	42	26	171.5	68	0.4	0.011	0.035	0.060	1.3	325	11.1	8.38	3.01	0.628	5.332
75%	66.3	8.09	17	24	8.1	52	35	225.3	77	0.4	0.016	0.070	0.133	2.1	408	26.7	11.72	3.72	0.678	6.743
95%	89.1	8.29	22	31	10.6	72	61	357.1	98	0.5	0.034	0.140	0.280	3.7	607	83.3	15.57	4.76	0.801	9.995
Max.	223	8.98	104	69	15.5	195	180	1185	163	1.1	0.270	1.770	2.750	25	1711	816.7	43.55	28.15	2.153	27.321
	#8 - B1H004 - Klipspruit at Zaaihoek																			
n	678	678	678	678	678	678	678	678	678	678	678	678	674	678	678	678	678	678	678	678
Min.	17.1	2.34	7	2	12	5	2	61.0	2	0.1	0.003	0.020	0.020	0.2	101	0.4	2.41	2.72	0.428	1.415
5%	54.4	3.26	43.9	4.1	34	13	12.9	201.7	2	0.1	0.003	0.020	0.020	1.9	345	3.7	3.22	11.91	1.422	5.091
25%	78.2	3.74	69	5.7	47	19	31.3	287.3	2	0.3	0.008	0.020	0.100	2.9	499	15.6	4.74	33.05	2.023	7.400
50%	97.4	4.09	94	7.8	60.5	24	44	387.0	7	0.4	0.013	0.070	1.135	4.1	633	103.5	6.52	79.13	2.598	9.299
75%	118.4	6.12	123.8	10.3	79	28	56.8	495.8	12	0.7	0.021	1.020	2.660	5.6	808	324.6	8.52	227.97	3.201	11.765
95%	155.2	7.38	169	13.3	99	36	88	620.3	26	1.1	0.049	5.453	6.942	7.3	1011	1165.1	14.63	357.93	4.066	14.669
Max.	186.0	8.34	249	23.7	169	73	149	793.0	152	1.7	0.146	16.450	11.770	20.8	1307	3743.3	149.47	490.78	5.624	18.774

Table A3. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
#9 - B2H008 - Koffiespruit at Rietvallei																				
n	445	445	445	445	445	445	445	445	445	445	445	445	442	445	445	445	445	445	445	445
Min.	14.4	6.55	1	0.2	12	6	2	2	42	0.1	0.003	0.020	0.020	1.4	71	0.5	0.11	0.05	0.035	1.356
5%	17.1	7.08	1	0.2	15	9	2	2	68.2	0.1	0.003	0.020	0.020	3.8	86	2.0	0.18	0.07	0.044	1.652
25%	19.0	7.62	3	0.4	17	10	4	2	80	0.1	0.007	0.020	0.020	5.0	97	4.7	0.30	0.11	0.128	1.890
50%	20.6	7.93	4	0.7	19	11	5	5	90	0.1	0.012	0.020	0.060	5.4	107	9.1	0.74	0.15	0.167	2.078
75%	22.5	8.15	4	1.3	21	12	7	8	98	0.2	0.018	0.060	0.140	5.9	117	19.2	1.23	0.20	0.195	2.285
95%	27.1	8.41	7	3.3	24.8	15	11	20.8	114.8	0.3	0.032	0.090	0.290	6.7	139	54.7	2.46	0.40	0.310	2.628
Max.	64.2	8.97	68	10.8	31	20	99	74	141	0.6	0.467	0.360	0.930	10.3	325	115.7	8.41	1.63	2.424	5.977
#10 - B2H004 - Osspruit at Boschkop																				
n	712	712	712	712	712	712	712	712	712	712	712	712	712	712	712	712	712	712	712	712
Min	10.8	5.20	3	0.2	7	6	2	2	14	0.1	0.003	0.020	0.020	0.2	57	0.2	0.12	0.09	0.119	1.071
5%	18.6	7.44	6	0.6	14	10	4	4	75.6	0.1	0.003	0.020	0.020	5.9	105	2.5	0.30	0.12	0.262	1.879
25%	21.9	7.98	7.0	0.8	17	12	5	8	91.8	0.2	0.008	0.020	0.040	7.1	117	6.4	0.66	0.16	0.315	2.173
50%	24.3	8.18	8	1.1	19	14	7	9	103	0.2	0.014	0.050	0.130	8.1	130	15.4	1.03	0.19	0.346	2.437
75%	27.2	8.34	9	1.6	21	16	10	12	118	0.2	0.021	0.070	0.280	9.0	146	31.0	1.48	0.25	0.387	2.815
95%	32.6	8.52	12	2.8	25	20	14	19	143	0.3	0.041	0.114	0.490	10.4	175	73.3	2.21	0.40	0.456	3.394
Max.	73.5	8.93	77	8.3	36	27	72	191	161	1.1	1.279	0.770	1.280	12.5	401	183.3	10.7	16.40	2.523	7.076
#11 - B2H003 - Bronkhorstspruit River at Bronkhorstspruit																				
n	505	505	505	505	505	505	505	505	505	505	505	505	505	505	505	505	505	505	505	505
Min.	13.8	6.01	4	0.8	7	7	3	2	43	0.1	0.003	0.020	0.020	0.5	69	0.6	0.08	0.10	0.199	1.235
5%	17.9	7.40	6	1.8	11	10	5	7	67.2	0.1	0.006	0.020	0.020	1.8	97	1.8	0.49	0.21	0.306	1.764
25%	22.9	7.92	9	3.4	15	13	8	12	89	0.2	0.012	0.020	0.050	2.7	120	4.4	0.78	0.26	0.400	2.227
50%	26.7	8.17	11	4.1	18	14	11	14	104	0.2	0.018	0.020	0.100	3.8	139	7.6	0.96	0.29	0.463	2.629
75%	30.3	8.31	12	5.4	20	16	13	17	116	0.3	0.026	0.060	0.170	5.8	155	13.3	1.29	0.33	0.505	2.965
95%	35.3	8.46	15	7	23	18	17	21	135	0.4	0.055	0.120	0.380	7.8	180	36.7	2.00	0.44	0.581	3.422
Max.	40.5	8.69	28	8.2	31	21	21	30	164	0.6	0.186	0.840	0.860	9.2	212	90	2.66	0.77	1.115	4.087
#12 - B2H014 - Wilge River at Onverwacht																				
n	464	464	464	464	464	464	464	464	464	464	464	464	464	464	464	464	464	464	464	464
Min	10.3	6.43	4	1.2	6	4	3	4	20	0.1	0.003	0.020	0.020	0.9	60	0.5	0.25	0.14	0.254	0.953
5%	17.4	7.41	7	1.8	11	8	5	8	51	0.2	0.006	0.020	0.020	2.6	87	2.0	0.74	0.23	0.379	1.571
25%	20.6	7.84	9	2.3	14	9	7	13	67.8	0.3	0.012	0.020	0.040	4.0	105	5.3	1.26	0.32	0.437	1.936
50%	24.3	8.04	10	2.8	17	11	9	23	79	0.3	0.015	0.020	0.120	4.8	126	9.2	2.01	0.47	0.496	2.307
75%	28.3	8.18	13	3.4	20.0	14	10.3	37	92.3	0.3	0.023	0.050	0.233	5.7	153	16.7	2.95	0.65	0.582	2.730
95%	35.6	8.36	17	4.5	25	17	13	59.9	107.0	0.5	0.047	0.090	0.370	6.9	194	42.2	5.40	1.10	0.718	3.437
Max.	63.9	9.16	30	7.3	49	33	49	195	140	0.7	0.392	0.370	0.990	10.9	391	93.3	12.55	4.94	1.362	6.553

Table A3. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
#13 - B2H015 - Wilge River at Zusterstroom																				
n	396	396	396	396	396	396	396	396	396	396	396	396	396	396	396	396	396	396	396	396
Min.	10.2	6.87	4	1.7	7	3	4	14	4	0.1	0.003	0.020	0.020	1.1	55	0.2	1.48	0.35	0.200	0.916
5%	16.9	7.39	7	2.1	12	5	5	23	22.8	0.2	0.006	0.020	0.020	2.1	93	1.9	2.29	0.57	0.347	1.528
25%	21.0	7.65	9	2.6	16	7	7	33	36	0.2	0.010	0.020	0.040	2.7	112	4.7	3.05	0.80	0.430	1.893
50%	24.3	7.81	10	3.2	20	8	9	45.5	46	0.2	0.014	0.020	0.080	3.3	132	7.6	4.22	1.39	0.478	2.219
75%	29.1	7.98	12	3.7	27	10	11	69	58	0.3	0.020	0.050	0.150	3.9	159	13.7	5.79	2.10	0.530	2.668
95%	53.5	8.18	15.3	4.7	68	13	14	197.5	73	0.4	0.046	0.100	0.300	5.2	329	30.0	13.18	7.79	0.642	5.099
Max.	104.0	8.37	27	6.9	193	31	28	565	88	0.6	0.682	0.200	0.920	6.7	829	126.7	37.91	147.8	0.824	12.496
#14 - B3H017 - Olifants River downstream of Loskop Dam																				
n	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421
Min.	16.9	6.44	7	2.7	8	3	5	5	33	0.2	0.003	0.020	0.020	0.2	94	1.3	0.41	0.27	0.324	1.593
5%	26.5	7.28	13	3.9	18	9	8	60	38	0.3	0.006	0.020	0.040	1	146	4.2	3.74	1.63	0.547	2.361
25%	33.8	7.66	17	4.5	23	12	11	88	46	0.3	0.008	0.020	0.070	2	189	10	5.17	1.97	0.665	3.054
50%	41.5	7.87	21	4.8	29	16	13	108	55	0.3	0.013	0.050	0.140	2.6	233	17.5	5.86	2.34	0.793	3.845
75%	44.5	8.00	24	5.4	32	18	16	123	63	0.3	0.019	0.100	0.240	3.5	251	30.6	6.87	2.74	0.897	4.123
95%	50.5	8.19	29	6	37	21	19	148	71	0.4	0.034	0.300	0.490	4.4	294	70	8.44	3.61	1.045	4.817
Max.	68.2	8.52	51	6.5	48	32	32	182	281	0.9	0.183	0.560	1.270	104.1	391	206.7	12.25	4.67	1.454	7.334
#15 - B3H001 - Olifants River at Loskop North																				
n	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570
Min	17.5	6.63	6	0.5	9	5	5	2	34	0.1	0.003	0.020	0.020	0.2	87	0.3	0.10	0.32	0.614	1.498
5%	27.9	7.20	17.5	3.1	16	8	12	26	52	0.3	0.003	0.020	0.020	2.6	149	2.9	0.51	0.61	1.045	2.540
25%	42.2	7.74	32	4.2	24	14	22	54	82	0.5	0.009	0.020	0.080	4.6	239	10.0	0.83	1.00	1.430	3.999
50%	55.5	8.07	58	4.9	29	18	46.5	90	132	0.9	0.015	0.040	0.330	6.3	312	22.0	1.21	1.37	1.712	5.506
75%	77.3	8.33	88	5.7	36	25	74	116.8	167	1.1	0.023	0.060	0.530	8.4	460	41.7	2.42	1.65	2.144	8.020
95%	117.1	8.53	150.1	7.1	51	39.6	137	197	217	1.3	0.069	0.116	0.965	10.9	726	123.3	5.39	2.30	2.956	12.498
Max	185.4	9.11	240	16.5	88	57	309	384	302	2.2	0.822	0.860	2.990	14.4	1027	390.0	10.50	11.58	4.169	18.266
#16 - B3H005 - Moses River at Mosesriviermond																				
n	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132
Min.	13.1	6.74	10	2	5	4	6	5	40	0.1	0.003	0.020	0.020	0.2	71	1.8	0.12	0.30	0.809	1.131
5%	27.7	6.92	23.1	2.9	14.6	8	18	10	68.6	0.5	0.003	0.020	0.020	5.8	146	4.7	0.38	0.45	1.114	2.636
25%	42.4	7.28	39.5	3.7	22	12	36.8	30.8	113	0.9	0.006	0.020	0.280	8.7	231	18.6	0.49	0.74	1.702	3.954
50%	54.7	7.51	59	4.4	29.5	17	54	46.5	143	1.1	0.011	0.020	0.730	10.6	308	62.7	0.55	0.93	2.183	5.447
75%	94.0	7.83	107.5	5.0	45	30	118.5	85	194	1.4	0.019	0.060	2.110	11.8	524	311.7	0.66	1.31	3.104	9.717
95%	139.4	8.27	172.0	6.3	62.5	44.5	202.3	150.9	242	1.6	0.051	0.100	4.928	17.8	794	1079.8	1.08	1.86	3.956	13.911
Max.	164	8.60	192	11.8	79	56	267	186	290	2.1	0.262	0.170	8.900	21.8	928	2376.7	1.67	2.50	4.496	16.287

Table A3. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
#17 - B3H021 - Elands River at Scherp Arabie																				
n	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292
Min.	28.5	7.04	6	2.3	16	7	6	2	62	0.1	0.005	0.020	0.020	0.2	142	0.3	0.23	0.08	0.232	2.651
5%	40	7.94	34.6	6.2	23	10.6	37.6	34.6	90.6	0.8	0.011	0.020	0.020	1.5	221	1.3	0.38	1.13	1.551	3.860
25%	89.2	8.18	91	7.3	48	27	125.8	99.8	155	1.2	0.019	0.020	0.040	4.2	515	3.0	0.48	1.75	2.565	8.971
50%	115.3	8.30	126.5	8.6	60	37.5	180.5	140	195	1.5	0.028	0.020	0.185	6.4	683	7.6	0.56	2.09	3.168	11.834
75%	159	8.43	172	9.6	71	54	251.5	182	240.3	1.7	0.044	0.060	0.653	8.4	879	21.9	0.63	2.36	3.653	15.780
95%	248.5	8.61	224.5	11.9	104	112.9	465.8	276.9	293.5	1.9	0.094	0.130	1.290	11.2	1388	64.0	0.81	3.24	4.075	24.725
Max.	301	8.79	293	14.2	139	163	592	402	332	2.2	0.415	1.030	1.920	16.7	1720	111.1	8.34	4.54	5.562	30.575
#18 - B5H004 - Olifants River downstream of Flag Boshielo Dam																				
n	107	107	411	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107
Min.	42.7	7.20	51	1.6	24	12	13	40	90	0.4	0.006	0.020	0.020	4.6	266	0.9	0.53	1.04	1.636	4.639
5%	48.8	7.81	51.0	4.8	25.0	14.0	31.3	50.0	94.3	0.6	0.006	0.020	0.020	5.0	279	3.4	0.65	1.15	1.682	4.754
25%	53.1	8.01	51.0	5.3	28.0	16.0	38.0	66.0	103.0	0.7	0.012	0.020	0.050	5.5	301	6.4	0.82	1.27	1.768	5.135
50%	55.6	8.13	51.0	6.2	30	18.0	55	89	110	0.8	0.014	0.050	0.130	6.3	312	10.7	1.16	1.42	1.818	5.335
75%	59.4	8.20	51.0	6.8	33.0	19.0	61.0	100.0	121.0	0.9	0.022	0.070	0.210	8.1	326	18.3	1.84	1.56	1.896	5.510
95%	67.2	8.34	51.0	7.5	37.0	20.0	65.0	110.4	132.0	1.2	0.037	0.154	0.308	8.9	357	39.6	2.50	1.69	2.040	5.887
Max.	69.1	8.41	51.0	7.7	44.0	23.0	72.0	129.0	138.0	1.3	0.365	0.190	0.660	13.5	365	51.7	7.32	1.79	2.083	6.019
#19 - B5H002 - Olifants River at Zeekoegat																				
n	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109
Min.	36.4	7.11	21	1.5	28	11	17	10	81	0.1	0.003	0.020	0.020	5.5	193	0.4	0.02	0.25	0.811	3.555
5%	46.9	7.31	30	2.0	33	14	38	24.8	112.2	0.2	0.003	0.020	0.028	6.2	242	5.7	0.20	0.86	1.130	4.531
25%	96.8	7.65	103	3.7	43	29	155	66	145	0.5	0.003	0.020	0.170	8	499	23.3	0.24	1.60	2.749	9.298
50%	144.7	7.87	168	4.7	54	51	271	96	195	0.7	0.008	0.040	0.400	9.9	822	54.0	0.28	2.40	3.735	15.450
75%	195.1	8.12	218	5.2	60	74	354	137	230	1	0.016	0.060	0.960	11.5	989	96.7	0.31	3.17	5.007	17.884
95%	249.5	8.37	306.2	7.0	72.6	88	516.8	200.8	299.8	1.1	0.059	0.110	1.658	25.0	1292	358.0	0.66	4.78	6.101	22.771
Max.	563.2	8.48	797	15.3	140	161	1433	484	345	1.3	0.168	0.990	2.700	27.7	3195	513.3	2.34	10.51	10.899	55.294
#20 - B4H011 - Steelpoort River at Alverton																				
n	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452
Min.	16.7	6.65	5	0.5	1	4	5	2	49	0.1	0.003	0.020	0.020	0.2	83	0.8	0.07	0.10	0.258	1.505
5%	20.2	7.50	9	0.8	15	8	7	5	75	0.1	0.003	0.020	0.060	7.6	109	5.6	0.23	0.18	0.424	1.924
25%	31.3	7.98	19	1.1	21	14	17	12	115.8	0.2	0.007	0.020	0.360	9.6	168	17.4	0.32	0.30	0.772	3.110
50%	48.4	8.31	36.5	1.5	26	24	33	20	175.5	0.2	0.014	0.040	0.740	11.5	256	51.7	0.39	0.40	1.230	4.923
75%	79.9	8.58	78.3	1.8	31	43	73	41.3	271	0.3	0.024	0.060	1.350	13.7	459	134.6	0.67	0.55	2.080	8.830
95%	132	8.83	172.4	2.6	42	65	162.4	83	390.4	0.7	0.047	0.100	2.160	18.6	776	478.2	1.16	0.98	4.136	14.428
Max.	197	9.21	230	6.5	81	87	375	150	470	1	0.326	0.460	9.920	45.2	972	3320.0	2.95	2.69	5.521	17.252

Table A3. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#21 - B7H009 - Olifants River at Finale Liverpool																			
n	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404
Min.	8.6	6.18	5	1	5	3	6	2	19	0.1	0.003	0.020	0.020	3	48	0.5	0.04	0.14	0.365	0.750
5%	29.1	7.36	16	1.7	21	11.2	15	9	88	0.2	0.003	0.020	0.020	5.3	149	1.9	0.25	0.29	0.661	2.789
25%	42	7.99	29	2.2	26	18	28	21	130	0.3	0.010	0.020	0.070	6.9	225	6.0	0.33	0.46	1.059	4.195
50%	57.2	8.34	45	2.8	30	27	50	33.5	180.5	0.3	0.017	0.020	0.210	7.9	310	14.2	0.44	0.61	1.419	5.983
75%	68	8.59	59	3.4	33	35	71	46	209	0.4	0.029	0.043	0.410	9.1	371	30.5	0.65	0.83	1.745	7.154
95%	78.9	8.85	75	4.6	39	40	99	69	234	0.6	0.063	0.080	0.804	10.8	441	83.1	1.89	1.16	2.155	8.239
Max.	249	9.05	188	75.5	97	166	198	743	315	4	0.362	5.900	3.090	20.4	1677	239.2	4.39	3.34	3.350	28.609
	#22 - B6H004 - Blyde River at Chester																			
n	577	577	577	577	577	577	577	577	577	577	577	577	577	577	577	577	577	577	577	577
Min.	6.3	6.00	1	0.2	3	2	2	2	15	0.1	0.003	0.020	0.020	0.2	35	0.6	0.25	0.05	0.046	0.592
5%	10.9	6.87	3	0.3	9.0	5	3	5	37.0	0.1	0.003	0.020	0.020	3.3	56	4.0	0.55	0.18	0.149	1.045
25%	15.2	7.40	4	0.4	12	8	5	8	55	0.1	0.003	0.020	0.060	4.3	78	10.0	0.98	0.24	0.205	1.451
50%	17.9	7.78	5	0.5	15	9	6.0	10	67	0.1	0.009	0.020	0.110	4.9	92	17.5	1.37	0.29	0.252	1.725
75%	20.7	8.06	6	0.6	17	11	7	13	81	0.2	0.014	0.060	0.170	5.7	106	36.7	1.85	0.35	0.296	1.997
95%	27.0	8.31	8	1.3	22	14	9	19.2	102.2	0.3	0.026	0.110	0.282	7	135	73.3	2.71	0.49	0.381	2.651
Max.	58.5	8.56	42	5.5	33	28	56	41	162	0.7	0.143	0.360	0.600	10.7	295	196.7	7.38	1.88	1.352	5.529
	#23 - B7H007 - Olifants River at Oxford																			
n	666	666	666	666	666	666	666	666	666	666	666	654	666	654	666	666	666	666	666	666
Min.	7.9	6.18	4	0.2	4	2	4	2	26	0.1	0.003	0.020	0.020	1.1	58	0.6	0.05	0.11	0.241	0.763
5%	23.7	7.22	12	1.2	17	10	10	8.3	79.3	0.1	0.003	0.020	0.020	5.3	145	2.2	0.27	0.26	0.541	2.288
25%	34.9	7.67	22	1.6	22	15	22.3	16	112	0.2	0.005	0.020	0.060	6.7	216	7.3	0.37	0.40	0.871	3.403
50%	45.3	7.98	33	2	25	20	34	22	149	0.3	0.013	0.030	0.180	7.7	285	16.8	0.48	0.49	1.173	4.523
75%	52.7	8.31	44	2.5	29	25	45.8	30	173	0.3	0.023	0.060	0.330	8.6	340	38.0	0.63	0.59	1.462	5.471
95%	64	8.56	57	3.8	35	31	65	47.8	200.8	0.5	0.064	0.110	0.658	10.2	407	106.7	1.53	0.88	1.798	6.443
Max.	323	8.85	273	42.5	146	194	289	944	361	3.2	0.350	1.470	8.610	13.7	2444	360.0	4.55	3.85	3.483	36.211
	#24 - B7H004 - Klaserie River at Fleur-De-Lys																			
n	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159
Min.	3.9	5.76	4	0.2	1	1	2	2	12	0.1	0.003	0.020	0.020	2.5	31	0.4	0.09	0.14	0.227	0.453
5%	6.2	6.07	6	0.4	2	1	4	2	15	0.1	0.003	0.020	0.020	7.6	39	1.3	0.13	0.24	0.541	0.548
25%	7.5	6.84	7.5	0.6	3	2	5	2	21	0.1	0.009	0.020	0.020	9.1	47	3.3	0.18	0.37	0.767	0.683
50%	8.7	7.40	9	0.7	4	2	7	2	25	0.1	0.016	0.020	0.040	10.1	52	5.8	0.30	0.50	0.917	0.776
75%	9.8	7.71	10	0.9	5	2	9	5	32	0.1	0.025	0.050	0.095	11.1	60	10.0	0.60	0.71	1.019	0.906
95%	13.2	7.93	13	2.0	12.1	3.1	12.1	10.1	47.8	0.2	0.049	0.090	0.240	12.4	79	31.8	1.11	1.20	1.277	1.301
Max.	57.3	8.70	40	4	28	24	49	36	153	0.4	0.419	0.170	0.710	13.8	282	73.3	2.21	2.51	1.861	5.181

Table A3. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#25 - B7H019 - Ga-Selati River at Loole																			
n	377	377	377	377	377	377	377	377	377	377	377	377	376	377	377	377	377	377	377	377
Min.	22.3	7.24	15	0.2	11	11	16	26	58	0.1	0.003	0.020	0.020	0.2	129	0.1	0.37	0.41	0.741	2.188
5%	75.7	7.87	59.4	9.3	35.0	37.2	68.0	132.0	143.6	0.6	0.017	0.020	0.040	7.9	440	0.4	1.15	1.60	1.537	7.708
25%	204.0	8.19	160	34.5	80	120.0	176.0	530.0	215	2.4	0.061	0.020	0.330	12.6	1391	1.5	2.25	2.77	2.333	23.112
50%	237.0	8.32	176	73.4	94	164	196	809	246	3.6	0.227	0.070	0.635	14.8	1686	3.8	3.02	4.35	2.487	27.617
75%	255	8.45	188	82.6	103	182.0	213.0	900.0	272.0	4.2	0.349	0.140	0.973	16.4	1817	13.0	3.35	4.99	2.679	30.018
95%	276.0	8.62	214	92.6	123.2	201.4	240.2	1021.4	368.0	4.8	0.592	0.290	2.275	19.1	1986	47.1	3.75	6.28	3.432	32.476
Max.	326	8.87	303	124	161	224	321	1119	402	18.6	2.422	0.510	4.810	23.4	2344	258.5	4.35	7.78	4.039	38.880
	#26 - B7H015 - Olifants River at Mamba																			
n	592	592	592	592	592	592	592	592	592	592	592	592	591	592	592	592	592	592	592	592
Min.	18.3	6.52	3	0.2	12	9	2	2	50	0.1	0.003	0.020	0.020	0.7	93	0.2	0.13	0.08	0.106	1.755
5%	31.7	7.41	17	2.5	20	13	17	24	83	0.2	0.005	0.020	0.020	5.2	167	1.5	0.68	0.48	0.723	3.031
25%	46.3	7.80	30	4.3	26	20	30	50	114	0.4	0.013	0.020	0.080	6.8	256	5.1	1.11	0.82	1.030	4.610
50%	64.0	8.17	47	7.2	33	33	49	94.5	145	0.6	0.021	0.055	0.260	7.8	362	13.4	1.66	1.25	1.407	6.633
75%	116.3	8.43	91	23.9	51.3	73	92	330	179	1.4	0.035	0.080	0.530	8.7	777	32.5	2.70	2.68	1.933	13.224
95%	204.9	8.75	149.5	56.9	80.4	143.9	156	722	220	3.0	0.080	0.164	1.425	10.4	1425	159.7	3.80	5.44	2.439	23.278
Max.	250.0	9.30	187	80.5	120	193	201	1288	308	4.7	0.740	2.060	6.340	12.7	1909	1670.0	45.34	9.52	2.992	29.380
	#27 - B7H017 - Olifants River at Balule Rest Camp (KNP)																			
n	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389
Min.	22.3	5.26	9	2.1	15	7	5	5	48	0.2	0.003	0.020	0.020	2.2	111	0.5	0.08	0.29	0.437	2.039
5%	32.5	7.60	18	2.8	22	13	17.4	21.4	88.4	0.3	0.006	0.020	0.020	4.7	172	1.7	0.60	0.44	0.704	3.162
25%	50.3	7.99	35	5	28	24	37	54	130	0.4	0.012	0.020	0.020	6.1	272	3.3	1.06	0.77	1.158	4.974
50%	73.5	8.28	54	9.2	36	38	60	108	165	0.6	0.019	0.050	0.040	6.9	427	6.7	1.48	1.17	1.526	7.567
75%	113.4	8.44	92	20.9	53	72	104	282	214	1.3	0.027	0.070	0.180	8	758	13.3	2.33	2.19	2.003	13.021
95%	214	8.64	169.2	54.9	93	160	186	752.8	281.4	2.9	0.058	0.170	0.680	9.4	1575	36.8	3.09	4.08	2.514	26.773
Max.	301	8.90	250	79.9	112	234	278	1055	466	3.9	0.107	0.440	3.070	12.8	2170	426.7	9.30	7.07	3.433	36.512

Appendix 4

Percentile Statistics for Fourteen Measured Water Quality Variables and Six Calculated Water Quality Indices for Ten DWA Reservoir Monitoring Sites in the Olifants River catchment

Table A4. Percentile statistics for fourteen (14) measured water quality variables and six (6) calculated water quality indices for data from ten (10) DWA reservoir monitoring sites in the Olifants River catchment. Details of each monitoring site are given in **Table 2**. (Units: E.C. = mS/m; Cl, Na, K, Ca, Mg, SO_4, F, PO_4-P, NH_4-N, NO_3-N, Si, TDS = mg/litre; Tot. Alk. = mg $CaCO_3$/litre; Sum of Cations = milliequivalents/litre; the Inorganic N:P ratio, SO_4/Cl ratio, Corrosion ratio, and SAR are dimensionless; Colour shading indicates values exceed Chronic Effect Value (CEV) guidelines: green = aquatic ecosystem, blue = domestic, yellow = agriculture).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#R-1 - B1R002 - Middelburg Dam on Klein Olifants River																			
n	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
Min.	21.5	6.22	6	4.3	14	7	5	34	31	0.1	0.003	0.020	0.020	0.2	117	1.2	2.22	1.02	0.290	2.049
5%	32.2	7.06	14	5.8	20.5	11	10.5	73.9	46	0.3	0.003	0.020	0.020	0.2	177	4.4	4.01	1.68	0.470	2.937
25%	45.9	7.68	20	6.9	33	21	14	132	62	0.3	0.007	0.020	0.040	0.6	272	10.0	6.08	2.40	0.605	4.506
50%	53.4	7.89	23	7.7	38	26	16	167.5	68	0.4	0.012	0.070	0.110	1.3	321	17.4	7.54	2.77	0.666	5.245
75%	67.8	8.05	26	8.9	51	35.8	19	224.8	77	0.4	0.018	0.140	0.170	2.3	416	30.8	10.37	3.64	0.744	6.921
95%	86.7	8.21	32	10.5	64.6	58.1	23	322.3	96	0.5	0.027	0.340	0.376	3.8	570	81.8	14.88	4.94	0.867	9.552
Max.	134	8.48	88	14.7	106	81	140	426	145	1.1	0.727	1.040	1.970	4.9	870	303.3	19.04	11.34	2.111	14.895
	#R-2 - B1R001 - Witbank Dam on Olifants River																			
n	486	486	486	486	486	486	486	486	486	486	486	483	480	483	486	486	486	486	486	486
Min.	14.8	6.63	8	3.7	9	6	2	11	44	0.1	0.003	0.020	0.020	0.2	73	0.1	2.09	0.27	0.451	1.442
5%	32.2	7.03	16	4.9	24.3	13	11	79.3	52.3	0.3	0.003	0.020	0.020	0.2	190	2.5	3.73	1.57	0.586	3.139
25%	40.4	7.63	20	5.3	30	16	13	103	64	0.4	0.006	0.020	0.040	0.5	229	5.9	5.05	1.85	0.697	3.857
50%	49.8	7.99	25	6.1	40	22	15	139.5	81	0.5	0.012	0.040	0.120	1.2	304	13.4	6.77	2.04	0.770	5.114
75%	60.5	8.16	29	6.7	48	27	18	175	94	0.5	0.020	0.070	0.220	2.4	360	39.1	7.99	2.42	0.849	6.103
95%	72.7	8.36	34	7.3	60.8	37	22	238.8	108	0.7	0.036	0.120	0.421	4.5	460	113.3	11.27	3.16	0.945	7.598
Max.	79.7	8.90	75	8.5	69	45	33	297	149	0.9	2.181	7.760	1.130	5.9	506	396.7	37.05	4.18	2.551	8.823
	#R-3 - B2R001 - Bronkhorstspruit Dam on Bronkhorstspruit River																			
n	336	336	336	336	336	336	336	336	336	336	336	333	336	333	336	336	336	336	336	336
Min.	16.7	3.90	6	1.3	11	7	2	2	56	0.1	0.003	0.020	0.020	0.2	88	0.3	0.08	0.10	0.291	1.562
5%	24.1	7.00	11	3.8	17	13	8	10	90	0.2	0.003	0.020	0.020	0.7	125	1.0	0.56	0.22	0.438	2.481
25%	27.1	7.73	12	4.3	18	15	10	13	106	0.3	0.006	0.020	0.020	1.4	143	2.5	0.74	0.26	0.491	2.813
50%	30.1	8.02	13	5.6	20	16	14	15	114	0.3	0.022	0.020	0.040	2.3	154	6.1	0.91	0.30	0.526	2.978
75%	33	8.22	14	7.1	22	17	16	18	123	0.3	0.038	0.070	0.090	4.6	168	18.0	1.08	0.34	0.554	3.208
95%	37.9	8.51	17	7.8	24	19	18	25	135.3	0.4	0.071	0.214	0.315	6.3	186	58.4	1.48	0.46	0.650	3.660
Max.	50.4	9.14	23	8.7	42	38	23	72	201	1	0.312	0.700	1.750	6.9	307	583.3	3.80	0.62	0.859	5.822
	#R-4 - B3R002 - Loskop Dam on Olifants River																			
n	406	406	406	406	406	406	406	406	406	406	406	377	406	377	406	406	406	406	406	406
Min.	12.5	5.68	7	1.8	7	5	2	9	18	0.1	0.003	0.020	0.020	0.1	69.2	0.1	0.20	0.30	0.443	1.327
5%	17.4	6.69	12	2.8	11.3	7	6	27	29	0.2	0.003	0.020	0.020	0.76	98.0	2.6	2.26	0.70	0.586	1.778
25%	27.2	7.25	16	3.8	18	9	12	57	36	0.3	0.003	0.020	0.040	1.8	147.6	6.4	2.95	2.04	0.738	2.443
50%	31.7	7.66	20	4.4	20	10	15	79.5	43	0.3	0.011	0.050	0.080	2.4	176.0	13.6	4.14	2.55	0.841	2.846
75%	40.8	7.87	23	5	28	15	17	114	49	0.4	0.018	0.070	0.170	3	234.0	37.6	5.75	3.13	0.971	3.786
95%	48.8	8.13	29	6.1	33.8	21	22.8	143	61	0.5	0.043	0.130	0.520	4.0	278.1	93.3	7.33	4.32	1.304	4.594
Max.	54.3	10.18	52	12	42	26	41	169	154	2.2	0.590	5.600	3.840	5.4	329.5	1286.7	12.18	7.45	2.140	5.594

Table A4. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#R-5 - B3R005 - Rhenosterkop Dam on Elands River																			
n	328	328	328	328	328	328	328	328	328	328	328	328	326	328	328	328	328	328	328	328
Min.	8.4	5.53	3	0.8	6	2	2	2	29	0.1	0.003	0.020	0.020	0.2	53	1.0	0.05	0.16	0.218	0.864
5%	19.5	7.43	12	5.6	13	5	8	2	69	0.5	0.003	0.020	0.020	1.2	100	2.5	0.09	0.23	0.685	1.818
25%	25.6	7.88	18	6.3	18	7	14	6	91.8	0.7	0.009	0.020	0.040	2.7	131	5.7	0.22	0.29	0.896	2.400
50%	31.4	8.10	26	7.3	21	8	19	9	112	1	0.014	0.060	0.070	3.6	164	9.5	0.30	0.34	1.219	3.038
75%	39.6	8.23	37.3	9.4	23	10	31	12	136	1.3	0.022	0.083	0.130	4.6	207	18.4	0.42	0.44	1.667	3.828
95%	49.1	8.41	53	11.6	26	12	44	16.7	158.3	1.5	0.040	0.130	0.288	7.3	256	50.8	0.80	0.53	2.203	4.859
Max.	54.6	8.73	58	14.3	30	15	54	30	173	2.2	0.606	2.360	0.910	11.3	278	326.7	3.69	0.73	2.400	5.115
	#R-6 - B5R002 - Flag Boshielo Dam on Olifants River																			
n	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192
Min.	27.1	6.88	15	3.7	17	8	12	50	51	0.3	0.003	0.020	0.020	3.6	145	0.3	0.48	1.04	0.715	2.254
5%	37	7.55	20	4.4	24	13	15	73	58	0.4	0.006	0.020	0.040	4.1	201	1.9	0.96	1.32	0.774	3.335
25%	46.6	7.94	30	5.2	28	17	22.8	91	80	0.5	0.013	0.020	0.040	4.9	261	3.8	1.09	1.46	1.061	4.444
50%	53.1	8.10	40	6.1	32	19	30.5	101.5	98.5	0.6	0.018	0.020	0.060	5.5	300	6.6	2.57	1.57	1.316	5.104
75%	65.2	8.26	64.3	6.9	35	20	64.3	107	123.3	1.0	0.026	0.063	0.150	7.2	371	12.4	3.26	1.74	2.230	6.184
95%	75.8	8.40	85	8.2	40	23	78.5	114.5	151.9	1.2	0.063	0.110	0.280	8.5	436	28.5	4.40	2.04	2.705	7.562
Max.	281	9.07	231	11.1	124	143	557	360	239	1.6	0.258	0.130	0.460	9.7	1575	116.7	5.11	4.85	3.354	28.287
	#R-7 - B6R003 - Blyderivierspoort Dam on Blyde River																			
n	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188
Min.	6.7	6.13	1	0.2	3	2	2	2	14	0.1	0.003	0.020	0.020	1	27	0.1	0.20	0.11	0.045	0.455
5%	10.0	6.90	1.4	0.3	8	5	2.4	5	33.4	0.1	0.003	0.020	0.020	2.2	52	3.8	0.62	0.15	0.094	0.905
25%	14.7	7.51	3	0.4	11	7	4	8	51.8	0.1	0.006	0.020	0.090	3.2	72	10.7	1.05	0.21	0.158	1.347
50%	17.7	7.80	4	0.5	15	9	5	10	67	0.1	0.011	0.020	0.160	3.9	89	16.8	1.62	0.27	0.196	1.714
75%	21.0	8.08	5	0.7	18	11	6	12	83	0.2	0.015	0.050	0.240	4.8	105	31.7	2.21	0.36	0.239	2.007
95%	26.5	8.30	6.7	1.3	20	13.7	9	15	93.7	0.3	0.037	0.100	0.330	5.8	120	75.5	3.19	0.48	0.309	2.371
Max.	30.0	8.46	12	2.8	24	16	12	20	110	0.5	1.161	0.200	1.740	11.1	135	160.0	4.80	0.66	0.832	2.791
	#R-8 - B7R002 - Phalaborwa Barrage on Olifants River																			
n	156	156	156	156	156	156	156	156	156	156	156	153	156	153	156	156	156	156	156	156
Min.	16	6.47	7	0.2	12	7	5	4	47	0.1	0.003	0.020	0.020	4.2	76	0.3	0.21	0.12	0.397	1.513
5%	23.9	7.23	13.5	1.3	16.8	10	10.8	9	78	0.2	0.003	0.020	0.020	5.4	120	3.2	0.29	0.28	0.601	2.342
25%	33.9	7.69	24	1.6	21	14	24	15	101	0.2	0.003	0.020	0.020	6.4	174	9.2	0.36	0.39	0.978	3.357
50%	44.2	7.91	34.5	2	25	20	34	21	137	0.3	0.010	0.040	0.090	7.3	239	17.7	0.44	0.48	1.226	4.502
75%	51.9	8.30	43	2.9	28	24	43	30	165	0.4	0.017	0.070	0.240	8	281	34.3	0.63	0.61	1.440	5.317
95%	58.6	8.63	54	4	33.3	28.3	62	55.8	187.3	0.5	0.042	0.120	0.493	9.2	320	92.3	1.43	0.90	1.803	6.063
Max.	64.7	8.86	61	5	47	33	76	100	199	0.6	0.158	0.400	1.030	11.6	350	166.7	4.34	1.34	2.030	6.685

Table A4. (Continued).

Statistic	E.C.	pH	Cl	Na	K	Ca	Mg	SO_4	Tot. Alk.	F	PO_4-P	NH_4-N	NO_3-N	Si	TDS Calc.	Inorg. N:P	SO_4/Cl Ratio	Corr. Ratio	SAR Calc.	Sum of Cations
	#R-9 - B8H018 - Engelhard Dam on Great Letaba River																			
n	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142
Min.	13.6	6.08	9	1.8	8	4	10	2	36	0.1	0.003	0.020	0.020	0.2	73	0.8	0.02	0.09	0.615	1.297
5%	24.9	7.18	17	2.8	13	8	15.1	2	64.5	0.2	0.010	0.020	0.020	3.3	119	1.9	0.07	0.12	0.784	2.129
25%	31.2	8.03	22.0	3.9	20	11	23	7	103.3	0.2	0.016	0.050	0.040	6.0	167	5.0	0.11	0.30	0.915	3.034
50%	40.6	8.25	31	4.7	25	16	32	11	137	0.3	0.024	0.095	0.100	8	219	12.8	0.23	0.46	1.109	4.095
75%	61.2	8.44	40	5.4	34	24.8	42.8	16	217.3	0.3	0.031	0.253	0.388	9.8	328	40.2	0.34	0.64	1.382	6.405
95%	107.4	8.68	130.8	7.9	57	56	154.9	23.0	416.0	0.6	0.074	5.269	1.136	23.0	581	208.2	0.63	0.83	3.582	10.903
Max.	130	8.91	161	9.8	63	60	188	42	456	0.8	0.445	6.530	7.050	24.2	691	473.3	1.62	1.11	4.173	12.924
	#R-10 - B9H003 - Kanniedood Dam on Shingwidzi River																			
n	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Min.	9	6.29	6	2.3	6	3	2	2	26	0.1	0.003	0.020	0.020	0.4	51.8	0.2	0.01	0.06	0.462	0.869
5%	16.4	7.70	10	3.4	11	5.0	6.0	2	58.0	0.1	0.007	0.020	0.020	2.7	85.3	1.1	0.06	0.10	0.519	1.495
25%	27.9	8.15	16	4.5	21	9	8	6	119.5	0.2	0.015	0.020	0.020	5.1	150.1	4.2	0.16	0.15	0.741	2.774
50%	38.6	8.39	27	5.3	29	15	15	8	179	0.2	0.024	0.050	0.140	5.9	212.3	11.7	0.34	0.21	1.038	4.105
75%	53.4	8.54	48	6.4	34	19	44.3	13	215	0.3	0.038	0.140	0.390	6.8	284.7	20.8	0.59	0.41	1.638	5.346
95%	137.5	8.75	179.1	15.6	43	45.2	206.2	30.1	370.3	0.4	0.124	0.562	1.174	10.1	740.1	77.3	1.16	0.93	4.753	13.854
Max.	173.0	8.99	256	23.3	74	91	289	176	531	0.5	1.666	17.420	5.540	15.4	1021.4	651.7	2.00	1.89	6.002	18.448