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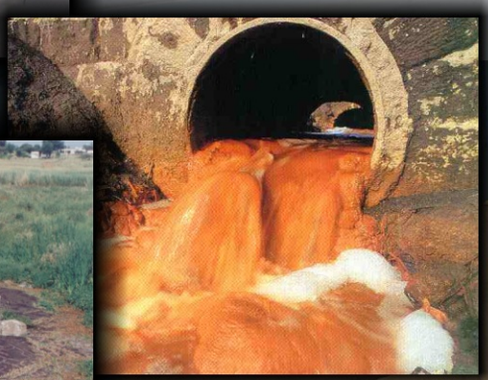
Orange River Integrated Water Resources Management Plan

Water Quality in the Orange River



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Reports:	Review of Existing Infrastructure in the Orange River Catchment
	Review of Surface Hydrology in the Orange River Catchment
	Flood Management Evaluation of the Orange River
	Review of Groundwater Resources in the Orange River Catchment
	Environmental Considerations Pertaining to the Orange River
	Summary of Water Requirements from the Orange River
	Water Quality in the Orange River
	Demographic and Economic Activity in the four Orange Basin States
	Current Analytical Methods and Technical Capacity of the four Orange Basin States
	Institutional Structures in the four Orange Basin States
	Legislation and Legal Issues Surrounding the Orange River Catchment
	Summary Report

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1 INTRODUCTION

A desktop assessment of the surface water quality status of the Orange River catchment was required as input into the development of the Integrated Water Resource Management Plan (IWRMP) for the Orange River. The objectives of the study were:

- Collection and assessment of information in reports dealing with water quality
- Collection and assessment of water quality data on the Vaal and Orange Rivers
- Approach to water quality management
- Overview of water quality status
- Identification of issues and gaps.

2 DESCRIPTION OF CATCHMENT FROM WATER QUALITY PERSPECTIVE

There are four countries making up the Orange River basin. These countries are Lesotho, Botswana, Namibia and South Africa. The catchment area that falls in South Africa has been divided into 5 Water Management Areas (WMAs) to facilitate the management of the catchment. The WMAs are the Upper, Middle and Lower Vaal WMAs and the Upper and Lower Orange WMAs. A brief description of the predominant land use in each of the WMAs and Lesotho as it pertains to water quality is given in the following sections.

2.1 Upper Vaal WMA

The Upper Vaal WMA is characterised by large urban centres, industrial areas, power generation, mining and agriculture. This part of the catchment is the economic hub of South Africa and is highly developed. The development has resulted in the local water resources being unable to meet the water requirements. As a result water is transferred into the catchment from surrounding WMAs and from Lesotho. Water is also transferred from the Upper Vaal WMA to adjacent WMAs. These transfers of water into the Upper Vaal WMA are often released into rivers for conveyance to Vaal Dam. These volumes of water are substantial, the impact of these transfers on the water quality in the receiving streams and the Vaal River System needs to be considered in the future water resource planning of the Orange River basin.

The large urban centres are located around Johannesburg and on the east and west Rand. These areas include industrial complexes and gold mining operations. There are many gold tailings dams located in these areas. The water quality in these areas are impacted on by discharges from the gold mines, seepages from the tailings dams, discharges from industry directly to the river, urban runoff and discharges from the large number of sewage treatment plants located in the urban areas. The return flows from these sewage treatment plants have resulted in the flows in many of the river systems exceeding the natural flows.

The largest sewage works are located in the Suikerbosrand and Klip River catchments. A summary of the capacity of the major water treatment works run by Johannesburg Water and Erwat are listed in Table 1.

Table 1: Summary of wastewater treatment plant discharge volumes in the Klip and Suikerbosrand River catchments

Catchment	Wastewater treatment plant	Nominal discharge volume (Mℓ/day)
Klip River	Goudkoppies	105
	Olifantsvlei	120
	Bushkoppies	170
	Dekema	36
	Rondebult	36
	Vlakplaats	83
	Waterfall	105
Total Klip River		655
Suikerbosrand	Ancor	41.3
	Benoni	18
	Daveyton	16
	Heidelberg	8
	JP Marais	21
	Jan Smuts Dam	9.1
	McComb	9.5
	Ratanda	5
	Rynfield	13
	Tsakane	12.4
	Herbert Bickley	10
	Carl Grundling	6
Total Suikerbosrand		169.3
Total Discharge		824.3

The treatment works return a total volume of 824.3 Ml/d to the river system. This amounts to an annual volume of 301 million m^3. The discharge volume is a significant portion of the naturalised Mean Annual Runoff (MAR) for the Vaal Dam of about 1800 million m^3/a. This represents a significant point source pollution load. The capacities of these plants will expand in the future as the urban areas grow and the sanitation systems are upgraded.

The coal mining is located in the Waterval and Grootdraai Dam catchments in the upper reaches of the Vaal River. The mining in the Waterval catchment supports the petrochemical industries located at Secunda while the mining in the Grootdraai Dam catchment supplies power stations with coal and coal for export. There is further coal

mining along the banks of the Vaal Barrage below Vaal Dam. The coal mining supplies the petrochemical industries located in Sasolburg and coal for power generation.

There are also industrial discharges into the Waterval catchment and directly to the Vaal River from the petrochemical plants located in Secunda and Sasolburg respectively. The other major industrial discharges are from the steel industry in Vanderbijlpark the pulp and paper industry in the Suikerbosrand catchment.

The gold mines in the Upper Vaal WMA also discharge dewatering water into the Vaal River and its tributaries. The average volumes and TDS concentrations of the mine discharges are listed in Table 2.

Table 2: Average discharge volumes from gold mines in upper Vaal WMA

Mine	Average discharge volume (Mℓd)	Average TDS concentration (mg/ℓ
Grootvlei Mine	65	3153
ERPM	37	2780
Western Areas Gold Mine	3.1	880
Harmony Randfontein	60	450
Blyvaruitzicht Gold Mine	11	850
Driefontein Gold Mine	36	1047
Kloof Gold Mine	50	570

2.2 Middle Vaal WMA

The Middle Vaal catchment is less urbanised than the Upper Vaal WMA and more rural in character. There are gold mines located in the Schoonspruit and Koekemoerspruit as well as in the Virginia area of the Sand Vet River system. There is also some diamond mining taking place in the WMA. There will be water quality issues related to the current discharges and seepage from the mines. In the long term there are issues in dealing with the decant from the mines post closure. Options of treating and re-using the mine water are being investigated.

The larger urban areas of Klerksdorp-Orkney-Stilfontein and Virginia are associated with the mining activities in the WMA. The point sources of pollution include the sewage treatment plants associated with these urban centres. There are generally issues related to the management of the sewage works and the sanitation systems in the urban areas.

The systems have become overloaded and there is further pressure on the works with the possible replacement of dry sanitation systems with water borne sanitation systems.

The agricultural activities taking place in the WMA include dry land and irrigation farming as well as stockwatering. The abstractions for agriculture are directly from the Vaal River and dams constructed on tributaries of the Vaal River.

2.3 Lower Vaal WMA

The predominant land use in the Lower Vaal WMA is agriculture. There are extensive irrigation schemes located on the Vaal River and along the Harts River. The water supply for the schemes is supported with releases from the Bloemhof Dam. The Vaal-Harts irrigation scheme draws its water from the Vaal Harts weir on the Vaal River. There are substantial return flow volumes from these schemes particularly the Vaal-Harts Scheme. These return flows impact on instream TDS concentrations and contribute significantly to the nutrient loads.

2.4 Lesotho

The runoff from the Lesotho Lowlands drains to the west to the Caledon River while the highlands drain to the south via the Senqu River to the Orange River. The lowlands area is susceptible to erosion and the Caledon River has transported large sediment loads causing extensive sedimentation of dams such as the Welbedacht Dam.

Lesotho is a source of significant quantities of good quality water. The transfer of water from the Lesotho Highlands to the Vaal Dam catchment results in a reduction in the volume of good quality water entering the Orange River. This will impact on the water quality of the Orange River and must be considered in future planning.

2.5 Upper Orange WMA

The two major river systems that drain the Upper Orange WMA are the Modder-Riet and the Orange River. The Modder-Riet drains to the Vaal River joining upstream of the Douglas weir. Bloemfontein and Thaba ‘Nchu are the main urban and industrial developments in the Upper Orange WMA. Two large hydropower stations were constructed at Gariep and Vanderkloof Dams in the Orange River. Mining activities have significantly declined and currently mainly relate to salt works and small diamond mining operations. The largest land use in the catchment is agriculture. There are a number of dams on the tributaries of the Modder-Riet which are used to supply irrigation water.

Agricultural water requirements represent 80% of the water requirements in the Upper Orange WMA.

2.6 Lower Orange WMA

The Lower Orange WMA is the lowest WMA in the Orange River Basin. The area is arid with rainfall varying from 400 mm in the east to 50 mm on the west coast. The topography of the area is flat with large pans or endoreic areas that do not contribute runoff to the Orange River system.

The Orange River forms the border between South Africa and Namibia. The Vaal River, the main tributary to the Orange River, has its confluence with the Orange River about 13 km west of Douglas. Other tributaries are the Ongers and Hartebeest Rivers from the south, and the Molopo River and Fish River (Namibia) from the north.

Sheep and goat farming is practised over most of the area, with large parts falling within conservation areas. Cultivation is restricted to isolated patches where somewhat higher rainfall occurs, and extensive irrigation is practised in the fertile alluvial soils along the Orange River valley. This irrigation is supplied with releases from the Vanderkloof Dam. Large mining operations occur in various parts of the water management area. The return flows from the irrigation areas contribute salinity and nutrients to the Orange River.

The water quality in the Lower Orange WMA is affected by upstream activities in the Vaal and Orange River catchments.

Given the arid nature of the Lower Orange River and the high potential evaporation, the evaporative losses result in an increase in concentrations along the length of the lower Orange River.

3 WATER QUALITY MANAGEMENT APPROACH

The water quality management approach adopted by the South African Department of Water Affairs and Forestry is described in the Internal Strategic Perspective (ISP) documents for the Vaal and Orange WMAs. The approach is to identify priority catchments where water quality management is urgently needed. A two phase approach is typically adopted to develop a strategy for the catchments.

The first phase involves a water quality situation assessment which is followed by the development of a catchment management strategy (CMS) as the second phase.

The water quality situation assessment studies typically involve the following:

- Collection and assessment of instream surface water quality data;
- The studies may include an assessment of the groundwater;
- Identification of pollution sources;
- Assessment of compliance of discharges with licence conditions;
- Collection of information on water management on mines and industrial facilities;
- Division of study area into management units;
- Collection of hydrological and water requirement information;
- Setting of Resource Water Quality Objectives (RWQO);
- Design of monitoring systems.

The setting of instream RWQO is based on the South African Water Quality guidelines and the water users in the study area. The RWQO were specifically developed to protect the water users and to guide the management of pollution sources. The RWQO were set as ideal, acceptable, tolerable and unacceptable. The second phase involves the development of a CMS to specifically develop strategies to meet the RWQO.

The RWQO have to date been developed for the priority catchments to protect the users within the catchment. The impacts of managing water quality in the individual catchments have not been aligned with the water user requirements of downstream water users. In other words the RWQO have not been integrated across the Orange River Basin. This was identified in developing the ISP for the Vaal and Orange Rivers. As a result a study to develop an integrated water quality management plan for the Vaal River has been commissioned by the South African Department of Water Affairs and Forestry and a study of the Orange River is planned.

4 COLLECTION AND EVALUATION OF REPORTS

Reports were collected from the library of the South African Department of Water Affairs and Forestry (DWAF) as well as from other sources such as Water Boards and Water Service Providers.

The assessment of the reports showed that the findings can be presented in two broad categories *viz* findings dealing with modelling and those describing the water quality situation. The list of reports collected is given in Appendix A.

4.1 Water quality modelling reports

The modelling reports described the calibration of the WQT hydro-salinity model on the Orange and Vaal Rivers. The model operates at a monthly time step and models total dissolved solids (TDS). The WQT model operates closely with the Water Resources Planning Model (WRPM). The water quality algorithms used in the WQT are replicated in the WRPM which allows the calibrated input parameters for the WQT to be used in the WRPM. This modelling system has been used to investigate blending and dilution water quality management options for the Vaal Barrage system.

Further models such as the NaCl suite of models has been applied to the Blesbokspruit and the Klip River to assess the impact of sewage treatment plant discharges on the receiving rivers. This work was done for ERWAT as part of the impact assessment process. The NaCl suite of models runs at a daily time step and models TDS. Nutrient modelling has also been undertaken on the Blesbokspruit and Klip River (Vaal Barrage Catchment) as part of the impact assessment process.

4.2 Water quality situation assessment reports

The water quality situation assessments have been undertaken on a number of catchments in the Orange River basin. The majority of the studies have been undertaken in the heavily mined areas of the Vaal River catchment. The results of the studies are that sets of RWQO have been established for a number of catchments. The water quality variables of concern differ between catchments but in general salinity as represented by EC, sulphate in the mining areas and nutrients as they relate to eutrophication are the common water quality variables of concern. The algae resulting from eutrophication has led to odour and colour problems in the intake water to water treatment plants which are not geared for dealing with eutrophic waters.

The presence of toxic algae has been reported in the Lower Orange River passing Upington. A monitoring system has been established to check on the development and movement of algal blooms in the lower reaches of the Orange River. The results of the monitoring program are communicated to the role players through the Lower Orange River Remediation Forum (LORRF) which has been established in the Lower Orange WMA.

Along the main stem of the Vaal organics has been raised as an issue by the water boards. Their monitoring programs have identified increases in Dissolved Organic Carbon (DOC) in the raw intake water to the water treatment plants.

This gives concerns regarding disinfection technologies used as the traditional chlorine disinfection can give rise to trihalomethanes if excessive organics are present in the intake water.

The Water quality monitoring programmes in the different areas of the Orange River Basin vary in frequency of measurement and water quality variables tested for. The water quality variables tested for depends on the sources of pollution present in the catchments. In general monthly grab samples are taken and at minimum the concentrations of the major cations and anions are determined.

At this stage there is limited continuous monitoring of water quality in the Orange River Basin. Attempts have been made in the past to install electrical conductivity probes and data logging systems at key points in the system but theft and vandalism has limited the life of the installation and precluded extensive use of these systems.

5 OVERVIEW OF WATER QUALITY STATUS OF ORANGE RIVER BASIN

A brief overview of the water quality status in the main stem of the Vaal and Orange Rivers was undertaken. The approach used was to collect water quality data at key stations on the Vaal, Caledon, Fish (Namibia) and the Orange Rivers. The water quality data was accessed from the South African Department of Water Affairs and Forestry, Windhoek Consulting Engineers and the Lesotho government databases and the details of the stations used in the analysis are listed in Table 3.

Table 3: Details of stations used in the water quality status overview

Station number	Station name	Lat	Long	Beg Date	End Date
DIH003Q01	Aliwal North	-30.679722	26.7125	29/01/1972	18/08/2004
D2H036Q01	Caledon	-30.279167	26.654167	12/05/1993	14/07/2004
D3R002Q01	Gariep Dam	-30.623056	25.507222	08/01/1971	12/10/2004
D3R003Q01	Vanderkloof Dam	-29.991111	24.731667	24/07/1971	29/10/2004
D7H002Q01	Prieska	-29.651389	22.746389	28/09/1965	08/05/2001
D7H005Q01	Upington	-28.460833	21.248889	01/11/1965	23/08/2004
D8H003Q01	Vioolsdrift	-28.760833	17.730278	11/11/1965	10/10/2004
C1R002Q01	Grootdraai Dam	-26.918056	29.295	18/11/1982	20/10/2004
C1H017Q01	Inflow Vaal	-27.0225	28.594444	16/11/1975	28/10/2004
C2R008Q01	Vaal Barrage	-26.853611	29.326111	06/06/1980	19/01/2005
C9H021Q01	Bloemhof Dam	-27.669167	25.618056	23/11/1972	19/10/2005
C9R003Q01	Douglas Barrage	-29.043333	23.836944	03/10/1977	26/10/2005
-	Naute Dam on Fish River (Purification plant raw water)	-	-	01/02/1997	01/09/2005
-	South Phuthiatsana River	-	-	20/10/1997	12/10/2002

The data covering the period 1994 to 2004 was analysed. The following water quality variables were analysed to give an overview of the water quality status of the basin:

- Electrical conductivity which gives an indication of the salinity or TDS of the river system. The EC was compared to the South African water quality guidelines for agriculture (most sensitive crops) and domestic. (Class 0, Class 1 and Class 2)

water uses to give an indication of the fitness for use of the water as far as salinity is concerned.

- Sulphate which gives an indication of the extent of mining pollution. The sulphate concentrations have been compared to the Class 0, Class 1 and Class 2 water quality guidelines for domestic use.
- Ortho-phosphate (as P) which gives an indication of the nutrient levels and the potential for eutrophication of the river system. The South African Water Quality guidelines give the trophic status associated with different concentrations of inorganic phosphorus

The concentrations associated with the different categories used in the water quality status assessment are summarised in Table 4.

Table 4: Concentrations associated with the different categories used in water quality status assessment

Water Quality variables	Ideal	Acceptable	Tolerable	Unacceptable
EC (mS/m)	<40 (irrigation)	40-70 (Class O)	70-150 (Class I)	>150 (Class II)
SO4 (mg/)	<200 (Class O)	200-400 (Class I)	400-600 (Class II)	>600 (Class III)
PO4 (mg/)	<0.005 (Oligotrophic)	0.005-0.025 (Mesotrophic)	0.025-0.25 (Eutrophic)	>0.25 (Hypertrophic)

The results of the analysis have been represented as pie charts on a map of the Orange River Basin. The sectors of the pies represent the fraction of the total samples that fall in the different concentration ranges used to assess the water quality. The results are given in,

Figure 1,

Figure 2 and Figure 3 for EC, sulphate and ortho-phosphate respectively.

The results of the analysis can be summarised as follows:

- The upper reaches of the Vaal River upstream of Vaal Dam has good quality water as far as salinity is concerned. The EC and sulphate concentrations meet Class 0 domestic water quality guideline. The general consensus as far as users are concerned is that the salinity aspects of the water quality meet their requirements but should not deteriorate any further.
- The salinity deteriorates along the stretch of the river from Vaal Dam to the Douglas weir. There is a significant deterioration in water quality from the Vaal Dam to the Vaal Barrage. This is due to the contributions from the Suikerbosrand, Rietspruit and Klip River catchments. This is largely driven by mine water sewage and industrial discharges as well as runoff from urban areas.
- The salinity in the Orange River from Lesotho to the confluence with the Vaal River is of good quality.
- The salinity deteriorates downstream of the confluence of the Vaal and Orange Rivers but still remains good. There is an increase in EC from the Prieska station to Vioolsdrift along the reaches of the lower Orange River. This is due to irrigation return flows and evaporative losses along the river.
- The measured EC data at Naute Dam on the Fish River (Namibia) showed that 93% of the EC reading met the Class 0 domestic water use guideline.
- The analysis of the water quality in the South Phuthiatsana River showed that the EC of the river is low with a maximum value of 25mSm. However, the ortho-phosphate concentrations are high with 43% exceeding 0.25 mg/ℓ i.e. falling in the hyperthrophic range. The source of the ortho-phosphate is from the runoff from the settlements scattered throughout the Lesotho lowlands catchment.
- The ortho-phosphate pie charts show that the ortho-phosphate concentrations are indicating potential for eutrophic conditions throughout the catchment and a possibility of hypertrophic conditions in the Vaal Barrage. There are a number of factors however that determine the extent of algal growth. These include the availability of other nutrients such as nitrogen, adequate sunlight and suitable temperatures. The turbid waters experienced in the catchment is limiting sunlight penetration and limiting algal growth. The pie charts shown in Figure 3 can only be considered indicative. However the indications are supported by observations and reports of algal blooms in impoundments, the Vaal Barrage and along the lower reaches of the Orange River downstream of the confluence of the Orange and Vaal Rivers.

6 ISSUES AND GAPS

The issues and knowledge gaps identified during this desk top overview of the water quality in the Orange River Basin are discussed in Table 5 below. Measures to address the gaps identified are also proposed for inclusion in the future phases of the development of the IWRMP for the Orange River Basin.

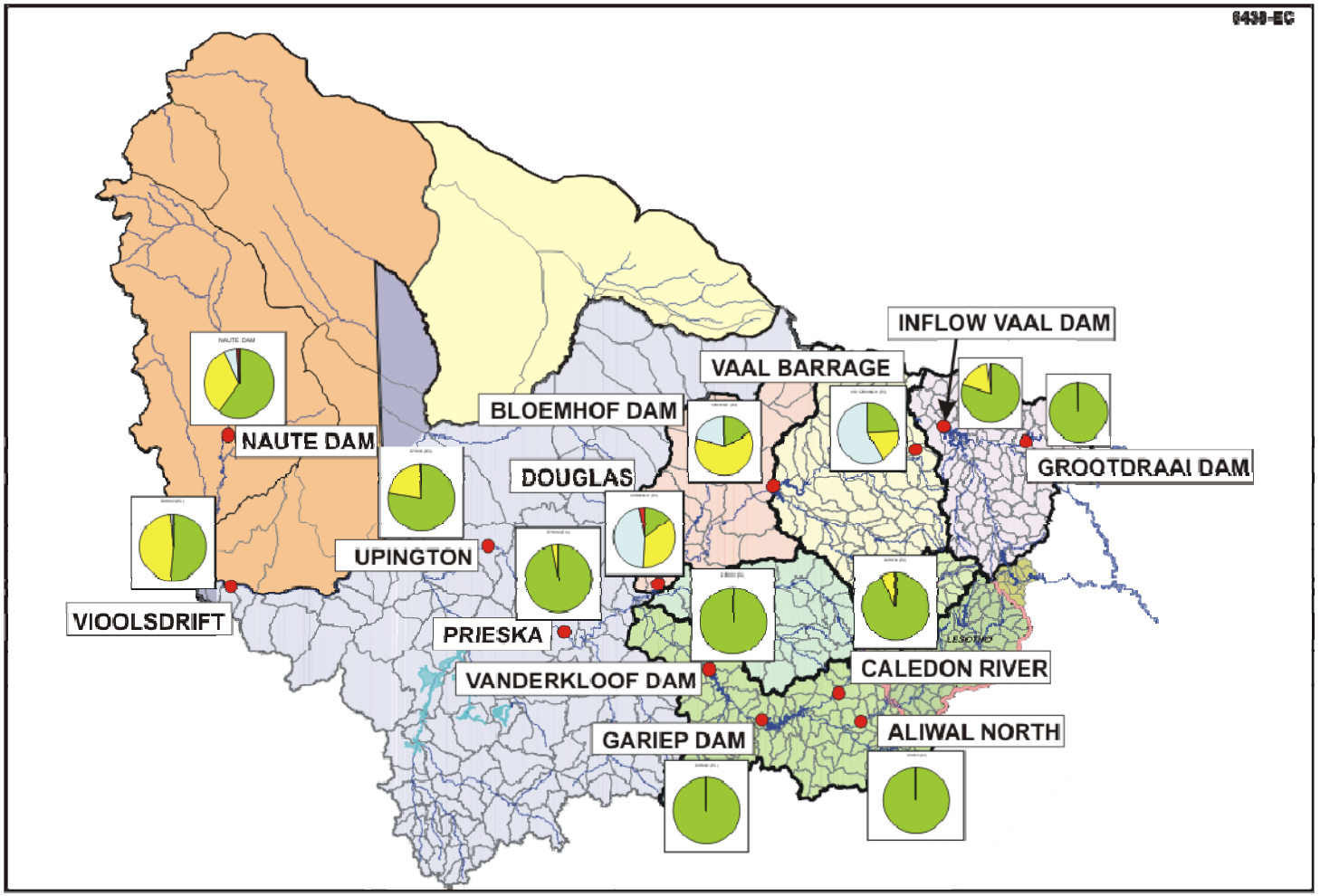

Figure 1: Pie charts showing water quality status for EC in the Orange River Basin

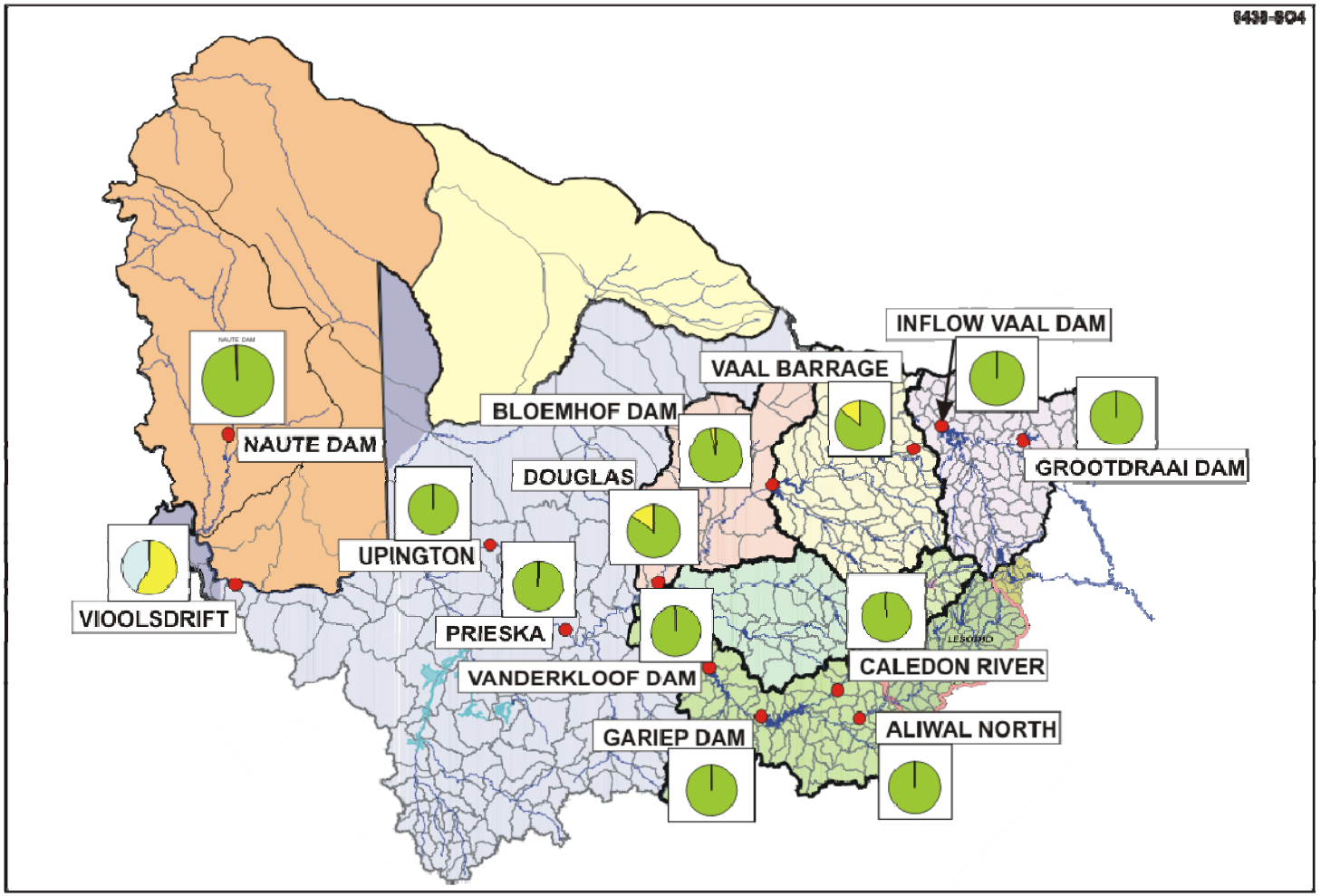

Figure 2: Pie charts showing water quality status for sulphate in the Orange River Basin

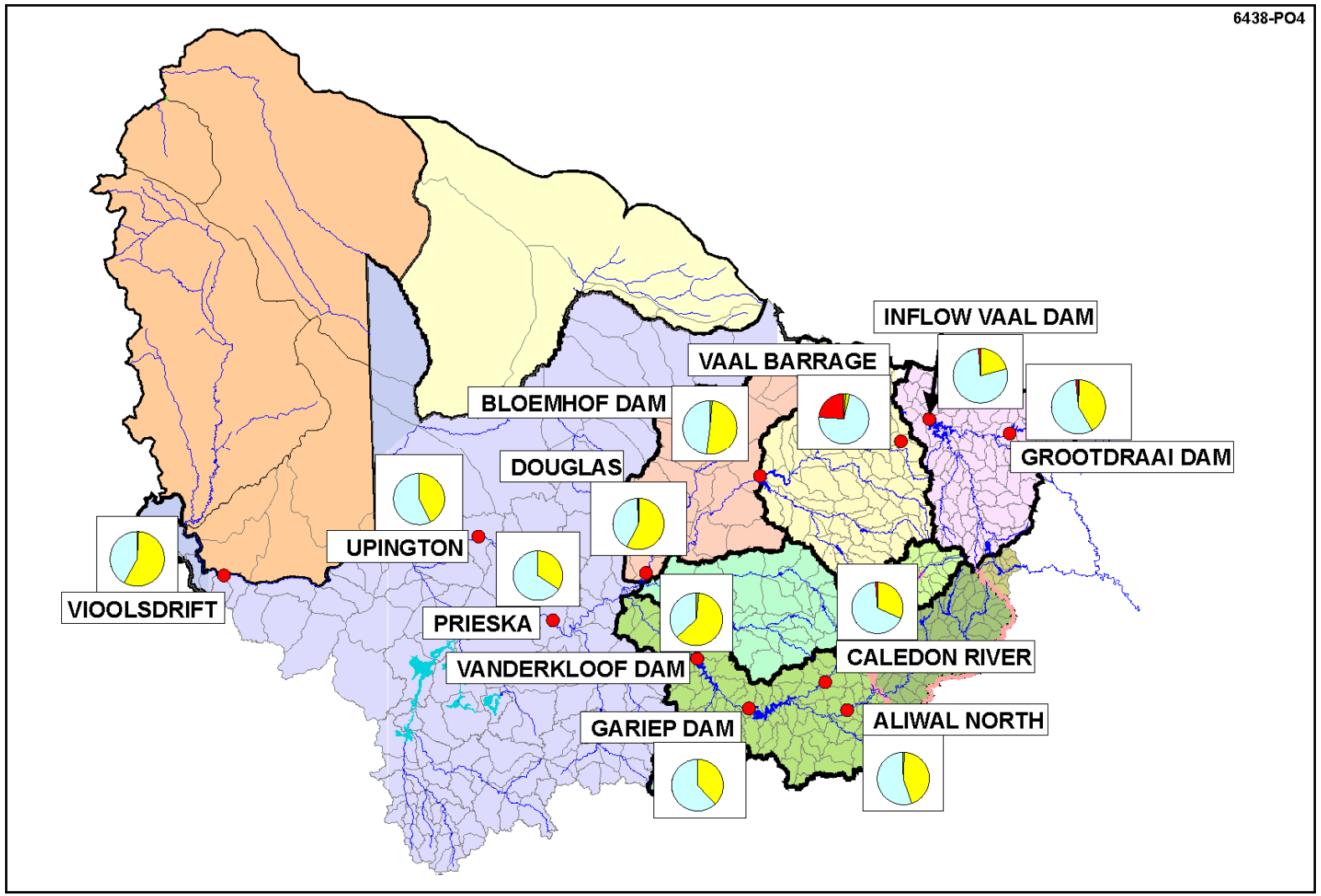

Figure 3: Pie charts showing water quality status for ortho-phosphate in the Orange River Basin

Table 5: Summary of issues and knowledge gaps

Issue	Description of issue and gap	Proposed measure to address gap
Insufficient water quality data and data management	During the analysis of the water quality data collected in the Orange River Basin, a number of issues related to data collection were identified : Data collection is fragmented between countries and institutions. The location of the water quality monitoring points are not optimal. The water quality variables analysed for are not consistent between institutions. The sampling frequency and the water quality variables. analysed for are insufficient to manage the Orange River Basin successfully. There is no single or standard data management and reporting systems. Lack of information on discharge volumes and qualities from sewage treatment works, mines and industries.	A coordinated monitoring programme needs to be developed to address : The establishment of monitoring objectives The monitoring point locations Frequency of monitoring and water quality variables to be tested for The current network of continuous water quality monitoring stations needs to be reviewed and expanded. In designing the system consideration should be given to real time management of both water quality and quantity Database systems, data management and reporting Institutional responsibilities and implementation program A series of workshops involving the major role players is the approach recommended to achieve the objectives listed above.
Eutrophication	The analysis of the water quality data showed that nutrient levels in the Vaal River, particularly in the Vaal Barrage, are such that there is a potential for eutrophic conditions to develop. The problems with excessive algae development are already reported by Sedibeng and MidVaal Water. The following gaps have been identified : A lack of understanding of the fate of nutrients once they are discharged to the river. The pathways for the nutrients, organics and algae growth need to be better understood. A planning level nutrient model needs to be developed and set up for the Orange River Basin. The model should allow for cause and affect modelling so that nutrient management strategies can be developed.	A project should be initiated that will investigate the nutrient mass balance and pathways. The Vaal Barrage catchment is the most impacted and the largest source of nutrients. A pilot scale project to determine the fate of nutrients within this catchment is proposed. If the pilot scale project proves to be successful the model can be rolled out to the entire catchment.

Issue	Description of issue and gap	Proposed measure to address gap
Integrated RWQO	The RWQO are being set in isolation in priority catchments. The integration of the RWQO for the Vaal River is being addressed in the Integrated Water Quality Management Plan (IWQMP) that is being developed for the Vaal River by the South African Department of Water Affairs and Forestry. The link between the Vaal and the Orange river needs to be addressed	The IWQMP for the Vaal River study needs to be extended to include the Orange River.
Mine water closure planning	The gold mine dewatering discharges contribute a significant salt load to the Vaal River System. The time frames for the continued mining depend on the gold price. Mines are starting to close down and flow of water between mines and the management thereof is becoming an issue. A management strategy for the mine water currently and post closure need to be developed.	Projects are being initiated by the South African Department of Water Affairs and Forestry and the Water Research Commission in South Africa to address the mine closure and water management issue.
Presence of pesticide and herbicides in the Vaal and Orange Rivers	There is extensive irrigation practised in the Vaal and Orange Rivers where herbicides and pesticides are used. These could be present in the return flows and conveyed in the surface runoff to the river systems. The current water quality database does not support the identification of pesticides and herbicides in the rivers.	A pesticide and herbicide monitoring program should be initiated to determine the extent of the problem

7 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be made as a result of this desktop study:

- The water quality has to be managed in conjunction with the development of the water resource for supply. The reduction in flow from Lesotho due to transfers to Vaal Dam could affect the water quality in the lower Orange. Similarly the management of the system to meet water requirements and generate hydropower should be coupled to the management of water quality;
- The salinity is currently being managed with releases of water for dilution from Vaal Dam. The modelling tools have been set up to manager the salinity aspects of the water quality of the Orange River Basin. The consensus is that the salinity aspects of the water quality meet user requirements. However the water quality must not be allowed to deteriorate further.
- Many of the coal and gold mines are closing down and the workings are starting to fill and will decant some time in the future. Management strategies have to be developed to manage the filling process and the decants.
- Nutrients and the resulting algal growth are an issue. The modelling of nutrients has not reached the same level as salinity and the nutrient pathways are not well understood. Attention will have to be given to the development of modelling tools, management of point sources such as sewage works as well as diffuse sources associated with runoff from urban areas and agriculture. A nutrient management strategy needs to be developed.
- Currently very little information is available on pesticides and herbicides in the river systems. There is extensive agriculture on the banks of the Vaal and Orange Rivers. The presence of these pollutant types should be determined by designing and carrying out a round of monitoring.
- An integrated water quality monitoring programme and data management systems need to be developed for the Orange River Basin. The monitoring programme should include discharge information.

8 APPENDIX A: REFERENCES

Title	Document No.	Author	Date
Water Quality Modelling for the Vals and Renoster Rivers	PC 000/00/8688	Stewart Sviridov& Oliver	1988
Preliminary estimation of the impact of air pollution on the water quality in the Vaal Dam	PC 000/00/8989	Stewart Sviridov& Oliver	1989
Kromdraai Option	PC 000/00/9089	Stewart Sviridov& Oliver	1990
Internal Strategic Perspective for the Vaal River System Overarching	PC 000/00/0103	PDNA,WRP, WMB and Kwezi-V	March 2004
Development of Resource Directed Water Quality Management Policies	Sub-Series No. WQP 1.5	DWAF	February 2005
Internal Strategic Perspective for the Upper Vaal WMA	PWMA 08/000/00/0304	PDNA, WMB, V_3 and WRP	March 2004
Preliminary evaluation of options for improving the Quality of the Water Supplied to Christiana	PC 000/00/9189	Stewart Sviridov& Oliver	November 1989
Blending options for the Western Transvaal Regional Water Company and the OFS Goldfields Water Board based on Rietfontein Dam and Klip Dam	PC 000/00/8788	Stewart Sviridov& Oliver	July 1989
The potential effects on the Eutrohpication of the Middle Vaal River	NC 200/00RPQ/2790	DWAF	March 1991
Initial Environmental Impact Report of the status quo of the existing wastewater infrastructure	Final report	PMFG Teurlings, DJ Otto,M Matsabu, CE Herold, G Schoeman, Mr. Howard, J Rall and HNS Wiechers	February 1997
Practical Implications of the Blending Option	PC 000/00/2885	Stewart Sviridov& Oliver	May 1985
Summary of the data acquisition and assimilation carried out by the consultants for the Southern PWV Catchment	PC 000/00/10190	Stewart Sviridov& Oliver	July 1991
The Development of techniques for the evaluation and effective management of surface and ground water contamination in the OFS Goldfields	WRC Report No. 224/1/92	Institute for Ground Water Studies-University of OFS	June 1996
Impact of the Mining Industry on reference to the Impact of Gold mine Residue Deposits	JVW-0024-WPD	DWAF	June 1996

Title	Document No.	Author	Date
Water Quality Monitoring Requirements for salinity Modelling	PC 000/00/92	DWAF	December 1992
Assessment of the feasibility and impact of alternative water pollution control options on TDS Concentrations in the Vaal Barrage and Middle Vaal	WRC Report No.326/1/93	JAC Cowan & P Skivinngton	Sep 1993
An assessment of Water related problems of the Vaal River between Barrage and Douglas Weir	TR 121	DWAF	
Water Quality Management Plan: Phase 1 scoping Report		Rand Water & DWAF	April 1996
Hydro-Salinity model calibration: upper Vaal Catchment	PC 000/00/18096	DWAF	December 1998
Grootdraai Catchment Water Quality Situation Assessment (Draft)	5005/6965/2/W	Golder Associates	February 2006
Annual Operating Analysis for the Integrated Vaal River System	2003/2004	DWAF	5 August 2003
Vaal river Liaison Forum	PC000/00/0193	DWAF	16 November 1993
Surface water Quality of South Africa(1979-1988) Volume 3: Drainage Region C and D	TR 145	DWAF	November 1990
Hydro-Salinity Model Calibration: Vaal Barrage Catchment	PC 000/00/18196	DWAF	April 1998
Hydro-Salinity Model Calibration: Middle Vaal Catchment	PC 000/00/18296	DWAF	January 1999
A Model to simulate the daily Water and Salt balance un the Vaal River Water Supply System	Report No.5/81	Hydrological Research Unit-WITS, Johannesburg	May 1981
Vaal Dam Salinity Assessment with particular reference to Atmospheric Deposition		D Stewart	February 1991
Mooi river Catchment Management study: Phase 1, Situation Analyses	16/14/231/1	DWAF	October 1998
Vaal River Water Quality Management Study: Kroomdraai Option	PC 000/00/9089	Sviridov& Oliver	March 1990

Title	Document No.	Author	Date
Development of a water Quality Management Plan for the Klip River Catchment, Situation Analyses (Phase 1)	4117	DWAF	August 1999
Evaluation of the Quantity and Quality of purified effluent discharged from Johannesburg Drainage Basin Waste water Treatment Works: volume 4	Pulles Howard and de Lange, Greater Johannesburg Transitional Metropolitan Council and Stewart		August 1996
Situation Analyses of Eutrophication related Water Quality		DWAF	February 1995
Southern Waste Water treatment Works on the Klip River, Volume 7	Pulles Howard and de Lange, Greater Johannesburg Transitional Metropolitan Council and Stewart		August 1996
Hydrology of the Klip River System: Volume 6	Pulles Howard and de Lange, Greater Johannesburg Transitional Metropolitan Council and Stewart		August 1996
Overview Report, Volume 1	Pulles Howard and de Lange, Greater Johannesburg Transitional Metropolitan Council and Stewart		August 1996
Development of a Waste Water Quality Management Plan for the Klip River Catchment: Situation Analyses, Phase 1	4117	DWAF	August 1999
Practical Implication for the and Blending Option (Development of water management Plan) volume 6		DWAF	September 1997
Background to the study and overview of the study area and Greater Soweto Water Quality Monitoring programme and Assessment of available data: Volume 2	Pulles Howard and de Lange, Greater Johannesburg Transitional Metropolitan Council and Stewart		August 1996
Land use/ Diffuse pollution surface relationships(Part 1), klip River Water Quality Situation	Pulles Howard and de Lange, Greater Johannesburg		August 1996

Title	Document No.	Author	Date
Analyses (part 2), point and Diffuse source pollution load projection: volume 6	Transitional Metropolitan Council and Stewart		
Selection, Calibration and verification of a river water quality model (part 1), simulation and Evaluation of Management options (part 2), Costing of Management options (part 3) Volume 7	Pulles Howard and de Lange, Greater Johannesburg Transitional Metropolitan Council and Stewart		August 1996
Catchment Management Strategy for the Modder and Riet Rivers (Water quality Assessment) Draft Report		BKS	May 2002