A Preliminary Examination of Water Quality Compliance in a Selected Lowveld River: Towards Implementation of the Reserve

Report to the

WATER RESEARCH COMMISSION

by

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Executive Summary

BACKGROUND AND RATIONALE

South Africa's National Water Act (No. 36 of 1998) provides for water in sufficient quantity and of sufficient quality for basic human needs and for maintenance of aquatic ecosystem function. South Africa has been recognised as having excellent water research, policy and law; however, these have not always translated into excellent water resource management. A notable failure has been a decline in the quality of surface waters in the country (CSIR 2010).

The Shared Rivers Initiative arose out of concerns that despite enabling legislative and institutional frameworks, the flows of rivers that flow eastwards from South Africa and are shared with a neighbouring country have not improved or have degraded. As these rivers offer direct benefits to a range of stakeholders and are also governed by international treaties regulating the quantity and quality of water leaving South Africa, the implications of degradation are considerable. Research arising out of the Shared Rivers Initiative focussed largely on flow-related issues, and found for the most part that the rivers under study were not compliant with flow levels as set out in recent ecological Reserve studies (Pollard and du Toit 2010).

This project aims to assess aspects related to the water quality component of the ecological Reserve, using the Crocodile River in the Inkomati catchment as a case study. The Crocodile River was selected as it has been identified as water-stressed, but has been receiving management attention of late. The Crocodile River is also one of the rivers that were assessed as part of the Shared Rivers Initiative.

AIMS

The specific aims of this research are presented below.

- To use recent Shared Rivers Initiative Phase 1 research products as a basis for engaging in deepening understandings of "compliance" with water quality requirements of the ecological Reserve.
- To examine synergies with the quality component of the basic human needs Reserve, other sectors and guidelines.
- To initiate the development of an analytical and conceptual framework for testing compliance with the water quality component of the ecological Reserve.
- To initiate testing of this for a selected river included in the Shared Rivers Initiative and to explore linking this project to the Shared Rivers Initiative.
- To initiate communication of the research process and outcomes with stakeholders and water resource managers.

WATER QUALITY AND QUANTITY IN THE ECOLOGICAL RESERVE

A comprehensive ecological Reserve study uses information on driving variables (hydrology, geomorphology and physicochemistry) and response variables (fish, aquatic invertebrates and riparian vegetation) in setting a Reserve. This chapter contrasts approaches to the water quality and quantity aspects of the ecological Reserve. The focus will mainly be on Reserve outputs and less on the

Reserve processes. Some attention is also given to research assessing compliance with the water quantity Reserve, as a potential indicator of the likelihood of compliance with other aspects of the Reserve and of issues related to the assessment of compliance.

Some flow patterns are more important than others in maintaining instream ecological functions, and these may be characterized in terms of the magnitude, frequency, duration, rate of change and timing of flows in a river (Poff et al. 1997). Consideration of the flow requirements of the ecological Reserve therefore requires consideration of more than simply the quantity of water present in the system.

The Reserve process for flows follows the standard eight-step Reserve process, from study initiation to Reserve implementation, with the majority of input for the flow process occurring in steps three and four. The output of an ecological Reserve flow assessment is a rule table that is equivalent to a flow duration curve. The tables contain Environmental Flow Requirements (EFR) for low flows, on a monthly basis and with varying levels of assurance. Low flow EFRs represent largely continuous or slowly changing background flows and account for seasonal changes in flow. High flow EFRs are considered in the rule table, but need more description elsewhere (to account for duration, peak flow, frequency, etc.).

Ongoing monitoring is imperative for the water quality and quantity aspects of the ecological Reserve in order to ensure that all targets are met and that targets may be revisited where it is appropriate.

The EFR at any point in time is described in relation to real-time natural flows. As such, the Reserve for water quantity can be viewed as a proportion of the natural flow at any point in time. The upshot of this is that compliance with the Reserve can be assessed in real time in a catchment where current natural flows are known or can be estimated, and, in a managed catchment, steps to address non-compliance can be taken promptly. This is fundamentally different to how compliance with the water quality aspect of the Reserve may be monitored, as, in the latter case, compliance is assessed by comparison of percentiles of a data set collected over time with boundaries set during the Reserve process (DWAF 2008a). As such, compliance is largely assessed retrospectively and real-time action to manage compliance with the Reserve is for the most part not possible.

Relatively little published work is available on compliance with the flow aspect of the Reserve. This report draws largely on work undertaken to assess compliance with the quantity aspect of the Reserve in the Levuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati Rivers (Pollard et al. 2010, Pollard and du Toit 2010).

These authors report as problematic that the precise nature of compliance with flow aspects of the ecological Reserve is not clear. Assessments of compliance may be modified by monitoring frequency and by the locations of gauging stations with respect to Environmental/Ecological Water Requirement (EWR) resource units. The degree of uncertainly in Reserve determinations also complicates the strict definition of compliance.

Assessment of compliance with the flow aspect of the ecological Reserve may be undertaken from a historical perspective by using historic flow records. This may be useful in identifying trends in compliance, but does not allow for contemporaneous management intervention to achieve compliance. However, given an estimation of natural system flow at a point, compliance can be assessed in real or near-real time, which is more tractable to management intervention and therefore to maintenance of compliance. However, obtaining an estimation of natural flow is not straightforward. One approach may be to extrapolate from measured flow in an undeveloped part of the catchment. Another approach is to model natural flow based on real-time rainfall combined with historical records.

Operationalizing the Reserve raises difficult questions as to future natural flows, as water users need information on future flows and the future Reserve in order to plan and manage water requirements. In a related light, the variability of South Africa's water resources mean that abstraction licenses need to acknowledge that curtailment of abstraction may be necessary at times. Given the lack of monitoring capacity, an element of self-regulation on the behalf of licensees (particularly run-of-river users) is essential to ensure compliance. Strengthening of institutional capacity and the involvement of stakeholders in management will help in this regard.

It has been reported that water resource managers have found the output of ecological Reserve determinations, as rule tables or flow duration curves, to be too complex to implement, and some default to earlier and simpler operating rules. As a result, the introduction and testing of tools, frameworks and management systems to enable operationalization of the Reserve is imperative.

REVIEW AND CRITIQUE OF METHODS FOR WATER QUALITY ASPECTS OF THE ECOLOGICAL RESERVE

This chapter reviews and critiques the methods used to determine the water quality component of the ecological Reserve. It should be noted although these methods have been written up (DWAF 2008a) and used in a number of Reserve studies, they have not been finalized at the time of writing. A recent comprehensive Reserve study on the Crocodile River in the Inkomati catchment is used as an example of the methods used in determining the water quality component of the ecological Reserve (DWA 2009a, 2010 and other Reserve documents). The findings are presented broken up into stages according to the eight-step Reserve process.

During project initiation and scoping, the geographic scope, depth of study, and level of confidence in the results is decided. A range of background data on the catchment are assembled, and the level of confidence in the study is determined based on the availability and quality of data collected (and the opportunities for further data collection), and the project time frame and budget. In the example of the Crocodile river, the study was undertaken on the Crocodile and Sabie river systems in the Inkomati catchment in WMA5. This Reserve study was undertaken at a comprehensive level, and therefore a wide range of water quality variables and biotic indicators were assessed. The methods used in this step of the study were considered to be generally adequate, although is noted that budgets assigned need to be sufficient to cover all data and analyses required.

The second stage of a Reserve study involves the delineation of Resource Units (RUs) along the river. When undertaking the water quality component of a Reserve study, this phase involves identification of Water Quality Sub-Units (WQSUs) used to define RUs. Once the RUs are defined, they are used to identify Environmental Water Requirement (EWR) sites. For this phase, information is required on dams, towns, tributaries and point-source pollution entry points along the length of the river. A part of this process is the identification of data that will be used to define the Reference Condition (RC) of the river, as well as data to define the Present Ecological State (PES) for each WQSU. During the Crocodile River study, data used in this step included publications regarding water quality in the catchment, geographic and geological data, land cover and ecoregions, and input from a range of stakeholders. Six EWR sites were selected along the river, plus one on a tributary, at the end of this phase. The methods critique found the approach used to be satisfactory.

The third step in a Reserve study involves analysis of available data leading to EcoClassification of the selected RUs. This step involves field surveying and data collection, identification of data for RC and PES, mapping, data analysis and production of appropriate summary statistics, classification of summary statistics against benchmarks, running the Physicochemical habitat Assessment Index (PAI) model to produce an integrated water quality category for each EWR site, and finally integration of PAI status with other driver and response indices to determine the overall site EcoStatus. In the Crocodile River example, a survey was undertaken and samples for water quality, chlorophyll-a, and diatom populations were collected. Water quality data tables were compiled from these and Department of Water Affairs' (DWA) data, and PAI models completed for each EWR site, followed by EcoStatus derivation. This phase enabled the identification of impacts on the quality of the water along the river. The methods critique identified the following flaws in the current methodology: no methods are available for derivation of the RC where data or conditions are unfavourable; method development would profit from a greater degree of peer review and input; the tool used to assess salt toxicity risk from ionic data (TEACHA) is crucial to the Reserve process (and water use licensing), but has several flaws that need to be addressed; the Reserve water quality methods have not been formally finalized; and a more structured process for communication regarding the methods or changes thereto is recommended.

The fourth and fifth steps in this process involve the production of additional water quality information together with interpretations of trends, and the production of water quality input to a range of Ecological Categories (ECs) and operational scenarios. The latter may involve water quality modelling for comprehensive Reserve studies. An example of the steps taken at one EWR site in the Crocodile River is presented. As appropriate models for all water quality parameters have not yet been developed, a qualitative approach to water quality modelling was used. The critique of the methodology in these steps relates to the lack of adequate water quality models. Although models are available for conservative compounds (e.g. many salts), modelling of more labile compounds (e.g. nutrients, oxygen) is far more problematic as concentrations of the latter are not dependant on water volume alone. A model is needed that can utilize data on all known point sources of pollutants and also estimate diffuse pollution loads based on land use patterns. Such a model would need to incorporate estimates of change owing to biological and chemical conversions, as well as rates of loss to the sediments. This model would ideally work on a catchment scale. The application of a model would facilitate the Reserve process and would also be valuable for other aspects of water quality management (e.g. setting Resource Quality Objectives (RQOs), licensing, etc.).

In the sixth step of the Reserve process, management classes for management units are selected. This involves the use of information beyond the ecological (e.g. social, cultural, economic, etc.).

The seventh step of the Reserve process involves specification of the Reserve. During this process, EcoSpecs and Thresholds of Potential Concern (TPCs) are set for each EWR site. EcoSpecs are clear and measureable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that define the EC and serve as input to RQOs. TPCs are values around the EcoSpecs that, once approached, initiate more detailed investigation or management intervention. During the Crocodile River study, Rapid Habitat Assessment Method (RHAM) TPCs were set to facilitate monitoring. TPCs were also set for physicochemical water quality parameters. TPCs are presented as 95^{th} percentiles (values not to be exceeded more than 5% of the time) for inorganic salts, physical variables, and toxins, and as 50^{th} percentiles for nutrients. EcoSpecs were set for quantifiable and measureable physicochemical parameters only. The major critique of this step is that no forum exists for methods development, review, and optimization.

The final step in the Reserve process is Implementation, and is the responsibility of the implementing agent, and utilizes a number of tools unrelated to Reserve methodology. Water quality input feeds into the Reserve templates prepared for gazetting.

COMPLIANCE WITH WATER QUALITY ASPECTS OF THE ECOLOGICAL RESERVE IN THE CROCODILE RIVER

This chapter assesses whether the test case selected, the Crocodile River in Water Management Area 5 (WMA5), is compliant, in terms of water physicochemistry only, with the specifications laid out in the recent comprehensive Reserve study (DWA 2009a, 2010). Methods for water quality monitoring have not been finalized, and as a result this chapter uses the Reserve recommendations for monitoring. Compliance was assessed against PES EcoSpecs, Recommended Ecological Category (REC) EcoSpecs (where these differ), and also against TPCs. The chapter also examines the implications of dataset selection for use in compliance monitoring.

Data sourced from DWA Water Management System (WMS) were used in monitoring of compliance. Appropriate percentiles for all monitoring sites were derived from monitoring datasets (where data was available) and these were compared with PES and REC EcoSpecs, and with TPCs given in Reserve documentation.

No data were available in WMS to assess compliance with physicochemical aspects of the Reserve at the two furthest upstream monitoring sites, and it was therefore not possible to assess compliance at these sites. As a result, physicochemical compliance along approximately 80km of the upper Crocodile River is not known.

All remaining monitoring sites were non-compliant with PES EcoSpecs for at least two water quality parameters. Non-compliance, as measured by the proportion of assessed parameters that were not compliant with Reserve PES EcoSpecs, increased downstream until peaking at Malelane (with 36% non-compliance with PES EcoSpecs in all datasets assessed). Levels of compliance improved slightly further downstream, but water at the most downstream of the monitoring sites (before the Crocodile River joins the Inkomati River and crosses the border to Mozambique) was not fully compliant with respect to water quality.

Levels of magnesium sulphate were found to be non-compliant with PES and REC EcoSpecs at all sites that could be assessed. The importance of this is not clear as the method used for derivation of magnesium sulphate levels from ionic data has been found to over-estimate magnesium sulphate levels (DWAF 2008b). Other general trends across sites include a tendency of pH levels to exceed EcoSpecs or TPCs on the lower 5^{th} percentile, levels of un-ionized ammonia exceeding EcoSpecs, and a severe lack of data on toxic substances identified in the Reserve study as potentially problematic in the catchment, as well as limited data on chlorophyll *a*, dissolved oxygen levels and turbidity.

Other trends along the length of the river include elevated levels of plant nutrients (as phosphate or total inorganic nitrogen) leading to non-compliance at upstream sites, and elevated sodium chloride levels leading to non-compliance at downstream sites.

Monitoring recommendations in DWA Reserve documents state that three to five years' worth of data, or a minimum of 60 data points, should be used for monitoring. Given the data available from WMS, and these monitoring data requirements, this chapter additionally assessed the impact of dataset selection for water quality monitoring. Despite a general agreement between datasets, use of longer five-year datasets returned somewhat lower levels of compliance than when other datasets were assessed. When the implications of differing sizes of monitoring datasets were examined, it was noted that the size of the dataset modified the power of the test, the sensitivity of monitoring to short-term changes, and also the "memory" of the dataset with respect to non-compliance events.

Other observations or recommendations made in this chapter include the recommendation that monitoring programmes at all sites be instituted or continued, and that such monitoring programmes should cover all water quality parameters in the Reserve study (including e.g. toxic substances that have been found at high levels). Even if physicochemical monitoring should not form part of a first level monitoring programme, the data need to be available should they be required.

The derivation of salt levels from ionic data allows ionic levels in river water to be linked to the risks posed by various salts as identified in toxicological tests. The use of "reconstituted" salt levels based on ionic data is therefore an important part of the Reserve process. The only tool currently available for salt concentration derivation from ionic levels in Reserve studies is TEACHA (Tool for Ecological Aquatic Chemical Habitat Assessment). It is recommended that TEACHA be revisited, with the primary aims of: reassessing methods for salt (especially magnesium sulphate) level derivation; revising data requirements, user interface and error handling; requirements for MATLAB; and methods for handling left-censored data.

INITIATION OF AN INTEGRATED WATER QUALITY MANAGEMENT FRAMEWORK FOR THE CROCODILE CATCHMENT

South Africa has been lauded for statutory reforms and conceptual and methodological sophistication with regard to the determination of environmental water requirements (both quality and quantity). However, despite such excellent research, policy and law, a decline in surface water quality evidences a failure to transform this into water quality on the ground. This report has reviewed water quality aspects of the ecological Reserve, and has assessed the state of compliance in a test catchment. In this chapter we focus on the factors that constrain or enable compliance. We emphasize that attaining a state of compliance is not something the water sector alone can address, but it will require the contributions and synergies of a number of players, strategies, plans and practices in a process termed integrated water resource management (IWRM).

This research uses the Crocodile catchment as a test case. The research builds upon work from the Shared Rivers Initiative (SRI) undertaken in this area. A participative research process was adopted that recognises inhabitants of a catchment as important role-players in the enquiry process. Organisation and maintenance of stakeholder processes is recognised as important and is built into the research design by promoting collective engagement and collaborative learning. Primary research questions relate to how stakeholders understand compliance with water quality aspects of the ecological Reserve, and what research and operational interventions might improve compliance with water quality aspects of the ecological Reserve. Research participants were selected to represent regulators, water users and researchers.

Water quality issues raised most frequently as problematic by participants were, in order: wastewater treatment works effluent; paper and pulping effluent irrigation; nitrate and phosphate pollution owing to commercial agriculture; elevated sediment loads owing to soil erosion processes; and elevated levels of manganese and iron in water. A wide range of perceived problems were raised less frequently than those presented above.

It was found that different sectors frequently used different water quality standards in their operations, and that even within one sector, different participants may use different standards. General Effluent Standards (GES) were the most widely applied, followed by Special Effluent Standards (SES), Water Use Licence (WUL) requirements, and instream biomonitoring using SASS5. Beyond these, water quality standards that were applied might derive from, amongst others, other standardization organisations (e.g. ISO, EU), particular industry or company standards, and standards laid out by government departments other than DWA. No participants beyond those representing the Inkomati Catchment Management Agency (ICMA) identified Resource Quality Objectives (RQOs) as applicable to the catchment.

It was noted during this research that the various sectors tend to identify sectors other than their own as sources of water quality management problems. In this respect there is little public admission of problems stemming from own practices. This is not unexpected, but it stands to hamper reflexivity, transparency and a spirit of cooperative learning. Ongoing engagement may reduce defensiveness and engender a greater sense of collaboration.

The number of institutions involved in water management and their scope and function were found to be confusing by the participants. This was exacerbated by the changing and evolving roles of DWA and ICMA. Centralization and/or coordination of roles in water management was recommended.

Participants identified a duplication of effort where quality monitoring was undertaken, and recommended that water quality monitoring by all stakeholders should be coordinated. In a similar fashion, all data collected during water quality monitoring should be shared or be available to all to facilitate management of the resource.

Ongoing frustration with the ability to enforce standards was expressed by participants. Poor enforcement has led to a lack of confidence in the regulator and to conditions where transgressors are defiant of the law. Poor enforcement is complex and stems from a number of issues relating to capacity and staff training, lack of experience with new legislation, failure to assign or delegate functions to the competent authorities and poorly coordinated enforcement practices.

The need for a more integrated water quality management framework was expressed. This would facilitate streamlining, minimise duplication of effort, and clearly specify roles and responsibilities.

The research reported on here outlines water quality issues as perceived by stakeholders in the catchment and their recommendations to address these issues; it also has initiated collaboration towards an integrated water quality management plan for the catchment.

GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The results presented in this report are discussed in the relevant chapters. Several major conclusions and recommendations arise from the work reported on here and are presented below.

The methodologies and approaches underlying the water quality aspects of the ecological Reserve and those underlying the water quantity or flow aspects of the ecological Reserve would benefit from reassessment and harmonization. This would be facilitated by the development of better methods for water quality modelling than are currently available.

The existing documentation of a methodology for the determination of the water quality aspects of the ecological Reserve needs to be revised as described in the methods critique sections of Chapter 3, externally reviewed, finalized and approved by the DWA.

A monitoring and compliance process for the regulation and enforcement of the water quality aspects of the ecological Reserve in relation to discharge licences and non-point-source pollution needs to be developed in collaboration with users, managers and the regulator, externally reviewed, finalized and approved by the DWA.

The catchment participatory processes initiated in this project need to be followed up and developed in co-operation with water users, the DWA and the ICMA into an Integrated Water Quality Plan, first for the Crocodile River, and then extended into the broader Inkomati Catchment area.

A research process to address the above is presented.

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Abbreviations and Acronyms

AEC	Alternative Ecological Category
ASPT	Adjusted Score per Taxon
BBM	Building Block Methodology
BEC	Baseline Ecological Category
BOD	Biological Oxygen Demand
CARA	Conservation of Agricultural Resources Act, 1983
CD: RDM	DWA Chief Directorate Resource Directed Measures
chl-*a*	Chlorophyll *a*
CMA	Catchment Management Agency
COD	Chemical oxygen demand
D: RQS	DWA Directorate Resource Quality Services
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
DO	Dissolved oxygen
DoA	Department of Agriculture
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
dti	Department of Trade and Industry
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EC	Electrical Conductivity
EcoSpecs	Ecological Specifications
EFR	Environmental flow requirements
EIA	Environmental impact assessment
EIM	Environmental impact management
EIS	Ecological Importance and Sensitivity
ERA	Ecological Risk Analysis
EU	European Union
EWR	Ecological/Environmental Water Requirements
FDC	Flow duration curve

FSC	Forestry Stewardship Council
FSR	Flow Stressor Response
GA	General Authorization
GES	General Effluent Standard
IB	Irrigation Board
ICMA	Inkomati Catchment Management Agency
IDP	Integrated Development Plan
ISO	International Organization for Standardization
IWRM	Integrated Water Resources Management
MRU	Management Resource Unit
NGO	Non-governmental organizations
NRF	National Research Foundation
NTU	Nephelometric Turbidity Unit
NWA	National Water Act (No. 36 of 1998)
PAI	Physicochemical habitat Assessment Index
PES	Present Ecological State
PPE	Paper pulping effluent
PPP	Polluter pays principle
RC	Reference Condition
REC	Recommended Ecological Category
RHAM	Rapid Habitat Assessment Method
RHP	River Health Programme
RQO	Resource Quality Objective
RU	Resource Units
SADC	Southern African Development Community
SANPAD	South African Netherlands Alternatives in Development Programme
SANS	South African National Standards
SASS	South African Scoring System
SCI	Socio-Cultural Importance
SEM	Strategic environmental management
SES	Special Effluent Standard
SFR	Stream flow reduction
SHEQ	Safety, health and environmental and quality [management]
SoE	State of the Environment

SRI	Shared Rivers Initiative
SRP	Soluble Reactive Phosphorus
TD	Transdisciplinarity
TEACHA	Tool for Ecological Aquatic Chemical Habitat Assessment
THRIP	Technology and Human Resources for Industry Programme
TIN	Total inorganic nitrogen
TPC	Threshold(s) of Potential Concern
TPTC	Tripartite Permanent Technical Committee
TWQR	Target Water Quality Range
WMA	Water Management Area
WMS	DWA Water Management System
WQ	Water quality
WQSU	Water Quality Sub-Unit
WRC	Water Research Commission
WRCS	Water Resources Classification System
WSA	Water Services Act (No. 108 of 1997)
WSA	Water Services Authorities
WSP	Water Services Providers
WUA	Water User Associations
WWTW	Waste water treatment works

1 GENERAL INTRODUCTION

1.1 Background

Despite excellent water research, policy and law in South Africa (Huntjens et al. 2011), barriers are still painfully evident in the implementation of sustainable integrated water resource management (IWRM). One of the clearest failures is evidenced by the continuous decline in the quality of South African surface waters (CSIR 2010). The aims of this project fall within the overall objective of contributing to the effective use of knowledge in realising the goals of equity and sustainability in the practice of IWRM and development in South Africa.

Deteriorating water quality is an example of those intractable, complex problems that are termed "wicked" (Rittel and Webber 1973, Ritchey 2011). Recently there has been an upsurge in awareness of the shifts in research and practice that are necessary to deal with wicked problems. Concepts such as complexity (e.g. Cilliers 2001), transdisciplinarity (TD) (e.g. Max-Neef 2005), strategic adaptive management (e.g. Rogers and Luton 2011), social learning (e.g. Wals et al. 2009) and systems thinking (e.g. Meadows 2008) have been innovatively applied to IWRM in South Africa (e.g. Pollard and du Toit 2010, Rogers 2006, Rogers 2008). Action research is required to move these concepts into common practice, together with an accessible language and practical guidelines.

The National Water Act (No. 36 of 1998) (NWA) and the Water Services Act (No. 108 of 1997) were regarded at the time of promulgation as "enabling" legislation that would allow for the specific and practical development of appropriate regulations. However, in many instances, regulation and governance processes have been slow to emerge, if they have emerged at all. The NWA was founded on the principles of equity, sustainability and efficiency. The idea was to promote a balance between resource protection (using the processes of resource classification and setting resource quality objectives) and resource use (control and regulation through an administrative allocation and discharge system based on licensing and appropriate enforcement).

This has been challenging enough for flow, or water quantity, but has proved almost impossible for water quality, which covers the wide range of dissolved and suspended matter in water. In the period since promulgation, there has been little research-based investigation of the huge challenges posed by "water quality" as a multivariate concept, and methods and processes for "water quality" to be integrated into guidelines and licensing in a manner that is scientifically sound and societally sensible are elusive. As a result a diverse set of practices has emerged, where a range of guidelines are used to describe resource directed measures, and the criteria in discharge licences are not always consistent or useful. Added to this, there is little understanding even within the Department of Water Affairs (DWA) of the implementation of resource protection measures (King and Pienaar 2011).

Given these challenges this project was started with modest aims, and draws on existing data, information and community engagement and action research processes within the Crocodile River Catchment (Pollard and du Toit 2010).

1.2 Research aims

The aims of this study were as follows:

1. To use recent Shared Rivers Initiative (SRI) Phase 1 research products as a basis for engaging in deepening understandings of "compliance" with water quality requirements of the ecological Reserve.

2. To examine synergies with the quality component of the basic human needs Reserve, other sectors and guidelines.
3. To initiate the development of an analytical and conceptual framework for testing compliance with the water quality component of the ecological Reserve.
4. To initiate testing of this for a selected river included in the Shared Rivers Initiative (SRI) and to explore linking this project to the SRI.
5. To initiate communication of the research process and outcomes with stakeholders and water resource managers.

These aims were met and results are presented in the four substantive chapters of this report:

1. The reserve, water quantity and compliance: contrasting the water quantity and quality aspects of the ecological Reserve (Meeting Aims 1 and 2).
2. Water quality and the ecological reserve: methods review and critique (Meeting Aims 2 and 3).
3. The ecological reserve, water quality, and compliance: the case of the Crocodile River (Meeting Aims 3 and 4).
4. Initiating an integrated water quality management framework for the Crocodile catchment (Meeting Aims 4 and 5).

2 THE RESERVE, WATER QUANTITY AND COMPLIANCE

2.1 Introduction

The Reserve describes the water set aside, in the National Water Act (No. 36 of 1998) (NWA), for maintenance of sustainable aquatic ecosystems and for basic human requirements. The NWA defines the Reserve in terms of quantity and quality. While the quantity and quality of water resources cannot be uncoupled, they are traditionally addressed by different groups of specialists. This report deals largely with issues relating to water quality; here we will briefly consider issues relating to the water quantity, or flow, in the light of the ecological Reserve and in particular with compliance with the Reserve in order that similarities and differences in approaches adopted for management of the Reserve in terms of water quantity and quality may be highlighted.

The NWA indicates that the quantity of water set aside for the environment needs to be sufficient to maintain the river in a designated condition (Hughes and Hannart 2003). The condition selected will depend on the natural and the current state of the river, and its socio-economic and ecological importance. The consequence of this is that rivers need not be managed with the aim of maintaining a natural state, and that a number of factors bear on what management goals may be designated. However, all rivers should maintain a level of basic ecological functioning, and as such there is a minimum management class that sets a baseline for the ecological functioning of South African rivers regardless of other pressures on the resource.

It was recognised that some particular flow patterns are more important than others in maintaining instream ecological functions, and that these may be characterized in terms of the magnitude, frequency, duration, rate of change and timing of flows in a river (Poff et al. 1997). The natural flow patterns of a river are important in determining the biodiversity and ecological processes and functions of the aquatic ecosystem, and these have to be accounted for if a river is to be appropriately managed. As a result, consideration of the flow requirements of the ecological Reserve requires consideration of more than simply the quantity of water present in the system.

2.2 Summary of flow and the Reserve

Although the NWA was promulgated in 1998, the issue of ecological flow requirements of South African rivers had been addressed as of 1987 (King and Louw 1998, and refs therein). As a part of this process, there was a recognition that fluvial ecosystems were providers of various goods and services and that their continued existence underlies the value of the resource itself. As a result, the value of setting aside water for the environment entered the policy of the then Department of Water Affairs and Forestry (DWAF) (DWAF 1992). Research was undertaken on the links between flows and riverine ecosystem functioning, leading on to an assessment of tools that might be used to link flow to the ecological state of a river and thereby to assess management options in the light of flow changes (King and Louw 1998).

Determination of the ecological Reserve, from study initiation to Reserve implementation, follows the eight steps illustrated on the left of Figure 1. Although specialists will be involved in a number of stages, the majority of input with regards to ecological flows will be in stages 3-4. As the ecological Reserve is defined as water to maintain an ecosystem in a determined ecological state, the starting point of this process is to determine the Present Ecological State (PES), and a reference state of the river at each of the nodes selected for the river under study.

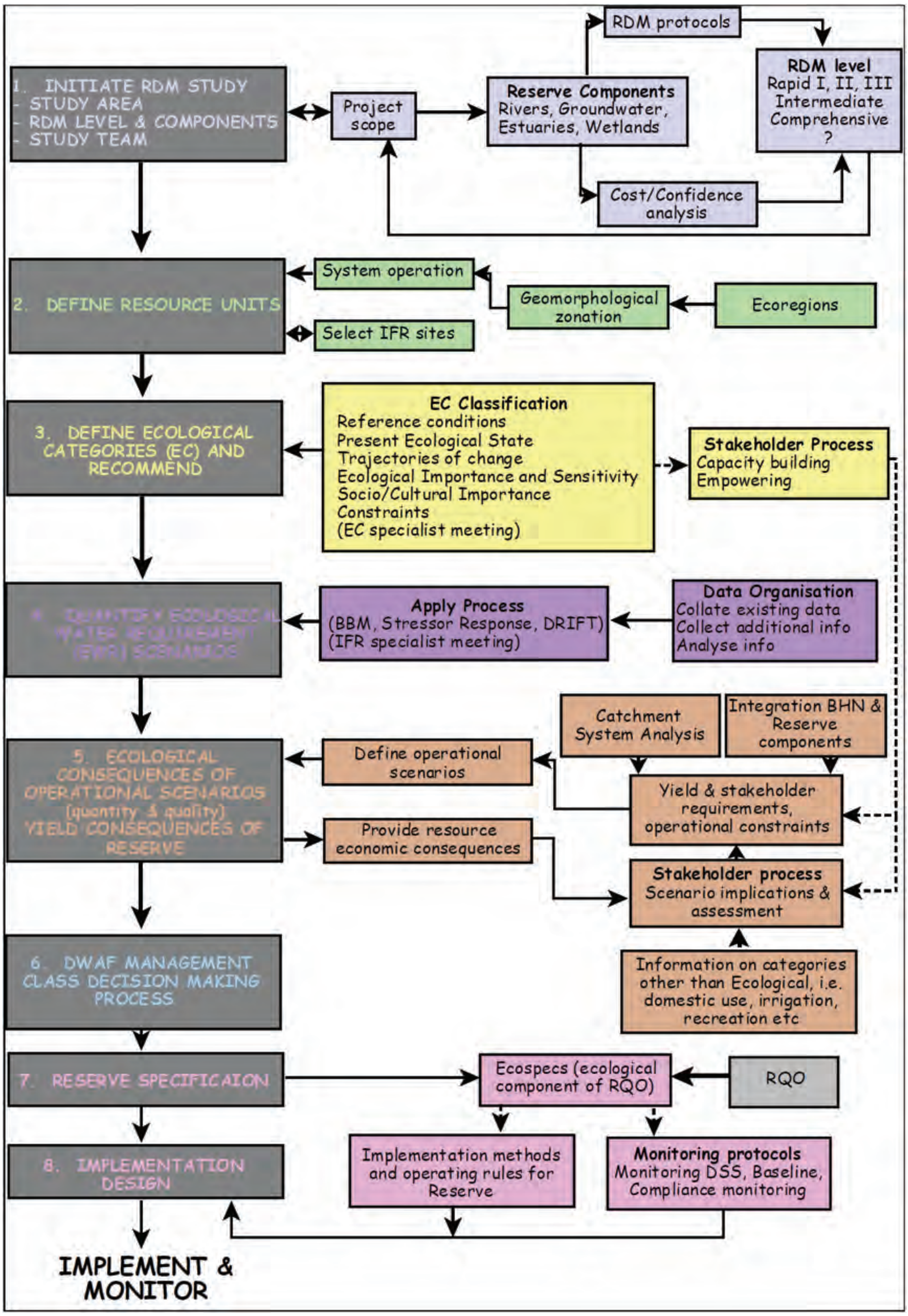

Figure 1 Eight step Reserve procedure (from DWAF 2003).

The PES and the reference condition are determined and classified using a Multi-Criteria Decision Making Approach as outlined in Kleynhans and Louw (2007) (step 3 in Figure 1). This approach aims to determine an ecologically integrated state from information on driving variables (hydrology, geomorphology and physicochemistry) and response variables (fish, aquatic invertebrates and riparian vegetation) using a rule-based modelling approach. The outcome of the process is an Ecological Category expressed in terms of classes A to F (where A is natural or near-natural, and F is critically modified). At the same time, the Ecological Importance and Sensitivity (EIS) and Socio-Cultural importance of the various nodes will be determined.

The EcoStatus of a site needs to be linked to changes in flow dynamics in order that environmental flow requirements for that location may be determined. In order to address this, a number of holistic methods have been developed and are applied in South Africa. The Building Block Methodology (BBM) (King et al. 2008) uses input from a range of specialists to identify the differing flow events required for maintenance of a range of biota, their habitats, and biological and geomorphological processes. The Downstream Response to Imposed Flow Transformations (DRIFT) (Brown et al. 2005) approach uses an interactive scenario-based process to determine biophysical consequences of flow reductions. In addition, the Flow Stressor Response (FSR) (O'Keeffe and Hughes 2005), designed for use within a holistic method such as BBM and DRIFT, assesses the likely impacts of modified flow using an approach derived from Ecological Risk Analysis (ERA). The application of these tools enables using input from a range of specialists on varying aspects of river function to determine the likely outcome of flow modification and in this way enables assessment of the environmental consequences of flow management scenarios (step 4 in Figure 1).

The output of an ecological Reserve flow assessment is a rule table showing a series of flows associated with a range of assurances, and is directly equivalent to a flow duration curve (FDC) (Hughes et al. 2008). Rule tables have Environmental Flow Requirements (EFR) for low flows, on a monthly basis, at varying levels of assurance. Low flow EFRs represent largely continuous and slowly changing background flows and account for seasonal changes in natural flows. High flows are considered in the rule table, but need to be described in more detail elsewhere (e.g. duration, peak flow, frequency, etc.) (Hughes and Mallory 2008). High flow EFRs need to be included as they are important to maintenance of the ecological and geomorphological condition of a river.

Ongoing monitoring of all biophysical variables used as input to the Reserve process is necessary to ensure that all targets are being met. In cases where flow targets are met but other targets are not, the EFR rule tables may need to be revisited. Monitoring is imperative to enable assessment of methodological and managerial approaches and to facilitate reassessment and modification, where necessary, of the approaches in place.

The EFR at any point in time is described in relation to real-time natural flows. As such, the Reserve for water quantity can be viewed as a proportion of the natural flow at any point in time. The upshot of this is that compliance with the Reserve can be assessed in real time in a catchment where current natural flows are known or can be estimated, and, in a managed catchment, steps to address non-compliance can be taken promptly. This is fundamentally different to how compliance with the water quality aspect of the Reserve may be monitored, as, in the latter case, compliance is assessed by comparison of percentiles of a data set collected over time with boundaries set during the Reserve process (DWAF 2008a). As such, compliance is largely assessed retrospectively and real-time action to manage compliance with the Reserve is for the most part not possible.

2.3 Flow, quantity and the Reserve: compliance with the Reserve

Relatively little published work is available on compliance with the flow aspect of the Reserve. The section will draw largely on work undertaken to assess compliance with the quantity aspect of the

Reserve in the Levuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati Rivers (Pollard et al. 2010, Pollard and du Toit 2010). This research assessed compliance in these rivers by designating flows below the Reserve at the time of assessment as non-compliant. As such, excessively high flows were not considered, although consideration of these might identify further non-compliance. In addition, the Basic Human Needs Reserve was not included, although this too forms part of the Reserve as defined by the NWA.

At this point it is worth noting that the ecological Reserve is defined by a number of biophysical components that include drivers (hydrology, geomorphology and physicochemistry) and response (fish, riparian vegetation, macroinvertebrates and to some extent diatoms) variables. Monitoring of the Reserve and assessment of compliance therefore involves more than simply flow compliance assessment.

The nature of compliance with the flow component of the Reserve was identified as unclear, a situation that, particularly from an enforcement and legal perspective, is less than desirable (Pollard et al. 2010). The simplest and most obvious interpretation of compliance would be a flow above that specified in the Reserve. However, this approach would render any failure, no matter how infrequent and regardless of the extent, as formally non-compliant, and hence legally at fault. This interpretation of compliance also implicitly assumes that the Reserve as determined is correct for the resource unit for which it has been set, and therefore that the methods and data underlying the Reserve determination are sufficient and representative for time and climatic conditions under which compliance is monitored. Depending on the method used to determine the Reserve (from Rapid to Comprehensive), and given that data constraints may introduce some uncertainty into the result of the analyses, the accuracy of the Reserve determination may vary. In this light, it is important to remember also that South African rivers may have highly variable flows (Poff et al. 2006). The issue of what may constitute compliance and whether the Reserve might reasonably be represented by an absolute value is discussed at some length in Pollard and du Toit (2010) and Pollard et al. (2011).

Hughes et al. (2008) note that absolute values of stream flow volume are not critically important in maintaining ecological functioning, but rather that seasonality, and frequency, duration and sequencing of wet and dry periods be maintained as part of the Reserve in order that resultant flows act to adequately simulate natural flows. Factors like this, together with all other aspects of the Reserve, need to be carefully considered when a legally binding definition of compliance is considered.

Frequency of compliance monitoring may modify the results of compliance assessments (Pollard et al. 2010). Where a catchment is monitored using a monthly time step, assessment of non-compliance will generally be more conservative than when a catchment is monitored using a daily time step. Where a catchment might be non-compliant for one or several days in a month, it may be found to be compliant for the month in question owing to the moderating effect of flow on other days leading to an average monthly flow that is compliant.

Location of gauging stations relative to Environmental/Ecological Water Requirement (EWR) resource units may complicate assessment of compliance where gauges are spatially separated from the location where compliance is to be monitored (Pollard et al. 2011). The further a gauge is removed from the site where compliance is monitored, the more likely that water losses and gains may occur between the site and the gauge. In these cases, results from gauges will need to be calibrated for the EWR site in question.

Assessment of compliance may be undertaken from a historical perspective, where past compliance (since operationalization of the Reserve) can be assessed to determine whether the Reserve has been met in the past. This may be useful in identifying trends in compliance which, together with knowledge on management practices in place at the time, would help in identifying approaches to management that might help or hinder sustainable management of freshwater systems. However, knowledge of historical non-compliance does not allow for management interventions in order to attain compliance at the time.

An alternate approach to compliance assessment that is more tractable to management interventions to improve compliance is to assess current day or real-time compliance. This requires an estimate of natural system flow at the time of assessment, as the ecological Reserve is defined in terms of the natural flow.

However, obtaining an estimate of up-to-date natural flow is not straightforward. Natural flow can be extrapolated from a measurement of flow in an undeveloped part of the catchment. However, there are few undeveloped but gauged catchments in areas where the Reserve is implemented. In addition, differences in rainfall between sites can restrict the accuracy of extrapolations. Nevertheless, Mallory (in Pollard et al. 2011) examined methods for estimation of natural flow in a catchment and found that they have some promise given that accurate and reliable information on real-time gauged flow, water use, stream reduction activities and storage in significant impoundments was available.

An alternate approach is to model the natural flow based on real-time rainfall data combined with historical records (Hughes et al. 2008). One drawback of this approach is that real-time rainfall data in South Africa are relatively scarce as a result of the closure of rainfall monitoring stations round the country leading to at times an inadequate data base for modelling (although other sources of rainfall data may be used e.g. radar or satellite sensing). A second issue relating to the use of rainfall data is that model parameters used in the Pitman model are different depending on the types of rainfall data used in model calibration, and, as a result, real-time rainfall data that differ from the calibration set need to be addressed when modelling runoff from the catchment in question.

An issue that arises with respect to operationalization of the Reserve is the question of future natural flows (Pollard et al. 2011). An understanding of future flows and the likely future Reserve is required for water users (particularly irrigators) to plan for the future and so to manage their water requirements appropriately.

In a related light, the variability of South Africa’s water resources mean that abstraction licenses need to include acknowledgement that curtailment of abstraction may be necessary at times (the alternative being very low abstractions with a high level of assurance) (Hughes and Mallory 2008). Given the lack of monitoring capacity, an element of self-regulation on the behalf of licensees (particularly run-of-river users) is essential to ensure compliance. Strengthening of institutional capacity and the involvement of stakeholders in management will help in this regard (Pollard and du Toit 2010).

Hughes and Mallory (2008) note that water resource managers in South Africa have indicated that the outputs of ecological Reserve determinations, as rule tables or flow duration curves, are too complex to implement. This observation is supported by Pollard and du Toit (2010), who indicate that managers may default to older, simpler operating rules (e.g. Pollard and du Toit 2008). Hughes and Mallory (2008) suggest a method for managing the low flow Reserve that may be practical to operate, but note that methods for high flow events are more complex to implement. The introduction and testing of tools, frameworks and management systems to enable the operationalization of the Reserve is imperative in order to ensure appropriate catchment management and the implementation of the ecological Reserve.

3 WATER QUALITY AND THE ECOLOGICAL RESERVE: METHODS REVIEW AND CRITIQUE

In this section we will review the methods used to determine the water quality component of the ecological Reserve using a recent comprehensive Reserve study on the Crocodile River in the Inkomati catchment (DWA 2009a, 2010 and other Reserve documents) as an example. This is followed by a critique of the methods used in determining the water quality component of the ecological Reserve.

3.1 Steps of the Ecological Water Requirements (EWR) or Ecological Reserve process

The following figure (Figure 2) outlines how an Ecological Reserve study is currently undertaken in South Africa; i.e. outside of the Water Resources Classification System (WRCS) which is currently being piloted on a number of South African rivers.

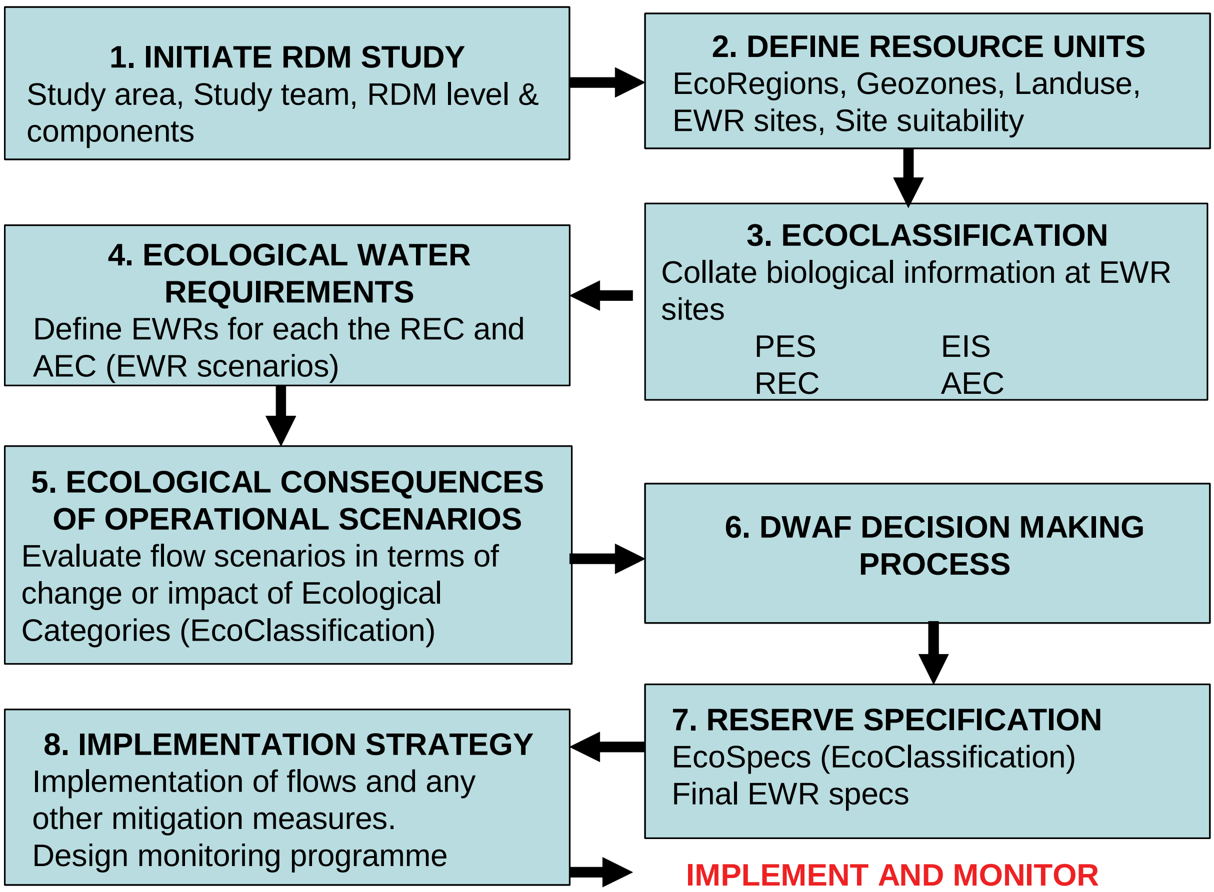

Figure 2 The eight major steps in an Ecological Reserve study.

The following section outlines each step of the Reserve process, then outlines the results at selected EWR sites on the Crocodile River, and finally provides a critique on the water quality methods associated with each step.

3.1.1 Step 1: Initiate RDM study

The responsibility of this step is largely that of the client and the project leader. The client generally (1) defines the geographic scope of the study area in collaboration with the study manager and key project team members; (2) decides what level of study is needed (e.g. Desktop versus Intermediate); and (3) defines the level of confidence in the assessment required by the Department of Water Affairs (DWA) as a regulator and resource manager. Note that if the Resource Directed Measures Chief Directorate (CD: RDM) is not involved as client, they should be consulted as the DWA department is directly responsible for Reserve assessments.

At the conclusion of Step 1, i.e. project initiation and scoping, the water quality team would have completed the following tasks:

- Identified the list of water quality variables to be included in the study, linked to the level at which the study is to be conducted.
- Collated a map of the catchment showing the location and names of DWA monitoring stations, any other monitoring points (e.g. by the DWA regional office or industries, municipalities), towns, EcoRegion Level II and quaternary catchment boundaries. These maps would have to be generated as GIS maps.
- Produced a list of the DWA monitoring stations in the study area showing the length of the data record at each monitoring station or sample size (n), frequency of sampling, variables sampled. etc.
- Compiled an initial list of reports dealing with water quality in the study area (river basin studies, water quality assessment studies, situation assessment studies. etc.).
- Collected information regarding the geology of the area (particularly if reference condition data are not available).
- Completed an assessment of the level of confidence at which the study will be conducted, depending on available information and the opportunity to collect more data. Depending on the constraints of the budget, available time and the quality of existing data, Ecological Reserve assessments can be undertaken so as to produce high, medium or low confidence results. The objective is to provide the highest level of confidence within the resources available. An important consideration is therefore whether the available data can satisfy the level of confidence required by the client.

Crocodile River Reserve study

- The **geographic study area** was determined to be the Crocodile River catchment, including main tributaries. The Crocodile catchment is part of the Inkomati Water Management Area (WMA), i.e. WMA5.
- Water quality data were available from the DWA gauging weirs shown in Table 1.
- The study was conducted at a **comprehensive** level, and as a result the full list of water quality variables and biotic indicators was to be assessed.

Table 1 DWA gauging weirs for the Crocodile River system.

Station	Place	Latitude	Longitude	Data record
X2H003	Krokodil River @ Broedersvrede	25° 29′ 17.1″	31° 09′ 29.2″	
X2H004	Krokodil River @ Nelspruit	25° 27′ 02.2″	30° 57′ 52.2″	1923-10-09 to 1928-12-31
X2H006	Krokodil River @ Karino	25° 28′ 11.2″	31° 05′ 17.3″	1929-10-02 to 2007-05-17
X2H013	Krokodil River @ Montrose	25° 26′ 55.1″	30° 42′ 42.4″	1959-01-21 to 2007-07-13
X2H016	Krokodil River @ Tenbosch	25° 21′ 49.9″	31° 57′ 20.6″	1960-08-24 to 2007-05-23
X2H017	Krokodil River @ Kruger National Park	25° 26′ 18.2″	31° 38′ 04.3″	1959-08-28 to 1998-09-01
X2H032	Krokodil River @ Weltevrede	25° 30′ 51.1″	31° 13′ 28.3″	1968-09-15 to 2007-07-16
X2H033	Krokodil River @ Sterkdoorn	25° 22′ 38.2″	30° 26′ 46.2″	1970-07-06 to 1992-05-15
X2H048	Krokodil River @ Kruger National Park	25° 27′ 37.2″	31° 32′ 07.3″	
X2H049	Krokodil River @ Kruger National Park	25° 20′ 02.2″	31° 48′ 52.3″	
X2H050	Krokodil River @ Kruger National Park	25° 21′ 39.2″	31° 53′ 39.3″	
X2H074	Krokodil River @ Goedehoop	25° 24′ 32.2″	30° 18′ 59.1″	
X2H075	Krokodil River @ Sterkspruit	25° 26′ 32.2″	30° 53′ 14.2″	
X2H076	Krokodil River @ Lions Club	25° 27′ 47.1″	30° 59′ 54.2″	
X2H077	Krokodil River @ Krokodilpoort	25° 29′ 52.1″	31° 10′ 44.2″	
X2H078	Krokodil River @ Kaapmuiden	25° 32′ 17.1″	31° 18′ 39.3″	
X2H091	Krokodil River@At Rivulet @ Barclays Vale	25° 25′ 18.2″	30° 45′ 24.2″	
X2H092	Krokodil River @ Boschrand	25° 26′ 52.2″	30° 57′ 03.2″	
X2H093	Krokodil River @ Boschrand	25° 27′ 42.1″	30° 57′ 13.2″	
X2H094	Krokodil River @ Friedenheim	25° 27′ 23.2″	31° 00′ 47.2″	
X2H095	Krokodil River @ Boschrand	25° 27′ 41.1″	30° 57′ 54.2″	
X2H096	Crocodile at Montrose	25° 07′ 18.2″	30° 43′ 33.4″	2004-09-15 to 2007-07-13
X2H097	Crocodile River at Esselen	25° 29′ 52.3″	31° 28′ 33.9″	
X2H007	Kaap River @ Dolton	25° 32′ 30.1″	31° 18′ 59.3″	1930-06-25 to 1947-12-01
X2H022	Kaap River @ Dolton	25° 32′ 35.6″	31° 19′ 00.1″	1960-08-31 to 2007-07-16
X2H024	Suidkaap River @ Glenthorpe	25° 42′ 42.6″	30° 50′ 06.0″	1964-09-25 to 2007-07-11
X2H031	Suidkaap River @ Bornmans Drift	25° 43′ 48.9″	30° 58′ 42.2″	1966-06-23 to 2007-07-11
X2H083	South Kaap River @ Dixie	25° 42′ 54.1″	31° 03′ 26.2″	
X2H084	South Kaap River @ Dixie	25° 42′ 46.1″	31° 03′ 32.2″	
X2H085	Kaap River @ Italian Farm	25° 40′ 04.1″	31° 07′ 52.2″	
X2H086	Kaap River @ Bon Accord	25° 40′ 25.1″	31° 10′ 12.2″	
X2H087	Kaap River @ Bon Accord	25° 40′ 49.1″	31° 10′ 54.2″	
X2H088	Kaap River @ Lovedale	25° 38′ 57.1″	31° 14′ 32.2″	
X2H089	Kaap River @ Caraceto (Tonetti)	25° 34′ 49.1″	31° 18′ 24.3″	
X2H080	North Kaap River @ Segalla	25° 39′ 10.1″	31° 03′ 37.2″	

The following variables were used for the assessment of water quality, according to established methods (DWAF 2008a):

Inorganic salts

- Sodium chloride (NaCl).
- Sodium sulphate (Na_2SO_4).
- Magnesium chloride ($MgCl_2$).

- Magnesium sulphate ($MgSO_4$).
- Calcium chloride ($CaCl_2$).
- Calcium sulphate ($CaSO_4$).
- Electrical Conductivity (EC) – used as a surrogate for individual aggregated salts (as shown on the list above) when all ionic data are not available and TEACHA (Tool for Ecological Aquatic Chemical Habitat Assessment) could not be used.

Note that salt ionic data, i.e. Ca^{2+}, Na^{+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, is run through TEACHA to generate aggregated salts. TEACHA has strict data input requirements, e.g. all salt ionic data is needed to generate aggregated salts. This data is normally sourced from the DWA water quality monitoring points and available on DWA's Water Management System (WMS).

Nutrients

- Total inorganic nitrogen or TIN (i.e. the N portion of all inorganic nitrogen sources, viz. NO_2^{-}+NO_3^{-} +NH_4^{+}-N).
- Phosphate as orthophosphate or soluble reactive phosphorus (SRP) ($PO_4^{\ 3-}$ -P).
- Response indicator: chlorophyll-*a* (chl-*a*) (required for a Comprehensive study).
- Response indicator: diatoms (recommended for a Comprehensive study).

Systems variables

- pH.
- Temperature: Although temperature is considered particularly important in the instances of thermal impacts, e.g. outlet of high-temperature effluent from the Tsb Sugar mill between EWR4 and 5 on the Crocodile River, it is also important to consider if the EWR site is located below a dam, or if changes in flow would result in extreme temperature changes in rivers.
- Dissolved oxygen (DO).
- Turbidity.

As quantitative data (other than that measured in the field) were not available for DO, temperature and turbidity, a qualitative assessment was conducted for these variables (as outlined in the EcoStatus manual of Kleynhans et al. 2005). Data from previous Reserve studies (i.e. Birkhead et al. 2002) were also extensively used.

Toxic substances

- Those listed in the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996), including toxic metal ions, toxic organic substances, and/or substances selected from the chemical inventory of an effluent/discharge. The rating tables in Kleynhans et al. (2005) provide values for selected toxics. Information on the geology of the area, as outlined in Birkhead et al. (2002) was also used to provide the background template of naturally elevated metals.

Methods critique

The approach is considered adequate, although the budget assigned may not always cover the list of analyses to be undertaken, e.g. additional data collection, in-stream toxicity testing or quality-quantity modelling.

3.1.2 Step 2: Define Resource Units

The delineation of Water Quality Sub-Units (WQSUs), i.e. zones of homogenous water quality, is used to define Resource Units (RUs) necessary for selecting EWR sites. The following information was used to define WQSUs.

- The location of dams, towns, tributaries, and point source pollution entry points in the rivers and the placement of these in the RUs.

This step also requires the following:

- Identification of the data that will be used to define the Reference Condition (RC), i.e. either the earliest data record before human intervention, the generic benchmark boundary values (as shown in the EcoClassification tables), or the recalibrated benchmark boundary values.
- Identification of the data that will be used to define Present Ecological State (PES), i.e. describing the current situation for water quality, per WQSU. As the principle of EcoClassification is to assess deviation from natural state, it is essential to also define natural conditions (or Reference Conditions) for water quality.
- Production of a table of WQSUs. The production of a WQSU table will assist in defining where WQSUs may need to be combined due to a lack of data (should such an amalgamation be appropriate) and the available data can be used to define the water quality status of the combined WQSUs.
- Definition of areas where data collection needs to take place as a priority.
- The position of the DWA gauging weir or water quality data collection points in the WQSU must be shown, particularly in relation to the EWR site and RU, as this will assist in defining the confidence in the water quality assessment for the EWR site.

Crocodile River Reserve study

A number of data sources were used for this assessment, as follows:

- Literature regarding water quality issues in the catchments, e.g. RHP (2001), DWAF (2004a) and Birkhead et al. (2002).
- 1:50 000, and 1:250 000 maps of the study area, depicting land use activities, point and diffuse sources of pollution, and catchment characteristics such as towns, tributaries, gauging weirs, etc.
- Maps of land cover classes and EcoRegions.
- A meeting with representatives of DWA regional offices to access information about point and diffuse sources of pollution and available water quality data.
- Regional water quality data from the DWA office in Nelspruit.
- Liaison with the national DWA office and access to available water quality information from the DWA-WMS database.
- Water quality on CD (version 1.0); produced by the CSIR in 1999.
- Information on the geology of the area to provide the background template of naturally elevated metals (Birkhead et al. 2002).

Delineation of WQSUs within Management Resource Units (MRUs) are shown in Table 2, with final MRUs shown in Figure 3.

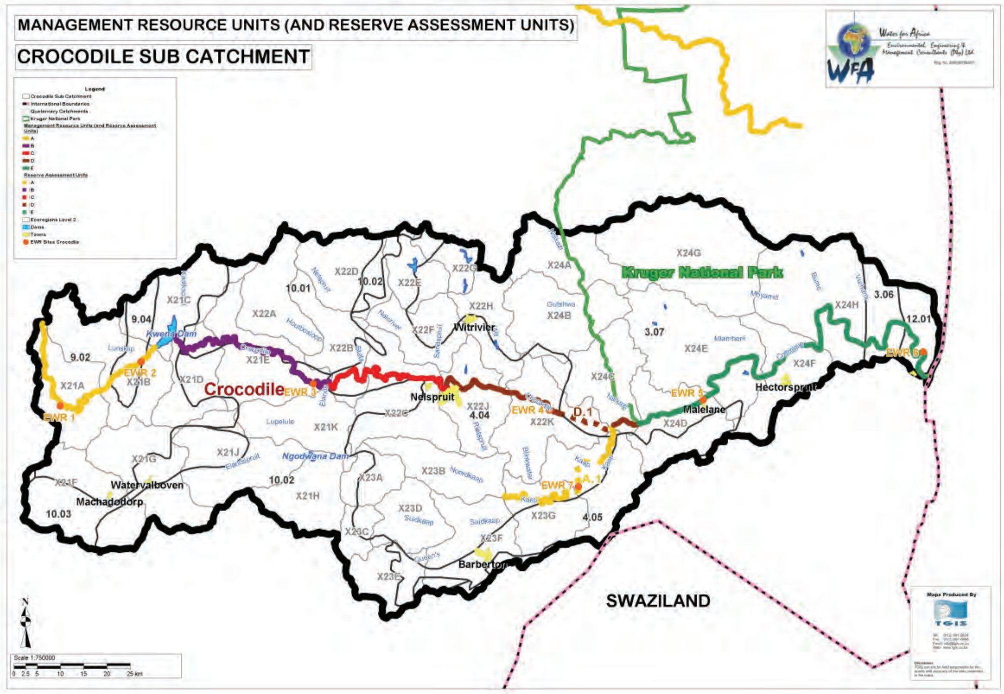

Figure 3 Management Resource Units for the Crocodile catchment.

Methods critique

The approach is considered adequate.

3.1.3 Step 3: Data analysis and EcoClassification

The following tasks were completed during this step:

- Conducting field survey(s) and collecting data as required.
- Selection of the appropriate data to be used for RC and PES, using the rules in DWAF (2008a).
- Generation of a map showing the DWA gauging weirs and additional water quality monitoring points (if required) in relation to the EWR sites.
- Analysis of the selected data (using methods and tools such as TEACHA, Excel or Statistica), and production of the required summary statistics.
- Comparison of the summary statistics to the benchmark tables in DWAF (2008a) and designation of appropriate categories for EWR sites.
- Running the Physicochemical habitat Assessment Index (PAI) model, and producing an integrated water quality category per EWR site. This category was then amalgamated with categories of other drivers and biotic response variables to determine the EcoStatus for each EWR site.

Table 2 Water Quality Sub-Units and descriptive information for the Crocodile River Reserve study.

WQSU No. (MRU No.)	Description and map no.	Monitoring points	Land use activities
Crocodile River			
1 (MRU A)	WQSU 1 stretches from the source of the Crocodile River to above Dullstroom.		Land-cover is largely grassland. A blue crane conservancy is found in the area.
2 (MRU A)	WQSU 2 stretches from Dullstroom to Kwena Dam.	This stretch contains two EWR sites, EWR1 (Valyspruit) and EWR2 (Goedehoop), with on-site water quality samples taken on 2007-11-16. DWAF undertook water quality sampling at X2H074Q01 from 1992-1994.	Land-cover is largely grassland with some agricultural, forestry and urban activities, e.g. trout-farming around Dullstroom.
3 (MRU B)	WQSU 3 stretches from below Kwena Dam to the confluence with the Elands River.	This stretch contains one EWR site, EWR3 (Poplar Creek), with on-site water quality samples taken on 2007-11-12. DWAF monitoring point, X2H013Q01 at Montrose is present in this WQSU, with monitoring from 1959-2007.	Land-cover is farming (largely citrus), with alien vegetation, plantations and urban settlements present. Sappi Ngodwana is located on the Elands River system, with associated pollution problems.
4 (MRU C / D)	WQSU 4 stretches from the confluence with the Elands River to below Nelspruit and KaNyamazane, and includes the confluence with the Wit River.	This stretch contains one WQ site at Rivulets, with on-site water quality samples taken on 2007-11-12, and one EWR site, EWR4 (KaNyamazane). On-site water quality samples were taken from EWR4 on 2007-11-13. DWAF monitoring points, X2H006Q01 at Karino, and X2H032Q01 at Weltevrede are present in this WQSU, with monitoring from 1929-2007 and 1968-2007 respectively.	Land-cover is farming (largely citrus), with extensive alien vegetation, plantations and urban settlements and associated activities present, i.e. Nelspruit and KaNyamazane. A number of hazardous waste sites, mines and processing plants are found in the area. The polluted Wit River enters the Crocodile River in this WQSU.
5 (MRU D)	WQSU 5 stretches from below KaNyamazane to the confluence with the Kaap River, and includes Krokodilrivierspoort (RAU 1).		The river goes through Krokodilrivierspoort.

WQSU No. (MRU No.)	Description and map no.	Monitoring points	Land use activities
6 (MRU E)	WQSU 6 stretches from the Kaap River confluence to the confluence with the Komati River.	This stretch contains two EWR sites, EWR5 at Malelane and EWR6 at Nkongoma, with on-site water quality samples taken on 2007-11-13. DWAF monitoring points, X2H048Q01 at Malelane bridge and X2H050Q01 at Crocodile bridge, are present in this WQSU. Monitoring took place from 1983-2005.	Land-cover is urban areas and associated impacts, extensive irrigation of sugar-cane, Selati sugar mill, forestry, agriculture e.g. banana and citrus plantations, citrus processing, conservation activities i.e. Kruger National Park, recreation i.e. lodges.
Kaap River			
7 (MRU A)	WQSU 7 is defined by the Kaap River from the confluence of the Noord and Suid Kaap to the confluence with the Crocodile River.	This stretch contains one EWR site, EWR7 at Honeybird, with on-site water quality samples taken on 2007-11-13. DWAF monitoring points, X2H031Q01 on the Suidkaap at Bornmans Drift, and X2H022Q01 at Dolton on the Noord Kaap, area present above the WQSU, with monitoring from 1960-2007 and 1966-2007 respectively.	Land-cover is farming (e.g. paw-paws, bananas, sugar cane), sawmill and pole treating in the vicinity, and mining upstream. Pollution sources from upstream users include irrigation, urban areas and old gold mining activities.

Crocodile River Reserve study

- A field survey of the study area was undertaken in November 2007. Water quality measurements were taken at specific points, including the EWR sites (Table 3). Samples were also taken for chlorophyll-*a* analysis (Table 4) and diatom analysis (Table 5).
- A map of the study area was generated as part of the reporting for the study (Figure 4).
- Water quality data tables and PAI models were drafted per EWR site – see Table 6 and Table 7 for EWR site 5, i.e. the Crocodile River at Malelane. *Note that this site is used as an example to demonstrate the outputs of the study*. The PAI categories were then used as the integrated water quality input to the EcoStatus model (Table 8).

Table 3 On-site water quality data collected during the 2007 field survey for the Crocodile Reserve study.

Site	NO_3 (mg/ℓ-N)	NO_2 (mg/ℓ-N)	NH_4 (mg/ℓ-N)	PO_4 (mg/ℓ-P)	pH	Temp.	DO (mg/ℓ)	DO (% sat)	EC (µS/cm)
Crocodile River									
EWR1	0.593	<0.01	0.037	<0.02	7.46	20.4	6.94	95.6	1741
EWR2	0.633	<0.01	0.043	<0.02	7.47	25.2	6.35	92.1	157
EWR3	1.430	<0.01	0.047	<0.02	7.32	22.4	5.62	71.5	94
WQ1	0.617	<0.01	0.037	<0.02	7.66	22.1	7.72	96.2	171
EWR4	1.437	0.03	0.083	0.203	7.55	25.3	7.4	94.6	187
EWR6	1.267	0.01	0.060	0.037	7.64	28.5	7.64	95.3	395
Kaap River									
EWR7	0.697	<0.01	0.040	0.020	8.02	24.7	7.69	96.4	385

Table 4 Chlorophyll-*a* analysis for samples collected for the Crocodile River Reserve study.

Site	Phytoplankton biomass (µg chl-*a* /ℓ)	Periphyton biomass (mg chl-*a* /m^2)
Crocodile River		
EWR1, Krokodilspruit	2.76	20.52 (SD: 13.67)
EWR2, Goedehoop	3.44	47.63 (SD: 13.43)
EWR3, Poplar Creek	8.87	29.81 (SD: 9.36)
WQ1 at Rivulets	4.00	25.28 (SD: 9.03)
EWR6	3.32	
Kaap River		
EWR7, Kaap River	8.66	31.42 (SD: 16.74)

Table 5 Diatom assessment for the Crocodile River Reserve study.

EWR site	Site name	No of species	SPI score	Class	Category
Crocodile River					
EWR1	Valyspruit	35	16.5	Good quality	B
EWR2	Goedehoop	37	15.3	Good quality	B
EWR3	Poplar Creek	28	14.6	Good quality	B
EWR4	KaNyamazane	46	9.7	Moderate quality	C
EWR5	Malelane	26	13.2	Moderate quality	B/C
EWR6	Nkongoma	36	13.1	Moderate quality	B/C
Kaap River					
EWR7	Honeybird	33	15.8	Good quality	B

Table 6 EWR5 – PAI model.

Physico-chemical Metrics	Rank	%wt	Rating	CONFIDENCE	WEIGHTED RATING
pH	4	50	1.00	5.00	0.50
SALTS	3	70	2.00	3.00	1.40
NUTRIENTS	2	85	2.00	4.00	1.70
TEMPERATURE	1	100	2.00	3.00	2.00
TURBIDITY	4	50	2.00	4.00	1.00
OXYGEN	1	100	1.00	3.00	1.00
TOXICS	1	100	1.50	5.00	1.50
PHYSICO-CHEMICAL PERCENTAGE SCORE	**67.21**				
PHYSICO-CHEMICAL CATEGORY	**C**				
BOUNDARY CATEGORY					

EWR 5: Crocodile River at Malelane

The present state of the water quality at EWR5 was scored as a **C category** (see Table 6). Due to the data available, the assessment was of **moderate** confidence. Table 7 shows the input data used for the PAI model. (Note that the PAI model output has been substantially revised since this 2008 study – see DWAF 2008a).

Notes

- Nutrients: Chl-*a* samples and diatoms (n=1 for both indicators) indicate some pollution.
- Turbidity: Elevated turbidity was expected due to catchment activities, including suspended solid loads from Tsb Sugar mill effluents.

- Toxics: Many potentially impacting activities in the area were noted, e.g. sugar cane plantations and processing, citrus plantations and processing, urban areas, agricultural activities.
- Temperature and oxygen: High temperature effluents from Tsb Sugar mill were reported to have resulted in localized fish kills.
- Elevated salt levels were noted.

Table 7 Input data used for the PAI model – EWR5.

RIVER	Crocodile River	**Water Quality Monitoring Points**	
WQSU	6	**RC**	X2H017Q01, '77-'80, n=125
EWR SITE	5	**PES**	X2H017Q01, '04-'07, n=114
Confidence assessment	Confidence in the assessment is **moderate**, as little DO, temp., turbidity or metal data.		
Water Quality Constituents		**PES Value**	**Category (Rating) / Comment**
Inorganic salts (mg/ℓ)	$MgSO_4$	52 (F category)	E (4) (TEACHA output), but modified despite presence of indicator diatoms
	Na_2SO_4	5	
	$MgCl_2$	6	
	$CaCl_2$	12	
	NaCl	1	
	$CaSO_4$	0	
Nutrients (mg/ℓ)	SRP	0.041	B (1)
	TIN	0.684	B (1)
Physical variables	pH (5^{th}-95^{th} percentiles)	7.51-8.4	B (1)
	Temperature	-	Although not downstream of a dam, alluvial bottom will result in temperature and oxygen fluctuations at low flows. There are many abstractions in this WQSU
	Dissolved oxygen	-	
	Turbidity (NTU)	-	
	Electrical conductivity (mS/m)	57.75	A (0), as benchmark table re-calibrated
Response variable	Chl-*a*: periphyton	-	
	Chl-*a*: phytoplankton	-	
	Biotic community composition: macroinvertebrate (ASPT) score	5.1	
	Diatoms	SPI=13.2	B/C (1.5) (n=1)
OVERALL SITE CLASSIFICATION (from PAI)		**C (67.21)**	

-: no data

Table 8 EcoStatus table for EWR5.

Driver Components	PES Category	Trend	REC	AEC↓
HYDROLOGY	C		B	D
WATER QUALITY	C		B	D
GEOMORPHOLOGY	C/D	Negative	C	D
Response Components	**PES Category**	**Trend**	**REC**	**AEC↓**
FISH	C	Stable	B	D
MACRO INVERTEBRATES	C	Stable	B	D
INSTREAM	C		B	D
RIPARIAN VEGETATION	C	Negative	B	D
ECOSTATUS	C		B	D

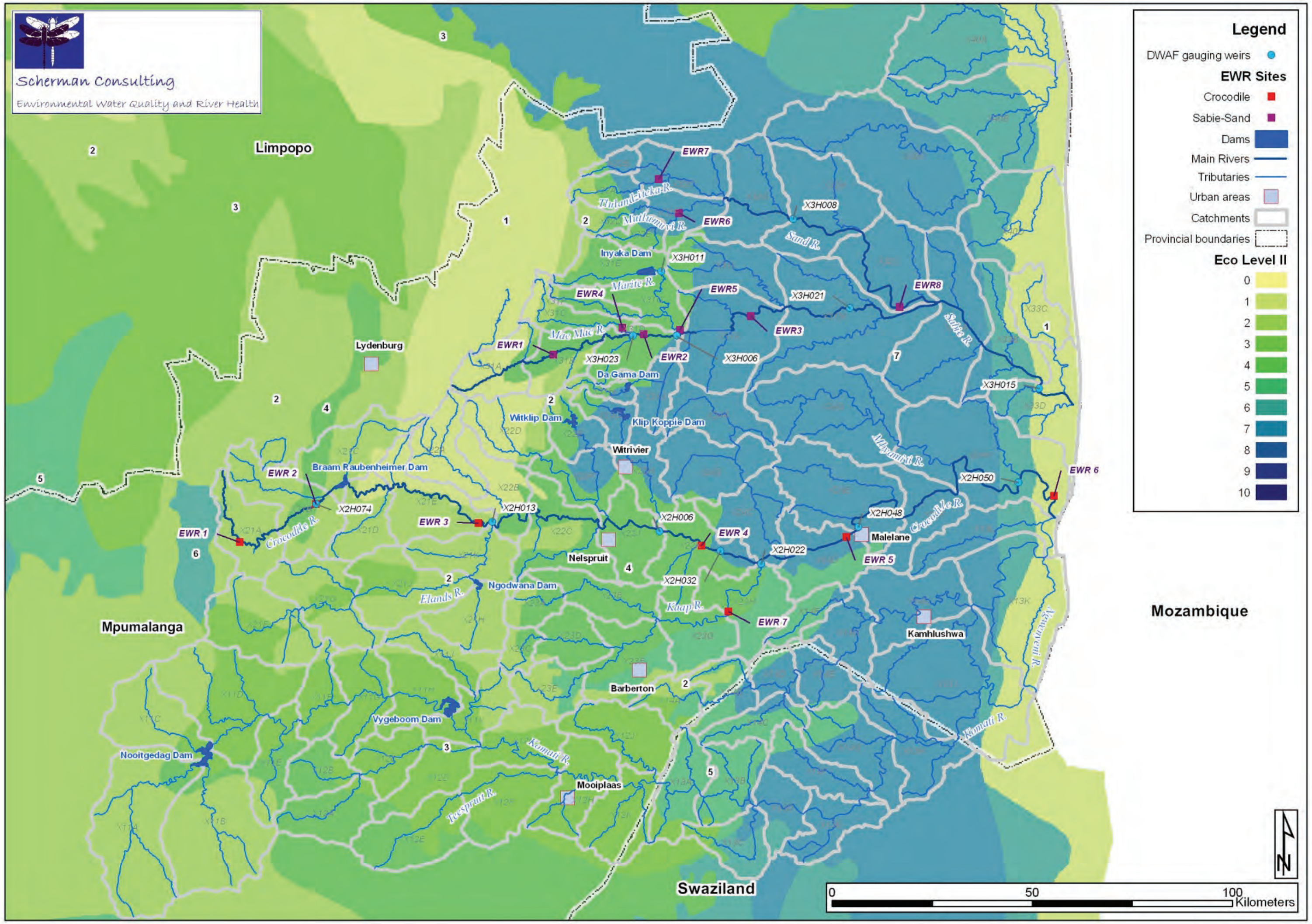

Figure 4 Locality map showing the position of the EWR sites, additional water quality sites and gauging weirs.

Methods critique

A method does not currently exist for the derivation of RC when no adequate data or field site exists. The current recommendation in DWAF (2008a) is as follows:

> **If no suitable RC data are available**
>
> Use existing data or reports, geological information and expert judgement to define RC if suitable RC data is not available, and benchmark boundary values not deemed suitable. The development of Reference Conditions for water quality has been identified as a development requirement and should be investigated as a separate study.

The development of methods (e.g. TEACHA and PAI) has not followed a strict peer-review process. Note that the manual produced in 2008 (DWAF 2008a) (which included the TEACHA and PAI models) was sent to a number of water quality professionals in South Africa. Comments on the manual (not specifically on the tools) were received from three specialists and incorporated into the document. The manual is also a compilation of work over many years by a wide range of water quality specialists.

TEACHA is currently the <u>only</u> tool currently available for generating aggregated salts from ionic data and conducting inorganic salt assessments. As a desktop tool, it is also essential for processing water quality licenses for the Ecological Reserve. However, a number of issues have been identified with the use of TEACHA (e.g. an over-estimation of $MgSO_4$). The following developmental requirements have been identified and communicated with CD: RDM, DWA.

- Re-evaluation of the toxicity data and algorithms underlying the model (i.e. to more accurately assess categories for certain variables).
- Address perceived data input incompatibilities.
- The data confidence in TEACHA is currently based on a power calculation which assumes a normal distribution of data. As this is almost never the case, future development must address the issues of confidence and possibly include an explicit non-parametric test for confidence calculations.
- Work on the interface areas is required to make the tool more user-friendly, e.g. data import and export, data analysis and presentation, and links to EcoStatus. As the programme can only be run on Matlab at present (with associated cost and licensing issues), addressing this issue will improve the accessibility to TEACHA.
- Expand pilot testing of the use of TEACHA.

The DWAF (2008a) manual has never been finalized or approved by DWA as DWA has yet to provide comments and input, despite this being accepted as the best available suite of methods for assessing the water quality component of the Ecological Reserve for rivers.

There is no formal process of communicating changes or updates in methods, besides the existing informal network of professionals. Method development is solely through Reserve studies as additional outputs of the study.

Methods should be discussed at a meeting of specialists so as to identify gaps, issues and identify ways forward in terms of method development and peer review.

3.1.4 Steps 4 and 5: EWRs and ecological consequences of flow scenarios

This step of the process consists of the following:

- Produce additional water quality information and interpretation of trends, etc.
- Water quality input to a range of Ecological Categories and operational scenarios, including water quality modelling for Comprehensive studies (if required and given that methods available).

Crocodile River Reserve study

As appropriate modelling methods have not yet been developed to undertake this task, the following qualitative approach is followed:

- Evaluate flow-duration curves and hydrological information for expected flow changes during a particular scenario, or under the Alternative and Recommended Ecological Categories (AEC and REC), and compare with the present state.
- Use the water quality conditions from the present state as a baseline, and run the PAI model to assess expected conditions under the various scenarios.
- Produce an integrated water quality category under various scenarios.

EWR5 is again used as an example to demonstrate this approach. Figure 5 shows the predicted flows for June for all scenarios at EWR5.

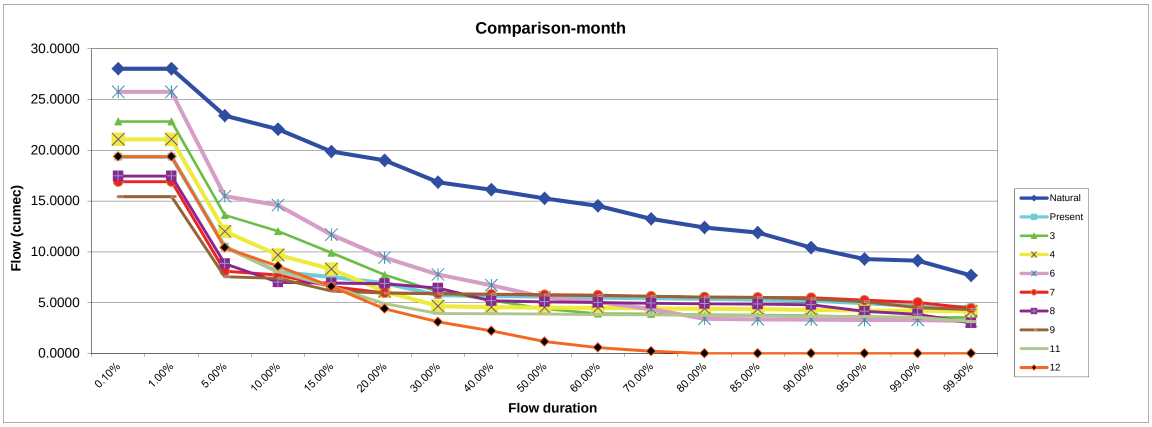

Figure 5 Flow-duration curve for all scenarios during June at EWR5.

Outputs from the assessment would be shown as follows for the AEC and REC in the Ecological Consequences report for the study (Table 9, Table 10). Descriptions and PAI tables are also produced for the expected consequences under each flow scenario.

Table 9 PES and REC for EWR5.

PES	REC	Comments
C	B	Increased flows, particularly low flows, will improve the water quality state by dilution. It is assumed that enough water will be provided at the right time to reduce the toxics by a category.

Table 10 PES, REC and AEC for EWR5.

PES	REC	AEC	Comments	Conf
C	B	D	Lower flows will result in a poorer water quality state, with elevations in nutrients, salts and toxics Increases in temperatures and drops in oxygen level will also be seen.	4

Methods critique

Modelling of water quality-quantity interactions is an important component of Comprehensive Ecological Reserve studies. It can be used to integrate water quality and water quantity during the EWR process and to provide the water quality consequences of a range of predicted flow scenarios. However, the current available modelling method, i.e. the flow-concentration method of Malan and Day (2002) is of limited use for non-conservative variables such as nutrients (i.e. those variables that undergo biological and chemical conversion, and their concentration is altered by factors other than water volume e.g. bacterial degradation).

The development of a more detailed modelling approach for water quality has been identified as a developmental requirement. An example of such a model is a distributed catchment model which can be set up for all catchments for which a Reserve is being determined. The model should utilize data on all major point-sources of pollutants, but should also be able to estimate loads from diffuse pollutants (using export coefficients for different chemical constituents under different land-uses). The model will need to include parameters to estimate processes such as chemical and biological conversions, sedimentation, etc. Such models could be set-up and then used to predict not only the effect of different flow scenarios on water quality, but also changes in pollutant loading through point sources or changes in land-use. This approach would be essential for managing the resource on a catchment-basis (HL Malan, *pers. comm.*).

The development of a water quality model is also essential to a number of current water quality issues. Examples are the further development of water quality methods for the Ecological Reserve and setting Resource Quality Objectives (RQO) (required for implementation of the WRCS). There is also a need to develop a catchment-scale water quality model that can support the different activities associated with Resource Directed Measures, including desktop licensing where it is critical to understand water quality on a catchment basis. However, the features of the model (business requirements) need to be well defined based on the needs of the different RDM components.

3.1.5 Step 7: Reserve specification (production of EcoSpecs)

The information below indicates the latest thinking on monitoring (DWA 2009a), developed in part during the Crocodile Reserve study.

EcoSpecs (or ecological specifications) are clear and measurable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that define the Ecological Category and serve as an input to RQOs. EcoSpecs refer explicitly and only to ecological information whereas RQOs include economic and social objectives.

Thresholds of Probable Concern (TPCs) indicate the values around the EcoSpecs that, if being approached, would initiate more detailed investigation or even management action. TPCs are based on the acceptance that there is uncertainty as to accuracy or validity of EcoSpecs i.e. is deviation from EcoSpecs due to natural variation, sampling error, etc. TPCs are therefore regarded as early warning indicators of potential change from a particular Ecological Category (EC) to another (lower) EC.

The PES of the system must therefore be determined prior to management interventions, and will then serve as the baseline ecological state from which all changes can be measured and evaluated. i.e.:

PES = BASELINE = BASELINE ECOLOGICAL CATEGORY (BEC)

Management actions are designed to maintain, or attain (if different from the PES) the REC. These management actions relate to the management objectives which are described in terms of EcoSpecs. Additional land use objectives may also be described if non-flow related aspects are contributing to the PES of the system.

Different flow regimes are identified for a range of ECs (referred to as EWR scenarios). These serve as the flow EcoSpecs for different ECs. Water quality EcoSpecs are finalized during the EcoSpec phase of the study. Once a decision is made on which future EC the river will be managed for, the EcoSpecs associated with this scenario are used to describe the management objectives for the system.

One must therefore clearly distinguish between setting management objectives in terms of the drivers to achieve/maintain certain EC, and defining EcoSpecs for the biophysical responses that describe the EC.

Crocodile River Reserve study

The approach that was followed for each site, developed during the Inkomati Reserve study and RDM Implementation Study (under leadership of MD Louw and CJ Kleynhans, DWA 2009a), is shown below:

- Data collected per site during the Rapid Habitat Assessment Method (RHAM, developed for the RDM Implementation project) monitoring surveys (August 2009, i.e. at low flows) represented the first monitoring data for the Crocodile River.

- RHAM water quality indicator TPCs were then set for the following RHAM water quality indicators. Visible biotic response was not assessed as it should be covered during other strategic monitoring or management activities.

    - Water odour.
    - Water colour.
    - Turbidity / clarity. Due to data limitations for this parameter, the TPC is set in terms of a RHAM water quality indicator only.
    - Water surface indicators.
    - Algal cover on hard surfaces.
    - Filamentous algae present in the water column.

- TPCs were also set for physicochemical parameters for the site. TPCs are presented as 95th percentiles (values not to be exceeded more than 5% of the time), for inorganic salts, physical variables and toxicants; and 50th percentiles for nutrients (TIN, SRP) and chlorophyll-*a*. The TPC ranges are defined by the upper boundary of the PES category and 80% thereof for the lower boundary, e.g. if a B category for a PES EcoSpec is < 15 mg/ℓ, the associated TPC would be 12-15 mg/ℓ.

Note: Percentiles should be calculated within the framework of the current assessment method (DWAF 2008a), using the PES monitoring point for the relevant EWR site, and the most recent 3 to 5 years of data, equivalent to a minimum of 60 data points. Data used from the DWA gauging weir may be requested from DWA's WMS database.

- EcoSpecs were set for physicochemical parameters only, i.e. quantifiable measurable parameters.

NB: Quality EcoSpecs are therefore related to attaining the water quality category of the overall REC or PES, and are presented as the range that each variable should be in to maintain the required category for that variable. The category specified per variable, and the composition of categories for all variables, will depend on the drivers of water quality per site.

Table 11 contains an example of the EcoSpec and TPC tables produced for EWR5 of the Crocodile River. Visual cues were not monitored for this site.

Methods critique

The major critique for this step is that no forum exists for the review of methods developed during Reserve studies. Method development is always an additional task to a study, meaning that the major objectives of the study have to be met within required time-frames and budgets. Although specialists of the Directorate Resource Quality Services (D: RQS) are often closely involved in Reserve studies, there is little feed-back from CD: RDM as to whether developments are meeting their requirements. This lack of communication seems to be largely due to limited capacity, and little communication between CD: RDM and other specialists who could adopt, adapt or review methods developed. The impression created is that Reserve practitioners are "possessive" of methods developed, while the truth is that no forum has been created for proper method development, assessment and optimization.

3.1.6 Step 8: Implementation

Note that Step 8, i.e. the Implementation Plan, is the responsibility of an implementing agent, and utilizes a range of tools not strictly related to Reserve methodology.

Water quality input is provided for the Reserve templates signed off by DWA for the gazetting step of implementation. Consistency and direction is required from DWA regarding the structure and content of these templates.

Table 11 EcoSpecs and TPCs – EWR5, Crocodile River.

PES for physicochemistry: C category.
REC for physicochemistry: B category.

Physicochemical data: TPCs

River: Crocodile		
Monitoring site: X2H017Q01		
EWR Site: 5		
Water quality metrics		**TPC**
Inorganic salts *	$MgSO_4$	The 95^{th} percentile of the data must be 40-45 mg/ℓ **
	Na_2SO_4	The 95^{th} percentile of the data must be 16-20 mg/ℓ
	$MgCl_2$	The 95^{th} percentile of the data must be 12-15 mg/ℓ
	$CaCl_2$	The 95^{th} percentile of the data must be 17-21 mg/ℓ
	NaCl	The 95^{th} percentile of the data must be 36-45 mg/ℓ
	$CaSO_4$	The 95^{th} percentile of the data must be 280-351 mg/ℓ
Physical variables	EC	The 95^{th} percentile of the data must be 70-85 mS/m
	pH	The 5^{th} percentile of the data must be <6.1 and >6.3, and the 95^{th} percentile must be <8.2 and >8.6
	Temperature	Vary by more than 2°C, i.e. a large change to the temperature regime occurs often. Most moderately temperature sensitive species would be in lower abundances and frequency of occurrence than expected for reference. Biological assessments therefore recommended and initiate baseline monitoring for this variable if Level II or higher of the DSS
	Dissolved oxygen	The 5^{th} percentile of the data must be 7.2-7 mg/ℓ. Initiate baseline monitoring for this variable if Level II or higher of the DSS.
Nutrients	TIN	The 50^{th} percentile of the data must be 0.55-0.7 mg/ℓ
	PO_4-P	The 50^{th} percentile of the data must be 0.02-0.025 mg/ℓ
Response variables	Chl-*a* phytoplankton	The 50^{th} percentile of the data must be 8-10 µg/ℓ
	Chl-*a* periphyton	The 50^{th} percentile of the data must be 17-21 mg/m^2
	Toxics	An impact is expected if the 95^{th} percentile of the data exceeds the Target Water Quality Range (TWQR) as stated in DWAF (1996)

*: To be generated using TEACHA when the TPC for EC is exceeded or salt pollution expected.
**: Although the PES for $MgSO_4$ is an F category, the TPC is linked to a D category as the minimum requirement for this variable.

Physicochemical data: EcoSpecs – PES and REC.

River: Crocodile			
Monitoring site: X2H017Q01			
EWR Site: 5			
Water quality metrics		**EcoSpec: PES**	**EcoSpec: REC**
Inorganic salts *	$MgSO_4$	The 95th percentile of the data must be ≤ 45 mg/ℓ**	The 95th percentile of the data must be ≤ 45 mg/ℓ**
	Na_2SO_4	The 95th percentile of the data must be ≤ 20 mg/ℓ	The 95th percentile of the data must be ≤ 20 mg/ℓ
	$MgCl_2$	The 95th percentile of the data must be ≤ 15 mg/ℓ	The 95th percentile of the data must be ≤ 15 mg/ℓ
	$CaCl_2$	The 95th percentile of the data must be ≤ 21 mg/ℓ	The 95th percentile of the data must be ≤ 21 mg/ℓ
	NaCl	The 95th percentile of the data must be ≤ 45 mg/ℓ	The 95th percentile of the data must be ≤ 45 mg/ℓ
	$CaSO_4$	The 95th percentile of the data must be ≤ 351 mg/ℓ	The 95th percentile of the data must be ≤ 351 mg/ℓ
Physical variables	EC	The 95th percentile of the data must be ≤ 70 mS/m ***	The 95th percentile of the data must be ≤ 55 mS/m
	pH	The 5th percentile of the data must be 5.9-6.5, and the 95th percentile 8.0-8.8	The 5th percentile of the data must be 5.9-6.5, and the 95th percentile 8.0-8.8
	Temperature	Moderate deviation from the natural temperature range. Most highly temperature sensitive species in lower abundances and frequency of occurrence than expected for reference	Small deviation from the natural temperature range, with lower abundances and frequencies of some highly temperature sensitive species
	Dissolved oxygen	The 5th percentile of the data must be ≥ 7 mg/ℓ	The 5th percentile of the data must be ≥ 7.5 mg/ℓ
	Turbidity	Vary by a small amount from the natural turbidity range; minor silting of instream habitats acceptable	Vary by a small amount from the natural turbidity range; minor silting of instream habitats acceptable
Nutrients	TIN	The 50th percentile of the data must be ≤ 0.7 mg/ℓ	The 50th percentile of the data must be ≤ 0.7 mg/ℓ
	PO_4-P	The 50th percentile of the data must be ≤ 0.125 mg/ℓ	The 50th percentile of the data must be ≤ 0.025 mg/ℓ
Response variables	Chl-*a* phytoplankton	The 50th percentile of the data must be < 10 µg/ℓ	The 50th percentile of the data must be <10 µg/ℓ
	Chl-*a* periphyton	The 50th percentile of the data must be ≤ 21 mg/m^2 ****	The 50th percentile of the data must be ≤ 21 mg/ m^2 ****
	Toxics	The 95th percentile of the data must be within the Target Water Quality Range (TWQR) as stated in DWAF (1996)	The 95th percentile of the data must be within the Target Water Quality Range (TWQR) as stated in DWAF (1996)

*: To be generated using TEACHA when the TPC for EC is exceeded or salt pollution expected.

**: $MgSO_4$ concentration was 52 mg/ℓ, i.e. an F category. The minimum category accepted would be a D category of 37-45 mg/ℓ.

***: EcoSpec for the PES generated. Although the PES value was 57.75 mS/m, boundaries for the relevant category are 55.1-≤85 mg/ℓ. As the upper boundary was considered too high to maintain the present state for salts, a lower boundary was used.

****: No periphyton or phytoplankton data were available for this assessment. All EcoSpecs and TPCs need verification as based on expert judgement.

4 THE ECOLOGICAL RESERVE, WATER QUALITY, AND COMPLIANCE: THE CASE OF THE CROCODILE RIVER

4.1 Introduction

This module assesses whether the test case selected, the Crocodile River in Water Management Area 5 (WMA5), is compliant, in terms of water physicochemistry, with the specifications laid out in the recent comprehensive Reserve study (DWA 2009a, 2010). The Crocodile catchment was selected as the river has been identified as a water-stressed one that has been receiving management attention of late (Pollard and du Toit 2010, Pollard et al. 2011).

4.1.1 Monitoring and the ecological Reserve

A brief exploration of the nature of compliance and ecological Reserve monitoring requirements is required at this point. The Reserve describes the water set aside, in the National Water Act (No. 36 of 1998), for maintenance of sustainable aquatic ecosystems and for basic human requirements (RSA 1998). The NWA defines the Reserve in terms of quantity and quality. There is a requirement in the NWA for the establishment of a national monitoring system that provides for collection of data to facilitate management of water resources (Kleynhans and Louw in DWA 2009b). Monitoring is required in order facilitate compliance with Resource Quality Objectives (RQOs) and to ensure the health of aquatic ecosystems.

In terms of ecological Reserve monitoring, monitoring is required to ensure that the Ecological Specifications (EcoSpecs) set as part of the Reserve process are met and that the resource is managed to attain the goals set by management as the Recommended Ecological Category (REC) (Kleynhans and Louw 2007, Kleynhans and Louw in DWA 2009b). Both EcoSpecs and Threshold(s) of Potential Concern (TPCs) are set for the resource. The EcoSpecs are quantifiable and define a desired biological condition for a water body. In the case of water physicochemistry, they will define ranges of acceptable values for various water quality parameters. EcoSpecs may be defined for several management classes. These in particular include the Present Ecological State (PES) which defines the current state of the resource, and the REC, which is the class that the resource should be managed to attain. TPCs are effectively early warning indicators that indicate that an EcoSpec may be exceeded should appropriate management action not be taken. As such, TPCs are defined in the same terms as EcoSpecs, and specify a boundary value around the EcoSpec. They are deployed on the understanding that there may be some uncertainty as to the accuracy of the EcoSpecs. EcoSpecs and TPCs form part of an adaptive management process (Rogers and Bestbier 1997), and may be modified based on ongoing management experience.

In the case of water physicochemistry, EcoSpecs are specified as acceptable ranges that defined percentiles of a parameter from a water quality monitoring data set may fall into (DWAF 2008a). In the case of a comprehensive Reserve, EcoSpecs will typically be defined for inorganic salts (magnesium sulphate, calcium sulphate, sodium sulphate, magnesium chloride, calcium chloride, and sodium chloride), major plant nutrients (total inorganic nitrogen and phosphate), electrical conductivity, dissolved oxygen, pH, turbidity, temperature, chlorophyll *a* levels, and toxic substances (DWAF 2008a).

4.1.2 Monitoring and data requirements

A draft document proposing guidelines for ecological Reserve monitoring was produced in 2006, but it was not finalized following recommendations that further development and testing were required (Kleynhans and Louw 2006, Kleynhans and Louw in DWA 2009b). Within the 2006 document, it was noted that data assessment against EcoSpecs or TPCs would require that percentiles be derived from a monitoring data set that should be collected from the same site used for baseline monitoring, but should be updated and use the last three years of data or a minimum of 60 data points. Depending on data availability at the site, data used in the derivation of the baseline may be used for monitoring.

Although the methods in Kleynhans and Louw (2006) were never finalized, the data requirements for ecological monitoring of water quality were reiterated in a later (and also at this point a draft) publication as three years of data, or a minimum of 60 data points, or data collected during baseline monitoring (DWAF 2008a). Monitoring requirements set out in the comprehensive Reserve determination study for the Inkomati River system use the approach outlined in DWAF (2008a), and state that water quality monitoring should use the most recent three to five years of data, equivalent to a minimum of 60 data points, drawn from the DWA Water Management System (WMS) database for the same gauging weir used for the Reserve EWR site (DWA 2010). This is the monitoring approach that will be adapted for the current study.

It has since become clear that the quantity of data required for monitoring may be ambitious in the light of available capacity and that approaches to monitoring are changing (Kleynhans and Louw in DWA 2009b; CJ Kleynhans *pers. comm.*). The proposed minimum of 60 samples would generate an assessment of high confidence (DWAF 2008a). Where a smaller sample is used, 25 data points is the minimum number required for an estimate of moderate confidence, and 12 samples would only allow low confidence in an estimate. Preliminary assessment of data available for monitoring of Crocodile River catchment sites indicated that, at the majority of sites, where baseline data was collected over the period 2004-2007, between 20 and 27 water physicochemistry samples have been collected since baseline monitoring ended. If these samples alone were used to assess compliance, without including baseline data in the compliance monitoring data set, assessments would be of moderate power. If larger data sets, using baseline data, were employed in compliance monitoring, sampled time windows would increase, potentially leading to less sensitivity of monitoring to short term trends along with an increase in statistical power.

Although a full assessment of data requirements for ecological Reserve monitoring is beyond the scope of this report, we will assess the use of different datasets in compliance monitoring in order to crudely ascertain whether dataset size has an impact on the outcomes in this assessment of compliance.

4.2 Methodology

WMS datasets were downloaded in October 2011 for all EWR sites selected for the Reserve study on the Crocodile River (DWAF 2008b). These consist of six EWR sites along the Crocodile River, and one site on a tributary, the Kaap River. Data from water quality monitoring stations corresponding to those used for the comprehensive Reserve determination ecoclassification process (DWA 2009a) were selected for use in assessing compliance (Figure 6). These data alone were used for compliance assessment; there were no site visits or collection of data to support or complement WMS data.

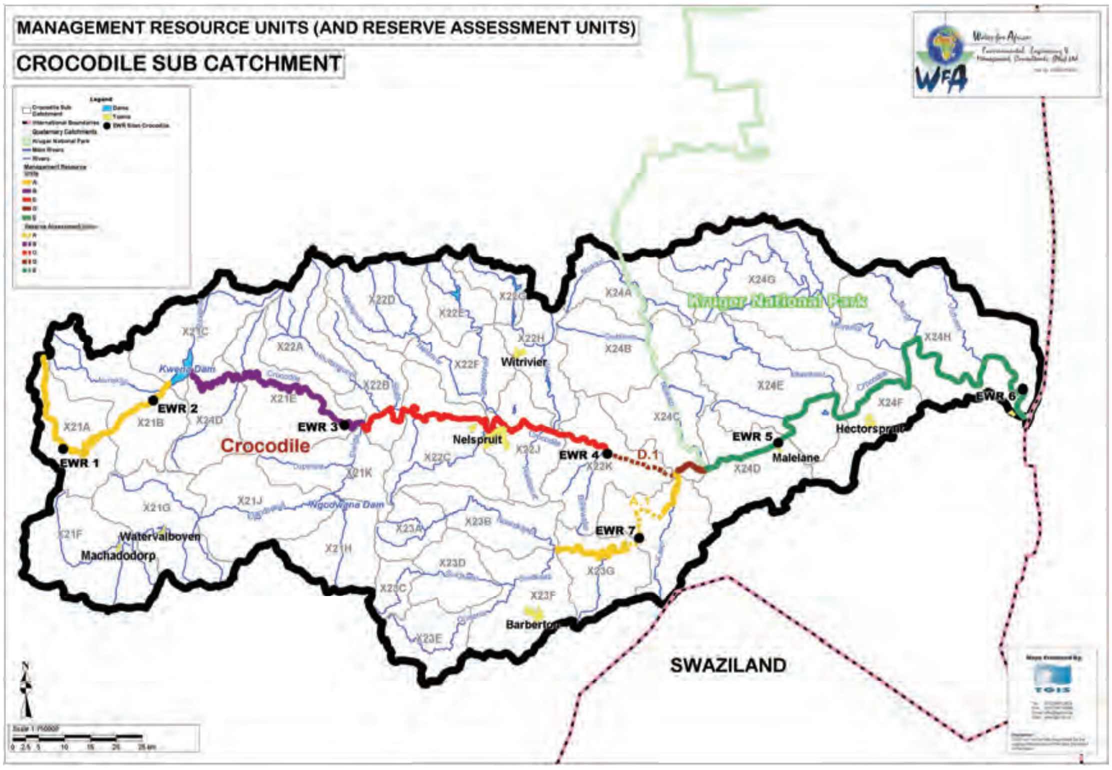

Figure 6 Environmental water quality monitoring stations on the Crocodile and Kaap Rivers referred to in this study. Map and graphics from DWA (2010).

EcoSpecs for the PES and REC, and TPCs were taken from the comprehensive Reserve report for the Inkomati WMA (DWA 2010). Appropriate summary statistics as outlined in DWA (2010) were then compared with these to determine compliance with PES and REC, and also to determine whether TPCs were exceeded. Summarized EcoSpecs and TPCs from DWA (2010) are presented in Appendix A.

Assessment of compliance with the ecological Reserve for the purposes of this study will be confined to the calculation of appropriate percentiles from monitoring data sets for comparison with EcoSpecs and TPCs from DWA (2010). Overall site monitoring would involve a number of aspects combined to give an overall ecological classification (Kleynhans and Louw 2007) and may involve levels of monitoring with physicochemical monitoring only being found at a higher level (Kleynhans and Louw in DWA 2009b). The aim of this study is simply to assess compliance with water quality requirements, and overall ecoclassification will not therefore be undertaken.

Individual ionic data were used to derive levels of aggregated salts using TEACHA[1], as per DWAF (2008a), for assessment against salt EcoSpecs. Attempts were made to monitor compliance in regards to all published EcoSpecs (where data was available). The only toxic substances that were assessed were those that were specifically mentioned in DWAF (2009a) as having been found to be high or potentially problematic.

[1] Tool for Ecological Aquatic Chemical Habitat Assessment v 1.32.

Datasets received from DWA WMS were merged into one based on shared fields. Datasets for import to TEACHA were extracted from this database (TEACHA processes left-censored data and multiple records per day internally, and these were not processed prior to application of TEACHA). Left-censored data (values below method detection limit) were then replaced with half the value of the detection limit as per DWAF (2008a). Finally, where multiple records per day were present in the dataset, data were aggregated to produce a mean value for all valid data from a given sample site and day. All data preprocessing used PostgreSQL 9.0.4, and summary statistics were calculated using R version 2.13.2 (R Development Core Team 2011).

Three different sets of data points were selected to assess compliance at each water quality monitoring station (Table 12). The datasets were chosen so as to include a range of post-baseline data points, and to vary in size in order to assess whether determinations of compliance were modified by the size of the data set (and consequent width of monitoring data time frame). One test dataset included all data points from the most recent five years of data from each water quality monitoring station. Another contained the most recent three years of data from the same station. The latter is clearly a subset of the former, and differences between the two may result from variations in sample size, or a trend in the data. The third test dataset comprised only data points collected after baseline (PES) data collection was complete, with a size of up to 60 samples. The latter were generally considerably smaller than 60 samples, as the quantity of data available since the collection of baseline data was often small.

4.3 Results

In the results presented below, percentiles from test data sets are compared with PES and REC EcoSpecs and TPCs for each water quality parameter at each site. In most cases, the EcoSpecs for REC and PES were the same (Appendix A). Where they differ, the REC EcoSpec specifies better water quality than the PES EcoSpec. TPCs are boundary values around the baseline EcoSpecs, and indicate that, in general, a PES/baseline EcoSpec may be exceeded should water quality deteriorate further. As such, the ranges specified by TPCs indicate better water quality than the PES EcoSpecs.

4.3.1 EWR1 Valyspruit and EWR2 Goedehoop

Although Ecoclassification and derivation of EcoSpecs and TPCs was undertaken for sites EWR1 and EWR2 (DWA 2009a, 2010), no data were available in WMS for use in compliance monitoring. During Ecoclassification, WMS gauge data for EWR1 was extrapolated from the gauge in EWR2 and supplemented with expert judgement as no appropriate gauge is present near EWR1. WMS water quality data were available for a gauge in EWR2; however, these comprise only 10 records over the period 1992-1994 and were used in PES Ecoclassification for this site. No data beyond this period was available for compliance monitoring.

PES and REC EcoSpecs and TPCs were taken from the comprehensive Inkomati Reserve determination (DWA 2010), and, for toxics, from DWAF (1996), and are summarized in Appendix A. Cadmium EcoSpecs and TPCs assumed water of medium hardness.

Table 12 Datasets used for assessment of compliance at each EWR site in the Crocodile catchment, Inkomati WMA. Number of samples and the range of sample dates in each data set are presented. Data on PES baseline data are from DWA (2009a).

Site	Data set	Date range	n
Crocodile River			
EWR1 Valyspruit	PES/baseline	Data extrapolated from EWR2	0
	Monitoring	No WMS data	0
EWR2 Goedehoop	PES/baseline	1992-1994	9
	Monitoring	No WMS data since PES dataset	0
EWR3 Poplar Creek	PES/baseline	1991-1999	39
	Recent 5 years	27 December 2005-13 December 2010	100
	Recent 3 years	8 January 2008-13 December 2010	41
	Post baseline 60 points	10 January 2000-15 April 2002	60
EWR4 KaNyamazane	PES/baseline	2004-2007	108
	Recent 5 years	31 January 2006-17 January 2011	72
	Recent 3 years	4 February 2008-17 January 2011	22
	Post baseline 60 points	7 January 2008-17 January 2011	24
EWR5 Malelane	PES/baseline	2004-2007	114
	Recent 5 years	14 June 2004-8 June 2009	137
	Recent 3 years	19 June 2006-8 June 2009	58
	Post baseline 60 points	7 January 2008-8 June 2009	20
EWR6 Nkongoma	PES/baseline	2004-2007	119
	Recent 5 years	6 December 2005-30 November 2010	85
	Recent 3 years	5 December 2007-30 November 2010	28
	Post baseline 60 points	8 January 2008-30 November 2010	27
Kaap River			
EWR7 Honeybird	PES/baseline	2004-2007	174
	Recent 5 years	10 April 2006-4 April 2011	64
	Recent 3 years	8 April 2008-4 April 2011	17
	Post baseline 60 points	15 January 2008-4 April 2011	22

4.3.2 EWR3 Poplar Creek

Data used in PES baseline derivation at this site were collected over the period 1991-1999, with the result that test datasets from this site overlap less in comparison to other monitoring sites in this catchment (Table 12). One upshot of this is that the post-baseline and recent datasets are entirely independent at this site, and that the post-baseline test data set only represents data until early 2002.

The results of compliance checks for a number of water quality parameters for site EWR3 are presented in Table 13. Relatively few of the parameters assessed are revealed to be non-compliant in terms of PES EcoSpecs, and only the higher pH values were non-compliant across all test databases. However, in two of the test data sets, phosphate values exceed the TPCs, and as such have reached levels that should trigger management intervention. In one each of the test data sets, values derived for magnesium sulphate and un-ionized ammonia exceed their respective PES EcoSpecs, in both cases by a small degree.

Table 13 Values of appropriate percentiles for comparison with site EWR3 (Poplar Creek) on the Crocodile River Ecospecs and TPCs, using recent 5 year, recent 3 year, and post-baseline test datasets. Sample size is given in parentheses. Exceedance of TPC values is shown by pale shading, exceedance of REC EcoSpecs by moderate shading, and exceedance of PES EcoSpecs by dark shading.

EWR3 Poplar Creek gauge X2H013Q01					
Metric		**%ile**	**5yr**	**3yr**	**Post base**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	10.2 (69)	9.5 (23)	16.4 (58)
	Na_2SO_4 (mg/ℓ)	95	0 (69)	0.5 (23)	0 (58)
	$MgCl_2$ (mg/ℓ)	95	3.1 (69)	3.3 (23)	2.8 (58)
	$CaCl_2$ (mg/ℓ)	95	3.8 (69)	5.8 (23)	3.2 (58)
	NaCl (mg/ℓ)	95	5.5 (69)	4.8 (23)	3.3 (58)
	$CaSO_4$ (mg/ℓ)	95	0.5 (69)	0.6 (23)	0.5 (58)
Physical variables	EC (mS/m)	95	15.6 (87)	15.1 (36)	15.5 (58)
	pH	5	7.1 ((88)	7.1 (37)	7.8 (58)
		95	8.1 (88)	8.1 (37)	8.1 (58)
	DO (mg/ℓ)	5	- (0)	- (0)	- (0)
Nutrients	TIN (mg/ℓ N)	50	0.18 (76)	0.15 (30)	0.18 (58)
	PO_4 (mg/ℓ P)	50	0.016 (85)	0.006 (34)	0.021 (58)
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	- (0)	- (0)	- (0)
	Chl-*a* periphyton (mg/m^2)	50	- (0)	- (0)	- (0)
Toxics	As (mg/ℓ)	95	- (0)	- (0)	- (0)
	Cd (mg/ℓ)	95	- (0)	- (0)	- (0)
	NH_3 (mg/ℓ)	95	0.008 (82)	0.006 (31)	0.005 (58)
	Zn (mg/ℓ)	95	- (0)	- (0)	- (0)

Non-compliance in terms of magnesium sulphate is not surprising as it has been reported that TEACHA may return unreasonably high values for this salt (DWAF 2008a). The exceedance of phosphate TPCs in the datasets that cover periods earlier than that in the recent 3 years may indicate an improving trend with higher values in earlier samples, but compliance over the most recent three year period. Of the toxics assessed, data were only available for un-ionized ammonia and conclusions regarding compliance with other toxicants will require that more data be collected.

4.3.3 EWR4 KaNyamazane

Data used for the derivation of the PES baseline at this site were collected over the period 2004-2007 (Table 12). This leaves a relatively small set of data for post-baseline monitoring, and means that the recent 5 year test datasets overlaps the data used for Reserve determination. The recent 3 year test dataset and the post-baseline test dataset are very similar and overlap heavily.

The results of compliance assessments using the three test databases are presented in Table 14. All test data sets concur as to where non-compliance with PES EcoSpecs were found. Magnesium sulphate levels in all test data sets were above the level required for compliance with PES EcoSpecs, and the lower pH percentiles were likewise above the range specified for this site in the PES EcoSpecs. Data from the recent 5 year data set also had upper pH percentiles below the level defined by the TPC, total inorganic nitrogen above the TPC threshold, and un-ionized ammonia above the REC EcoSpecs.

Table 14 Values of appropriate percentiles for comparison with site EWR4 (KaNyamazane) on the Crocodile River Ecospecs and TPCs, using recent 5 year, recent 3 year, and post-baseline test datasets. Sample size is given in parentheses. Exceedance of TPC values is shown by pale shading, exceedance of REC EcoSpecs by moderate shading, and exceedance of PES EcoSpecs by dark shading.

EWR4 KaNyamazane gauge X2H032Q01					
Metric		**%ile**	**5yr**	**3yr**	**Post base**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	42.5 (64)	41.8 (15)	41.5 (17)
	Na_2SO_4 (mg/ℓ)	95	0.4 (64)	0.4 (15)	0.5 (17)
	$MgCl_2$ (mg/ℓ)	95	4.3 (64)	6.1 (15)	5.9 (17)
	$CaCl_2$ (mg/ℓ)	95	12.7 (64)	13.7 (15)	13.4 (17)
	NaCl (mg/ℓ)	95	34.3 (64)	34.8 (15)	34.3 (17)
	$CaSO_4$ (mg/ℓ)	95	0.5 (64)	0.5 (15)	0.5 (17)
Physical variables	EC (mS/m)	95	32.1 (67)	29.4 (18)	29.3 (20)
	pH	5	7.4 (67)	7.4 (18)	7.4 (20)
		95	8.1 (67)	8.2 (18)	8.2 (20)
	DO (mg/ℓ)	5	- (0)	- (0)	- (0)
Nutrients	TIN (mg/ℓ N)	50	0.80 (65)	0.64 (16)	0.66 (18)
	PO_4 (mg/ℓ P)	50	0.072 (65)	0.054 (16)	0.054 (18)
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	- (0)	- (0)	- (0)
	Chl-*a* periphyton (mg/m^2)	50	- (0)	- (0)	- (0)
Toxics	As (mg/ℓ)	95	- (0)	- (0)	- (0)
	Cd (mg/ℓ)	95	- (0)	- (0)	- (0)
	NH_3 (mg/ℓ N)	95	0.008 (65)	0.006 (16)	0.006 (18)
	Zn (mg/ℓ)	95	- (0)	- (0)	- (0)

As in the results for EWR3, data on dissolved oxygen, chlorophyll *a* levels, and identified toxins beyond un-ionized ammonia are lacking.

4.3.4 EWR5 Malelane

Data used to determine the PES baseline for this site were collected over the period 2004-2007 (Table 12). Data from the recent 5 year test dataset overlap the baseline data set entirely, while data from the recent 3 year test data set overlap the baseline data set partially. The post-baseline data set does not, by definition, overlap with the baseline data set, but, as a result of a paucity of records since the baseline data set was collected, contains only 20 samples. The most up-to-date data that were available from WMS were from mid-2009 (although monitoring at this site is marked as active in the received WMS data inventory).

Table 15 Values of appropriate percentiles for comparison with site EWR5 (Malelane) on the Crocodile River Ecospecs and TPCs, using recent 5 year, recent 3 year, and post-baseline test datasets. Sample size is given in parentheses. Exceedance of TPC values is shown by pale shading, exceedance of REC EcoSpecs by moderate shading, and exceedance of PES EcoSpecs by dark shading.

EWR5 Malelane gauge X2H017Q01					
Metric		**%ile**	**5yr**	**3yr**	**Post base**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	61.0 (121)	62.5 (45)	48.3 (11)
	Na_2SO_4 (mg/ℓ)	95	4.3 (121)	3.6 (45)	3.5 (11)
	$MgCl_2$ (mg/ℓ)	95	7.1 (121)	8.6 (45)	6.8 (11)
	$CaCl_2$ (mg/ℓ)	95	9.8 (121)	10.2 (45)	8.5 (11)
	NaCl (mg/ℓ)	95	59.6 (121)	49.5 (45)	50.4 (11)
	$CaSO_4$ (mg/ℓ)	95	0.6 (121)	0.6 (45)	0.7 (11)
Physical variables	EC (mS/m)	95	57.0 (128)	51.1 (52)	48.6 (18)
	pH	5	7.4 (128)	7.2 (52)	7.0 (18)
		95	8.4 (128)	8.5 (52)	8.2 (18)
	DO (mg/ℓ)	5	- (0)	- (0)	- (0)
Nutrients	TIN (mg/ℓ N)	50	0.69 (122)	0.76 (46)	0.66 (12)
	PO_4 (mg/ℓ P)	50	0.047 (124)	0.051 (48)	0.046 (14)
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	- (0)	- (0)	- (0)
	Chl-*a* periphyton (mg/m^2)	50	- (0)	- (0)	- (0)
Toxics	As (mg/ℓ)	95	- (0)	- (0)	- (0)
	Cd (mg/ℓ)	95	0.005 (21)	0.005 (14)	0.005 (5)
	NH_3 (mg/ℓ N)	95	0.015 (123)	0.017 (47)	0.007 (13)
	Zn (mg/ℓ)	95	0.026 (21)	0.042 (14)	0.023 (5)

The percentiles of a range of physicochemical parameters from three test datasets for comparison with site TPCs and EcoSpecs are presented above in Table 15. The three test data sets are in accord in finding five parameters to be not compliant with PES EcoSpecs. Magnesium sulphate exceeded the PES EcoSpecs in all cases, and, in the recent 5 year and recent 3 year test data sets, the 95th percentile of the test data was slightly more than 30% greater than the EcoSpec boundary value. Another aggregated salt, sodium chloride, was also consistently higher than PES EcoSpecs for this site. Despite the fact that two out of six aggregated salts were non-compliant in all test datasets, electrical conductivity was only found to be non-compliant in the recent 5 year test dataset, and then, it is non-compliant with the REC EcoSpec and not the PES EcoSpec.

The lower percentile of pH in all three test data sets is above the range defined in PES and REC Ecospecs for this site. Finally, with the sole exception of the un-ionized ammonia in the post-baseline test data set, all toxicants for which data were available exceed the limit for PES EcoSpecs in all data sets. Levels of both cadmium and zinc were considerably above the range determined in the EcoSpecs.

In addition to the above, levels of phosphate in all three test samples are above the REC EcoSpecs, but below the PES EcoSpecs. The EcoSpecs for phosphate differ considerably between PES and REC (Table A.3), indicating that phosphate (along with salinity as electrical conductivity and dissolved oxygen) was at unsatisfactory levels in the baseline data set. Total inorganic nitrogen levels were also high in the test data sets, although only the recent 3 year data set exceeded EcoSpec boundaries.

No data were available to determine dissolved oxygen (where REC EcoSpecs are greater than PES EcoSpecs), chlorophyll *a*, and arsenic levels.

4.3.5 EWR6 Nkongoma

Data collection for PES baseline took place over the period 2004-2007 (Table 12). The recent 5 year test data set partially overlapped the baseline data set, while the recent 3 year test data set was largely independent. The post-baseline test data set was drawn from data collected after the baseline data, and was a subset of the recent 3 year and recent 5 year test data sets.

Appropriate percentiles calculated using three test data sets from this site for comparison with site EcoSpecs and TPCs are presented in Table 16. While there are differences in the values of the percentiles from the different test data sets, all are in complete agreement with regards to compliance assessment. As in the data from EWR5, aggregated salts that are present at levels exceeding the PES EcoSpecs are magnesium sulphate and sodium chloride. Overall salt levels, as measured by electrical conductivity, are compliant, however. The lower percentile of pH values is at least one pH unit greater than the range specified in the EcoSpecs. Again, as in the results from site EWR5, levels of cadmium and zinc are above the levels specified in the site EcoSpecs.

Table 16 Values of appropriate percentiles for comparison with site EWR6 (Nkongoma) on the Crocodile River Ecospecs and TPCs, using recent 5 year, recent 3 year, and post-baseline test datasets. Sample size is given in parentheses. Exceedance of TPC values is shown by pale shading, exceedance of REC EcoSpecs by moderate shading, and exceedance of PES EcoSpecs by dark shading.

EWR6 Nkongoma gauge X2H016Q01					
Metric		**%ile**	**5yr**	**3yr**	**Post base**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	56.7 (72)	50.0 (20)	50.3 (19)
	Na_2SO_4 (mg/ℓ)	95	3.3 (72)	3.2 (20)	2.8 (19)
	$MgCl_2$ (mg/ℓ)	95	9.9 (72)	9.4 (20)	9.5 (19)
	$CaCl_2$ (mg/ℓ)	95	15.4 (72)	12.1 (20)	12.2 (19)
	NaCl (mg/ℓ)	95	93.1 (72)	56.0 (20)	54.5 (19)
	$CaSO_4$ (mg/ℓ)	95	0.7 (72)	0.6 (20)	0.6 (19)
Physical variables	EC (mS/m)	95	66.2 (78)	52.6 (26)	52.8 (25)
	pH	5	7.7 (78)	7.7 (26)	7.7 (25)
		95	8.5 (78)	8.4 (26)	8.4 (25)
	DO (mg/ℓ)	5	- (0)	- (0)	- (0)
Nutrients	TIN (mg/ℓ)	50	0.41 (74)	0.48 (22)	0.47 (21)
	PO_4-P (mg/ℓ)	50	0.034 (75)	0.031 (23)	0.032 (22)
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	- (0)	- (0)	- (0)
	Chl-*a* periphyton (mg/m^2)	50	- (0)	- (0)	- (0)
Toxics	As (mg/ℓ)	95	- (0)	- (0)	- (0)
	Cd (mg/ℓ)	95	0.014 (25)	0.019 (10)	0.012 (9)
	NH_3 (mg/ℓ N)	95	0.013 (75)	0.009 (23)	0.009 (22)
	Zn (mg/ℓ)	95	0.014 (25)	0.018 (10)	0.014 (9)

No data were available for assessment of compliance of dissolved oxygen, chlorophyll *a*, or arsenic levels.

4.3.6 EWR7 Honeybird

Data for the PES baseline for this site were collected over the period 2004-2007 (Table 12). Data in the recent 5 year test data set partially overlap the baseline data set, but data from the recent 3 year test data set do not overlap the baseline data set at all. Data in the post-baseline test data set also do not, by definition, overlap the baseline data set. The recent 3 year test data set is a subset of the post-baseline data set.

Appropriate percentiles for comparison with site TPCs and EcoSpecs are presented below in Table 17 for three test data sets. It should be noted that EcoSpecs for PES and REC are the same for this site, and therefore that current management goals for this site are to maintain the site as it was at the baseline survey (rather than to improve the water quality). No EcoSpecs or TPCs were generated for aggregated salts during the Reserve study (DWA 2010) and, as a result, compliance with salts cannot be assessed for this report. Of all the parameters assessed, only unionized ammonia exceeded EcoSpecs in all three test data sets. The lower percentile of pH was found to exceed EcoSpecs in the recent 5 year test data set, and to exceed the TPC in the remaining test data sets.

Table 17 Values of appropriate percentiles for comparison with site EWR7 (Honeybird) on the Kaap River Ecospecs and TPCs, using recent 5 year, recent 3 year, and post-baseline test datasets. Sample size is given in parentheses. Exceedance of TPC values is shown by pale shading, exceedance of REC EcoSpecs by moderate shading, and exceedance of PES EcoSpecs by dark shading.

EWR7 Honeybird gauge X2H022Q01					
Metric		**%ile**	**5yr**	**3yr**	**Post base**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	113.3 (57)	116.9 (10)	112.0 (15)
	Na_2SO_4 (mg/ℓ)	95	18.5 (57)	19.9 (10)	16.1 (15)
	$MgCl_2$ (mg/ℓ)	95	5.5 (57)	5.0 (10)	4.8 (15)
	$CaCl_2$ (mg/ℓ)	95	7.7 (57)	7.8 (10)	7.3 (15)
	NaCl (mg/ℓ)	95	76.7 (57)	77.6 (10)	77.5 (15)
	$CaSO_4$ (mg/ℓ)	95	0.7 (10)	0.7 (10)	0.7 (15)
Physical variables	EC (mS/m)	95	87.4 (64)	78.5 (17)	78.1 (22)
	pH	5	8.1 (64)	8.0 (17)	8.0 (22)
		95	8.6 (64)	8.6 (17)	8.5 (22)
	DO (mg/ℓ)	5	- (0)	- (0)	- (0)
Nutrients	TIN (mg/ℓ N)	50	0.63 (59)	0.53 (12)	0.51 (17)
	PO_4 (mg/ℓ P)	50	0.029 (61)	0.020 (14)	0.027 (19)
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	- (0)	- (0)	- (0)
	Chl-*a* periphyton (mg/m^2)	50	- (0)	- (0)	- (0)
Toxics	As (mg/ℓ)	95	- (0)	- (0)	- (0)
	Cd (mg/ℓ)	95	- (0)	- (0)	- (0)
	NH_3 (mg/ℓ N)	95	0.028 (61)	0.019 (14)	0.018 (19)
	Zn (mg/ℓ)	95	(0)	(0)	(0)

In addition to the lack of EcoSpecs for assessment of aggregated salt levels noted above, relatively few data were available from this site for assessing other water quality parameters. No data were available to determine dissolved oxygen, chlorophyll *a*, or arsenic, cadmium and zinc levels. As a result, compliance assessment at this site only assessed electrical conductivity, pH, the nutrients total inorganic nitrogen and phosphate, and un-ionized ammonia.

4.4 Discussion

4.4.1 Overall trends in compliance

At all sites that EcoSpecs for magnesium sulphate were available in DWA (2010), at least one of the test datasets was found to exceed the specified EcoSpecs for PES and REC (the two did not differ at any site in this catchment). In nearly all of these, magnesium sulphate was found to be non-compliant in all test datasets. TEACHA has been found to over-estimate magnesium sulphate levels (DWAF 2008b), and as a result, it is not clear what importance to attach to this trend.

Another general trend across sites was a tendency of pH levels to exceed EcoSpecs or TPCs on the lower 5^{th} percentile. For the most part, test data sets exceeded the PES EcoSpec and, again, there was general concordance across the three test data sets. Although upper 95^{th} percentiles of test data pH were generally compliant, it appears that low pH events in the river are less common in all the test data sets than recommended.

In sites in upper reaches of the Crocodile River (excluding EWR6, the most downstream site in the Crocodile River, and EWR7, in the Kaap River), levels of major plant nutrients, either as total inorganic nitrogen, or phosphate, or, at EWR5, both, were found to exceed TPCs or EcoSpecs in one or more of the test data sets.

At sites EWR5 and EWR6, lower on the Crocodile River, all test data sets indicated that sodium chloride levels were above the levels specified for PES EcoSpecs. This seems to be function of these sites' downstream location, as no upstream sites had levels of sodium chloride that passed the TPC boundaries, despite a general increasing trend in sodium chloride with distance downstream.

Un-ionized ammonia was found to exceed TPCs or EcoSpecs in at least one test data set (in particular the recent 5 year data set) at all sites bar EWR6. Unlike the other toxicants assessed for this study, data availability was relatively high as un-ionized ammonia levels are related to those of ionized ammonia or ammonium (NH_4^+), as modified by factors such as pH, temperature, etc. (DWAF 1996), and these data were more available in the WMS data set than levels for toxic metals, for example. The more frequent occurrence of non-compliance in the recent 5 year test data set, which generally included older samples, may indicate an improving trend over time. Nevertheless, the absolute difference in un-ionized ammonia levels between non-compliant and compliant sites or data sets is not large, and even compliant sites have levels of this compound that are close to EcoSpec boundaries.

Compliance with EcoSpecs for the other three toxicants assessed in this study (arsenic, cadmium and zinc) cannot completely be assessed as insufficient data on these compounds at all sites is available. No data on arsenic levels at any site were available in the WMS data, despite this compound being identified as a potential problem at site EWR7 (DWA 2009a). Few data were available on cadmium and zinc levels, with the result that compliance for both compounds could only be assessed at sites EWR5 and EWR6. At both these sites, levels of both compounds exceeded the PES EcoSpecs in all test data sets. The small sample size for these compounds means that assessments have relatively low power and calculated percentiles can only be expressed with low to, at best, in the recent 5 year test data set, moderate confidence. This is despite these compounds having been noted as having elevated levels in DWA (2009a).

In general, a trend of decreasing compliance is noted in Crocodile River sites as one moves downstream, as frequency of exceedance of TPCs or EcoSpecs becomes greater at downstream sites. As noted above, magnesium sulphate and lower pH range percentiles are generally non-compliant at all sites. Non-compliance with sodium chloride EcoSpecs increases with distance downstream. Nutrient non-compliance is higher at sites in the upper- to midstream area. Generalization about compliance of toxic substances with distance downstream is not possible as, with the exception of un-ionized ammonia, data are only available for the lower sites on the Crocodile River, and, while these are non-compliant (but assessments have little power owing to the small size of available data sets), they cannot be compared to upstream sites where no data is available.

The combination of the above trends means that site EWR5 has the highest level of non-compliance, with 64% of compounds for which data were available exceeding one EcoSpec or TPC in at least one test data set. In the Crocodile River, upstream sites EWR3 and EWR4 have non-compliance levels of 33%, and in the Kaap River the sole EWR site, EWR7, has non-compliance levels of 17%. No site was completely compliant with EcoSpecs and TPCs, and all sites registered at least one of the assessed water quality parameters as non-compliant with PES EcoSpecs in all test data sets.

The lack of compliance with ecological Reserve specifications in regards water physicochemistry in the Crocodile catchment is in agreement with findings of non-compliance with the flow or water quantity aspect of the ecological Reserve in the same catchment (Pollard and du Toit 2010, Pollard et al. 2011). However, the Inkomati Catchment Management Agency (ICMA) has been found to have an understanding of the Reserve (both ecological and basic human needs Reserve) and the intention of meeting their obligations in this regard (Pollard and du Toit 2010). They have also to a certain extent focussed their efforts on the Crocodile catchment as a result of it having been identified as highly water stressed (Pollard and du Toit 2010). As a result, the potential for improvement in this catchment in the immediate future exists (Pollard and du Toit 2010).

4.4.2 Dataset choice

In this study, three test data sets were used to assess compliance at each site. This approach was selected as data requirements for monitoring were not clear. The use of at least three to five years of data points, or a minimum of sixty data points (Kleynhans and Louw 2006, DWAF 2008a; DWA 2010) have differing implications in terms of the width of the monitoring data set time frame (depending on sampling frequency), the number of samples and consequent statistical power, and the degree of overlap between the monitoring and the baseline data sets. It must be noted that these recommendations have not been finalized, and that approaches to monitoring requirements are changing (e.g. Kleynhans and Louw in DWA 2009b; move towards use of discharge/physicochemistry relationship, CJ Kleynhans *pers. comm.*; also see approach to integrated modelling in Hughes and Louw 2010 and refs therein). However, until changes are made in the approach to monitoring water physicochemistry, considerations relating to what data are used in monitoring compliance will remain valid.

In general, levels of non-compliance are greatest in the recent 5 year test data set. This data set contains the most samples of the three test data sets (64-137, Table 12), and as such the estimates of compliance can be made with high confidence (DWAF 2008a). In many cases (but not at sites EWR3 and EWR5), overlap between the remaining two test data sets is high and comparisons between them would not be meaningful. While there are exceptions, sample size in the latter two data sets is generally in the region of 20-25, and assessments using these data sets can therefore be made with, at best, moderate confidence.

At a given sampling frequency, a larger monitoring data set will comprise samples drawn from a longer time frame. Together with the greater statistical power implicit in a larger sample size, such a larger data set will amalgamate data over a longer time frame and, in this way, the impact of short term variations in water quality will be decreased. By way of an example, consider a hypothetical monitoring data set consisting of 96 data points from a site at which data are collected twice per month, giving a four year time window for the monitoring data set. Depending on the method used to calculate percentiles, should a period of non-compliance with any water quality parameter assessed using the 5^{th} or 95^{th} percentile of monitoring data occur, and should that period exceed five samples, or two and a half months under a bimonthly sampling regime, the outcome would be that regardless of the values of that parameter over the remaining samples in the four year time window, the data set would be non-compliant. If the non-compliant samples were contiguous, it would take nearly four years after the period of non-compliance for a routine 96 sample monitoring data set to be again compliant, and only if all samples after the non-compliant period were compliant. However, as a 96 sample, four year monitoring dataset would require at least five non-compliant samples for the data set to be non-compliant overall, the likelihood of error in identifying non-compliance is low.

A smaller data set would be more sensitive to short-term variation, and would have a shorter "memory" for historic non-compliance than that illustrated above for a larger data set. However, relatively few non-compliant samples would be required for a smaller data set to be non-compliant overall. To use an example with the same sampling frequency used in the illustration of a large data set above, and again depending on the method used to calculate percentiles, in a monitoring data set of 18 samples, or nine months of data, a single non-compliant event would render the data set non-compliant. Following a non-compliant event, routine 18 sample monitoring data sets would remain non-compliant for nine months, until the non-compliant sample fell outside the sampling time frame in use. A smaller data set or sampling time frame is potentially more sensitive to change in conditions, as fewer non-compliant samples are required for the data set to register as non-compliant. It also has a shorter "memory" of historic non-compliance. However, a smaller data set is more prone to be affected by natural variation, and sampling and laboratory error.

The above examples apply to cases where either 5^{th} or 95^{th} percentiles are used in assessment of compliance. Where 50^{th} percentiles are assessed (e.g. nutrients; DWAF 2008a) monitoring data sets will be less affected by few extreme values.

In the light of the results presented here, several points regarding test data set size emerge. One is that sampling size for cadmium and zinc in most test data sets is small enough that a single non-compliant event would render the data set non-compliant. In a similar light, the relatively small size of the recent 3 year test data set and the post-baseline test data set means that only one or two non-compliant samples may render these data sets non-compliant. Another is that the greater frequency of non-compliance or of exceeding TPC boundaries in the recent 5 year test data set (especially at site EWR4) may reflect the extended "memory" of a larger data set and so be indicative of a greater degree of non-compliance three to five years before the most recent sample.

Nevertheless, it is important to note that for the most part there is agreement between the various test data sets assessed here, and therefore that, in most cases, the size of the test data set (within the boundaries given in Table 12) has in this example had little impact on the outcome of assessing compliance. It should be borne in mind that this assessment of the impact of monitoring data set size is rudimentary and applies only to the test case assessed in this report and not necessarily to others.

4.4.3 Other observations

It was noted prior to this study that there is no routine water physicochemistry monitoring at site EWR1 (DWAF 2008b, DWA 2009a). Although a water quality monitoring station is present at EWR2, very few data are available and it appears that water physicochemistry monitoring at this point has been suspended. Although full monitoring of the Reserve involves considerably more than physicochemical monitoring and physicochemical monitoring will likely not be at the first level of monitoring (DWA 2009b, 2010), physicochemical data will be required should monitoring pass to a higher level where more intensive monitoring is required to identify causes of ecological changes. As physicochemical monitoring requires data collected over a period of time, these data will need to be available should an ecological impact be identified, and if regular sampling and analysis is not undertaken, these data will not be available should they be required.

Of the water physicochemistry parameters specified in the Reserve determination and assessed during this study, several were not available for the monitoring sites assessed here. Data on chlorophyll *a* levels, dissolved oxygen levels and the quantity of those toxins that were assessed during this study (apart from un-ionized ammonia) were rare or not available at all sites assessed here. As a result, these were for the most part not assessed during this study. While acknowledging the cost and effort implied by monitoring of a wider range of compounds than are currently monitored, it would be advantageous in terms of implementation of the Reserve that compounds identified in the Reserve determination be monitored on an ongoing and routine basis.

The use of EcoSpecs and TPCs in water resource management forms part of an adaptive management system (Rogers and Bestbier 1997). One important aspect of this is for monitoring data to be used to reconsider, recalibrate and potentially reconstruct the specifications set for biophysical components relating to a desired management goal (Kleynhans and Louw 2007). Monitoring of ecological responses together with drivers will test the predictions made in the Reserve process, and will determine whether EcoSpecs and TPCs need adjustment (DWA 2010). Trends of non-compliance identified in this study need to be assessed in the light of a full monitoring programme in order to assess their significance, and to determine whether EcoSpecs and TPCs need adjusting, and whether they are significant in the light of changes to biological response variables.

The data used to draw up Reserve PES specifications for the Crocodile catchment were for the most part collected over the period 2004-2007 (DWA 2009a). For monitoring to be effective, it should start immediately after the baseline data set has been collected (DWA 2010). Should monitoring not be implemented soon after the baseline, new baseline data will need to be assembled at a later data for monitoring to be implemented.

It has been noted that TEACHA, used for generation of aggregated salts from ionic data, may overestimate the levels of magnesium sulphate in samples (DWAF 2008a). The results from this study identify magnesium sulphate as one of the least compliant of the various parameters assessed. It is not clear whether these results indicate a real problem, or are an artefact generated by the method (despite TEACHA being used in the Reserve study to generate magnesium sulphate levels in the same way as in this report). TEACHA requires installation of MATLAB, or distribution of appropriately compiled MATLAB libraries (S Jooste, *pers. comm.*). It has strict data requirements, and, in our experience, is intolerant of data or user errors. It is also the only tool available for derivation of aggregated salts from ionic data, and is necessary for the physicochemical aspect of both Reserve specification and monitoring (depending on the level of Reserve). In order that ecological Reserve specification, implementation and monitoring be facilitated, it is strongly recommended that TEACHA be revisited, assessed and modified in the light of user experience with generation of aggregated salt data and the end-user experience, as regards the requirement for MATLAB or MATLAB libraries, approaches for dealing with left-censored data (e.g. see Helsel 2006), aggregated salt generation methods, and user interface and error handling.

5 INITIATING AN INTEGRATED WATER QUALITY MANAGEMENT FRAMEWORK FOR THE CROCODILE CATCHMENT

5.1 Introduction and background to the study area

5.1.1 Introduction

South Africa is regarded as a forerunner of change and is widely acclaimed for statutory reforms and conceptual and methodological sophistication particularly with respect to the determination of environmental water requirements (EWRs). EWRs, called the Ecological Reserve in the South African context, have both quality and quantity aspects (Box 1). There is no universal definition of EWRs or environmental flows. Generally, environmental flows refer to the flow regimes needed to keep freshwater ecosystems healthy and productive and to maintain the services they provide (Smakhtin et al. 2004). South Africa is fortunate in having a benchmark for the commitment to freshwater sustainability captured in the concept of the Ecological Reserve, for which it is widely acclaimed.

Box 1: The Reserve (NWA: RSA 1998)

The Reserve refers to the quantity and quality of water required:

a) to satisfy basic human needs (Basic Human Needs Reserve).
b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource (Ecological Reserve).

The Reserve refers to the modified EWR where operational limitations and stakeholder considerations are taken into account.

The focus of this work is progress in implementation of water quality aspects of the Reserve in one of the major rivers of the Lowveld, the Crocodile River. However meeting water quality standards (i.e. a state of "compliance") tells us little about underlying processes and practices, hence in this module of the study there is an emphasis on understanding what factors constrain or enable compliance.

In this work we stress that capacity for achieving water quality standards does not reside within the water sector alone. It is predicated on the introduction of Integrated Water Resources Management (IWRM) as a new and transformative way of managing the nation's water resources with and by all users. Hence it is the collective contribution by and synergies of a number of strategies, plans and practices (as envisaged in the National Water Act and the National Water Resources Strategy (DWAF 2004b) that make up IWRM. This is best exemplified by the Catchment Management Strategy. Operationalizing the Reserve moves the discourse and practice into a much wider arena than that of water conservation and protection alone. In other words, simply determining the Reserve (or any of the additional water resource protection measures outlined in the NWA) does not ensure achieving the Ecological Reserve or any other aspect of water resources management in South Africa. Rather, this goal relies on ensuring there is stakeholder participation, a collective vision for the catchment, an effective and transparent authorization process coupled with monitoring and regulation, and of course sufficient skills and funds to support this (DWAF 2004a, Pollard and du Toit 2009). Critically, it is also predicated on ensuring there is high-level collaboration between a spectrum of role-players, including all the major water users, government (including departments other than DWA), non-governmental agencies and in some cases, neighbouring sovereign states.

That the NWA views water resources as a resource of diverse goods and services (rather than simply a source of water) is evident in the classification system comprising three permissible classes[1]. Each of these – in effect a negotiated desired state – delivers a different complement of ecosystem services and each has attached risks and trade-offs. Associated with each class is a recommended ecological category[2] and a Reserve which is a composite description of a dynamic hydrological, geomorphological, physicochemical, and biological state. Once a management class has been selected by stakeholders it forms the basis of planning. All Reserve determinations done ahead of resource classification are considered preliminary Reserve determinations. There are four levels of Reserve determination (desktop, rapid, intermediate and comprehensive[3]) that are required for different circumstances that reflect the degree of use, the sensitivity and importance of the catchment, and the potential impact of the proposed water use. It is important to separate the above process (planning) from implementation.

This project builds on the work of the Shared Rivers Initiative (Phase 1) (SRI). The SRI project arose out of concerns that despite enabling legislative and institutional frameworks for water reform and environmental flows, the integrity of almost all of the rivers that flow eastwards and that are shared with neighbouring countries have not improved, or are continuing to degrade both in terms of quality and quantity. Given the direct benefits to peoples' livelihoods and the fact that these rivers are shared with other states, and hence are bound by international agreements, the implications are far-reaching. Indeed, as the SRI started there was evidence suggestive of deteriorating conditions. For example, the lower Olifants River ceased flowing on a number of occasions in 2005 despite a Reserve determination having been undertaken for the catchment. Likewise, the Sand River flows stopped on a number of occasions, most notably during 2005 and 2006 (see Pollard et al. 2010). In the Crocodile a reversal of seasonality together with very low-flows was a major concern. Although these are quantity related aspects they are inextricably related to water quality management actions.

While the SRI (Phase 1) focused largely on the water quantity aspects of the Reserve, water quality issues were regularly confronted. This gave rise to the dedicated research that is the subject of this report.

5.1.2 The Crocodile catchment

The greatest demand for water in the Crocodile catchment is from irrigated agriculture and forestry. In terms of water infrastructure the catchment has one major dam, the Kwena Dam, in the upper catchment (which augments low flows) and a number of smaller dams in the central portion (Witklip, Primkop, Klipkoppie/Longmere).

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[1] "natural", "moderately used or impacted", or "heavily used or impacted".

[2] Based on Present Ecological State (PES), as well as Ecological Importance and Sensitivity (EIS) and Socio-Cultural Importance (SCI).

[3] Comprehensive Reserve determination is required in the case of (a) compulsory licencing; (b) water use allocation planning; (c) large impacts; (d) sensitive or stressed catchments (DWAF 2003a).

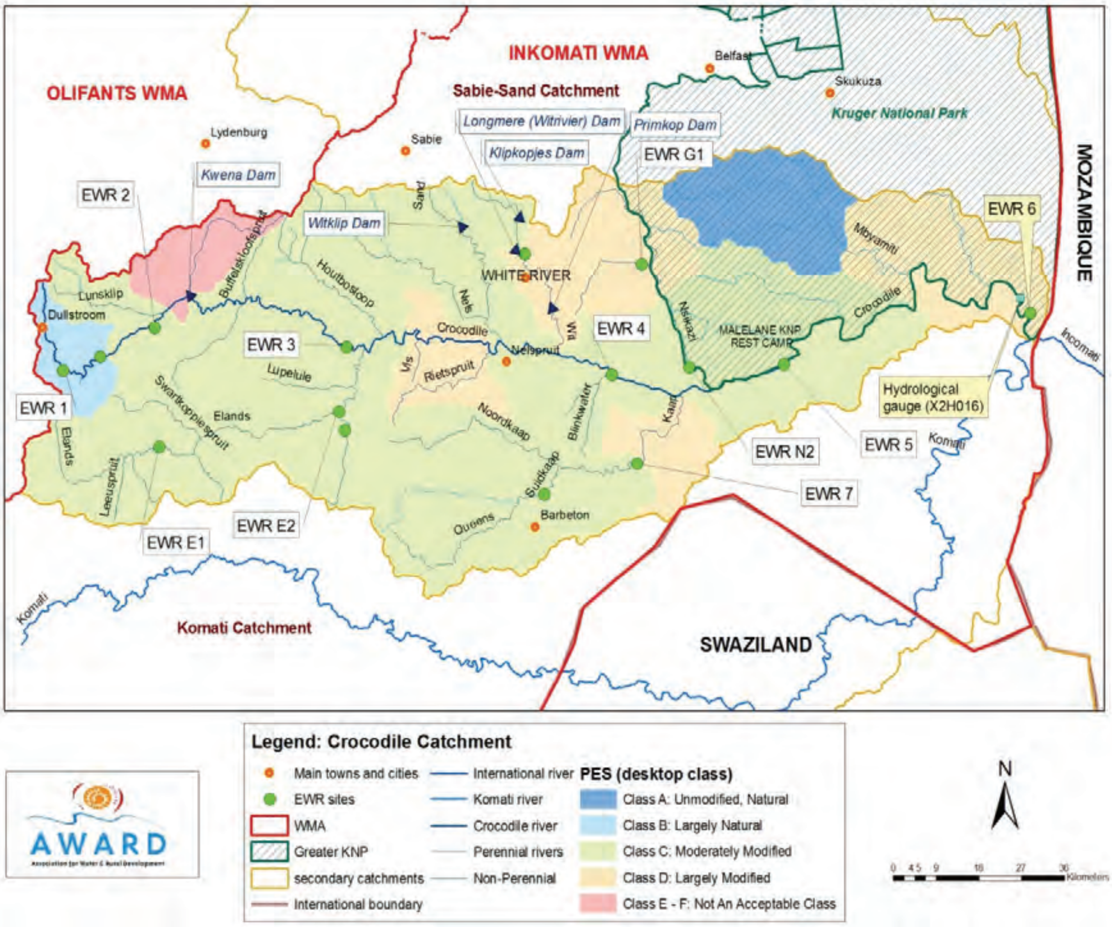

Figure 7 The Crocodile Catchment showing Environmental Water Requirement (EWR) monitoring sites.

The water requirements exceed the available resource, and the catchment is considered to be highly stressed (see Table 18). Irrigation demands have been increasing since the 1990s up to their current levels. The current policy of the Department of Water Affairs (DWA) has for many years been not to issue any more water use licences to irrigation. However, there are indications of unlawful developments.

Currently there is a real time study underway to address key problems east of the Kwena Dam. The objectives of this study, known as the Real Time Operating Decision Support System for the Crocodile East River System, are to assist with water distribution (run of river) and water releases (dams), and to ensure compliance with the Reserve and with international obligations (Crocodile East RTOS meeting Nov 2007). The Decision Support System (DSS) must be capable of determining operational plans and should include a water allocation and utilization management and monitoring system (DSS Team *pers. comm.).*

Table 18 Water availability and demand and water balance of the Inkomati WMA including the Reserve estimates (based on the preliminary 2008 estimate[1]) (DWAF 2009).

Availability/ Use	X1: Komati	X2: Crocodile	X3: Sabie	Inkomati WMA
Availability	**775**	**555**	**116**	**1446**
Current use (excl. Reserve)	**858**	**632.3**	**179.5**	**1670**
Allocated use with Reserve				
Cross Border	62	51	0	112
Reserve	228	205	209	
Domestic	47	73	82	202
Industry/Mining	2	27	0	29
Irrigation	642	482	98	1222
Strategic	105	0	0	105
Total demand with Reserve	1086	837	389	2311
Afforestation	117	158	90	365
Alien Vegetation	32	32	16	80
Balance currently	**-83**	**-77.3**	**-63.5**	**-223.8**
Balance with Reserve	**-311**	**-282**	**-273**	**-865**

International agreements

The Crocodile River is one of a number of South African rivers that contribute to transboundary flows. South Africa's international obligations to Mozambique, according to the Piggs Peak Agreement and the more recent Interim IncoMaputo Water Use Agreement (TPTC 2002) are to ensure a minimum cross-border flow of 2.6 m^3/s at Ressano Garcia for environmental purposes. Over and above this are requirements for 29 Mm^3/a for irrigation and 1 Mm^3/a for domestic purposes. The quality of this water is specified in an appendix to the Agreement. The water quality standards are currently being finalized.

The agreement is based on the SADC Revised Protocol on Shared Watercourses, and reflects the principle of equitable and reasonable utilization of shared watercourses for economic and social purposes between the three countries, as well as ensuring protection of the environment. The main objective of the agreement is to promote cooperation between the countries and to ensure the protection and sustainable utilization of the shared water resources. The agreement covers a wide spectrum of aspects, including exchange and access to information, drought and flood controls, water quality and pollution prevention, incidents of accidental pollution and other emergency situations.

The Agreement is supported by a resolution concerning short-term water quality management, the exchange of and access to information and data among the countries, and a framework for capacity building within the three countries (Inco-Maputo Agreement, TPTC 2002).

[1] This has been updated in 2009.

5.2 Research questions and methodology

The decentralization of management efforts that aim to engage water users is fundamental to IWRM as there is a drive for greater integration between users and management functions. In respect of this, this research aims to understand the meanings given to compliance with water quality standards. In order to shed light on the intentions to operationalize integrated water quality management two research questions were devised to guide the process. The two research questions are:

a) How do selected stakeholders understand compliance with water quality aspects of the ecological Reserve in the Crocodile Catchment?

b) What research and operational interventions are needed to improve compliance with water quality aspects of the ecological Reserve in the Crocodile Catchment?

A participative research method was adopted that recognises inhabitants of a catchment as important role-players in the enquiry process. However, the most challenging component of any participatory research approach is the organization and maintenance of the stakeholder processes (Cooperrider and Dutton 2001). Success, therefore, hinges on positive interactions and creating a spirit of collaboration between researchers, role-players and other partners. This is recognised and built into the research design of promoting collective engagement and collaborative learning. To this end the research did not draw solely on water quality “experts” or on the regulator alone, but rather, a multi-sector engagement process was adopted.

The research design is also built on the assumption that out of the enquiry process options will be tabled and future actions tried and tested in order to manage towards a shared goal.

5.2.1 Research participants

Research participants from the catchment were from three major categories, and these were further subdivided into groups as follows:

1. Regulators:
    - Regional Department of Water Affairs (DWA).
    - The Inkomati Catchment Management Agency (ICMA).
    - Government departments where appropriate (e.g. Department of Agriculture, Forestry and Fisheries (DAFF), Department of Environmental Affairs (DEA)).
2. Water users:
    - Water User Associations (WUA).
    - Municipalities as Water Services Authorities or Providers (WSA/WSP).
    - Industry (mineral processing, food and paper/pulp production).
    - Forestry.
    - Bulk water suppliers.
3. Researchers:
    - Consultants.
    - Non-governmental organizations (NGO) and academics.

More specifically, stakeholders included managers of water quality and waste water treatment works (WWTW), water quality officers from the ICMA, a water user association (or irrigation board) (WUA/IB) chairman, an environmental manager, an environmental control officer/ISO standards manager from an industrial smelting plant, a chairperson of an environmental NGO, private water quality consultants responsible for water quality reporting, a CARA (Conservation of Agricultural Resources Act; RSA 1983) enforcement officer from the DAFF, a deputy director of strategic environmental management (SEM), a deputy director of environmental impact management (EIM), a deputy director of the CMA, and safety, health, environment and quality (SHEQ) managers from industry and mining. A full list of stakeholders who participated in the process is contained in Appendix B (see attached CD).

5.2.2 The research process

In order to address the two research questions presented above, a specific research process was followed. A review and assessment of existing water quality management practices that impact on water quality compliance in the Crocodile catchment was conducted through a series of interviews with 26 stakeholders (identified above). The two largest categories interviewed were water users with a discharge licence and those that have some regulatory role in water quality management. The findings were synthesized and presented to the same participants/sectors at a group meeting three months later. This enabled a collective discussion regarding the issues raised in the interviews, as well as deliberations on the operational and research needs for achieving compliance at the catchment level.

The aim was not to arrive at conclusive answers but to open up dialogue with stakeholders so that the systemic nature of the issue could be addressed. To this end themes were identified and used as the basis for engagement of stakeholders. The intention was to feed back a synthesis of the interviews to respondents for further comment and for deepening understanding within the collective.

5.2.3 Semi-structured interviews

Most interviews were held with individuals, though in a few instances a number of representatives from the same institution were interviewed simultaneously. Where necessary, initial dialogues were followed up with a second contact where issues were unclear or where gaps were evident. The questions were presented as an open framework for discussion with the respondents playing an important role in raising their own issues.

The key questions for the semi-structured interview were:

1. What water quality standards apply to your (a) sector and then (b) organization? Are they the same?
2. Where are these captured/formalized? (Licence, ISO, agreement, etc.).
3. What procedures do you follow in meeting these standards?
4. What concerns do you have in relation to meeting and reporting on these standards?
5. Do you know anything about water quality standards for the Crocodile catchment as a whole? Have you heard of RQO's? If so describe what you know.
6. Do you think there are water quality problems in the Crocodile catchment and why? What can be done?
7. What key water quality issue/s would you like to have reported by this research?

It is important to note that although the interviews collect perceptions of compliance, the accuracy of these perceptions is not the main concern of the research. It is the consequences of the perception that are important. It is not whether perceptions are "true" or "false". In other words, managers act on perceptions and understandings, and this has consequences for practice. Reasons for non-compliance may, for example, be given as "poorly-skilled staff", although the issue may be "insufficient staff"; or high ambient levels of manganese may be blamed on upstream users. It is the synthesis of meanings that prevail in a given catchment and their implications for practice that are important.

In order to move beyond individual meanings a synthesis and analysis of data was conducted according to a number of steps. After the initial scoping of issues an interpretation was executed. Broadly, there are three steps to this analysis, as shown below.

1. Listing the issues that people raise – their experiences on a daily basis. This is a descriptive of personal and institutionally held understanding, experience of practices and conceptualization of "the problem" in relation to the questions posed.
2. Synthesis and analysis – grouping the issues into key themes.
3. Mirror-data approach – the themes and analysis are fed back to participants to elicit their response and gain acceptance for a collaborative set of future actions.

The themes emerging from the interviews and a discussion of the collaborative meeting and its outcomes are provided in the sections that follow.

5.3 Results

5.3.1 Emergent themes

In this section the emerging themes are identified and key issues raised by those interviewed are presented.

Water quality standards

Under this theme we were able to gather from the various sectors a number of standards and standard setting instruments as understood and applied within/by a particular sector. The information from the interviews was analysed and is reflected in Table 19.

The key issues to emerge are the following:

- The initial scoping shows that different sectors use varying water quality standards. Although 10 groups were identified amongst stakeholders, stakeholders from the same group use a variety of standards. For example, some industries may comply with ISO standards whilst others do not.
- The naming and conceptualization of the various standards is not uniform resulting in the same set of standards being termed differently or being understood in a different context. For example, the same standard may feature as European Union (EU) standards or ISO standards. Although this may appear trivial it has important consequences for initiating collaborative dialogue and collective action around standard setting and implementation. In the absence of common understanding or shared conceptualization it is difficult to proceed with participatory processes and collective action.
- The ICMA identified the highest number of standards (8) applied in the Crocodile catchment.
- Only the ICMA identified the RQOs as applicable to the catchment.
- Only the ICMA recognised the need to meet international standards (with Mozambique).

Table 19 Water quality standards applied by the different sectors and stakeholders in the Crocodile catchment.

WQ STANDARD	CMA	DWA	DEA	Local Govt	Industry (chrome process)	Industry (sugar mill)	Industry (paper)	Industry (metal)	Agric.	Agric. WUA/IB	Forestry	Bulk supplier	NGO	Consult.
RQOs	■													
Drinking WQ stds	■	■								■				
SANS 241	■	■		■								■		
SES	■	■		■								■	■	
GES	■	■		■				■		■	■	■		
GAs	■													
Licence		■		■	■	■	■							
EIAs			■											
Biomonitoring	■													
SASS						■	■			■	■			■
SFR											■			
WSA				■										
Industrial stds					■									
COD							■							
ISO							■				■		■	
EU stds							■							
Sappi							■							
By-laws								■						
CARA sect 6									■					
International stds	■													
Green drop												■		
Green status													■	
Aq ES guideline														■

Key

Red	Regulators	Light green	Forestry
Beige	Municipality	Light blue	Water service provider
Yellow	Industry	White	NGO
Green	Agriculture	Purple	Private consultant

- Certain sectors such as industry and forestry are associated with meeting internationally recognised standards such as the ISO and Forestry Stewardship Council (FSC) standards in order to sell their products aboard. A local NGO also identifies ISO standards as relevant.
- In the case of the Department of Environmental Affairs the focus is on the standards that apply to themselves, which points perhaps to a lack of integration or a lack of understanding of the need to integrate.
- A noteworthy standard was raised by the DAFF who highlighted that farmers are required to apply for wetland cultivation permits under the CARA Act section 6 since wetlands are an essential tool for better water quality.

Formalization of water quality standards

Under this theme we examined where stakeholders understand water quality standards to originate from, be housed, be contained or be described. Again a variety of responses was noted. The following key issues emerged:

- The majority were aware that applicable water quality standards are contained and formalized in the water use licence issued by the DWA.
- Additional locations are ISO standards, General Authorizations, forestry certification standards, environmental waste standards, South African Bureau of Standards (SABS), and RQOs (see next point).
- RQOs were only mentioned by the DWA in this instance.

Procedures implemented for meeting water quality standards

Under this theme we explored the variety and nature of procedures employed in monitoring and meeting water quality standards. The following points emerged:

- Monthly monitoring of effluent discharge for WWTW is conducted by the WSAs and WSPs. These may be contracted companies or the local municipalities.
- Compliance audits are conducted by the regulator (DWA) where discharge licences to WWTW have been issued: "Our role in WWTW is that we conduct compliance audits where there is a licence that includes water quality and we take samples upstream and downstream".
- During these audits Section 19 and 20 of the NWA are applied. Here the potential to cause pollution and actual causes of pollution are assessed and if necessary directives are issued.
- In the case of a pollution incident being reported to the DEA a letter is written by that department to the DWA requesting an intervention. Where relevant, the incident is reported to the DAFF.
- The ICMA has only recently been assigned functions for water quality compliance monitoring and enforcement. It has until now issued letters to transgressors and has conducted sampling for evidence collection. Further procedures include the evaluation of water quality against licence conditions, investigation of reasons for non-compliance, and suggesting measures for the mitigation of non-compliance.
- Mining industry representatives noted that they follow corporate governance systems for internal monitoring, reporting and management. They follow a procedure of (full legal) compliance audits every two years that are conducted by external auditors. They also follow internal monitoring procedures which they have set up in conjunction with Environmental Impact Assessment (EIA) requirements and water use licensing procedures.
- Another industrial user followed a procedure of monthly sampling in rivers near discharge points. They held quarterly meetings with a monitoring committee that DWA attends.

- Mining, industry and one representative from the major food industry maintained that some of the procedures for monitoring called for in licences are irrelevant to their sectors and a source of frustration (ref. standards for landfill sites applied to discharge monitoring).
- Nkomazi local municipality noted that they oversee water services providers in conducting water quality standards monitoring for drinking water and that the water quality officer monitors effluent discharges. One municipality noted that private enterprise assists them with quality testing.
- Mbombela local municipality noted that they have a variety of procedures in place. They do not control all their WWTW and water purification plants themselves (Sembcorp is contracted in). They noted that where they are in control they conduct daily tests at discharge points and when problems occur they notify downstream irrigation boards.
- The Department of Health plays a role in monitoring for *E. coli* and cholera.

Stakeholders' concerns with respect to water quality standards

Under this theme two aspects were explored with stakeholders. These are concerns related to a) meeting the various water quality standards, and b) reporting on compliance with these standards. The following issues emerged:

a) Meeting water quality standards.
   - Most stakeholders pointed out that the most critical constraint in meeting water quality standards is personnel. The issue of lack of personnel in the operation of WWTW was highlighted by this group of stakeholders. In addition to this the qualifications of the current operators were noted as being very low, and appointment of new staff for WWTW is slow. Also pertinent is that salaries are not motivating enough to attract new staff.
   - A high turnover of staff at DWA means that there are low levels of trust and that institutional memory is lacking with respect to compliance monitoring and reporting.
   - Another highly ranked issue by local government official stakeholders is that of priority for waste water treatment and the associated availability of finances. Categories identified relate to the budget for water and sanitation within the Integrated Development Plan (IDP) (which is too little), as well as the misuse of funds allocated for replacement of broken equipment.
   - Standards in water licences were mentioned as unachievable and unrealistic by some stakeholders.
   - DWA was perceived to be inconsistent in acting as a regulator of water quality. Although stakeholders felt that DWA should be the sole regulator, the following problem areas were indicated: missing licence applications, lack of enforcement and limited feedback in cases of emergency.
   - Representatives from DWA noted that they lack capacity as staff move to the more financially attractive private sector.
   - At a catchment scale, it was highlighted that managing for "unknowns" was very challenging. For instance, meeting quality standards is contingent on upstream events, and water quality monitoring carries addition responsibilities in terms of monitoring inflow as well as outflow in order to prove compliance.
   - Some stakeholders in the mining sector felt that there are "double licensing" procedures and that procedures need to be integrated and streamlined. The involvement of EIA procedures, Department of Mineral Resources (DMR) and DWA in water-related approvals was costly and sometimes counterproductive as it was claimed that not all three authorizing bodies agree. It was felt that the sole entry point for water-related approvals and monitoring needs to be the DWA.

- Sampling-related issues were identified as problematic by stakeholders. The regulator felt that there are limited points in the Crocodile catchment where samples are taken. On the other hand they highlighted the challenges of sampling at all EWR sites. Also mentioned in this regard were issues relating to laboratories. Firstly, meeting specified time frames for sample transport to laboratories for valid analysis was challenging, and secondly, there were insufficient laboratory facilities within the catchment in general. Both the lack of accredited laboratories in the area and the perceived lack of clarity regarding appropriately accredited laboratories were noted as of concern.

b) Reporting against water quality standards.
   - The regulator noted that the shortage of staff able to treat reports forwarded to them is a real constraint in monitoring for compliance.
   - The mismatch between the South African National Standards (SANS) and water use licence requirements was noted as a problem for reporting by the bulk water supplier.
   - The major concern for local municipalities was lack of well trained personnel, especially those running the WWTW. Training was identified as having an important impact on the quality of written reports and of record keeping, and hence influences the meeting of water quality standards.
   - The cost of laboratory testing (especially with respect to some elements) was noted as prohibitively expensive.
   - The lack of availability of a record of mining authorizations by the DMR making it difficult to hold mining sector accountable was reported as a problem by an NGO involved in a "watchdog" role in the catchment.

Knowledge of water quality standards

Under this theme stakeholder knowledge of water quality standards was explored. This was done both in terms of standards for the Crocodile Catchment specifically and RQOs in general. The following issues emerged:

a) Catchment standards.
   - The vast majority of respondents were unclear what was meant by a catchment water quality standard.
   - Two definitive mentions of catchment standards were that General Authorization Standards apply to the Crocodile River, and that the IncoMaputo agreement requires a particular water quality at the border with Mozambique.
   - The majority of stakeholders pointed out catchment-based water quality concerns in response to this question. This may indicate a lack of familiarity with these standards and may be indicative of the relatively low priority accorded to planning and implementation of water quality standards at the level of a catchment.

b) The resource quality objectives (RQOs).
   - RQOs proved to be foreign to most stakeholders that were interviewed. Stakeholders knew more about the Ecological Reserve than RQOs. Where the term was recognised, familiarity had been engendered through involvement with the Reserve determination process.
   - Stakeholders that have heard of the Reserve were the regulators (ICMA and DWA), and some participants from the industrial sector (Tsb Sugar mill, Manganese mining company and Sappi Ngodwana), the forestry and the consulting sectors.

- RQOs were only known to regulators, a private consultant and one stakeholder in industry. The representative for Sappi even went further to highlight that they were still interim resource quality objectives. A private consultant also shared his concerns about RQOs, pointing out that the system is a venture into the unknown.

Crocodile catchment water quality problems

This theme elicited the most responses from stakeholders. We present the issues that arose categorized by the various groups of stakeholders consulted. This theme is addressed in two parts. The first is the a) identification of water quality issues in the Crocodile Catchment and b) suggested solutions.

a) Water quality issues

A wide range of water quality issues were mentioned. An analysis of the interviews was conducted and results are presented in Figure 8. The most common issue raised by participants was that of waste water treatment followed by irrigation related pollution with specific mention being made of nitrates and phosphates. Sedimentation also featured significantly with manganese and iron just below that. Although actual issues need to be verified, the graph provides a broad view of how stakeholders perceive water quality issues in the catchment. In the section that follows we provide details of discussions according to the various respondents' sectors.

Regulators

- Regulators indicated that WWTWs were problematic throughout the province and a major threat to water quality. Specific examples of non-compliance were WWTWs at Komatipoort and Malelane.
- Cooperative governance protocols that constrain the regulator from applying legal sanctions against another sphere of government were identified as an obstacle in achieving compliance of WWTW.
- Two companies (iron/manganese processing) were identified as major contributors to iron and manganese-related water quality issues in the catchment. Effluent coming from Sappi (paper pulping/processing) was perceived to be causing sodium-related problems in the Elands River, and downstream testing revealed suspected high chlorine levels apparently from their mill that were affecting tobacco farmers.
- Citrus farmers/juice producers were identified as responsible for the discharge of hot water in the river.
- The regulators felt, in general, that agricultural pollution lacks close monitoring.
- A "blame situation" between two mining industries for iron and magnesium was highlighted.
- Regulators acknowledged lack of capacity in terms of staff for monitoring in their organizations.

Industry

Under industry are included the mineral processing activities, food processing (sugar) and paper processing.

- Role players in industry identified WWTWs in the catchment as responsible for water quality degradation.
- The industrial sector noted the purported impacts that informal settlements have on the resource. They also reported impacts owing to abattoirs. Some industries noted that upstream of their operations, there were problems of water contaminated with iron which is associated with blood. However, stakeholders were not sure of the existence of abattoirs in the catchment.

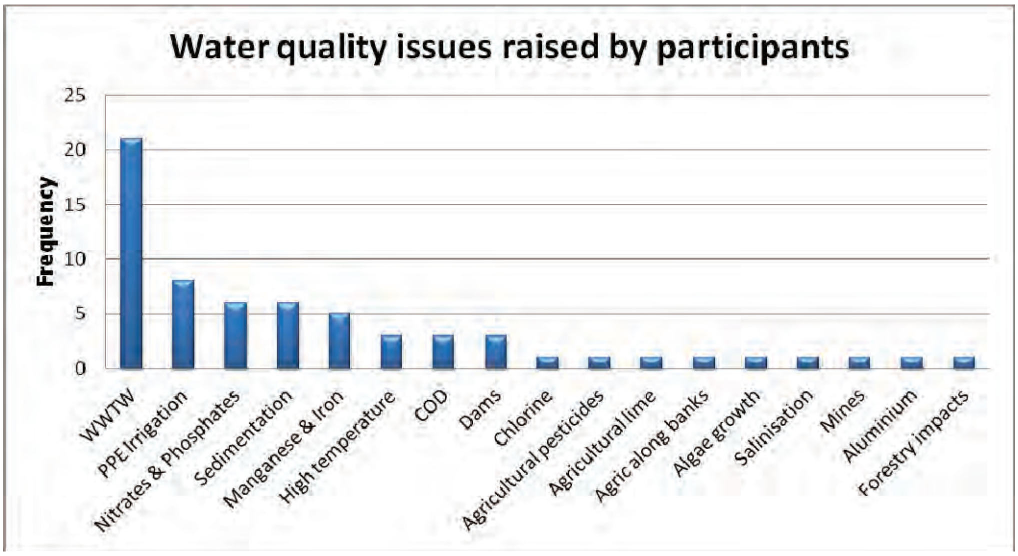

Figure 8 Frequency of Crocodile catchment water quality issues raised by participants.

Key

WWTW	Waste water treatment works operation and maintenance
PPE Irrigation	Paper pulping effluent irrigation
COD	Chemical oxygen demand
Agric along banks	Crop production next to river banks
Mines	Unsealed mining tunnels affecting groundwater after closure

Notes to Figure 8

1. Brief notes are provided to assist with the context within which respondents raised issues. These are by no means comprehensive or conclusive but suffice to scope the issues as they were raised by the respondents themselves. Further and more detailed investigations are warranted in a more detailed study.
2. WWTW: these are waste water treatment works operated by Local Government, as well as those run by private companies, industry and forestry.
3. PPE irrigation is undertaken as a way of preventing return flows of treated water to the river. However concerns are that partially treated water is returned to the river by groundwater seepage.
4. Nitrates and phosphates are taken in this context to originate from commercial agriculture.
5. Sedimentation was perceived to be a consequence of soil erosion processes in the catchment.
6. Manganese and iron: problems owing to these metals were frequently reported together.
7. High temperatures refer to effluents discharged at temperatures above those authorized in water use licences.
8. Chemical oxygen demand was mentioned by respondents, but Biological Oxygen Demand (BOD) was not.
9. Dams: the release of turbid water from dams was identified as water quality issue.
10. Chlorine: in reference to paper pulping/bleaching processes.
11. Agriculture along river banks refers to small scale farming close to streams and rivers.
12. Algal growth is perceived to be a consequence of nutrient release and increased temperatures.
13. Mines: an unspecified group perceived to contribute to water quality issues through, amongst others, acid mine drainage, chemicals from metal processing, water seepage and improper closure of mine dumps.
14. Aluminium: this refers to the accumulations of aluminium from commercial agriculture (source unclear).
15. Forestry impacts include contributions to erosion by roads, water pollution from irrigation of burnt logs and waste water effluent from forest housing developments.

- Waste water treatment was seen as a problem, owing to a lack of attention to monitoring. Instances of high peaks of chemical oxygen demand (COD) upstream from the Sappi mill were noted.
- Nutrients were identified as the cause of serious water quality problems, with major culprits perceived to be nitrates and phosphates. Sources of nutrients mentioned included agricultural activities, informal settlements and human settlements along the river banks.
- Illegal sand mining in the river and sand coming from Kanyamazane were also identified by some stakeholders as causing massive siltation problems.

Agriculture

The agriculture sector active in the catchment is extremely varied and extensive. Representatives from WUAs and the DAFF were engaged. What follows is an initial scoping and cannot be taken to be representative of all water quality issues raised by the sector.

- One of the main water quality problems highlighted by agriculture was siltation. Perceptions are that siltation is caused by poor agricultural practices and “IDP programmes” (housing developments) which increase the speed of water runoff.
- Salinization problems on sugarcane plantations were also noted.
- Excessive use of fertilizers and poor drainage planning were identified as a problem for water quality management.
- Although agriculture-based pollution was acknowledged by the sector, participants also identified non-agricultural sources of water quality degradation. The leading one was waste water treatment by local government. One of the agricultural sector participants claimed that "...sewage is the biggest threat to our rivers…" (in the form of *E. coli* contamination).
- Other polluters were identified as the mill at Ngodwana and the Inkomati mine.

Local government

The management of water quality by local authorities is complex and highly contingent on specific arrangements made by and within particular municipalities. In some cases waste water management is contracted out whilst in others it is done “in-house” or, in some cases, both. Problems have generally arisen where local government structures have inherited WWTW from DWA or public works after 1994.

Local government authorities generally acknowledge that water quality issues stem from the management of WWTWs in the catchment. They admit to the problem being embedded in local government structure and functioning.

- Manganese and iron entering WWTWs was highlighted as a major issue. However, in the case of manganese, the geology of the catchment was perceived to be a factor.
- Complying with Inco-Maputo agreement was viewed as a major challenge by all participants in local government.
- The failure of WWTWs was identified as an issue owing to:
    - Lack of flow meters.
    - Directors not giving feedback after evaluations.
    - Junior staff being neglected by senior management.
    - The Nelspruit plants struggle with magnesium and iron levels.
    - Lack of training: "Our operators are not qualified to really operate these facilities".

- “Before transfer of WWTW from DWA there was no enforcement”. Dysfunctional plants were inherited by local government, and in this regard DWA is identified as the main culprit: "They (DWA) have offloaded their problems on us".
- Staff salaries are a major disincentive.

Private consultants

There is a large consulting community associated with water quality monitoring and reporting in the catchment. The relatively affluent sectors are capable of outsourcing their water quality monitoring obligations (in licences) to private consultants. Internal monitoring is also sometimes conducted by this group. They generally represent a highly skilled and competent group of individuals who operate own companies or who work as a network of consultants to provide water quality monitoring and management services to the various sectors. The complex field means that there is some level of specialization and focus. Each consultant interviewed focussed on his/her area of specialization. The issue of accreditation was later raised in the collective meeting of stakeholders (see later). Wider discussion in this regard is probably necessary for future research processes.

- Problems identified related to low pH, high water temperatures (above/below the acceptable ranges), and conductivity.
- Forestry consultants noted that water quality problems were mostly due to sedimentation caused by runoff from roads. The number of roads per hectare far exceeds the FSC guidelines.
- Informal settlements using rivers as dumping sites were also identified as a cause of water quality problems.
- Abandoned mines were considered a major contributor to water pollution in the catchment (acid mine drainage).

Forestry

A number of forestry companies are operating in the catchment. Two of the most important were consulted in this scoping.

- Forestry perceived mining sector activities to be a serious water quality threat in the catchment. Mine closures were mentioned, in the context of some companies abandoning operations with potential for acid mine drainage. Pollution from explosives, etc. was also reported.
- Road construction contributed to water quality problems through siltation.
- The agricultural sector was also identified as causing pollution, mainly through irrigation. The sugar industry was used by one respondent as an example of this.
- Industrial pollution was also mentioned, but was not perceived to be a major problem.

Non-governmental organization (NGOs)

The major NGO associated with water quality monitoring noted that there are major water quality issues along the White River and Elands River.

- WWTWs in the catchment were linked to pollution through over-chlorination and poor maintenance of infrastructure at the plants, with the latter resulting in sewage entering the river.
- The area around the Witklip Dam was pointed out as amongst the most polluted, purportedly as a result of *E. coli* from effluent from informal settlements flowing into the rivers [this was speculation]. The *E. coli* problem, it was claimed, is associated with nutrients coming from settlement septic tanks.

- The agricultural sector was ranked as one of the major polluters owing to the use of agricultural chemicals. Apart from agricultural chemicals, farming in river beds and lack of licensing of irrigation by business was noted as a major problem.
- The NGO representatives felt that there is lack of regulation of micro-industry such as bed and breakfast (B'n'B) operators, fast food enterprises and small-scale industry.

Water service providers

There are two main privately operated WSPs in the catchment. The service provider that supplies waste water treatment services to Nelspruit is a highly competent and efficient services provider according to the Green Drop Report (DWA 2011).

- They noted water quality problems are associated with metal processing (manganese) along the Crocodile river. This waste water enters the domestic sewage processing system and the costs for treatment are transferred to the WSP. This has become a source of tension in that under the bylaws the WSP is able to institute fines for water quality transgressions. The problem is complicated by high levels of naturally occurring manganese in the geology surrounding Nelspruit.
- The Matsulu WWTW was identified as the worst polluter followed by another plant in near Kanyamazane.
- A major irregular event when starch was deposited in the river was noted.
- High COD coming especially from food processing industries was also noted as a major water quality problem.

5.3.2 Stakeholder recommendations

In this section we consider the recommendations made by the various sectors on the need for achieving compliance in the catchment, and the means by which this might be achieved. These recommendations are synthesized from the interview process. It is important to note that these recommendations originate from the individual sectors, and do not represent a debated and agreed-upon outcome. Whether these recommendations collectively constitute solutions to water management problems needs to be the subject of future research.

Regulators

The regulators (DWA, DAFF and ICMA) saw the improvement of administration of the monitoring and enforcement unit at DWA as critical for facilitating better water quality management in the catchment. Without the appropriate capacity they felt that compliance would not be realized.

Regulators felt that there is a need to conduct research focusing mainly on the impact of agricultural pollution as it is not well understood. On the other hand, the agriculture sector felt that it had been unfairly vilified and that local government was largely the transgressor through waste water treatment transgressions.

Inadequate skills and competency of WWTW operators was identified by the regulator as a major concern. They maintained that a study of operator skill levels was necessary.

The ICMA recommended that the water resource classification process be finalized as this will give meaning to the Reserve and the RQOs. Besides classification, the ICMA also highlighted that proper administration of the compliance monitoring and enforcement unit needs to be in place. In addition, cooperative governance was identified as a major problem. Compliance notices issued to local government departments were rarely adhered to.

The DEA wanted to know why the State of the Environment (SoE) report has not been updated. The now outdated 2001 SoE report (CSIR 2002) stated that the Crocodile catchment was stressed yet very little was being done in terms of management to address this status. They noted that they are understaffed with budget constraints resulting in failure to send out inspectors to sites or attend meetings. They requested serious attention to this matter.

Industry

The key recommendation was that industry, through self-regulation, should look at applying the principle of “zero discharge” over the coming decade. This means that industry would invest in “closed systems” with 100% recycling of water. To speed this up incentives, in the form of rebates, should be offered to industries that adopted these practices.

Industry generally felt that there is poor feedback from DWA especially when a transgression was detected. This lack of feedback hampered their attempts to remedy and improve their water quality management practices.

Representatives from a chrome smelting plant felt that waste water treatment should be the major focus of future efforts to improve water quality in the upper Crocodile catchment. They offered to be involved in future action and had already assisted one local municipality with fixing damaged pumps. They noted that sewage from the local WWTWs overflows into the river almost once a month. This poses health risk to their employees since 60% of the labour force lives in the local town. They also recommended a focus on municipal landfill sites as they had detected seepage from the local landfill into their water quality monitoring boreholes.

A major sugar producer pointed out that there should be strict control over abstraction from the rivers as this affected dilution potential of the river at certain times of the year. Furthermore, they felt that current illegal abstraction is unmonitored in the catchment. The industry representative made a plea that regulators ought to have more “compassion for industry” regarding reasonability of standards in licences. They maintain that industry “gives back to communities” and this should be considered when taking water management decisions. Population growth and informal human settlement expansion were highlighted as key factors affecting water quality in the catchment. Industry called for another dam in the upper catchment in order to augment river flows and enhance water security over the long term.

Agriculture

The WUA located in the upper Crocodile catchment felt that there is irresponsible management and that local municipalities need to be “brought on board”. They called for special attention to be directed at Machadodorp where there is a “persistent problem of raw sewage entering into the river”. The chairperson of the WUA felt that there was no compliance monitoring and enforcement along most of the Elands River.

Local government

Local municipalities expressed the view that the DWA was largely to blame for water quality issues in the catchment. They felt that DWA needs to improve its management functions considerably. The largest local government in the catchment acknowledged that there needs to be attention to internal municipal management procedures as well. This should include upgrading of procurement processes for WWTWs. They felt that plant operators are being excluded from planning and that a more inclusive management process should include them.

Politics and power were issues discussed by these practitioners. They were concerned that politically appointed councillors have too much control over municipal functioning, marginalizing officials and practitioners in the management process. The servicing of "personal interests" (corrupt practices) was also identified in two municipalities as a problem for transparency. An extensive investigation and forensic audit was called for with regard to tender processes and services provision. Suspected collusion between service providers and high-ranking municipal officials who have information on procurement needs was pointed out as fuelling "corrupt practices". Lastly, municipalities requested their own laboratories as there were "too many irregularities" regarding water quality testing and the appointment of service providers.

The local government officials that were interviewed requested more workshops on water quality related issues and updates from water quality research conducted in the catchment.

Non-governmental organizations (NGOs)

The largest environmental NGO operative in the catchment called for WWTWs to be operated effectively in order to address high nutrient levels in rivers. Enforcement needs to ensure that discharges meet minimum standards. The position taken by the NGO was that there should be no leniency on polluters. Transgressions should be met with a "shut-down policy" and the polluter pays principle (PPP) must be applied in remediation. However, although they suggested application of the PPP, they highlighted that challenges to its implementation include companies who are defiant, as revealed by comments such as: "...fines do not work ...industry would rather pay fines...".

Housing developments and informal settlements were also indicated as major problems which one NGO felt needed immediate attention. The "lack of governance and political will" were the two key issues pointed out as hampering progress in this regard. They went on to suggest that a practical approach in tackling water quality problems in the catchment might be to start with point source pollution and later move to non-point source pollution. One NGO member recommended the installation of automated cut-off devices at discharge points. When specified effluent levels are exceeded the discharge is automatically cut off.

Forestry

The forestry representative suggested that there should be a strong focus on the monitoring of cumulative environmental impacts for the various sectors. They also felt that there needs to be more efforts at integrated planning with a breakdown of the "silo approach in water quality monitoring and management". They felt that stakeholders, "even from the same sector, operate in isolation" and that this would ultimately hamper catchment-level compliance.

This sector felt too that there needs to be a database of point source and non-point source pollution for the catchment and that the regulator needs to drastically improve water quality management practices.

Private consultants

Consultants that were interviewed generally focussed their recommendations on their area of expertise. One consultant working in the forestry sector felt that the issue of sedimentation is insufficiently monitored and reported. Erosion and consequent soil sedimentation causes siltation problems in the major tributaries of the Crocodile resulting in changes to the hydrology and geomorphology. He maintained that the full effects of siltation are poorly understood and that there could be serious implications for water quality when toxins and pollutants (phosphates and hydrocarbons) bind with the silt.

The main call from the consultants was that there should be a much greater focus on research into water quality issues in general and that this be co-ordinated by competent authorities such as the ICMA in conjunction with research organizations such as the WRC and AWARD.

Improved community awareness of water quality issues was raised by this group as an important way forward. They felt that unless community members are turned into custodians of water resources, curbing water pollution will continue to be a challenge in the catchment.

5.3.3 Collective deliberation: group meeting

The second step of the research process entailed bringing the key stakeholders that were part of the interviews together to deliberate as a collective on the state of water quality in the catchment as well as to identify future research and operational needs as they perceived them.

The process

On 1 February 2012 a group meeting for all those involved in earlier discussions was held in Nelspruit. There were 17 participants who came mainly from the sectors that had been interviewed in November 2011 (Appendix D, see attached CD). All sectors involved in the earlier process were represented except for one representative from the Nkomati mine who had not been part of the interview process.

The agenda and a full record of the meeting are contained in Appendix E (see attached CD). The programme involved provision of feedback from the interview process, and a presentation on the status of compliance with the current Ecological Reserve for the catchment. During the second part of the meeting the group received an overview of the challenges facing water quality compliance, before being asked to identify research as well as operational needs in order to inform an integrated water quality management plan for the Crocodile catchment.

Integrated water quality management framework

The concept of “integration” sparked some discussion from the group. The issues of overlap and duplication were the subjects of considerable deliberation. It was noted that industry does a large amount of routine monitoring and has access to considerable data. In this regard it was noted that overlap could be avoided where river quality is being monitored.

The participants were then spilt into groups of two to discuss research needs and operational needs for creating an integrated water quality management framework for the Crocodile Catchment. The issues that emerged are given below.

Research needs

On the status of water quality

There was a general sentiment that there needs to be an adequate understanding of the current status of the quality of the rivers and especially those that are being discharging into. Although much work has been done this needs to be synthesized and available to all. There is also a need for more specific scientific knowledge of the catchment, including the identification of research "gaps". The point was made that if we are to determine compliance (or non-compliance), (a) the links between water quality and quantity and (b) the cumulative impacts of various activities in the catchment need to be better understood.

Specific identified research needs included the following:

- Key water quality indicators should be formulated that can then inform the classification process.
- Studies should be undertaken to provide an understanding of what critical constituents or parameters are needed for a biomonitoring plan for the Reserve.
- Studies are needed to provide information on the carrying capacity of the systems (catchments) as far as assimilating effluent that is discharged.
- There is a need to gain a better understanding of groundwater pollution as well as the interaction between surface water and groundwater.
- A better understanding of ambient levels of elements such as manganese and zinc in water in the catchment.
- Indicators that stakeholders and the public can understand and use are required.
- Ongoing research is needed to inform the appropriateness and choice of water quality indicators.

It was noted that research would need to be "fully transparent", and that stakeholders would need to clarify their involvement in such research.

The need for a single database

It was suggested that there be a single database from which all water quality studies can be sourced. The database needs to be easily accessible and open to all.

Use, regulation and governance

Lawfulness and licensing were considered to be important research foci. Specifics raised were:

- Scoping research on planned water use is needed in order to plan for future water use (including both quality and quantity aspects).
- Lawful and unlawful users need to be identified (validation and verification) with respect to water quality.
- More research is required to understand the process determining the conditions for the issuing of an effluent licence.
- A status report or "snapshot" is required on the political challenges and opportunities for water quality management in the Crocodile catchment (including transboundary issues with Swaziland and Mozambique).
- Research is needed on the effectiveness of licensing in water quality regulation.

Operational needs

There was general agreement that there are many capacity and competence challenges facing water quality management in the catchment. Some participants felt however that they had offered support that had not been taken.

Monitoring plan and information plan

A comprehensive and coordinated monitoring plan is required, which should incorporate a better understanding of monitoring needs, timing, frequency, data management, site selection and refinement of existing procedures. This plan should include an information management plan and an improved sharing of information across sectors and users. Many pointed to the need for improved public awareness of catchment-based water quality monitoring. For this to be meaningful, attention would be needed to address the diversity of language in the catchment around water quality issues. Information would need to be generated in such a way that non-technical people could understand it.

In this regard, participants also pointed to the need for:

- Standardization of monitoring tools to improve communication and integration.
- Engagement among departments involved in water quality issues.
- Clear procedures for everything.
- Operating rules supported by proper scientific models.
- Simple tools to assist in the evaluation of new licences.
- A focus on prosecution and law enforcement, including the identification of the most common water quality infringements, and a decision on what can be done about these.
- Much clearer directives from government departments regarding water quality issues.

On laboratories

It was clear that there are a number of issues related to laboratory services (see above) and the following suggestions were made in this regard:

- Databases of accredited laboratories are required. The establishment of new local laboratories is recommended.
- Better co-ordination of laboratory services would be advantageous. This would include the matching of laboratory functions with accreditation.
- Agreement is required on procedures that require accredited laboratories. This would also involve the establishment of clear guidelines for exemptions from the use of accredited laboratories, as well as recommendations regarding the frequency of laboratory use (for example, only quarterly tests to accredited laboratories).
- The accreditation of those monitoring ISO standards and biomonitoring using SASS methodology needs clarification.

Skills, capacity and retention of staff

This is, in our experience, a perennial issue, but it remains one that requires attention (as raised by participants). As noted earlier, there is little incentive to work as a senior plant operator – and to carry the accompanying responsibility – if one does not (a) have the skills and (b) is not remunerated accordingly. Specific points were also highlighted as follows:

- Revisit staff salaries and recruit and train more operating and administration staff for WWTWs.
- Focus more on competence and capacity development. In particular, skills to interpret results and evaluate information for decision making are required.

General

- Explore how the regulator can maintain credibility amongst stakeholders.

- Water quality management needs to be linked to the quantity operating rules at particular sites in the river.

5.4 Discussion

5.4.1 Synthesis of the group deliberations

The group had an opportunity to deliberate as a collective around the key and fundamental water quality issues for the Crocodile Catchment. The most important issues are synthesized from the interaction and presented here.

One of the most important aspects to emerge from this work is that the various sectors identify sectors other than their own as sources of water quality management problems. In this respect there is little public admission of problems stemming from own practices. This situation might be expected but it stands to hamper reflexivity, transparency and a spirit of cooperative learning. Ways of dealing with this tension need to be explored. It is likely that ongoing engagement will reduce defensiveness and engender a greater sense of collaboration.

The variety of institutions and sectors present at the meeting highlighted the complexity of integrated water quality management. Participants were not entirely clear as to the roles of the different institutions and their scope of functions. This is apparently complicated by the evolving roles of DWA and the ICMA. To this end a number of participants felt that the ICMA should play an overarching role in integrated water quality management and that it should hold the key functions in this regard. It was also felt that the ICMA should provide a co-ordinating role in water quality research. This would include the identification of research needs, co-ordinating research programmes and communicating research findings to stakeholders.

Monitoring was a central concern for most of the participants. The duplication of water quality monitoring was seen as wasteful of resources and there was a call to co-ordinate monitoring activities more widely for the catchment. Use of shared databases and much higher levels of stakeholder involvement were strongly recommended. Some sectors such as industry have considerable databases that are not being exploited to maximum effect. The potential of sharing these needs to be explored. It was suggested that the public should be encouraged to play a much greater role in resource quality monitoring. Poor public awareness of water quality issues was identified as a major obstacle to catchment compliance.

Ongoing frustration with the ability to enforce standards was expressed by participants. Poor enforcement has led to a lack of confidence in the regulator and to conditions where transgressors are defiant of the law. Poor enforcement is complex and stems from a number of issues relating to capacity and staff training, lack of experience with new legislation, failure to assign or delegate functions to the competent authorities and poorly coordinated enforcement practices.

The group emphasized the need for integration and the formal drafting of an integrated water quality management framework. This framework would need to show how management practices would be synergized so that duplication is minimized and processes are streamlined. The integrated plan should specify roles and responsibilities as well as outline the management processes required for efficient water quality management.

5.4.2 Concluding comments

Whilst this research cannot claim to be comprehensive or conclusive it has aimed to achieve two things: firstly, to provide a scoping of the most critical water quality issues for the Crocodile catchment as perceived by stakeholders and, secondly, to initiate sectoral collaboration towards an integrated water quality management plan.

This report hopefully highlights some of the challenges that are likely to be confronted in moving towards catchment compliance and, in that respect, prepares researchers and stakeholders for the task at hand. Although a more comprehensive and detailed study of specific water quality issues might be useful we believe that this report adequately highlights the key concerns and provides a base from which to design future actions.

6 GENERAL CONCLUSION AND RECOMMENDATIONS

The conclusions to be drawn from this study are direct and straightforward:

1. The methodologies and approaches underlying the water quality aspects of the ecological Reserve and those underlying the water quantity or flow aspects of the ecological Reserve would benefit from reassessment and harmonization. This would be facilitated by the development of better methods for water quality modelling than are currently available.
2. The existing documentation of a methodology for the determination of the water quality aspects of the ecological Reserve needs to be revised as described in the methods critique sections of Chapter 3, externally reviewed, finalized and approved by the DWA.
3. A monitoring and compliance process for the regulation and enforcement of the water quality aspects of the ecological Reserve in relation to discharge licences and non-point-source pollution needs to be developed in collaboration with users, managers and the regulator, externally reviewed, finalized and approved by the DWA.
4. The catchment participatory processes initiated in this project need to be followed up and developed in co-operation with water users, the DWA and the ICMA into an **Integrated Water Quality Plan**, first for the Crocodile River, and then extended into the broader Inkomati Catchment area.

The following process could be followed to achieve the above:

Stage 1: Assemble a suite of collaborative funding that builds on existing funding investment.

- WRC KSAs 1 and 2 could collaboratively contribute, building on the Shared Rivers Initiative, the work of Professor Kevin Rogers with the ICMA, and this project.
- DWA Water Quality planning could contribute so as to contribute to realistic water quality planning for the implementation of balanced protection from discharge and non-point-source pollution, and use of the dilution and processing capacity of freshwater ecosystems.
- The National Research Foundation (NRF), through the Department of Trade and Industry (dti) and the Technology and Human Resources for Industry Programme (THRIP) could contribute through adding to cash contributions by participating industries.
- The new collaborative research project would also build on a Water Research Commission (WRC) STRP linked with a current R2M South African Netherlands Alternatives in Development Programme (SANPAD): *From policy to practice: enhancing implementation of water policies for sustainable development*, that includes the ICMA as a case study.

Stage 2: Assemble a transdisciplinary project team.

Stage 3: Undertake an action research project that would have tangible, on-the-ground improvement to water quality management and ultimately instream water quality outcomes in the Crocodile catchment and the wider Inkomati catchment.

It is anticipated this would require two 3-year, or at least one 5-year project with an extensive team. Therefore Stage 1 of collaborative funding is essential.

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Appendix A PES and REC EcoSpecs and TPCs for sites on the Crocodile and Kaap Rivers

This appendix presents summarized tables of PES and REC EcoSpecs and TPCs from the comprehensive Reserve determination (DWA 2010) for comparison with the test data sets generated in this study. Data on turbidity and temperature are not presented here as no data on these parameters was available from WMS, and EcoSpecs and TPCs were not presented as numeric data in the Reserve report.

Table A.1 Summary of Ecospecs for PES and REC, and TPCs, for water quality monitoring gauge X2H013Q01 at site EWR3 on the Crocodile River. Data on toxics presented only when toxins are specifically mentioned in DWA (2009b). All data from (DWA 2010), and, for toxics, from DWAF (1996).

EWR3 Poplar Creek X2H013Q01				**EcoSpecs**	
Metric		**%ile**	**TPC**	**PES**	**REC**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	13-16	≤ 16	≤ 16
	Na_2SO_4 (mg/ℓ)	95	16-20	≤ 20	≤ 20
	$MgCl_2$ (mg/ℓ)	95	12-15	≤ 15	≤ 15
	$CaCl_2$ (mg/ℓ)	95	17-21	≤ 21	≤ 21
	NaCl (mg/ℓ)	95	36-45	≤ 45	≤ 45
	$CaSO_4$ (mg/ℓ)	95	280-351	≤ 351	≤ 351
Physical variables	EC (mS/m)	95	24-30	≤ 30	≤ 30
	pH	5	<6.7	6.5-8.0	6.5-8.0
		95	>7.8	6.5-8.0	6.5-8.0
	DO (mg/ℓ)	5	6.0-6.2	≥ 6.0	≥ 6.5
Nutrients	TIN (mg/ℓ N)	50	0.20-0.25	≤ 0.25	≤ 0.25
	PO_4 (mg/ℓ P)	50	0.012-0.015	≤ 0.025	≤ 0.025
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	8-10	< 10	< 10
	Chl-*a* periphyton (mg/m^2)	50	42-52	≤ 52.5	≤ 52.5
Toxics	As (mg/ℓ)	95	≤ 0.010	≤ 0.010	≤ 0.010
	Cd (mg/ℓ)	95	≤ 0.0003	≤ 0.0003	≤ 0.0003
	NH_3 (mg/ℓ N)	95	≤ 0.007	≤ 0.007	≤ 0.007
	Zn (mg/ℓ)	95	≤ 0.002	≤ 0.002	≤ 0.002

Table A.2 Summary of Ecospecs for PES and REC, and TPCs, for water quality monitoring gauge X2H032Q01 at site EWR4 on the Crocodile River. Data on toxics presented only when toxins are specifically mentioned in DWA (2009b). All data from (DWA 2010), and, for toxics, from DWAF (1996).

EWR4 KaNyamazane X2H032Q01				**EcoSpecs**	
Metric		**%ile**	**TPC**	**PES**	**REC**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	30-38	≤ 38	≤ 38
	Na_2SO_4 (mg/ℓ)	95	16-20	≤ 20	≤ 20
	$MgCl_2$ (mg/ℓ)	95	12-15	≤ 15	≤ 15
	$CaCl_2$ (mg/ℓ)	95	17-21	≤ 21	≤ 21
	NaCl (mg/ℓ)	95	45-191	≤ 191	≤ 191
	$CaSO_4$ (mg/ℓ)	95	280-351	≤ 351	≤ 351
Physical variables	EC (mS/m)	95	44-55	≤ 55	≤ 55
	pH	5	<6.1 & >6.3	5.9-6.5	5.9-6.5
		95	≤8.2 & ≥8.6	8.0-8.8	8.0-8.8
	DO (mg/ℓ)	5	7.5-7.8	≥ 7.5	≥ 7.5
Nutrients	TIN (mg/ℓ N)	50	0.8-1.0	≤ 1.0	≤ 1.0
	PO_4 (mg/ℓ P)	50	0.100-0.125	≤ 0.125	≤ 0.050
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	8-10	< 10	< 10
	Chl-*a* periphyton (mg/m^2)	50	17-21	≤ 21	≤ 21
Toxics	As (mg/ℓ)	95	≤ 0.020	≤ 0.020	≤ 0.010
	Cd (mg/ℓ)	95	≤ 0.0005	≤ 0.0005	≤ 0.0003
	NH_3 (mg/ℓ N)	95	≤ 0.015	≤ 0.015	≤ 0.007
	Zn (mg/ℓ)	95	≤ 0.004	≤ 0.004	≤ 0.002

Table A.3 Summary of Ecospecs for PES and REC, and TPCs, for water quality monitoring gauge X2H017Q01 at site EWR5 on the Crocodile River. Data on toxics presented only when toxins are specifically mentioned in DWA (2009b). All data from (DWA 2010), and, for toxics, from DWAF (1996).

EWR5 Malelane X2H017Q01				**EcoSpecs**	
Metric		**%ile**	**TPC**	**PES**	**REC**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	40-45	≤ 45	≤ 45
	Na_2SO_4 (mg/ℓ)	95	16-20	≤ 20	≤ 20
	$MgCl_2$ (mg/ℓ)	95	12-15	≤ 15	≤ 15
	$CaCl_2$ (mg/ℓ)	95	17-21	≤ 21	≤ 21
	NaCl (mg/ℓ)	95	36-45	≤ 45	≤ 45
	$CaSO_4$ (mg/ℓ)	95	280-351	≤ 351	≤ 351
Physical variables	EC (mS/m)	95	70-85	≤ 70	≤ 55
	pH	5	<6.1 & >6.3	5.9-6.5	5.9-6.5
		95	<8.2 & >8.6	8.0-8.8	8.0-8.8
	DO (mg/ℓ)	5	7.0-7.2	≥ 7.0	≥ 7.5
Nutrients	TIN (mg/ℓ N)	50	0.55-0.70	≤ 0.7	≤ 0.7
	PO_4 (mg/ℓ P)	50	0.020-0.025	≤ 0.125	≤ 0.025
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	8-10	< 10	< 10
	Chl-*a* periphyton (mg/m^2)	50	17-21	≤ 21	≤ 21
Toxics	As (mg/ℓ)	95	≤ 0.010	≤ 0.010	≤ 0.010
	Cd (mg/ℓ)	95	≤ 0.0003	≤ 0.0003	≤ 0.0003
	NH_3 (mg/ℓ N)	95	≤ 0.007	≤ 0.007	≤ 0.007
	Zn (mg/ℓ)	95	≤ 0.002	≤ 0.002	≤ 0.002

An apparent typographical error in the Reserve report REC EcoSpecs table for site EWR6 meant that values for several parameters were not available for comparison with test data (Table A.4).

Table A.4 Summary of Ecospecs for PES and REC, and TPCs, for water quality monitoring gauge X2H016Q01 at site EWR6 on the Crocodile River. Data on toxics presented only when toxins are specifically mentioned in DWA (2009b). All data from (DWA 2010), and, for toxics, from DWAF (1996).

EWR6 Nkongoma X2H016Q01				**EcoSpecs**	
Metric		**%ile**	**TPC**	**PES**	**REC**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	40-45	≤ 45	≤ 45
	Na_2SO_4 (mg/ℓ)	95	16-20	≤ 20	≤ 20
	$MgCl_2$ (mg/ℓ)	95	24-30	≤ 30	≤ 22
	$CaCl_2$ (mg/ℓ)	95	46-57	≤ 57	≤ 57
	NaCl (mg/ℓ)	95	36-45	≤ 45	≤ 45
	$CaSO_4$ (mg/ℓ)	95	280-351	≤ 351	≤ 351
Physical variables	EC (mS/m)	95	68-85	≤ 85	≤ 85
	pH	5	<6.1 & >6.3	5.9-6.5	5.9-6.5
		95	<8.2 & >8.6	8.0-8.8	8.0-8.8
	DO (mg/ℓ)	5	7.0-7.2	≥ 7.0	≥ 7.5
Nutrients	TIN (mg/ℓ N)	50	0.55-0.70	≤ 0.7	≤ 0.7
	PO_4 (mg/ℓ P)	50	0.060-0.075	≤ 0.125	≤ 0.025
Response variables	Chl-*a* phytoplankton (µg/ℓ)	50	8-10	< 10 µg/ℓ	-
	Chl-*a* periphyton (mg/m^2)	50	17-21	≤ 21	-
Toxics	As (mg/ℓ)	95	≤ 0.020	≤ 0.020	-
	Cd (mg/ℓ)	95	≤ 0.0005	≤ 0.0005	-
	NH_3 (mg/ℓ N)	95	≤ 0.015	≤ 0.015	-
	Zn (mg/ℓ)	95	≤ 0.004	≤ 0.004	-

No inorganic salt EcoSpecs or TPCs were generated as part of the Reserve report for site EWR7 (Table A.5) (DWA 2010).

Table A.5 Summary of Ecospecs for PES and REC, and TPCs, for water quality monitoring gauge X2H022Q01 at site EWR7 on the Kaap River. Data on toxics presented only when toxins are specifically mentioned in DWA (2009b). All data from (DWA 2010), and, for toxics, from DWAF (1996).

EWR7 Honeybird X2H022Q01				**EcoSpecs**	
Metric		**%ile**	**TPC**	**PES**	**REC**
Inorganic salts	$MgSO_4$ (mg/ℓ)	95	-	-	-
	Na_2SO_4 (mg/ℓ)	95	-	-	-
	$MgCl_2$ (mg/ℓ)	95	-	-	-
	$CaCl_2$ (mg/ℓ)	95	-	-	-
	NaCl (mg/ℓ)	95	-	-	-
	$CaSO_4$ (mg/ℓ)	95	-	-	-
Physical variables	EC (mS/m)	95	90-100	≤ 100	≤ 100
	pH	5	<6.7 & >7.8	6.5-8.0	6.5-8.0
		95	<8.2 & >8.6	8.0-8.8	8.0-8.8
	DO (mg/ℓ)	5	8.0-8.2	≥ 8.0	≥ 8.0
Nutrients	TIN (mg/ℓ N)	50	0.8-1.0	≤ 1.0	≤ 1.0
	PO_4 (mg/ℓ P)	50	0.060-0.075	≤ 0.125	≤ 0.125
Response variables	Chl-*a* phytoplankton (μg/ℓ)	50	8-10	< 10	< 10
	Chl-*a* periphyton (mg/m^2)	50	42-52	≤ 52.5	≤ 52.5
Toxics	As (mg/ℓ)	95	≤ 0.020	≤ 0.010	≤ 0.010
	Cd (mg/ℓ)	95	≤ 0.0005	≤ 0.0003	≤ 0.0003
	NH_3 (mg/ℓ N)	95	≤ 0.015	≤ 0.007	≤ 0.007
	Zn (mg/ℓ)	95	≤ 0.004	≤ 0.002	≤ 0.002