DETERMINATION OF RESOURCE QUALITY OBJECTIVES IN THE LOWER VAAL WATER MANAGEMENT AREA (WMA10)

WP10535

RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS REPORT

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Title: *Resource Quality Objectives and Numerical Limits Report*

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Determination of Resource Quality Objectives in the Lower Vaal Water Management Area (WMA10) - WP10535

Resource Quality Objectives and Numerical Limits Report

Executive Summary

The Resource Quality Objectives (RQOs) determination procedures for the Lower Vaal Water Management Area (WMA) involved the application of the seven step framework established by the Department of Water Affairs in 2011. Some of these steps were achieved in the Water Resource Classification Study and not repeated in this study. The procedural steps established for this case study to determine RQOs for rivers, groundwater, dams and wetland resources in the WMA include:

- Step 1. Delineate the Integrated Units of Analyses (IUAs) and Resource Units (RUs).
- Step 2. Establish a vision for the catchment and key elements for the IUAs.
- Step 3. Prioritise and select RUs and ecosystems for RQO determination.
- Step 4. Prioritise sub-components for RQO determination, select indicators for monitoring and propose the direction of change.
- Step 5. Develop draft RQOs and Numerical Limits.
- Step 6. Agree Resource Units, RQOs and Numerical Limits with stakeholders.
- Step 7. Finalise and Gazette RQOs.

Components of steps 1 and 2 were available from the WRC study to which this RQO determination process was aligned. This report documents the selection of and prioritisation of sub-components and indicators for in the Lower Vaal Water Management Area (Step 4). These components and sub-components include:

- Quantity components including low and high flow sub-components.
- Quality components including nutrients, salts, system variables, toxicants and pathogen sub-components.
- Habitat components including instream and riparian habitat sub-components.
- Biota components including fish, plants, mammals, birds, amphibians and reptiles, periphyton, invertebrates and diatom sub-components.

Through this step a total of 118 RQOs were determined for the Lower Vaal WMA:

- A total of 28 RQOs were determined for river resources.
- A total of 24 RQOs were determined for wetlands resources.
- A total of 29 RQOs were determined for dam resources.
- A total of 37 RQOs were determined for groundwater resources.

Table 1 provides a summary of the hydrological nodes, river names and their associated Present Ecological State (PES) and Recommended Ecological Category (REC) within each IUA as well as the management class for the IUA. Table 2 provides a summary of all the sub-components for which RQOs and NLs were determined for each IUA.

Table 1: Summary of the Integrated Units of Analyses, Management Classes, Hydrological nodes (and Resource Unit RU numbers), river names and the associated Present (PES) and Recommended (REC) ecological categories considered in the study.

IUA Name	Class for IUA	RU	Hydro Node	River Name	PES	REC
LA1.Upper Harts River	**II**	1	VC55	Vaal	C	C
		2	VC61	Harts	C	C
LA2. Middle Harts River	**II**	3	VC57	Vaal	C	C
LA3. Dry Harts River	**III**	4	VC58	Harts	D	D
LA4. Lower Harts River	**II**	5	H1	Vaal	C	C
		6	EWR17	Vaal	D	D

IUA Name	Class for IUA	RU	Hydro Node	River Name	PES	REC
		7	VC59	Harts	A/B	A/B
LB. Vaal River from downstream of Bloemhof Dam to Douglas Weir	III	8	EWR16	Vaal	D	D
		9	VC60	Vaal	A/B	A/B
		10	EWR18	Vaal	C	C
		11	Douglas EWR	Vaal	C/D	C

Table 2: Integrated Units of Analyses (IUAs) for which Resource Quality Objectives (RQOs).

IUA	RIVERS				WETLANDS	DAMS				GROUND WATER
	Quantity	Quality	Habitat	Biota		Quantity	Quality	Habitat	Biota	
LA1. Upper Harts River					X					X
LA2. Middle Harts River		X	X	X	X					X
LA3. Dry Harts River					X					X
LA4. Lower Harts River	X	X	X	X	X	X		X		X
LB. Vaal River from downstream of Bloemhof Dam to Douglas Weir	X	X	X	X	X	X		X		X

Determination of Resource Quality Objectives in the Lower Vaal Water Management Area (WMA10) - WP10535

Resource Quality Objectives and Numerical Limits Report

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ABBREVIATIONS

Acronym	Meaning
Al	Aluminium
As	Arsenic
$CaCO_3$	Calcium Carbonate
Cd	Cadmium
Chl-a	Chlorophyll a
Cl	Chlorine
Cr(VI)	Hexavalent chromium
Cu	Copper
DOC	Dissolved organic carbon
DRM	Desktop Reserve Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
F	Fluorine
FEPA	Freshwater Ecosystem Priority Areas
FRAI	Fish Response Assessment Index
GIS	Geographical Information Science
Hg	Mercury
□g/l	Micrograms per litre
IBA	Important Bird Areas
IRHI	Index of Reservoir Habitat Impairment
IUA	Integrated Unit of Analysis
IWRM	Integrated Water Resource Management
IWRMP	Integrated Water Resources Management Plan
KNP	Kruger National Park
m^3/s	Cubic meters per meter (cumecs)
MAR	Mean Annual Runoff
MC	Management Class
mg/l	Milligrams per litre
MIRAI	Macroinvertebrate Response Assessment Index
Mn	Manganese
NFEPA	National Freshwater Ecosystem Priority Areas
NL	Numerical Limit
NO_2	Nitrite
NO_3	Nitrate
NTU	Turbidity
NWA	National Water Act
NWRS	National Water Resource Strategy
O_2	Oxygen

Pb	Lead
PES	Present Ecological State
pH	power of hydrogen
PO_4	Phosphate
RDM	Resource Directed Measures
REC	Recommended Ecological Category
REC	Recommended ecological category
RHAM	Rapid Habitat Assessment Method
RHP	River Health Programme
RO	Regional Office
RQOs	Resource Quality Objectives
RR	Reporting rates
RU / RUs	Resource Unit/s
RUET	Resource Unit Evaluation Tool
RUPT	Resource Unit Prioritisation Tool
SASS5	South African Scoring System version 5
Se	Selenium
SPI	Specific Pollution sensitivity Index
TDS	Total Dissolved Solids
TIN	Total Inorganic Nitrogen
TPC	Threshold of Probable Concern
VEGRAI	Vegetation Response Assessment Index
VMAR	Virgin Mean Annual Runoff
WE	Water Ecosystems
WMA	Water Management Area
WRC	Water Resource Classification
WWTW	Waste Water Treatment Works
Zn	Zinc

DEFINITION OF PROJECT SPECIFIC ACRONYMS:

EWR – Ecological Water Requirements is synonymous with the ecological component of the Reserve as defined in the Water Act (1998).

IUA – Integrated Unit of Analysis or spatial units that will be defined as significant resources (as prescribed by the NWA).They are finer-scale units aligned to watershed boundaries, in which socio-economic activities are likely to be similar.

MC – The Management Class is set by the WRC and describes the degree of alteration that resources may be subjected to.

REC – Recommended Ecological Category – this is a recommendation purely from the ecological perspective designed to meet a possible future state.

RU – Resource Unit is a stretch of river that is sufficiently ecologically distinct to warrant its own specification of Ecological Water Requirements

WRC – Water Resources Classification is a procedure required by the Water Act 1998 that produces a MC per IUA for all water resources.

Determination of Resource Quality Objectives in the Lower Vaal Water Management Area (WMA10) - WP10535

Resource Quality Objectives and Numerical Limits Report

1 INTRODUCTION

The rationale for requiring RQOs, their components, their applicability and implementation procedures emanate from the National Water Act of South Africa (NWA, 1998). The Water Act (1998) requires that all water resources are protected in order to secure their future and sustainable use. It lays out a plan where significant water resources (surface water, wetlands, groundwater and estuaries) are classified according to a WRC System. In the process, the Reserve (i.e. the amount and the quality of water required to sustain both the ecosystem and provide for basic human needs) is also determined for the water resource This Reserve then contributes to the Classification of the resource. This classification produces in a Management Class and associated RQOs for water resources, which then gives direction for future management activities in the WMA. According to the Water Act (NWA, 1998), the purpose of RQOs are to establish clear goals relating to the quality of the relevant water resources and stipulates that in determining RQOs a balance must be sought between the need to protect and sustain water resources and the need to use them (sensu DWA, 2011). Resource Quality Objectives are numerical and narrative descriptors of conditions that need to be met in order to achieve the required management scenario as provided during the resource classification. Such descriptors relate to the:

(a) quantity, pattern, timing, water level and assurance of instream flow
(b) water quality including the physical, chemical, and biological characteristics of the water
(c) character and condition of the instream and riparian habitat; and
(d) characteristics, condition and distribution of the aquatic biota (DWA, 2011).

This section of the RQO determination procedure includes the development of the RQOs and associated NLs (Step 5 and 6; DWA, 2011). Step 5 in the study included the development of the draft RQOs and NLs for the sub-components and indicators that were selected during Step 4. The RQOs are essentially narrative but sometimes broadly quantitative descriptions of the resource and include the requirements necessary for achieving the objectives. Step 6 follows on Step 5 where the outcomes from Steps 3, 4 and 5 are presented to stakeholders in a workshop process. The aim of this step is to verify and refine:

- The prioritisation of Resource Units for RQO determination.
- The selection of sub-components and indicators for RQOs, and the proposed direction of change for these.
- The Draft RQOs and Numerical Limits.

The final RQOs and NLs are then published by way of government notice in the government gazette Step 7.

2 SCOPE OF THE STUDY

The study entails the determination of Resource Quality Objectives (RQOs) for all significant water resources (rivers, wetlands, dams (or lakes) and groundwater) in the Lower Vaal Water Management Area (WMA). The RQO determination procedure established by DWA (2011) has been implemented to determine RQOs in this case study. The RQO determination procedure is based on a seven step framework including (DWA, 2011; Figure 1):

- Step 1. Delineate the Integrated Units of Analysis (IUAs) and define the Resource Units (RUs)
- Step 2. Establish a vision for the catchment and key elements for the IUAs
- Step 3. Prioritise and select preliminary Resource Units for RQO determination
- Step 4. Prioritise sub-components for RQO determination, select indicators for monitoring and propose the direction of change
- Step 5. Develop draft RQOs and Numerical Limits
- Step 6. Agree Resource Units, RQOs and Numerical Limits with stakeholders
- Step 7. Finalise and Gazette RQOs

In 2012 the Department of Water Affairs completed the Water Resource Classification (WRC) study for the Lower Vaal WMA which included the delineation IUAs and established a vision for the catchment and key elements for the IUAs (DWA, 2012). This resulted in the determination of Management Classes (MC) for each IUA and Recommended Ecological Categories (REC) for biophysical nodes selected to represent the riverine ecosystem in the WMA. As such this study did not include these components but rather adopted the outcomes from the WRC study (DWA, 2012). Apart from these components that were obtained from the WRC study, some developments/adaptations were made to the DWA (2011) RQO determination procedure to the groundwater, wetland and dam components of the study in particular. This report documents the approach adopted and the outcomes of the implementation of Step 4 of the RQO determination procedure (DWA, 2011).

3 METHODOLOGY

3.1 RESOURCE QUALITY OBJECTIVES OVERVIEW

The procedures to Develop and Implement Resource Quality Objectives established by DWA (2011) have been implemented in this study. This includes the implementation of a seven step procedural framework (Figure 1), that is repeatable and as such allows for an adaptive management cycle with additional steps. Overall the procedure involves defining the resource, setting a vision, determining RQOs and NLs, gazetting the RQOs and NLs and then moving to implementation, monitoring and review of these RQOs and NLs before starting the process all over again. A summary of the procedural steps established for this case study with some adaptations that were required to include groundwater, dams and wetland resources includes (Figure 1):

- **Step 1. Delineate the IUAs and RUs:** In this case study IUAs were obtained from the WRC (DWA, 2012) and applied to all water resources considered in the study (rivers, wetlands, dams and groundwater ecosystems). Three spatial levels for resources were considered for RQO determination in this case study including:
  - Regional (IUA) scale assessments were considered for rivers, wetlands and groundwater resources in the study.
  - Resource Unit scale assessments that were aligned to biophysical nodes obtained from the WRC study (DWA, 2012) were considered for river and groundwater resources alone.
  - Ecosystem scale assessments were considered for wetland and dam ecosystems/resources in the study.

  The RU delineation procedure initially involved the identification of sub-quaternary reaches of rivers in the WMA for each biophysical node obtained from the WRC study (DWA, 2012; DWA, 2013a). The RU delineation process then involved amalgamating the upstream associated sub-quaternary reaches of riverine ecosystems, and their associated catchment areas, (DWA, 2013a). As a result, the number of RUs selected for the study is identical to and can later be aligned to the information associated with the biophysical nodes from the WRC study. The delineation procedure for ecosystem scale resource assessment involved the use of Geographical Information System (GIS) spatial ecosystem data. Refer to the delineation report (Step 1) for more information (DWA, 2013a).

- **Step 2. Establish a vision for the catchment and key elements for the IUAs:** The stakeholder requirements and their associated outcomes which includes the Management Classes for IUAs and RECs for RUs from the WRC study were adopted as the vision for this study (DWA, 2012). No further visioning process was appropriate as this could have conflicted with the WRC process. The WRC outcomes were skewed towards river resources in the WMA which necessitated obtaining additional information for the other resources considered in the study (wetlands, dams and groundwater ecosystems). This additional information is highlighted in the reports where applicable.

- **Step 3. Prioritise and select RUs and ecosystems for RQO determination:** Within this case study only 11 IUAs were delineated, as such the RU Prioritisation Tool for rivers (DWA, 2011) was not implemented. Priority RUs were selected during the following step (STEP 4) (DWA, 2013b).

- **Step 4. Prioritise sub-components for RQO determination, select indicators for monitoring and propose the direction of change:** This step included the hosting of a range of specialist workshops for rivers, dams and groundwater resources where RU Evaluation Tools were used to select sub-components for RQO determination, select indicators and propose the direction of change. The RU Evaluation Tools used in this section for wetlands, dams and groundwater were developed for this study. This information could then be used to develop draft RQOs and Numerical Limits in the next step (DWA, 2014). The relevant activities of this step are:
  4.1 Identify and assess the impact of current and anticipated future use on water resource components

4.2 Identify requirements of important user groups
4.3 Selection of sub-components for RQO determination
4.4 Establish the desired direction of change for selected sub-components
4.5 Complete the information sheet for the Resource Unit Evaluation Tool.

- **Step 5. Develop draft RQOs and Numerical Limits**: This step is based on the outcomes of the RU and ecosystem prioritisation step (Step 4). From the outcomes of the RU and ecosystem prioritisation step draft RQO were established and then provided to recognised specialists to establish NLs that are generally quantitative descriptors of the different components of the resource such as the water quantity, quality, habitat and biota. These descriptors were designed to give a quantitative measure of the RQOs (DWA, 2011). Although the NLs may have some uncertainty associated with them and were not originally intended for gazetting (DWA, 2011) the will be considered for gazetting in this case study at the request of the Department of Water and Sanitation (DWS) legal services. Consider the RQO and NL reports for more information. The relevant activities of this step are:
  5.1 Carry over sub-component and indicator information from the Resource Unit Evaluation Tool
  5.2 Extract available data to determine the present state for selected sub-components and indicators
  5.3 Assess the suitability of the data
  5.4 Where necessary, collect data to determine the Present State for selected indicators
  5.5 Determine the level at which to set RQOs
  5.6 Set appropriate draft RQOs
  5.7 Set appropriate draft Numerical Limits in line with the draft RQO
  5.8 Determine confidence in the RQOs and process

- **Step 6. Agree Resource Units, RQOs and Numerical Limits with stakeholders:** This component of the RQO determination process is carried out by the regulators of the WMA, assisted by the project team, and includes the consideration of RQO and NL outcomes with stakeholder, prior to the initiation of the gazetting process. The relevant activities of this step are:
  6.1 Notify stakeholders and plan the workshop
  6.2 Present and refine the Resource Unit selection with stakeholders
  6.3 Present the sub-components and indicators selected for the RQO determination
  6.4 Present the proposed direction of change and associated rationale
  6.5 Present and revise RQOs and Numerical Limits

- **Step 7. Finalise and Gazette RQOs:** This component of the RQO determination process is carried out by the regulators of the WMA assisted by the project team, and includes the development of gazette RQO and NL drafts for submission to legal services of the Department of Water and Sanitation for gazetting

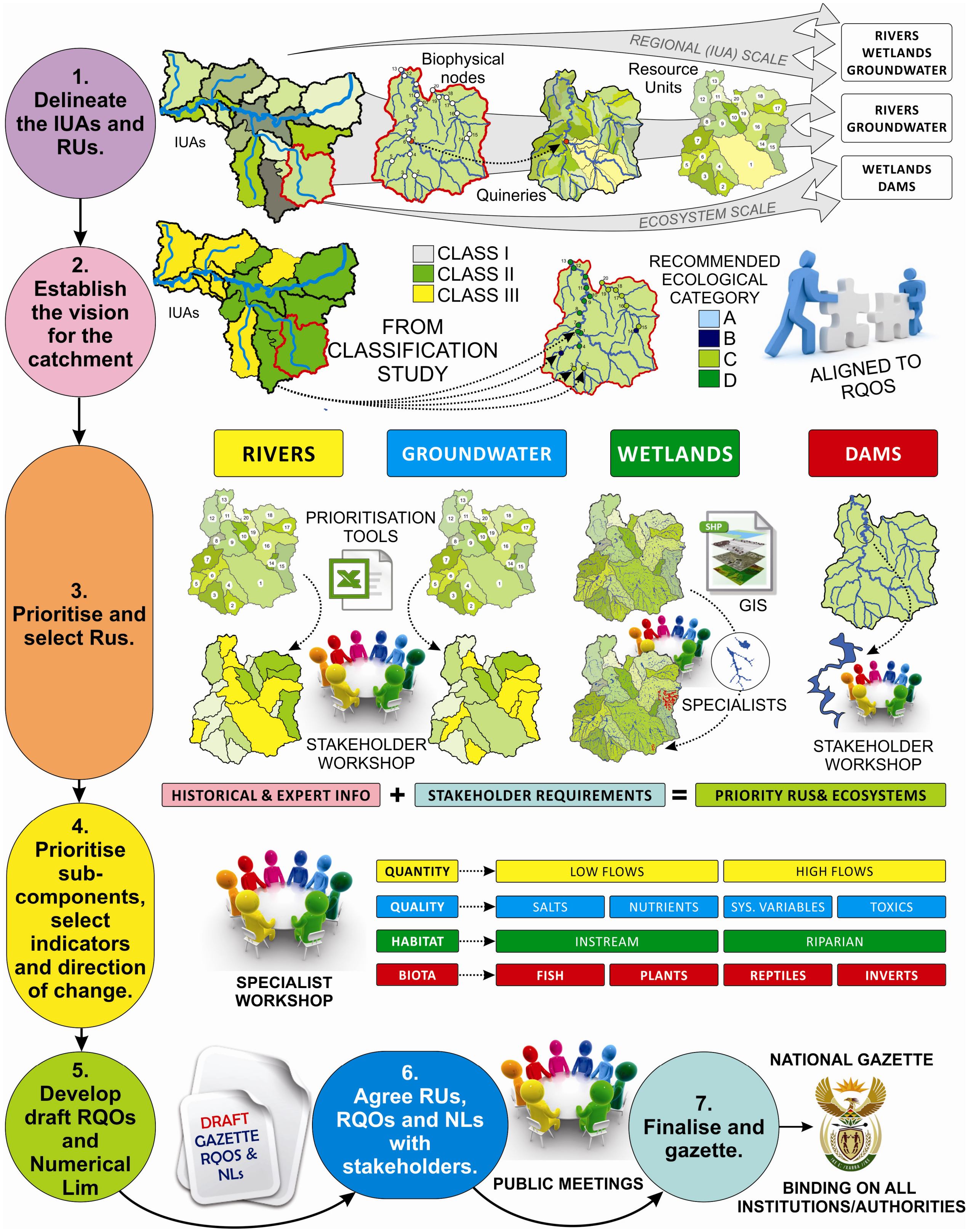

Figure 1: Schematic summary of the RQO determination procedure (adapted from DWA, 2011) which was implemented in this study.

3.2 RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS OVERVIEW

As indicated, following the completion of the sub-component and indicator information phase (Step 4) for all resources considered in the study, the outcomes of the application of the Resource Unit Evaluation Tool (RUET) include a list of sub-components and indicators selected for RQOs and their associated 'EcoSpecs', 'UserSpecs' or 'Integrated measure' associations which is used for RQO development (Step 5). Following the selection of RQOs, NLs which are generally quantitative descriptors of the different components/sub-components of the resource such as the water quantity, quality, habitat and biota were established. These descriptors were designed to give a quantitative measure of the RQOs and are associated with some uncertainties (DWA, 2011). The RQOs and NLs were established after consideration of the following:

- Available data to evaluate the present state for selected sub-components and indicators for RQO determination.
- Suitability of the data available for RQO and NL selection.
- Determine the level at which to set RQOs
  - Carry over the proposed direction of change from the RUET.
  - Consider the requirements defined by the WRC.
  - Review the stakeholder aspirations and translate into Numerical Limits.

Available data to evaluate the present state for selected sub-components and indicators for RQO determination: Available data which may assist in determining the present state of selected sub-components/indicators has been reviewed prior to RQO determination. This information has been used to determine the level at which to set RQOs, as it relates the present state of each sub-component to reference conditions. The PES of a water resource is expressed in terms of its bio-physical components including:

- Drivers (Physico-chemical, geomorphology, hydrology, instream and riparian habitat) which provide a particular physical habitat template.
- Biological responses (fish, riparian vegetation, aquatic invertebrates, diatoms, amphibians and reptiles for e.g.)

Where available, data has been used to contribute to the development of RQOs and associated NLs. There are however numerous examples of driver and responder components/sub-components that were selected for RQO determination for which no present ecological state and on occasion indicator information is available. This may have occurred for example where an uncommon indicator such as birds and selected as sub-components for the riparian habitat (components) for the study for which no information is available. For these occasions a specialist with local knowledge was commissioned to assess available literature, proposed indicators (if unavailable) and select NLs (Refer to the appendix).

Assess the suitability of the data: In addition, the suitability of available data for sub-components and indicators was considered in the study. Where suitable, the data was used to determine the present state of the selected indicators and select RQOs. Alternatively, specialists with local knowledge were commissioned to carry out desktop evaluations of available information to select PES'. Data suitability considerations incorporated in the study according to DWA (2011) included:

- The age of the data
- The techniques and methods used
- The format of data
- The season in which it was collected
- Whether the data has been extrapolated

To determine the level at which to set RQOs were to be set, the proposed direction of change from the RUET was considered as well as the requirements defined by the WRC for the component so that the outcomes could be synchronised with the WRC. And finally, considerations of the stakeholder aspirations to translate RQO endpoints into NLs were made. The following process was followed:

- Carry over the proposed direction of change from the Resource Unit Evaluation Tool: Step 4 of the RQO process entailed proposing the most appropriate and feasible direction and magnitude of change for each of the selected sub-components. This information should be carried forward to this sub-step as it provides an indication of the level at which to set the respective RQOs.

- Consider the requirements defined by the Water Resource Classification: The REC and MCs available from the WRC were initially considered. During this component REC would be matched with the EcoStatus from the Ecological Reserve and or any other available information.
- Review the stakeholder aspirations and translate into Numerical Limits: During Step 4, the aspirations of stakeholders for management of specific components were identified. These aspirations informed the 'proposed direction of change' for each of the components and also influenced the final selection of sub-components for RQO determination. These aspirations have also been captured, in part, in the rationales for selecting a particular sub-component.

Set appropriate draft RQOs and Numerical Limits in line with the draft RQOs

The established RQOs included contextual information to reflect the direction of change of a particular sub-component and/or indicator. They also included the reason for the selection of component, sub-component and/or indicator and the rationale for the level at which it has been set. This contextual information is available in the supplementary tables provided below. Numerical Limits translate the narrative RQOs into numerical values which can be monitored and assessed for compliance of RQO implementation (DWA, 2011). These NLs considered feasibility assessments undertaken by specialists with local experience in this study (refer to appendix).

3.3 PUBLIC MEETING PROCESS

The draft RQOs and NLs were presented to stakeholders of the study at a series of public meetings as follows (Appendix 2):

- Public meeting: 10 April 2014, Flamingo Casino, Kimberley (APPENDIX).

The presentations contained two components including an introductory and background section and a breakaway group discussions section for the RQO and NL considerations. The introduction section included the presentation of the following components:

- Resource Quality Objectives within Water resource management in South Africa
- Introduction to the process of determining Resource Quality Objectives
- Determination of RQOs in the Upper Vaal Water Management Area
- Water resources considered:
- Rivers, Wetlands, Dams & Groundwater
- Components and subcomponents
- Draft RQOs and Numerical limits

The breakaway group discussions considered:

- Catchment orientation, land uses type and water resource location considerations.
- Summary RQO outcome maps for major water resources considered:
- Rivers, Wetlands, Dams & Groundwater
- Draft RQO considerations and recommendations

Stakeholders were provided with an opportunity to query draft RQOs and NLs. All comments were captured, evaluated and where appropriate changes needed to be made they were. This resulted in some changes to various steps of the RQO determination process and draft RQO and NL outcomes. These changes have been clearly identified in the report where the change has relevance.

4 FINDINGS

The RQOs and NLs that were determined for the Lower Vaal WMA as well as the supplementary information are presented per resource considered.

4.1 RIVER RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS FOR THE LOWER VAAL WMA

The outcomes of the RQO and NL determination of the sub-components and indicators for the river component (Figure 2), of the RQO determination study for the Lower Vaal WMA, including a summary of additional supplementary information are provided as follows:

- RQOs for regional rivers in the Lower Vaal WMA are presented in Table 3.
- RQOs for the river water quantity component are presented in Table 4.
- RQOs for the river water quality component are presented in Table 5
- RQOs for the river water habitat component are presented in Table 6.
- RQOs for the river water biota component are presented in Table 7.
- Supplementary information for the river water quantity component is presented in Table 8.
- Supplementary information for the river water quality component is presented in Table 9.
- Supplementary information for the river water habitat component is presented in Table 10.
- Supplementary information for the river water biota component is presented in Table 11.

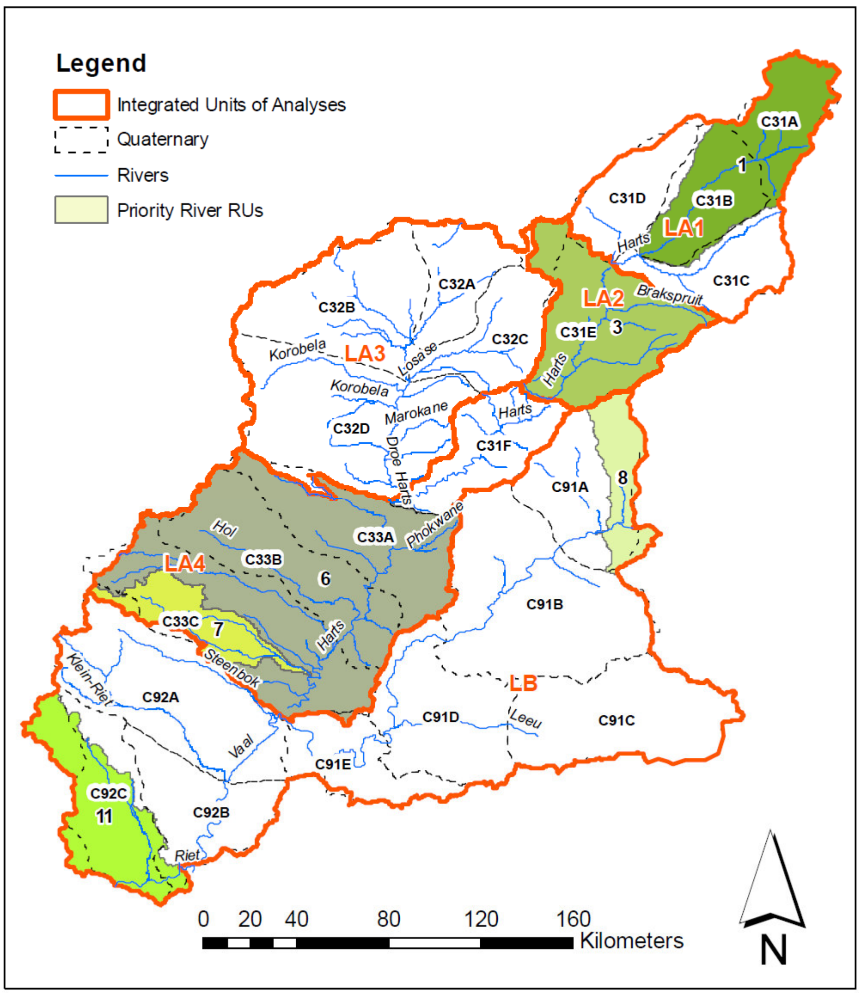

Figure 2: Map of the Integrated Units of Analysis (IUAs), Priority River Resource Units (RUs) and rivers considered in the study area with quaternary catchments included.

4.1.1 RIVER RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 3: RQOs for rivers on a regional (IUA) scale in the Lower Vaal WMA

REGIONAL RIVERS	
IUA	**RQO**
LA1	The rivers of this IUA include the headwaters of the Harts and Klien-Harts Rivers. Currently theses largely seasonal rivers have few dependent users and are largely in an acceptable ecological condition (≥C ecological state) which must be maintained. Due to the seasonality of the rivers the IUA does not permanently maintain instream biota. These rivers do however provide important recruitment areas for many aquatic species including a high diversity of fishes during the high flow period when the rivers are flowing which must be maintained. The consumption of fish harvested from rivers in the IUA must not pose a threat to human health. The recommended ecological category (REC) of any river reach as described in the Classification (Annexure A) must be adhered to.
LA2	The upper Harts River dominates this IUA which is used by agricultural and urban users is ecologically important within the catchment as it is more perennial than the upper reached of the Harts River catchment in IUA LA1. The Harts River in this IUA is ecologically important and sensitive and must be maintained in a C or better ecological category, and contributes to the maintenance and recruitment of aquatic biota from the middle reaches of the Harts. Access to the upper reaches is currently intact and must remain intact. The refuge provided by Taung Dam is important for this reach of the Harts River and must be maintained. The consumption of fish harvested from rivers in the IUA must not pose a threat to human health. The recommended ecological category (REC) of any river reach as described in the Classification (Annexure A) must be adhered to.
LA3	The IUA includes the episodic Droe Harts River catchment which is a highly sensitive but generally ecologically unimportant river ecosystem which, must be maintained in a D or better ecological category. Dry land agriculture and urban and peri-urban communities occur in the IUA which negatively affects the wellbeing of the river resource. The consumption of fish harvested from rivers in the IUA must not pose a threat to human health. The recommended ecological category (REC) of any river reach as described in the Classification (Annexure A) must be adhered to.
LA4	This IUA contains the middle and lower reaches of the Harts River and the associated Harts River irrigation scheme which is a nationally important fresh produce growing centre. Activities upstream and in this IUA are placing high threat levels to the ecosystem and thus on the fitness for use of the water to local and downstream users. Reduction in flows and poor timing of flows and the associated water quality issues, in particular nutrients and salts, need to be managed in at least a D ecological category so that they do not deteriorate below a D category. The consumption of fish harvested from rivers in the IUA must not pose a threat to human health. The recommended ecological category (REC) of any river reach as described in the Classification (Annexure A) must be adhered to.
LB	This IUA contains the lower Vaal River from Bloemhof Dam which is affecting the volume, timing and duration of flows in the lower Vaal River to the confluence of the Vaal and Orange Rivers below Douglas. The ecosystem in this IUA is highly stressed by the upstream dam and associated upstream activities and also by the land based activities that occur in this IUA. Stream flows and also water quality are a constant threat to instream stability and must be managed to at least a D category. The fish communities in this system should also be managed to at least a D category. The consumption of fish harvested from rivers in the IUA must not pose a threat to human health. The recommended ecological category (REC) of any river reach as described in the Classification (Annexure A) must be adhered to unless superseded by the detailed Resource Quality Objectives for the RUs below.

Table 4: RQOs for river water quality in priority RUs in the Lower Vaal WMA.

RIVER WATER QUANTITY												
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**		
LA4	II	Harts River	RU6	EWR17	D	Quantity	Low Flows	Low flows need to be managed to keep the ecosystem in a sustainable condition, including reducing unnatural daily fluctuations.	1. EWR maintenance low and drought flows: Harts EWR17 in C33C MAR = 147.85x10^6m□ REC=D category*	Maintenance low flows (m³/s) (%ile)		Drought flows (m³/s) (%ile)
										Oct	1.5 (10)	0.001 (99)
										Nov	2 (10)	0.001 (99)
										Dec	2.5 (20)	0.001 (99)
										Jan	3 (20)	0.001 (99)
										Feb	4 (30)	0.001 (99)
										Mar	5 (30)	0.001 (99)
										Apr	4 (30)	0.001 (99)
										May	3 (10)	0.001 (99)
										Jun	2.5 (10)	0.001 (99)
										Jul	2 (10)	0.001 (99)
										Aug	1.5 (10)	0.001 (99)
										Sep	1 (10)	0.001 (99)
LB	III	Vaal River	RU8	EWR16	D	Quantity	High Flows	High flows need to be used to introduce habitat variability.	1. EWR maintenance high flows: Vaal EWR16 in C91A MAR = 1699.3x10^6m□ REC=D category*	Maintenance high flows (m³/s) (%ile)		
										Oct		
										Nov	15.8 (60)	
										Dec		
										Jan	15.29 (90)	
										Feb	16.929 (99)	
										Mar	15.29 (99)	
										Apr		
										May		
										Jun		
										Jul		
										Aug		
										Sep		
	III	Vaal River	RU11	Douglas EWR	C	Quantity	Low Flows	The low flows should be improved to support the ecosystem and no zero flow conditions should be allowed.	1. EWR maintenance low and drought flows: Vaal at outlet of C92B	Extrapolate Lower Vaal_EWR18		

**Per Rule Table*

Table 5: RQOs for river water quality in priority RUs in the Lower Vaal WMA

RIVER WATER QUALITY											
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**	**95%tile**
LA2	II	Vaal River	RU3	VC57	C	Quality	Nutrients	Nutrient concentrations need to be managed to achieve a mesotrophic or good state.	Phosphate(PO_4)*	≤ 0.025 mg/L P	No data
									Nitrate (NO_3) & Nitrite (NO_2)*	≤ 1.00 mg/L N	No data
									Total Ammonia*	≤ 73 µg/L N	No data
LB	III	Vaal River	RU11	Douglas EWR	C	Quality	Nutrients	Nutrients concentrations should be maintained at low levels to limit algal growth.	Phosphate(PO_4)*	≤ 0.025 mg/L P	No data
									Nitrate (NO_3) & Nitrite (NO_2)*	≤ 1.00 mg/L N	No data
									Total Ammonia*	≤ 73 µg/L N	No data
LA4	II	Vaal River	RU6	EWR17	D	Quality	Salts	Salt concentrations need to be reduced to levels which are acceptable for irrigation.	Electrical conductivity*	≤ 111 mS/m	103.4
LB	III	Vaal River	RU11	Douglas EWR	C	Quality	Salts	Salinity concentrations in this RU must be managed to ensure that water quality is suitable for irrigated agriculture.	Electrical conductivity*	≤ 85 mS/m	No data
LB							System Variables	High temperatures and low oxygen levels must be improved in order to keep the ecosystem in a sustainable condition.	Temperature *	≤ abs(dev. from ambient) 2°C	No data
									Dissolved oxygen *	≥ 6 mg/L O_2	No data
LB	III	Vaal River	RU8	EWR16	D	Quality	Toxicants	Toxicants should not pose a high risk to human health.	F*	≤ 3.0 mg/L	0.36
									Al*	≤ 150 µg/L	No data
									As*	≤ 130 µg/L	No data
									Cd hard*	≤ 5.0 µg/L	No data
									Cr(VI)*	≤ 200 µg/L	No data
									Cu hard*	≤ 8.0 µg/L	No data
									Hg*	≤ 1.70 µg/L	No data
									Mn*	≤ 1300 µg/L	No data
									Pb hard*	≤ 13.00 µg/L	No data
									Se*	≤ 30 µg/L	No data
									Zn*	≤ 36 µg/L	No data
									Chorine*	≤ 5.0 µg/L free Cl	No data
									Endosulfan*	≤ 0.200 µg/L	No data
									Atrazine*	≤ 100 µg/L	No data
LB	III	Vaal River	RU11	Douglas EWR	C	Quality	Pathogens	Microbial contamination must be minimised to reduce the impact on usability of irrigated crops.	*E.coli**	≤ 130 counts/100 ml	No data
**as per standard methods of America Water Works Association (www.awwa.org)*											

Table 6: RQOs for river habitat in priority RUs in the Lower Vaal WMA

RIVER HABITAT										
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**
LA2	II	Vaal River	RU3	VC57	C	Habitat	Instream Habitat	The instream habitat must be managed to support the ecosystem including a high diversity of species.	State of instream habitat according to Rapid Habitat Assessment Method (RHAM)	EcoStatus (RHAM) ≥C category (≥62), and or maintenance of habitat for indicator species in a ≥C ecological category.
LA4	III	Vaal River	RU6	EWR17	D	Habitat	Instream Habitat	The instream habitat must be managed to support the ecosystem including a high diversity of species.	State of instream habitat according to Rapid Habitat Assessment Method (RHAM)	EcoStatus (RHAM) ≥D category (≥42), and or maintenance of habitat for indicator species in a ≥D ecological category.
LB	III	Vaal River	RU8	EWR16	D	Habitat	Instream Habitat	The instream habitat must be managed to support the ecosystem including a high diversity of species.	State of instream habitat according to Rapid Habitat Assessment Method (RHAM)	EcoStatus (RHAM) ≥D category (≥42), and or maintenance of habitat for indicator species in a ≥D ecological category.
			RU11	Douglas EWR	C					
LB	III	Vaal River	RU 8	EWR16	D	Habitat	Riparian	The riparian habitat must be maintained to retain ecological processes, property values and for recreational purposes.	State of riparian habitat according to Riparian Vegetation Response Assessment Index (VEGRAI) III	VEGRAI (Level III) in ≥D category (equivalent to EcoClassification score >40)

Table 7: RQOs for river biota in priority RUs in the Lower Vaal WMA

RIVER BIOTA										
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**
LA4	II	Harts River	RU7	VC59	A/B	Biota	Fish	Fish communities should be improved so that they include viable populations of ecologically important species.	State of fish populations according to Fish Response Assessment Index (FRAI) Score.	FRAI Score ≥70 (≥B/C category (equivalent to EcoClassification score >60))
									State of critical instream habitat for the Orange-Vaal largemouth yellowfish (*Labeobarbus kimberleyensis*) according to Rapid Habitat Assessment Method (RHAM).	EcoStatus (RHAM) ≥B/C category (≥78). Maintenance of habitat for indicator species in a ≥B/C ecological category.
LB	III	Vaal River	RU8	EWR16	D	Biota	Fish	Fish communities should be improved so that they include viable populations of ecologically important species.	State of fish populations according to Fish Response Assessment Index (FRAI) Score.	FRAI Score ≥70 (≥B/C category (equivalent to EcoClassification score >70-80)
			RU11	Douglas EWR	C				State of critical instream habitat for the Orange-Vaal largemouth yellowfish (Labeobarbus kimberleyensis) according to Rapid Habitat Assessment Method (RHAM).	EcoStatus (RHAM) ≥C/D category (≥58). Maintenance of habitat for indicator species in a ≥C/D ecological category.
LA2	II	Vaal River	RU3	VC57	C	Biota	Aquatic invertebrates	Invertebrates should be maintained to a good condition to support biodiversity.	State of aquatic invertebrates according to Macroinvertebrate Response Assessment Index (MIRAI) Score, using the SASS5 sampling method and Maintenance of critical habitat according to Rapid Habitat Assessment Method (RHAM).	MIRAI Score ≥C category (equivalent to EcoClassification score >60) and EcoStatus (RHAM) ≥C category (≥62). Maintenance of habitat for indicator species in a ≥C ecological category.
LA4	III	Vaal River	RU6	EWR17	D	Biota	Aquatic invertebrates	Invertebrates should be improved to a good condition to support biodiversity.	State of aquatic invertebrates according to Macroinvertebrate Response Assessment Index (MIRAI) Score, using the SASS5 sampling method and Maintenance of critical habitat according to Rapid Habitat Assessment Method (RHAM).	MIRAI Score ≥C/D category (equivalent to EcoClassification score >40) and EcoStatus (RHAM) ≥C/D category (≥58). Maintenance of habitat for indicator species in a ≥C/D ecological category.
LB	III	Vaal River	RU 8	EWR16	D	Biota	Aquatic invertebrates	The invertebrates must be maintained to indicate an ecosystem in a sustainable state.	State of aquatic invertebrates according to Macroinvertebrate Response Assessment Index (MIRAI) Score, using the SASS5 sampling method and Maintenance of critical habitat according to Rapid Habitat Assessment Method (RHAM).	MIRAI Score ≥D category (equivalent to EcoClassification score >40) and EcoStatus (RHAM) ≥D category (≥42). Maintenance of habitat for indicator species in a ≥D ecological category.
LA4	III	Vaal River	RU6	EWR17	D	Biota	Diatoms	Diatoms should be maintained to indicate an ecosystem in a moderately healthy state.	Diatom community structure according to Specific Pollution sensitivity Index (SPI) Score, using sampling method as per Taylor et al (2005)	SPI score C/D category (equivalent to EcoClassification score >50-60) (equivalent to EcoClassification score >40).
LB	III	Vaal River	RU 8	EWR16	D	Biota	Diatoms	Diatoms should be maintained to indicate an ecosystem in a sustainable state.	Diatom community structure according to Specific Pollution sensitivity Index (SPI) Score, using sampling method as per Taylor et al (2005)	SPI score D category (equivalent to EcoClassification score >40).

4.1.2 SUPPLEMENTARY INFORMATION FOR THE RIVER RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 8: Supplementary information for river water quantity RQOs on RU Scale.

WATER QUANTITY									
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**Context of the RQO**	**Reference**
LA4	II	Vaal River	RU6	EWR17	D	Quantity	Low Flows	Upstream activities are having a significant impact on the low flows, where fluctuations are affecting the habitat and response components including the riparian vegetation and fish/invertebrates which are responsive to environmental cues for life cycle activities. The low flows need to be managed to provide a D category in the river, with an emphasis on reducing the daily unnatural fluctuations. Percentiles associated with low flows specify duration requirements.	DWA, 2010
LB	III	Vaal River	RU8	EWR16	D	Quantity	High Flows	Moderate high flows are important to provide ecological cues for the ecosystem. High flows need to be used to introduce variability as described in the Reserve. High flows need to be managed at a D category. The high flow requirements include flood and freshet flows and their associated flow duration requirements which are defined by the percentiles associated with the numerical limits of flows.	DWA, 2010
	III	Vaal River	RU11	Douglas EWR	C	Quantity	Low Flows	Low flows are important to maintain the ecosystem and also to provide water for irrigation. Upstream flow alterations and excessive abstraction for the Harts Scheme are affecting the state of the river. The low flows should be improved to a C category and no zero flow conditions should be allowed. Percentiles associated with low flows specify duration requirements.	DWA, 2010

Table 9: Supplementary information for river water quality RQOs on RU Scale.

RIVER WATER QUALITY											
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**Context of the RQO**		**TPC**	**Reference**
LA2	II	Vaal River	RU3	VC57	C	Quality	Nutrients	Upstream Wastewater Treatment Works are affecting the nutrient levels in this RU which are reducing the fitness for use of the water. Nutrient concentrations need to be managed to achieve a B category and must be maintained in a mesotrophic or better state. Where available the 95%ile of observed or modelled data has been provided. The 95%ile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	Phosphate(PO_4)*	0.020 mg/L P	DWAF, 2008
									Nitrate (NO_3) & Nitrite (NO_2)*	0.85 mg/L N	
									Total Ammonia*	58 µg/L N	
LB	III	Vaal River	RU11	Douglas EWR	C	Quality	Nutrients	Excessive nutrients from the Harts Scheme and the upstream Vaal River impact negatively on water treatment costs by promoting algal growth, and are also negative for recreation, ecotourism and real estate use. Excessive nutrients also impact negatively on the ecosystem of the RU. Nutrients should be improved to a C category. Where available the 95%ile of observed or modelled data has been provided. The 95%ile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	Phosphate(PO_4)*	0.020 mg/L P	DWAF, 2008
									Nitrate (NO_3) & Nitrite (NO_2)*	0.85 mg/L N	
									Total Ammonia*	58 µg/L N	
LA4	II	Vaal River	RU6	EWR17	D	Quality	Salts	This ecosystem is intolerant of the current high levels of salts which are negatively affecting ecosystem function and the fitness for use of the water for irrigation. Salt concentrations need to be reduced to levels which are acceptable for irrigation. Where available the 95%ile of observed or modelled data has been provided. The 95%ile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	Electrical conductivity*	98 mS/m	DWAF, 2008
LB	III	Vaal River	RU11	Douglas EWR	C	Quality	Salts	Salinity concentrations in this RU must be managed to ensure that water quality is suitable for irrigated agriculture, and should be improved to a C category. Where available the 95%ile of observed or modelled data has been provided. The 95%ile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	Electrical conductivity*	70 mS/m	DWAF, 2008
LB							System Variables	High temperatures and low oxygen levels resulting from low flows negatively impact on the ecosystem and should be improved to C category.	Temperature *	abs(dev. from ambient) 1°C	DWAF, 2008
									Dissolved oxygen *	7 mg/L O2	

LB	III	Vaal River	RU8	EWR16	D	Quality	Toxicants	Water from the upstream Bloemhof Dam is likely to contain Toxicants that are unacceptable for irrigation and local communities who consume water and fish. Toxicants should be maintained at a D category and not pose a high risk to human health. Where available the 95%ile of observed or modelled data has been provided. The 95%ile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	F*	2.8 mg/L	DWAF, 2008
									Al*	128 µg/L	
									As*	113 µg/L	
									Cd hard*	4.0 µg/L	
									Cr(VI)*	161 µg/L	
									Cu hard*	7.0 µg/L	
									Hg*	1.34 µg/L	
									Mn*	1145 µg/L	
									Pb hard*	11.25 µg/L	
									Se*	26 µg/L	
									Zn*	31 µg/L	
									Chorine*	4.1 µg/L free Cl	
									Endosulfan*	0.165 µg/L	
									Atrazine*	89 µg/L	
LB	III	Vaal River	RU11	Douglas EWR	C	Quality	Pathogens	Microbial contamination must be minimised to reduce the impact on usability of irrigated crops and should not occur in concentrations exceeding D category. Where available the 95%ile of observed or modelled data has been provided. The 95%ile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	*E.coli**	130 counts/100 ml	DWAF, 1996. (Recreational Use).

Table 10: Supplementary information for river habitat RQOs on RU Scale.

RIVER HABITAT										
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA2	II	Vaal River	RU3	VC57	C	Habitat	Instream Habitat	The instream habitat provides an important template for the ecosystem and in this way supports a range of ecosystem functions and a high diversity of aquatic species. Instream habitat is however negatively impacted on by upstream agricultural activities and communities.	EcoStatus (RHAM) ≥B/C category (≥78), and or maintenance of habitat for indicator species in a ≥B/C ecological category.	DWA, 2009
LA4	III	Vaal River	RU6	EWR17	D	Habitat	Instream Habitat	The instream habitat provides an important ecosystem template for the entire ecosystem and is important for ecosystem processes including the maintenance of a high diversity of aquatic biota. This river is also important for recreation but flow alterations are contributing to an impaired instream habitat state as well as allowing for the abnormal growth of periphyton within rocky substrates (in particular)	EcoStatus (RHAM) ≥C/D category (≥58), and or maintenance of habitat for indicator species in a ≥C/D ecological category.	DWA, 2009
LB	III	Vaal River	RU8	EWR16	D	Habitat	Instream Habitat	The instream habitat provides an important template for the ecosystem and provides for important structure and functioning but is significantly impacted by flow releases from the upstream dam and by surrounding land use activities.	EcoStatus (RHAM) ≥C/D category (≥58), and or maintenance of habitat for indicator species in a ≥C/D ecological category.	DWA, 2009
			RU11	Douglas EWR	C			The instream habitat is important for maintenance of the ecosystem and also for real estate and property value and recreational angling; however this value is being negatively impacted by flows and poor water quality.	EcoStatus (RHAM) ≥C/D category (≥58), and or maintenance of habitat for	DWA, 2009

									indicator species in a ≥C/D ecological category.	
LB	III	Vaal River	RU 8	EWR16	D	Habitat	Riparian	The riparian zone is important for ecological processes, stabilisation of banks and cover/habitat for biota and is also important for recreation and for real-estate values, but in this RU is being negatively impacted by altered flows and land use activities. The riparian zone should be improved to a D category.	EcoStatus (RHAM) ≥C/D category (≥58), and or maintenance of habitat for indicator species in a ≥C/D ecological category.	DWAF, 2008

Table 11: Supplementary information for river biota RQOs on RU Scale.

RIVER BIOTA										
IUA	**Class**	**River**	**RU**	**Node**	**REC**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA4	II	Harts River	RU7	VC59	A/B	Biota	Fish	This Resource Unit is needed to support and maintain local fish community structures	FRAI Score between 85-95 (A/B category)	Moulton et al, 2002
									A/B category	Moulton et al, 2002
LB	III	Vaal River	RU8	EWR16	D	Biota	Fish	Fish are important in this river as part of the ecosystem and are used by local communities who depend on the local subsistence fisheries. However the fish are negatively impacted by the upstream Bloemhof Dam which acts as a barrier to migration and where congregating fish are targeted by local communities and other predators. The potential poor water quality contamination of the fish for consumption is also of concern.	FRAI Score between 85-95 (A/B category)	Kleynhans, 2007
			RU11	Douglas EWR	C			Fish are an important component of the ecosystem and for recreational angling.	B/C category	Kleynhans, 2007
LA2	II	Vaal River	RU3	VC57	C	Biota	Aquatic invertebrates	Invertebrates form an important component of the ecosystem and are also good indicators of water quality, quantity and habitat.	MARAI Score B/C category	Taylor et al, 2005; DWAF, 2008
LA4	III	Vaal River	RU6	EWR17	D	Biota	Aquatic invertebrates	Invertebrates form an important component of the ecosystem and are also good indicators of water quality, quantity and habitat.	MARAI Score C category	Taylor et al, 2005; DWAF, 2008
LB	III	Vaal River	RU 8	EWR16	D	Biota	Aquatic invertebrates	Invertebrates form an important component of the ecosystem and are also good indicators of water quality, quantity and habitat.	MARAI Score C/D category	Taylor et al, 2005; DWAF, 2008
LA4	III	Vaal River	RU6	EWR17	D	Biota	Diatoms	Diatoms are useful indicators of overall ecosystem health and in particular of water quality.	SPI score C category	Taylor et al, 2005; DWAF, 2008
LB	III	Vaal River	RU 8	EWR16	D	Biota	Diatoms	Diatoms are useful indicators of overall ecosystem health and in particular of water quality.	SPI score C/D category.	Taylor et al, 2005; DWAF, 2008

4.2 WETLAND RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS FOR THE LOWER VAAL WMA

The outcomes of the RQO and NL determination of the sub-components and indicators for the wetland component (Figure 3), of the RQO determination study for the Lower Vaal WMA, including a summary of additional supplementary information are provided as follows (Figure 3):

- RQOs for regional wetland in the Lower Vaal WMA are presented in Table 12.
- RQOs for the wetland water quantity component are presented in Table 13.
- RQOs for the wetland water quality component are presented in Table 14.
- RQOs for the wetland water habitat component are presented in Table 15.
- RQOs for the wetland water biota component are presented in Table 16.
- Supplementary information for the wetland water quantity component is presented in Table 17.
- Supplementary information for the wetland water quality component is presented in Table 18.
- Supplementary information for the wetland water habitat component is presented in Table 19.
- Supplementary information for the wetland water biota component is presented in Table 20.

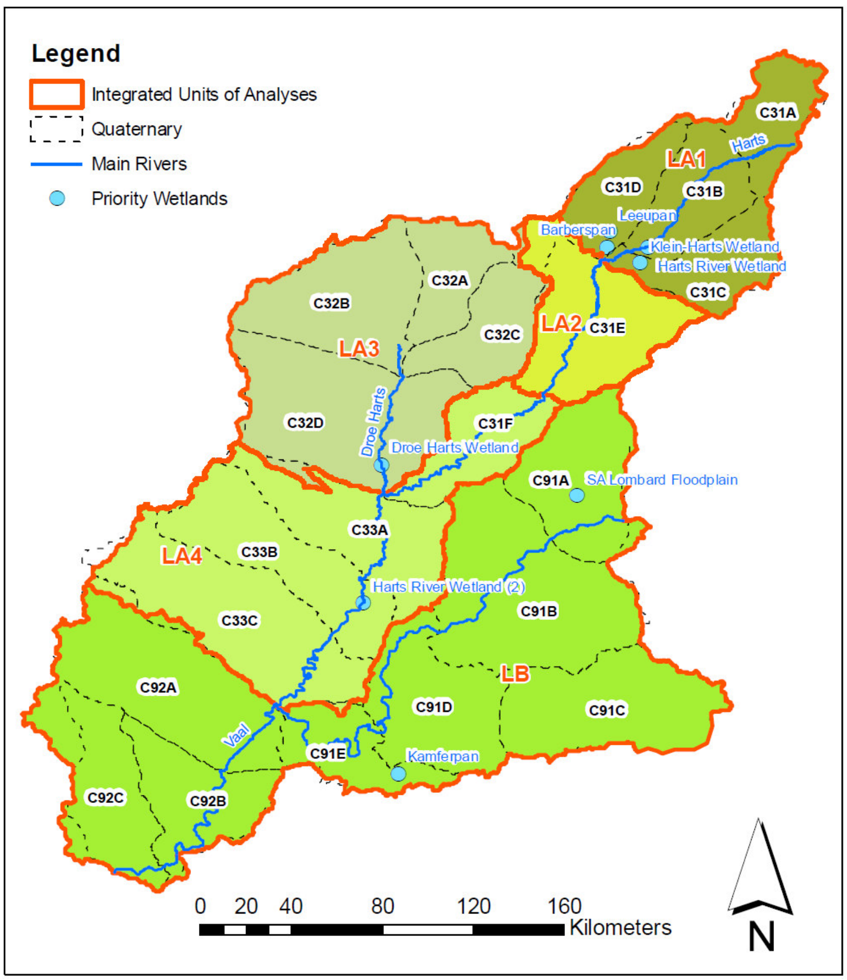

Figure 3: Map of the Integrated Units of Analysis (IUAs), priority Wetland Ecosystems considered in the study with main rivers and associated quaternary catchments presented.

4.2.1 WETLAND RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 12: Regional RQOs for wetlands in the Lower Vaal WMA

REGIONAL WETLANDS		
RQO	**Indicator/ measure**	**Numerical Criteria**
There must be no net loss in wetland functioning within the IUA.	Condition of wetlands in the IUA. IUA level desktop wetland assessment supplemented with a site-level assessment of a subset of indicator wetlands within the IUA. This assessment should be repeated every 5 years.	Hectare equivalents of wetlands in the IUA are unknown. An assessment of the current condition is required. The numerical criteria should equate to the hectare equivalents of the current condition of wetlands.
Validated wetland FEPAs in a good condition (equivalent to an A-B ecological category) must be maintained whilst wetland FEPAs in a modified condition (equivalent to a C-F ecological category) must be improved to their best attainable ecological condition.	Condition of validated wetland FEPAs in the IUA. IUA level desktop assessment of validated wetland FEPAs supplemented with a site-level assessment of a subset of these wetlands within the IUA. This assessment should be repeated every 5 years.	Hectare equivalents of wetlands in the IUA are unknown. An assessment of the current condition is required. The numerical criteria should equate to the hectare equivalents of the current condition of wetlands.
Land uses associated with validated FEPA wetland clusters must be controlled to maintain hydrological linkages that maintain connectivity between wetlands.	Land use associated with validated FEPA wetland clusters. Desktop assessment of land use compatibility within a 500m buffer of validated FEPA wetland clusters. This assessment should be repeated every 5 years.	Hectare equivalents of wetlands in the IUA are unknown. An assessment of the current condition is required. The numerical criteria should equate to the hectare equivalents of the current condition of wetlands.
Wetland FEPAs must be formally protected through appropriate protection mechanisms to secure key biodiversity values and meet wetland conservation targets.	Proportion of validated wetland FEPAs that are formally protected. IUA level assessment of protection status based on available protected area coverage's. This assessment should be repeated every 5 years.	Hectare equivalents of wetlands in the IUA are unknown. An assessment of the current condition is required. The numerical criteria should equate to the hectare equivalents of the current condition of wetlands.

Table 13: Water quantity RQOs for priority wetlands in the Lower Vaal WMA

WETLAND WATER QUANTITY							
IUA	**Wetland**	**RU**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**
LA1	1.1 Leeupan 1.2 Barberspan	RU2	Quantity	Water Inputs	The quantity and timing of inputs, and the distribution and retention patterns within the wetland must be maintained to avoid the loss of wetland hydrological function.	Wetland hydrology score. Detailed assessment of wetland hydrology using the hydrology module of Wet-Health (Level 2). Every 3-5 years	Present condition is unknown. An assessment of the current condition is required. The numerical criteria should equate to the maintenance of present condition.
LA1 LA3	1.3 Klein-harts 1.4 Harts River 3.1 Droe Harts	RU2 RU1 RU4	Quantity	Water distribution and retention patterns	Water distribution and retention patterns within the wetland must be maintained to avoid the loss of wetland hydrological function.	Water distribution & retention patterns score. Water distribution and retention assessment, hydrology module of Wet-Health (Level 2). Every 3-5 years	Present condition is unknown. An assessment of the current condition is required. The numerical criteria should equate to 10% less than the PES score determined.
LA4	4.1. Harts River	RU6	Quantity	Water Hydrology	The quantity and timing of inputs, and the distribution and retention patterns within the wetland must be maintained	Wetland hydrology score. Detailed assessment of wetland	Present condition is unknown. An assessment of the current condition is required. The numerical criteria should equate to the maintenance of

					to avoid the loss of wetland hydrological function.	hydrology using the hydrology module of Wet-Health (Level 2). Every 3-5 years	present condition.

Table 14: Water quality RQOs for priority wetland in the Lower Vaal WMA

WETLAND WATER QUALITY								
IUA	Wetland	RU	Component	Sub Component	RQO	Indicator/ measure	Numerical Limits	95%tile
LA1	1.4 Harts River	RU1	Quality	Nutrients	The wetland is threatened by sewerage pollution, nutrient concentrations entering must be limited.	TIN-N*	≤ 1.00 mg/L N	No data
						NH3*	≤ 0.073 mg/L N	No data
	1.2 Barberspan	RU2	Quality	Nutrients	Nutrient concentrations must be maintained at a level that does not pose a threat to biodiversity and long-term wetland functioning.	TIN-N*	≤ 1.00 mg/L N	0.04
						NH3*	≤ 0.073 mg/L N	0.2
	1.1 Leeupan		Quality	Toxicants	The wetland is a saline environment influenced by periodic high inflow events. Water quality parameters required to maintain fish populations must be monitored.	BOD*	≤ 3.0 mg/L O2	No data
						NH3*	≤ 0.073 mg/L N	No data
	1.2 Barberspan		Quality	Toxicants	There is a risk of toxic accumulation of contaminants in the pan as a result of upstream agricultural practices. The Toxicants must be maintained at a level that does not pose a threat to biodiversity and long-term wetland functioning.	TIN-N*	≤ 1.00 mg/L N	0.04
						NH3*	≤ 0.073 mg/L N	0.2

Table 15: Habitat RQOs for priority wetlands in the Lower Vaal WMA

WETLAND HABITAT							
IUA	Wetland	RU	Component	Sub Component	RQO	Indicator/ measure	Numerical Limits
LA1 LA3 LA4 LB	1.1 Leeupan 1.2 Barberspan 1.3 Klein-harts 1.4 Harts River 3.1 Droe Harts 4.1 Harts River 5.1 SA Lombard	RU2 RU1 RU4 RU6 RU9	Habitat	Wetland Vegetation	The wetland vegetation must be maintained to ensure that the ecosystem structure and function are maintained.	Wetland vegetation score. Vegetation module of Wet-Health (Level 2).Every 3-5 years	Present condition is unknown. An assessment of the current condition is required. The numerical criteria should equate to 10% less than the PES score determined.
LA1 LA4 LB	1.3 Klein-harts 1.4 Harts River 3.1 Droe Harts 4.1 Harts River 5.1 SA Lombard	RU2 RU1 RU4 RU6 RU9	Habitat	Wetland geomorphology	The wetland geomorphology must be maintained to ensure that the ecosystem structure and function are maintained.	Wetland geomorphology score. Geomorphology module of Wet-Health (Level 2). Every 3-5 years	Present condition is unknown. An assessment of the current condition is required. The numerical criteria should equate to 10% less than the PES score determined.

Table 16: Biota RQOs for priority wetlands in the Lower Vaal WMA

WETLAND BIOTA							
IUA	Wetland	RU	Component	Sub Component	RQO	Indicator/ measure	Numerical Limits
LA1	1.1 Leeupan	RU2	Biota	Birds	Populations of Lesser Flamingos and Greater Flamingos must be maintained at least at current levels to meet	Number of observed Lesser Flamingos (*Phoenicopterus minor*) and Greater Flamingos (*Phoenicopterus ruber*) present	Greater flamingo, RR 72-100%; 510-5000 individuals; Lesser flamingo, RR 40-52%; 261-5000

					conservation targets.	annually. Reporting Rate, or total numbers counted annually**	individuals.
LB	5.2 Kamferpan	RU10	Biota	Birds	Water quality and quantity must be maintained at a level that does not pose a threat to the population of Lesser Flamingo. A viable population of Red Data bird species must be maintained.	Number of observed Lesser Flamingos *(Phoenicopterus minor)* and Greater Flamingos *(Phoenicopterus ruber)* present annually. Reporting Rate, or total numbers counted annually**	Greater flamingo, RR 47-72%; Lesser flamingo, RR 61-100%.
**As per standard methods of America Water Works Association (www.awwa.org)*							
***Data obtained from bird clubs and conservation authorities. Measured as per methods prescribed by Avian Demography Unit, Department of Statistical Sciences University of Cape Town or Birdlife SA.*							

4.2.2 SUPPLEMENTARY INFORMATION FOR THE WETLAND RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 17: Supplementary tables for wetlands RQOs on ecosystem scale.

WETLAND WATER QUANTITY							
IUA	**Wetland**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA1	1.1 Leeupan	RU2	Quantity	Water Inputs	Water inputs are important in shaping habitat characteristics of pan systems. The pan receives inflows from a canal connecting to Barberspan. While Leeupan provides a flood attenuation service it has implications for land use activities adjacent to the pan. Maintenance of flow patterns is required to ensure that there is not a reduction in the capacity of the wetland to provide this service and adjacent land use activities are not compromised.	Given that the present condition is unknown, the TPC cannot be determined. Once the numerical criteria has been determined the TPC should be set at 30% more than the lowest score for the present condition score.	Macfarlane et al, 2007
	1.2 Barberspan				The size of the pan is determined largely by inflow of water from the Harts River. The wetland effectively acts as an off-channel storage dam that can significantly reduce flood peaks, particularly when the initial pan level is low. Maintenance of flow patterns is required to ensure that there is no loss in functional value.	Given that the present condition is unknown, the TPC cannot be determined. Once the numerical criteria has been determined the TPC should be set at 30% more than the lowest score for the present condition score.	
LA1 LA3	1.3 Klein-harts 1.4 Harts River 3.1 Droe Harts	RU2 RU1 RU4	Quantity	Water distribution and retention patterns	The integrity of wetland hydrology can be affected by alterations in the catchment that affects the quantity and timing of inputs, which in turn affects the distribution and retention patterns within the wetland system itself. The water distribution and retention patterns must be maintained.	Given that the present condition is unknown, the TPC cannot be determined. Once the numerical criteria has been determined the TPC should be set at 30% more than the lowest score for the present condition score.	Macfarlane et al, 2007
LA4	4.1. Harts River	RU6	Quantity	Water Hydrology	The integrity of wetland hydrology can be affected by alterations in the catchment, such as the upstream irrigation scheme, that affects the quantity and timing of inputs, which in turn affects the distribution and retention patterns within the wetland system itself. The wetland hydrology must be maintained.	Given that the present condition is unknown, the TPC cannot be determined. Once the numerical criteria has been determined the TPC should be set at 30% more than the lowest score for the present condition score.	Macfarlane et al, 2007

Table 18: Supplementary information for wetland water quality RQOs on ecosystem scale.

WETLAND WATER QUALITY								
IUA	**Wetland**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**		**Reference**
LA1	1.4 Harts River	RU1	Quality	Nutrients	The Harts River wetland is threatened by sewerage pollution from various sources, including WWTWs associated with Sannieshof. To maintain ecosystem functioning and the supply of ecosystem services, particularly regulating and supporting services, nutrient concentrations entering the wetland must be maintained.	TIN-N*	0.85 mg/L N	DWAF, 2008
						NH3*	0.058 mg/L N	
	1.2 Barberspan	RU2	Quality	Nutrients	Barberspan is threatened by sewerage pollution from various sources. There is a growing risk of eutrophication caused by increased nutrient inputs from wastewater and agricultural activities in the catchment. The nutrient concentrations must be maintained at a level that does not pose a threat to biodiversity and long-term wetland functioning.	TIN-N*	0.85 mg/L N	DWAF, 2008
						NH3*	0.058 mg/L N	
	1.1 Leeupan		Quality	Toxicants	The wetland is a haline environment. High flow events allow for fish to enter the system, which poses a risk of fish die off. This would allow for ideal conditions for toxic botulism to develop and result in mass bird moralities. Therefore, the risk of fish die offs in Leeupan must be managed.	BOD*	2.5 mg/L O2	Canadian Council of Ministers of the Environment, 1999
						NH3*	0.058 mg/L N	
	1.2 Barberspan		Quality	Toxicants	There is a risk of toxic accumulation of contaminants in the pan as a result of upstream agricultural practices. The Toxicants must be maintained at a level that does not pose a threat to biodiversity and long-term wetland functioning.	TIN-N*	0.85 mg/L N	DWAF, 2008
						NH3*	0.058 mg/L N	

Table 19: Supplementary information for wetland habitat RQOs on ecosystem scale.

WETLAND HABITAT							
IUA	**Wetland**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA1 LA3 LA4 LB	1.1 Leeupan 1.2 Barberspan 1.3 Klein-harts 1.4 Harts River 3.1 Droe Harts 4.1 Harts River 5.1 SA Lombard	RU2 RU1 RU4 RU6 RU9	Habitat	Wetland Vegetation	Wetland vegetation is a good indicator of the habitat and biodiversity value of a wetland and provides foraging and breeding habitat for a diversity of bird species, including both flamingo species. Maintenance is required to ensure that existing biodiversity values are not undermined.	Given that the present condition is unknown, the TPC cannot be determined. Once the numerical criteria has been determined the TPC should be set at 30% more than the lowest score for the relevant Present Vegetation State Category.	Macfarlane et al, 2007
LA1 LA4 LB	1.3 Klein-harts 1.4 Harts River 3.1 Droe Harts 4.1 Harts River 5.1 SA Lombard	RU2 RU1 RU4 RU6 RU9	Habitat	Wetland geomorphology	The Klein-Harts wetland is a wetland FEPA that plays a substantial hydrological and ecological role in the natural functioning of the Klein- Harts and Harts River. Management of the wetland is important to ensure that the ecosystem structure and function are maintained and that there is ongoing supply of ecosystem services, particularly regulating and supporting services. The wetland geomorphology must be maintained.	Given that the present condition is unknown, the TPC cannot be determined. Once the numerical criteria has been determined the TPC should be set at 30% more than the lowest score for the relevant Present Geomorphology State Category.	Macfarlane et al, 2007

Table 20: Supplementary information for wetland biota RQOs on ecosystem scale.

WETLAND BIOTA							
IUA	**Wetland**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA1	1.1 Leeupan	RU2	Biota	Birds	Leeupan is an IBA but it is not formally protected. There is a high diversity of bird species at the pan. In particular the pan system provides an important refuge for Red Data Lesser Flamingos (Phoenicopterus minor) and Greater Flamingos (Phoenicopterus ruber). Management of the pan system is required to maintain a viable population of both flamingo species.	Greater flamingo, RR <80%; 600 individuals; Lesser flamingo, RR 60%; 300 individuals.	Avian Demography Unit, 2011
LB	5.2 Kamferpan	RU10	Biota	Birds	Kamferspan is a South African Natural Heritage Site and an IBA. This wetland is home to the largest permanent population of Lesser Flamingos in southern Africa and is the only Lesser Flamingo breeding site in South Africa. It is one of only four Lesser Flamingo breeding sites in Africa, and six in the world. The pan also supports a host of other endemic and threatened water birds. Water quality and quantity must be maintained at a level that does not pose a threat to the population of Lesser Flamingo. A viable population of Red Data bird species must be maintained.	Greater flamingo, RR <55%; Lesser flamingo, RR <75%.	Avian Demography Unit, 2011

4.3 DAM RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS FOR THE LOWER VAAL WMA

The outcomes of the RQO and NL determination of the sub-components and indicators for the dam component of the RQO determination study for the Lower Vaal WMA, including a summary of additional supplementary information are provided as follows (Figure 4):

- RQOs for the dam water quantity component are presented in Table 21.
- RQOs for the dam water quality component are presented in Table 22.
- RQOs for the dam water biota component are presented in Table 23.
- Supplementary information for the dam water quantity component is presented in Table 24.
- Supplementary information for the dam water quality component is presented in Table 25.
- Supplementary information for the dam water biota component is presented in Table 26.

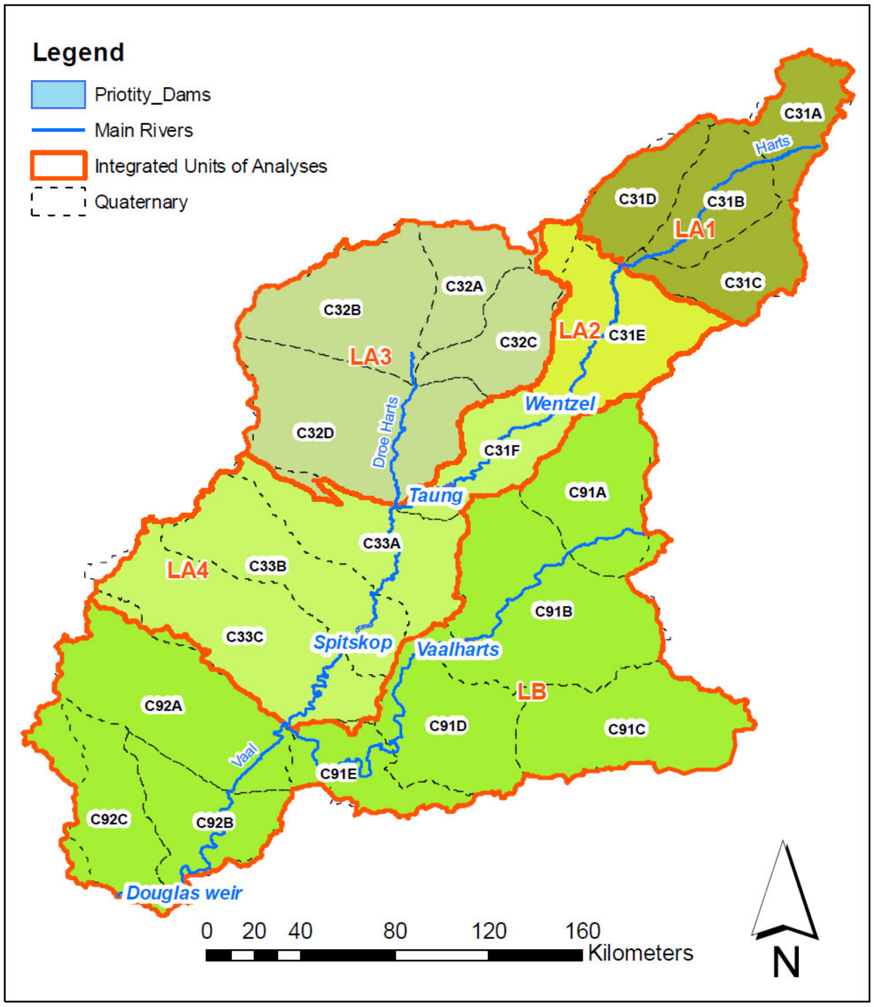

Figure 4: Map of the Integrated Units of Analysis (IUAs), priority Dam Ecosystems considered in the study, with main rivers and associated quaternary catchments presented.

4.3.1 DAM RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 21: RQOs for water quantity in priority dams in the Lower Vaal WMA

<table>
<tr><th colspan="10">DAM WATER QUANTITY</th></tr>
<tr><th>IUA</th><th>Dams</th><th>RU</th><th>Component</th><th>Sub Component</th><th>RQO</th><th>Indicator/ measure</th><th colspan="3">Numerical Limits</th></tr>
<tr><td>LA2</td><td>Wentzel Dam (27°10'25"S; 25°20'15"E)</td><td>RU 3</td><td>Quantity</td><td>Low Flows</td><td>The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation and urban use</td><td>EWR maintenance low and drought flow releases to Harts River in C31F PES=D category. (Daily releases from C3R001.)</td><td colspan="3">Use Desktop Reserve Model (DRM) and updated PES/EI/ES data to determine low and drought requirements for Harts River downstream Wentzel Dam</td></tr>
<tr><td rowspan="14">LA4</td><td>Taung Dam (27°31'34"S; 24°51'16"E)</td><td>RU 5</td><td rowspan="14">Quantity</td><td rowspan="14">Low Flows</td><td rowspan="14">The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation</td><td>EWR maintenance low and drought flow releases to Harts River in C31F PES=D category. (Daily releases from C3R006.)</td><td colspan="3">Use Desktop Reserve Model (DRM) and updated PES/EI/ES data to determine low and drought requirements for Harts River downstream Taung Dam</td></tr>
<tr><td rowspan="13">Spitskop Dam (28°7'30"S; 24°30'15"E)</td><td rowspan="13">RU 6</td><td rowspan="13">EWR maintenance low and drought flows releases to Harts in C33C* VMAR = $147.85x10^6m^3$. (Daily releases from C3R002 to meet requirements at EWR17.)
REC=D category</td><td colspan="2">Maintenance low flows (m^3/s) (%ile)</td><td>Drought flows (m^3/s) (%ile)</td></tr>
<tr><td>Oct</td><td>1.5 (10)</td><td>0.001 (99)</td></tr>
<tr><td>Nov</td><td>2 (10)</td><td>0.001 (99)</td></tr>
<tr><td>Dec</td><td>2.5 (20)</td><td>0.001 (99)</td></tr>
<tr><td>Jan</td><td>3 (20)</td><td>0.001 (99)</td></tr>
<tr><td>Feb</td><td>4 (30)</td><td>0.001 (99)</td></tr>
<tr><td>Mar</td><td>5 (30)</td><td>0.001 (99)</td></tr>
<tr><td>Apr</td><td>4 (30)</td><td>0.001 (99)</td></tr>
<tr><td>May</td><td>3 (10)</td><td>0.001 (99)</td></tr>
<tr><td>Jun</td><td>2.5 (10)</td><td>0.001 (99)</td></tr>
<tr><td>Jul</td><td>2 (10)</td><td>0.001 (99)</td></tr>
<tr><td>Aug</td><td>1.5 (10)</td><td>0.001 (99)</td></tr>
<tr><td>Sep</td><td>1 (10)</td><td>0.001 (99)</td></tr>
<tr><td rowspan="2">LB</td><td>Vaalharts Weir (28°7'1"S; 24°56'45"E)</td><td>RU 9</td><td rowspan="2">Quantity</td><td rowspan="2">Low Flows</td><td>The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation</td><td>EWR maintenance low and drought flow to Vaal River in C91D PES=D category. (Daily releases from C9R001 to meet requirements in C91D.)</td><td colspan="3">Use Desktop Reserve Model (DRM) and updated PES/ES/EI data to determine low and drought requirements for Vaal River below Vaalharts Weir in C91D using Lower Vaal_EWR16</td></tr>
<tr><td>Douglas Weir (29°02'36"S; 23°50'13"E)</td><td>RU 11</td><td>Water should be released for the maintenance of the ecosystem in this last reach of the Vaal River</td><td>EWR maintenance low and drought flow releases to Vaal River in C92C PES=D category. (Daily releases from C9R003 to meet requirements in C92C.)</td><td colspan="3">Use Desktop Reserve Model (DRM) and updated PES/EI/ES data to determine low and drought requirements for Vaal River downstream Douglas Weir</td></tr>
<tr><td colspan="10">* Per Rule Table</td></tr>
</table>

Table 22: RQOs for water quality in priority dams in the Lower Vaal WMA

DAM WATER QUALITY								
IUA	**Dams**	**RU**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**	**95%tile**
LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quantity	Nutrients	The nutrient state of the dam must be improved and maintained in a mesotrophic state.	Phosphate(PO_4) *	≤ 0.025 mg/L P	0.016
						Nitrate (NO_3) & Nitrite (NO_2) *	≤ 1.00 mg/L N	0
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6				Phosphate(PO_4) *	≤ 0.020 mg/L P	0.019
						Nitrate (NO_3) & Nitrite (NO_2) *	≤ 0.85 mg/L N	0
LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quantity	Nutrients	Nutrient levels must be improved and maintained in a mesotrophic state. Total inorganic nitrogen must be improved over present concentrations.	Phosphate(PO_4) *	≤ 0.020 mg/L P	0.006
						Nitrate (NO_3) & Nitrite (NO_2) *	≤ 0.85 mg/L N	0.025
	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11			Nutrient levels must be improved and maintained in a mesotrophic state.	Phosphate(PO_4) *	≤ 0.020 mg/L P	0.006
						Nitrate (NO_3) & Nitrite (NO_2) *	≤ 0.85 mg/L N	0.147
LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quantity	Salts	Salinity concentrations must be maintained at levels acceptable for irrigation	Electrical Conductivity*	≤ 85 mS/m	64.38
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6			Salinity concentrations must be maintained at levels acceptable for irrigation	Electrical Conductivity*	≤ 85 mS/m	155.76
LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quantity	Salts	Salinity concentrations must be maintained at levels acceptable for irrigation	Electrical Conductivity*	≤ 85 mS/m	78.5
	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11			Salinity concentrations must be maintained at levels acceptable for irrigation	Electrical Conductivity*	≤ 85 mS/m	111.5
LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quality	Toxicants	The numbers of cyanobacteria must be kept within mesotrophic levels.	Chl-a: phytoplankton*	≤ 20.0 µg/L	No data
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6				Chl-a: phytoplankton*	≤ 20.0 µg/L	No data
LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quality	Toxicants	The numbers of cyanobacteria must be kept within mesotrophic levels.	Chl-a: phytoplankton*	≤ 20.0 µg/L	No data

	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11				Chl-a: phytoplankton*	≤ 20.0 µg/L	No data
*as per standard methods of America Water Works Association (www.awwa.org)								

Table 23: RQOs for biota in priority dams in the Lower Vaal WMA

DAM BIOTA							
IUA	**Dams**	**RU**	**Component**	**Sub Component**	**RQO**	**Indicator/ measure**	**Numerical Limits**
LA4	Taung Dam (RU 5, 27°31'34"S; 24°51'16"E)	RU5	Biota	Fish	The wellbeing of the fish community of this artificial ecosystem must be maintained in a suitable condition to contribute to regional biodiversity (Including Maintenance of Orange-Vaal largemouth yellowfish population *(Labeobarbus kimberleyensis)* and to support local recreational angling industry. Consumption of fish must not pose a health risk to local communities. The genetic diversity of the cyprinids in the dam must not be contaminated by non-endemic cyprinids.	Implementation of the Index of Reservoir Habitat Impairment (IRHI) by Miranda and Hunt (2011).	Habitat suitability and fish wellbeing in a state which is equivalent to a C or better ecological category.
						Fish health evaluation	Fish health must not deviate significantly from baseline state.
							Toxicants in fish tissue must not exceed guideline thresholds.
LB	Douglas Weir (RU 11, 29°02'36"S; 23°50'13"E)	RU11	Biota	Fish	The wellbeing of the fish community of this artificial ecosystem must be maintained in a suitable condition to contribute to regional biodiversity (Including Maintenance of Orange-Vaal largemouth yellowfish population *(Labeobarbus kimberleyensis))* and to support local recreational angling industry. Consumption of fish must not pose a health risk to local communities. The genetic diversity of the cyprinids in the dam must not be contaminated by non-endemic cyprinids.	Implementation of the Index of Reservoir Habitat Impairment (IRHI) by Miranda and Hunt (2011).	Habitat suitability and fish wellbeing in a state which is equivalent to a C or better ecological category.
						Fish health evaluation	Fish health must not deviate significantly from baseline state.
							Toxicants in fish tissue must not exceed guideline thresholds.
LB	Vaalharts Weir - (RU9, 28°7'1"S; 24°56'45"E)	RU9	Biota	Aquatic Plants	Invasive aquatic plant population establishment must be prevented	Aquatic plant composition assessment. Methods to be developed.	No established populations of invasive aquatic plants

4.3.2 SUPPLEMENTARY INFORMATION FOR THE DAM RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 24: Supplementary information for dam water quantity RQOs on ecosystem scale.

DAM WATER QUANTITY							
IUA	**Dams**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA2	Wentzel Dam (27°10'25"S; 25°20'15"E)	RU 3	Quantity	Low Flows	Releases for EWR for the protection of ecosystem function downstream and for irrigation and urban use	Not Applicable	DWAF, 2013
LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quantity	Low Flows	Releases for EWR for the protection of ecosystem function downstream and for irrigation	Not Applicable	DWAF, 2013
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6			Releases for EWR for the protection of ecosystem function downstream and for irrigation	Not Applicable	DWA, 2010

LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quantity	Low Flows	Almost all of the water is transferred to the Vaal-Harts Irrigation Scheme and there is very little that caters for protection of ecosystem function.	Not Applicable	DWA, 2010, DWAF, 2013
	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11			A specific operating rule to manage the Lower Vaal below the weir to minimise spills for the protection of water quality in the Orange River causes very low flows in this river reach.	Not Applicable	DWAF, 2013

Table 25: Supplementary information for dam water quality RQOs on ecosystem scale.

DAM WATER QUALITY								
IUA	**Dams**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**		**Reference**
LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quantity	Nutrients	The dam is currently in a eutrophic to hypertrophic state with the possibility that cyanobacteria could reach nuisance conditions and negatively affect irrigated plants. Excessive algae can also affect the functionality of the irrigation infrastructure. The nutrient state of the dam must therefore be improved and maintained in a mesotrophic state.	Phosphate(PO_4) *	0.020 mg/L P	DWAF, 2008
						Nitrate (NO_3) & Nitrite (NO_2) *	0.85 mg/L N	
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6				Phosphate(PO_4) *	0.015 mg/L P	
						Nitrate (NO_3) & Nitrite (NO_2) *	0.70 mg/L N	
LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quantity	Nutrients	The system is currently in a eutrophic to hypertrophic state with a possibility that cyanobacteria could affect the irrigated plants. In order to control this, nutrient levels must be improved and maintained in a mesotrophic state. Total inorganic nitrogen must be improved over present concentrations.	Phosphate(PO_4) *	0.015 mg/L P	DWAF, 2008
						Nitrate (NO_3) & Nitrite (NO_2) *	0.70 mg/L N	
	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11			The system is currently in a eutrophic to hypotrophic state with increasing incidents of nutrient influxes from municipal waste. Nutrient levels must be improved and maintained in a mesotrophic state.	Phosphate(PO_4) *	0.015 mg/L P	DWAF, 2008
						Nitrate (NO_3) & Nitrite (NO_2) *	0.70 mg/L N	
LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quantity	Salts	Irrigation and mining return flows have resulted in the increase of salt concentrations. These salinity concentrations may affect crop yields so must be maintained at a C category in the dam.	Electrical Conductivity*	70 mS/m	DWAF, 2008
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6				Electrical Conductivity*	70 mS/m	
LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quantity	Salts	Increases in salinity are related to irrigation return flows. Salt concentrations must not exceed a D category for irrigation use.	Electrical Conductivity*	70 mS/m	DWAF, 2008
	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11			Salt levels must be maintained in a C category for irrigation use downstream.	Electrical Conductivity*	70 mS/m	DWAF, 2008

LA4	Taung Dam (27°31'34"S; 24°51'16"E)	RU 5	Quality	Toxicants	The possibility of cyanobacterial blooms and associated algae Toxicants occurring in the dam is a concern. In order to prevent this, the numbers of cyanobacteria must be kept within mesotrophic levels.	Chl-a: phytoplankton*	15 µg/L	DWAF, 2008
	Spitskop Dam (28°7'30"S; 24°30'15"E)	RU 6				Chl-a: phytoplankton*	15 µg/L	DWAF, 2008
LB	Vaalharts Weir (28°7'1"S; 24°56'45"E)	RU 9	Quality	Toxicants	The eutrophic state of the dam may result in toxic cyanobacteria that impact on ecosystem function. Phytoplankton composition must be monitored and cyanobacteria must be maintained in a mesotrophic state.	Chl-a: phytoplankton*	15 µg/L	DWAF, 2008
	Douglas Weir (29°02'36"S; 23°50'13"E)	RU 11			The possibility of cyanobacterial blooms and associated algae Toxicants occurring in the dam is a concern. In order to prevent this, the numbers of cyanobacteria must be kept within mesotrophic levels	Chl-a: phytoplankton*	15 µg/L	DWAF, 2008

Table 26: Supplementary information for dam biota RQOs on ecosystem scale.

DAM BIOTA							
IUA	**Dams**	**RU**	**Component**	**Sub Component**	**Context of the RQO**	**TPC**	**Reference**
LA4	Taung Dam (RU 5, 27°31'34"S; 24°51'16"E)	RU5	Biota	Fish	This dam provides an important refuge area for indigenous fishes and must be managed to maintain suitable populations of the local Orange-Vaal largemouth yellowfish (Labeobarbus kimberleyensis) and ecologically important Barbs (Barbus spp.).	Habitat suitability and fish wellbeing in a state equivalent to a low C ecological category.	IUCN, 2013; Wepener et al, 2011
						Risk of fish health posing a threat to human health exists.	
LB	Douglas Weir (RU 11, 29°02'36"S; 23°50'13"E)	RU11	Biota	Fish	This dam serves as one of the most important recreational and subsistence fisheries in South Africa. Alien invasive fish species are the most abundant fishes in this dam, including common carp (Cyprinids carpio) and grass carp (Ctenopharyngodon idella) and must be managed to maintain viable population of indigenous targeted cyprinid species (Labeo spp. and Labeobarbus spp.) for angling. The health of fishes in the dam must also be maintained in a state which does not threaten human health if the fish are consumed by local communities.	Habitat suitability and fish wellbeing in a state equivalent to a low C ecological category.	IUCN, 2013; Wepener et al, 2011
						Fish health must not deviates noticeably (not significant) from baseline state	
						Toxicants in fish tissue differ noticeably from base line state (to be determined)	
LB	Vaalharts Weir - (RU9, 28°7'1"S; 24°56'45"E)	RU9	Biota	Aquatic Plants	Invasive aquatic plants will negatively impact on ecosystem functioning and a zero tolerance attitude should be taken in order to prevent a dominance of the system.	Occurrence of alien aquatic plants	

4.4 GROUNDWATER RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS FOR THE LOWER VAAL WMA

The outcomes of the RQO and NL determination of the sub-components and indicators for the groundwater component of the RQO determination study for the Lower Vaal WMA, including a summary of additional supplementary information are provided as follows (Figure 5):

- RQOs for groundwater presented in Table 27.
- Supplementary information for groundwater is presented in Table 28.

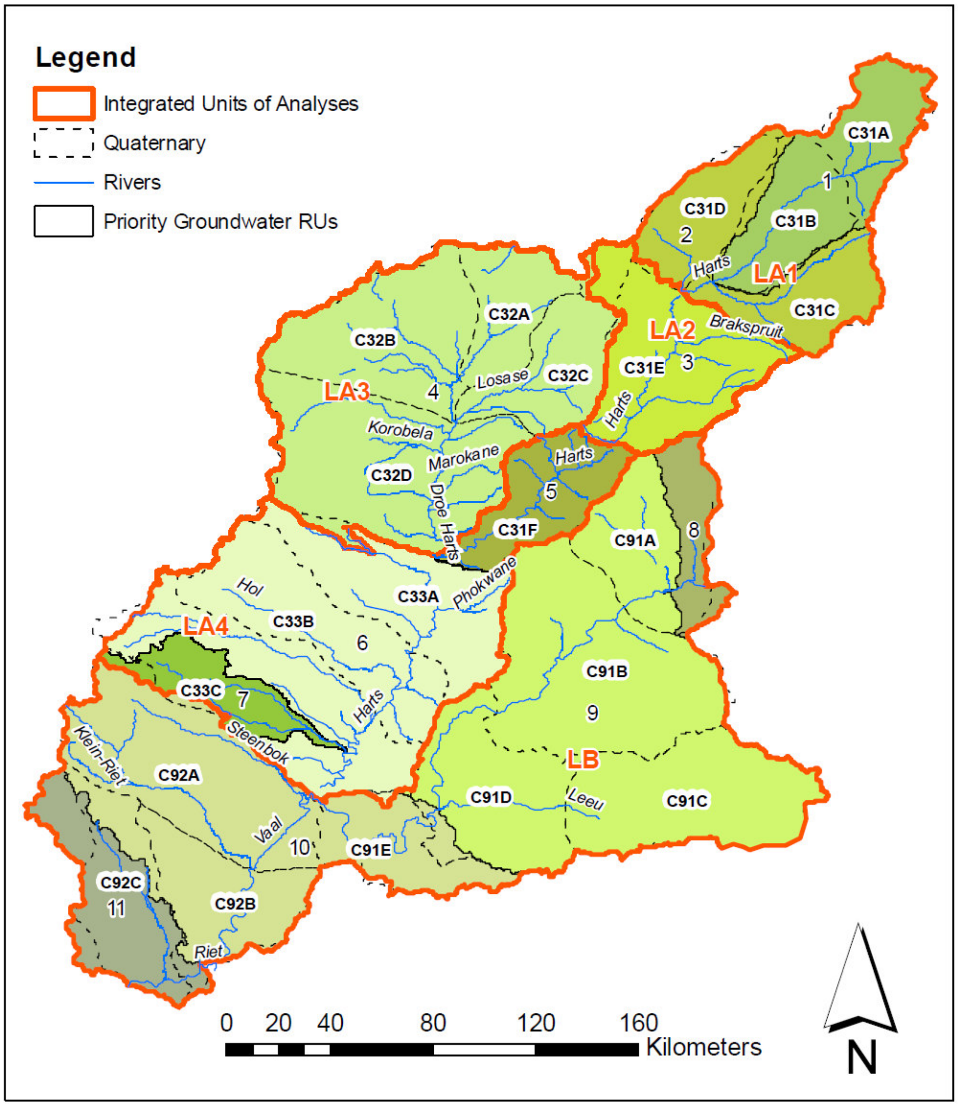

Figure 5: Map of the Integrated Units of Analysis (IUAs), priority Groundwater Resource Units considered in the study, with rivers and associated quaternary catchments presented.

4.4.1 GROUNDWATER RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 27: RQOs for groundwater in priority RUs in the Lower Vaal WMA

GROUNDWATER					
IUA	**RU**	**Component**	**RQO**	**Indicator/ measure**	**Numerical Criteria**
All	All Prioritised RUs	Quantity	Where water use is higher than requirements for Reserve, Schedule 1 and General Authorizations, abstraction rates should not exceed the average recharge values of the aquifer area.	Abstraction Rate (Q) per hectare > Reserve, Schedule[1] and General Authorizations.	Q < Average recharge per hectare
All	RU1	Aquifer	Medium to long-term water trends should not show negative deviation from the natural trend	Depth to Groundwater Level using Groundwater Monitoring Guidelines[2].	Water level fluctuations around the average site water level should not exceed 5.6 m.
	RU2				Water level fluctuations around the average site water level should not exceed 4.4 m.
	RU3				Water level fluctuations around the average site water level should not exceed 2.7 m.
	RU4 RU7 RU10				At least one NGwQI MP monitoring site that is representative of the aquifer. Water level fluctuations in Dolomitic aquifers[6] should not exceed 6m.
	RU5				Water level fluctuations around the average site water level should not exceed 16.2 m.
	RU6				Water level fluctuations around the average site water level should not exceed 27.8 m.
	RU8				Water level fluctuations around the average site water level should not exceed 30.6 m.
	RU9				Water level fluctuations around the average site water level should not exceed 3.7 m.
All	All Prioritised RUs	Quantity	The radius of influence should not intersect any other protection zone. In cases where an infringement already exits, the infringements will be used as baseline measurement.	Radius of influence (r)□. $r = 1.5*\sqrt{(T*t/S)}$, T=Transmissivity(m^2/d), t=Time(days), S=Storativity. Annual sampling via GIS algorithm or on introduction of new borehole	r should not overlap with any other radius of influence, cone of depression, protection zone or increase zone infringements
All	All Prioritised RUs	Ecological	A protection zone along a river/stream is required to protect the ecological reserve. In cases where an infringement already exits, the infringements will be used as baseline measurement.	Distance from river (L)4. L = (T*i)/R, T=Transmissivity(m2/d), i=Groundwater Gradient, R=Recharge(m/d). Annual sampling via GIS algorithm or on introduction of new borehole	L should not overlap with any other radius of influence, cone of depression, protection zone or increase zone infringements
All	All Prioritised RUs	Ecological	A protection zone along all wetlands is required to protect the ecological reserve. In cases where an infringement already exits, the infringements will be used as baseline measurement.	Distance from river (L)[4]. L = (T*i)/R, T=Transmissivity(m^2/d), i=Groundwater Gradient, R=Recharge(m/d) W=Wetland Perimeter. Annual sampling via GIS algorithm or on introduction of new borehole (perimeter is based on the Wetland Delineation Guidelines).	L should not overlap with any other radius of influence, cone of depression, protection zone or increase zone infringements
All	All Prioritised RUs	Quality	Boreholes require a protection zone from microbial pollution sources with a minimum requirement of 75m depending on the geohydrological condition of the area	Microbial radius (r)[4]. r = 2(0.28*T) + 53, T=Transmissivity(m^2/d). Annual sampling via GIS algorithm or on introduction of new borehole	Distance to pit latrine > r

All	All Prioritised RUs	Quality	Groundwater quality should be based on background groundwater quality. Sites that exceed the water use requirement should not be allowed to deteriorate in water quality.	Background water quality per borehole using Groundwater Monitoring Guidelines2[2]	Water quality should not be allowed to deteriorate significantly form background water quality

[1] General Authorization for the taking and storage of water, DWAF (2012)
[2] A Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa, DWAF (2008)
[3] The radius of influence is time dependent and the RU statistics is based on borehole pumping of 8 hours/day
[4] A protection zone is defined as a zone where the groundwater gradient is maintained
[5] South African Water Quality Guidelines, DWAF (1996)
[6] Groundwater Resource Directed Measures, WRC (2007)

4.4.2 SUPPLEMENTARY INFORMATION FOR THE GROUNDWATER RESOURCE QUALITY OBJECTIVES AND NUMERICAL LIMITS TABLES

Table 28: Supplementary information for groundwater RQOs on RU scale.

GROUNDWATER						
IUA	**RU**	**Component**	**Indicator/ measure**	**Context of the RQO**	**TPC**	**Reference**
All	All Prioritised RUs	Quantity	Abstraction Rate (Q) per hectare > Reserve, Schedule[1] and General Authorizations.	In areas where the abstraction per unit area exceeds the recharge per unit area, aquifer failure is likely. Although it is not possible to abstract all recharge from groundwater, the abstraction compared to the recharge gives an indication of the current aquifer stress.	Stress Index = Abstraction / Recharge, Highly Stressed = 0.65 to 0.95, Critically Stressed > 0.95	WRC, 2007
All	RU1 RU2 RU3 RU4 RU7 RU10 RU5 RU6 RU8 RU9	Aquifer	Depth to Groundwater Level using Groundwater Monitoring Guidelines[2].	Recovery in groundwater levels over time is an indication that over abstraction is not taking place. Although groundwater levels can vary significantly across a resource unit, groundwater monitoring points should be identified which is representative of the overall aquifer response.	Declining water level trend from average level after wet season	WRC, 2011
All	All Prioritised RUs	Quantity	Radius of influence (r)□. r = 1.5*√(T*t/S), T= Transmissivity (m^2/d), t=Time(days), S= Storativity. Annual sampling via GIS algorithm or on introduction of new borehole	The radius of influence of a borehole gives an indication of how far the effect of the borehole drawdown will reach. It should be noted that this is a theoretical estimate and is not dependent on the abstraction rate, but only on the aquifer parameters and the duration of abstraction. The borehole radius of influence should not intersect any other radius of influence or protection zone.	N/A	WRC, 2007
All	All Prioritised RUs	Ecological	Distance from river (L)4. L = (T*i)/R, T=Transmissivity(m2/d), i=Groundwater Gradient, R=Recharge(m/d). Annual sampling via GIS algorithm or on introduction of new borehole	The concept of a river protection zone is to ensure that the average groundwater gradient toward the river is not altered, as this is the driving force of the natural groundwater seepage toward the river. This gradient will stay intact as long as there are no other protection zones infringing on the river protection zone.	N/A	WRC, 2007
All	All Prioritised RUs	Ecological	Distance from river (L)[4]. L = (T*i)/R, T=Transmissivity(m^2/d), i=Groundwater Gradient, R=Recharge(m/d) W=Wetland Perimeter. Annual sampling via GIS algorithm or on introduction of new borehole (perimeter is based on the Wetland	The concept of a wetland protection zone is to ensure that the average groundwater gradient toward the wetland is not altered, as this is the driving force of the natural groundwater seepage toward the wetland. This gradient will stay intact as long as there are no other protection zones infringing on the wetland protection zone.	N/A	WRC, 2007

			Delineation Guidelines).			
All	All Prioritised RUs	Quality	Microbial radius (r)[4]. r = 2(0.28*T) + 53, T=Transmissivity(m^2/d). Annual sampling via GIS algorithm or on introduction of new borehole	Communities dependent on groundwater often don't have sufficient infrastructure for sanitation purposes. The result of this is that houses and pit latrines are often constructed close to the water supply which leads to microbial pollution of the groundwater emanating from the pit latrines. High Nitrate values are a known cause of the "blue baby" syndrome and is fatal to young children. The microbial protection zone aims to protect groundwater from being exposed to high Nitrate values.	N/A	WRC, 2007
All	All Prioritised RUs	Quality	Background water quality per borehole using Groundwater Monitoring Guidelines2[2]	Groundwater should be fit for use e.g. human consumption, stock watering or irrigation purposes. Due to the fact that groundwater quality is related to the underlying geology it is often found that the background water quality exceeds the guideline associated with a particular use. For these cases the groundwater quality should be managed against the natural background values and all other cases should be managed against the specified guideline applicable to the specific use.	Continued declining water quality trend from established background	N/A

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6 APPENDIX

6.1 APPENDIX B: TECHNICAL BRIEF FOR THE JUSTIFICATION OF WATER QUALITY NUMERICAL LIMITS USED IN THE STUDY.

DERIVATION OF WATER QUALITY RESOURCE QUALITY OBJECTIVES

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SCOPE OF THE BRIEF
The brief was to determine water quality RQOs and Numerical Limits i.e. numerical estimates of the values of water quality variables ensuring a balance between ecological functioning and economic use of water resources for the Lower Vaal River.

Variability and uncertainty in the data
The contributors to the indeterminacy of the value of a water quality variable characteristic of a desired state are divided into the two entities, *variability* and *uncertainty*:

- Uncertainty: in a system is partitioned into known elements, the behaviour of which are unknown, and elements interacting with and within systems, which are completely unknown. Known uncertainty is for example the direction and magnitude of climate change, of population migrations, of international commodity markets. Unknown uncertainty is that which is identified and reduced through the application of scientific research and management experience. Thus in order to account for uncertainty, RQOs may be regarded as “best estimates” in the light of current knowledge.
- Variability: in the system is the known or potentially known changing behaviour of elements within the system, such as annual fluctuations in temperature, rainfall, drought cycles and others.

In this assessment an attempt is made to quantify variability in water quality parameters by making the assumption that elements influencing immediate future behaviour of systems impacting on the water quality of a resource are relatively static in the short timeframe of the anticipated lifetime of the RQO. The variability in the water quality of the water resource is taken as the variance in the water quality parameters measured over a stipulated period. The variability embedded in the RQO is expressed as the 95^{th} %ile of the projected range of the water quality variable. In other words, embedded in the philosophy underlying the endeavour of quantifying RQOs for water quality is the knowledge that the Numerical Limits must change in future as understanding of the ecosystem is improved.

Compliance with water quality RQOs and Numerical Limits
Compliance with RQOs and especially Numerical Limits may be confused with compliance with a license condition. The main difference between compliances is that RQOs are *objectives* conceivably unattainable at present. In the present application, the managers of the water resource would be required to demonstrate

continual approach towards the RQO, as opposed to the situation of compliance with a license condition, which is strict adherence to an achievable range of water quality values.

Conceived future implementation of water quality RQOs

The expression of RQOs as numerical quantities, albeit with ranges to address variability and embedded uncertainty, is viewed by the author of this document as an interim strategy, pending a more sophisticated approach. It is conceived here that rather than documentation and Gazetting of numerical values of RQOs, a more favourable future approach would be documentation and Gazetting of an accepted, scientifically and technically defensible, *method* of deriving unambiguous RQOs, in the light of the complexity of each system examined. Within complex systems many factors are connected to each other as “trade-offs”, arising naturally and immutably, such that the behaviour of one entity is strongly negatively or positively impacted by another. In these situations the normal logic of fixed entities breaks down. An imperfect but simple example would be the definition of RQOs for winter and summer periods, when annual absolutes do not exist.

Bayesian logic handles fractional values of descriptors.

Since systems of interacting elements may be represented as networks of known or hypothesised relationships between known entities, the Bayesian Network Analysis approach is more subtle and dynamic than the approach assumed in the current endeavour. It is anticipated that this or similar instruments may be standardised, as opposed to the uncertain and changing numerical descriptors of a desired state of a water resource.

Sources of information for this study

Site Water Quality Monitoring Data

Water quality monitoring data informing the projected values of water quality parameters was obtained from the DWA WMS database.

Water Quality Standards

The sources of water quality standards were the:

- South African Water Quality Guidelines (second edition). Volume 1: Domestic Use (2006);

METHODS

Origin of the data

The Google Earth WMS templates were used to locate the most appropriate DWA water quality monitoring sites to adequately characterise the water quality status and trends in the resource under investigation. In the case of dams the choice of monitoring point is usually straightforward since for most dams there exists a water quality monitoring point at which samples are taken and analysed and the resultant water quality information is readily available on the WMS site. In the case of rivers the situation is much more complex as water quality monitoring points may fortuitously be located at the lowest point of the region (or Resource Unit) of interest, but often such DWA water quality monitoring points are located elsewhere on the water resource, or completely absent. Various strategies are implemented to estimate what the conditions might be in the water resource under investigation, including inspection of land use and assignment of data from similar water resources relatively close geographically.

Use of the data

Prior to the current determination of numerical values for characterising desired states of the water resources, analysis had been performed of the requirements of various entities within the ambit of the resource and the general RQO expressed in terms of DWA categories “A” to “E”. In deriving the current values, an adaptation of the methods for deriving site-specific water use license criteria was implemented. A reference monitoring point, supposedly representing data from a “pre-anthropogenic” impact, was chosen such that the water quality monitoring data represented a state several decades before the present. The “Present Ecological Status” monitoring location was chosen as described above.

Monitoring data points were examined for obvious spurious irregularities, such as those resulting from errors in input to the WMS database. These would typically be manifested as gross "outliers" from the range of the data representing the water quality parameter under investigation. Caution should be exercised, however, in excising these "outliers" from the dataset, as they may represent real occurrences which may be a feature of the system impacting the water resource, and thus should be retained in the analysis. There are methods of cross-checking such apparent anomalies. For instance, if a spike in electrical conductivity is observed in a water resource directly downstream of a coal-mining operation, the corresponding pH of the water sample would be expected to decrease significantly. If not, then traditional statistical outlier analyses may be implemented to test for advisability of deleting the value from the analysis. Water quality monitoring data is often sparse and there is a considerable temptation to use one of the "missing value interpolation" algorithms to yield a larger dataset for analysis. This practice was avoided in this endeavour, but may be considered in future implementations, particularly if a Bayesian analysis is used. The dataset representing the reference condition and the present ecological status were inputted into the Reserve Determination program TEACHA, the use and interpretation being provided in DWA (2008).

The distinct advantages of using this tool include

- Rigorous development of the algorithms
- Extensive implementation of the method for setting guidelines
- Similarity of purpose between the setting of guidelines and derivation of RQOs
- Embedded sophisticated methods for determining the 95^{th} %ile for the numerical limits.

Baseline adjustment of the "reference condition" data was implemented in order to project the output of the TEACHA program into the range of desirability of the water quality parameters. The latter implementation may seem at first glance to add an arbitrary modification to an exact procedure. The justification for this approach lies in the current high indeterminacy of the characteristics of the systems within the regions of interest, mindful of the objective of the exercise, that being to establish a range of values for the RQOs, expressed as a 95^{th} %ile. Workshops were convened and the required medium-term water quality objectives established based on current available information as described above. The outputs of the workshops as regarding water quality were the different levels of protection required for a water resource, including rivers, dams and wetlands. These levels of protection were translated into the well-known and widely implemented water resource classes. In some instances water quality classes have not been derived for water quality constituents of interest and of importance. Variables not currently analysed and graded in terms of the water resource class system include sulphate, uranium, biological oxygen demand (BOD) and Chemical Oxygen Demand (COD).

RQOs as indicators of water quality risk

The water quality RQOs and their associated Numerical Limits function as recommended upper concentrations for the resource to be managed. The RQOs and Numerical Limits thus function as target indicators for management, akin to the "Effects" values employed in an Ecological Risk Assessment (US EPA 1999). The observed concentrations of the water quality variables would function as "Exposure" parameters to be compared to the Effects values. The water quality variable in concern would be referred to as the "Stressor" and the measure of the water quality variable as the "Exposure". These two measures fit into the Tier I Risk Assessment method which is simply a comparison of the two values, Exposure and Effects values, in a mathematical relationship. More specifically the Tier I Risk Quotient is the value obtained when Exposure concentrations are divided by Effects concentrations. Thus if the Tier I Risk Quotient is less than 1.0 then the Exposure concentrations are less than the Effects concentrations, and one assumes that all is well with respect to that water quality parameter. In the case of the analysis performed in the derivation of the RQOs in the current study, the Tier I Risk Quotient would be less than 1.0 if the concentrations of water quality parameter were below the RQO Numerical Limit for that parameter.

Use of DWA Classifications for water quality RQOs.

The target quality of the water resource under investigation is expressed in the familiar DWA resource classifications expressed in Table A2.1 below. Acceptable resource classes range from A to D and are directly associated with PES ratings which range from 1 to 4. In the case of many water quality variables, the concentrations relate to the classes in a linear fashion, as shown in Figure A2.1.

Table A2.1: DWA resource classifications

Resource ecosystem values	Natural	Good	Upper Fair	Lower Fair
Deviation from reference condition	No change	Small change	Moderate change	Large change
Water Quality category	A	B	C	D
PES Ratings	1	2	3	4

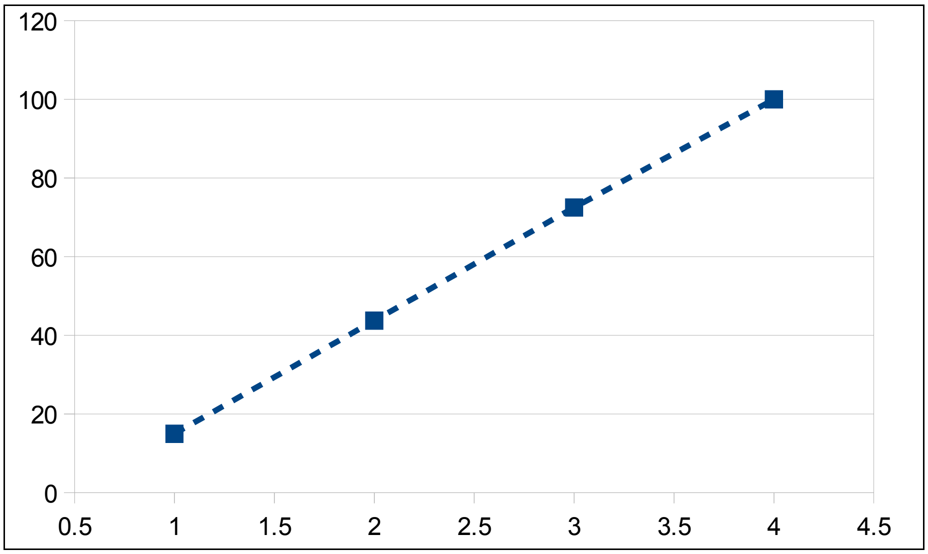

Figure A2:1 Concentrations (y-axis) of ammonia corresponding to DWA categories (x-axis).

The general method for establishing the concentration ratings is to establish the chronic effects concentration of a particular water quality variable on an indicator organism and to set the upper limit of the A category to this value. The acute effects value on the organism is set to the upper limit of the D category. The intervening categories are usually derived by interpolating a straight line through the A value and the D value, with the PES ratings acting as the numerical equivalent of the categories A to D. Fractional ratings are allowed for, given that some of the resource classes are broad in definition and some ecosystem requirements change within the classification. Thus if an ecosystem requirement falls between an A and a B category, the required value of the ecosystem category is designated AB. The numerical equivalent of the fractional ecosystem category is derived by interpolating between the categories on either side. Thus if a concentration value corresponding to an AB category is required, the concentration values of the water quality variable corresponding to A category (PES rating = 1.0) and B category (PES rating = 2.0) are interpolated to a PES rating of 1.5. E.g. for unionised ammonia the concentrations corresponding to the ecological categories are as presented in Table A2.2

Table A2.2 Ammonia (unionised) values at fractional levels of WQ category.

Water Quality category	**A**	**AB**	**B**	**BC**	**C**	**CD**	**D**
PES Ratings	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Ammonia (ug/L N)	**15.0**	**29.4**	**43.8**	**57.8**	**72.5**	**86.2**	**100**

Thresholds of potential concern (TPCs)

The threshold of potential concern (TPC) is the numerical value which serves as an alert that the ecological system is potentially threatened by approach of the relevant water quality variable to the RQO Numerical Limit value. The TPC is set to the concentration corresponding to the interpolated intermediate fractional value of the ecosystem category. Thus, for example, if the substance in question is ammonia and the Numerical Limit is the AB category, corresponding to a PES rating of 1.5 (mapping onto a concentration of 29.4 ug/L N), the TPC will correspond to a PES rating of 1.0 (mapping onto a concentration of 15.0 ug/L N).

Relationship of RQO Numerical Limits and TPCs with Risk Quotients

If the RQO Numerical Limit is the upper limit of tolerable effects, corresponding to stressor concentrations, a Risk Quotient of a stressor at the RQO is 1.0. Since in the case of a linear relationship of DWA categories with stressor concentrations corresponding to chronic ill effects (upper limit of A category) to acute ill effects (upper limit of D category) the intercept of the extrapolated line is not guaranteed to be zero, there is no clear regularity between TPC and Risk Quotient.

Water Quality Criteria defining risk

Exposure parameters

Water quality exposure parameters as classified in DWAF (2008) are presented below (Table A2.3). This list is incomplete with respect to the study of the catchments in this study, for which local guidelines were derived.

Table A2.3: Water quality indicators for which SA Guidelines exist

Algae	Cyanide	Phenol
Alkalinity	Dissolved Organic Carbon	Phosphorus
Aluminium	Dissolved Oxygen	Potassium
Ammonia	Endosulfan	Protozoan Parasites
Arsenic	Enteric Viruses	Radionuclides
Asbestos	Faecal Streptococci	Selenium
Atrazine	Fluoride	Silica
Beryllium	Iron	Sodium
Boron	Lead	Sodium Absorption Rate
Cadmium	Lithium	Sulphate
Calcium	Magnesium	Sulphides
Carbon Dioxide CO	Manganese	Suspended Solids
Chemical Oxygen Demand	Mercury	Total Dissolved Solids
Chloride	Molybdenum	Total Hardness
Chromium(VI)	Nickel	Trihalomethanes
Cobalt	Nitrate/Nitrite	Turbidity
Coliforms	Nitrogen (Inorganic)	Uranium
Coliphages	Odour	Vanadium
Contents	Organic Carbon	Zinc
Copper	pH	

SUBSTANCES RELEVANT TO THIS STUDY

Consideration of inclusion of WQ variables

The workshops defining the water quality categories of the selected geographical units, water resources, and the water quality constituents of relevance yielded the following comprehensive list for the Olifants, Upper Vaal and Lower Vaal catchments. The water quality constituents easily represent as indicators or measures of water quality in the geographical units. The values corresponding to the indicators or measures are specified in published texts. These are referenced in Table A2.4.

Table A2.4: Present State Rating variables used for the Water Quality RQO components (DWAF (2008)

Target	Type	Indicator
Human & ecosystem	Metal	Al
Human & ecosystem	Metalloid	As
Human & ecosystem	Pesticide	Atrazine
Human & ecosystem	Metal	Cd hard
Human, ecosystem & agriculture	Halogen	Chlorine (free)
Human & ecosystem	Metal	Cr(VI)
Human & ecosystem	Metal	Cu hard
Human & ecosystem	Pesticide	Endosulfan
Human & ecosystem	Halogen	F
Human & ecosystem	Metal	Hg
Wetland biota	Electron donor	Ammonia (unionised)
River and wetland biota	Oxidant	Dissolved oxygen
Human & ecosystem	Metal	Cu hard

Table A2.5: Variables used for the Water Quality RQO components (This study)

Target	Type	Indicator
Human	Algal Toxicants	Chl-a: phytoplankton
Wetland biota	Reductant	COD
Human & ecosystem	Metal	Mn
Human & ecosystem	Metalloid	Se
Wetland biota	Electron donor & acceptor	TIN-N
River organisms	Electron donor	Total Ammonia
Human & ecosystem	Metal	Uranium
Human & ecosystem	Metal	Zn
River and wetland biota	Oxidant	Dissolved oxygen

Nutrients

Nutrients - general

Total inorganic nitrogen (TIN = $[NO_2^-] + [NO_3^-] + [NH_4^+]$: species specified as concentration of nitrogen) – Note that unionised ammonia is regarded as a toxicant and described under "Toxics". At pH levels below 9.3 most ammonia is in the ionised ammonium (NH_4^+) form.
Phosphate (PO_4^{3-}) – also referred to as SRP (Soluble Reactive Phosphorous) or ortho-phosphate, as distinct from Total Phosphate, designated "TP".

Ammonia (Total)

Total ammonia as a nutrient was used in the context of river water quality.

Within the context of river water quality the total ammonia was specified as a RQO Numerical Limit in order to limit the trophic state of the river to mesotrophic (“good”) state, and to prevent nuisance conditions for ecotourism. Ammonia is very readily detected as a smell and is noxious at concentrations below that of many other naturally emitted gases.

Chl-a: phytoplankton

Chl-a: phytoplankton is used as an indicator for the presence of nutrients in a water resource. The indicator is useful because chlorophyll-a is readily and inexpensively measured by spectrophotometry.
Care has to be used in using Chl-a as an indicator where there is additional turbidity not due to algal biomass. If significant turbidity is a result of inorganic particle suspension the particles may occlude the chlorophyll and result in a measurement lower than actual.

Nitrate (NO_3) & Nitrite (NO_2)

Nitrate (NO_3) & Nitrite (NO_2) is a direct measure of nutrient concentration, the NOx being utilised by algae, high levels of which nutrient result in high levels of problematic algal biomass.

Total Inorganic Nitrogen (TIN)

Total Inorganic Nitrogen (TIN) is a useful measure of nutrient concentration.
Care must be taken, however, in systems in which ammonia is in high concentration. Ammonia will report to TIN, whilst it is not directly used as a nutrient by macroscopic organisms.
The assumption that ammonia is a useful component of TIN as describing nutrient status may not be valid. The conversion of ammonia to the actual nutrients NOx is slow and in many systems may be regarded as a “spectator ion”.

Phosphate (PO_4)

Phosphate (PO_4) is a nutrient, being readily absorbed by organisms and used to make DNA and cell-wall phospholipids. *The ratio of phosphate to NOx is an important factor in predicting the undesirable growth of algal biomass, being important to a number of algal species.*

Pathogens

E. coli

E. coli is an important indicator of pathogens in water resources. Whilst active as a pathogen on its own, it is usually present concomitant with other water-borne pathogens utilising or being emitted through the digestive tract. *Cholera vibrii* is one such pathogen. Whilst ingestion of any water containing *E. coli* and associated pathogens is discouraged, the water in the resources under study are deemed as being non-potable, the RQO of *E. coli* defaulting to the agricultural limit. Support for the RWQO set at the limit of 150 counts/100 mL comes also from a study commissioned by the Australian Government Department of Sustainability, Environment, Water, Population and Communities (ANZECC/ARMCANZ, 2000) (cit. in: Sinclair et al., 2011). This study quotes objectives relating to water quality as:

Good:	**<=150 CFU /100mL**
Fair:	**>150 and <500 CFU /100mL**
Poor:	**>500 and <1000 CFU /100mL**

Very poor:	**>1000 CFU /100mL**

Salts

"Salts" is a term describing dissolved solids. Dissolved solids impact biota by influencing the ionic strength of the environment in which aquatic biota function. Ionic strength is an important determinant of the natural extent of biochemical reactions. Aquatic organisms usually have the ability to "osmoregulate", being the capacity to pump ions into, or out of the local environment through membranes. These reactions are frustrated if the concentrations of ions are too high or too low.

Electrical conductivity (EC)

Electrical conductivity has long been known to be an indicator of bulk ionic strength of aqueous solutions. Electrical conductivity is readily measured on-site using relatively inexpensive equipment.

Care must be taken in applying blanket values for RQOs using EC. In naturally saline systems organisms are adapted to the ambient salinity and high EC readings may not indicate a problem for the ecosystems. Default trigger values for key water quality variables for ecosystems in Australia (ANZECC/ARMCANZ 2000) are presented in the following table:

Region	Upper riverine (uS/cm)	Lower riverine (uS/cm)	Dams and lakes
South-east Australia	30-350	125-2200	20-30
Tropical Australia	20-250	20-250	90-900
South-west Australia	120-300	120-300	300-1500
South central Australia	n/d	100-5000	300-1000

Thus there may be a great regional disparity in EC values to which local biota are conditioned and a more sensitive approach is required. Whilst studies on particular organisms form the basis of many water quality guidelines, broader concerns such as biodiversity have been studied. The relationship between stream macroinvertebrates and measures of conductivity in Queensland river systems was examined to assess if there were any broad patterns in community composition that were attributable to salinity. Family level presence/absence stream macroinvertebrate data from edge (2580 samples) and riffle (1367 samples) habitats collected throughout Queensland in spring and autumn from 1994 to 2002 was used in this analysis. Salinity Sensitivity Scores (SSS) wer e derived for individual macroinvertebrate families in Queensland. SSS were derived from the results of a sensitivity analysis using predictive Artificial Neural Network (ANN) models. After establishing the SSS for individual macroinvertebrates, A Salinity Index (SI) was proposed to reflect changes in macroinvertebrate communities caused by changes in conductivity. The SI was calculated using a formula including presence/absence of taxa and number of taxa in the samples. (Dunlop et al, 2005). The results show that as conductivity increases, sensitive taxa are being replaced by tolerant taxa, and this is reflected in decreasing values of SI with increasing conductivity (Figure A2.2). This trend is obvious in both habitats but appears to be more prominent in riffles. Figure 10 shows changes in the percentage of sensitive and very tolerant taxa with increasing conductivity (12 equal intervals). With reference to riffle data, sites having an EC in the range of 800 and 1500 µS cm -1 were observed to have a decrease in the mean percent of sensitive taxa from 33 to 16.7 relative to the low conductivity category (22-99 µS cm -1) and percent of very tolerant taxa increased accordingly from 9.4% to 32%. The following figures (Figure A2.2 and Figure A2.3) indicate a possible method of evaluating site-specific RWQOs in important catchments .

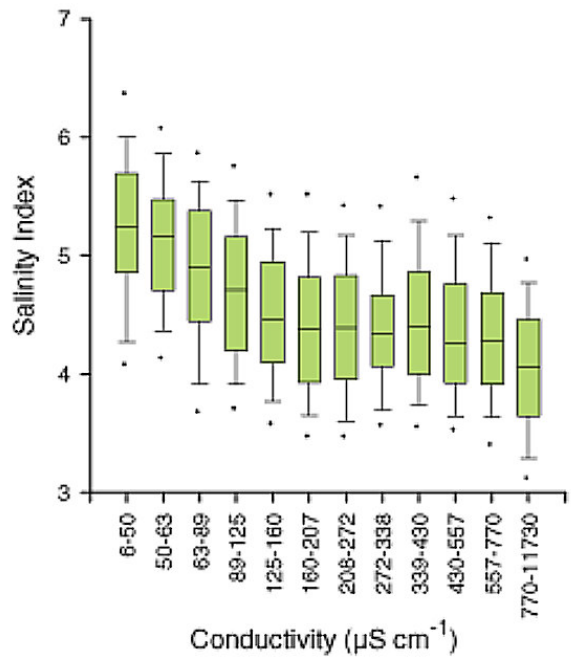

Figure A2.2: Salinity index along increasing conductivity gradient for edge habitats. Median values with boxes corresponding to 80th and 20th percentiles and horizontal bars to maximum and minimum.

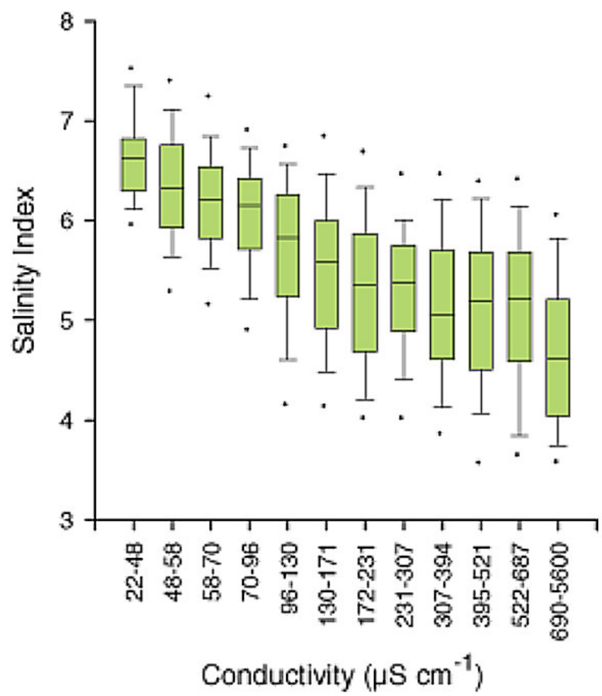

Figure A2.3. Salinity index along increasing conductivity gradient for riffle habitats. Median values with boxes corresponding to 80th and 20th percentiles and horizontal bars to maximum and minimum.

Sulphate (SO_4)

Sulphate is not usually considered a "Salt". It is an anion, and usually a minor component of environmental water resources. In the regions of concern, however, acid mine drainage (AMD) is a significant concern downstream of large formal coal-mining operations, and intense informal coal-mining operations. Sulphate a good indicator, in combination with EC values, of the origin of water pollution contributing to adverse environmental conditions. Sulphate is also involved in problematic behaviour in anaerobic sediments. Sulphate is converted to sulphide, which interferes with the iron-phosphorous cycles. In addition, sulphate may competitively bind to anion-adsorption sites in sedimentary organic matter. By both mechanisms phosphate is expelled from sediments and becomes a problem in eutrophication (Smolders et al, 2006; E. Tamis & C.C. Karman, 2008).

System variables

pH

The concentration of the hydrogen ion (H^+) is particularly important in the regulation of various biochemical reactions, and is measured as pH = -log[H^+]. All organisms operate within a range of pH values typical to their ability to regulate internal and external concentrations of hydrogen ion. This parameter is one of the most important parameters dictating limits on survival of species.

Alkalinity

Alkalinity is a "second-order" system variable, often correctly related to the capacity of the aqueous system to buffer bulk pH levels from small impacts by acidic or alkaline inputs. Usually carbonate anion, represented dominantly by bicarbonate anion at pH values about neutral (pH = 7), is the major factor in alkalinity of a system.

Dissolved oxygen

Dissolved oxygen is important for respiration of aquatic organisms. The levels of dissolved oxygen may be depleted by chemical reactions with organic matter, (reaction product being carbon dioxide). Dissolved oxygen may also be depleted by rapid, transient rise in temperature.

Temperature

Temperature is akin to pH in that all biochemical reactions are governed by temperature. Temperature governs the rate of reactions, and all organisms function within a range of temperature values, beyond which the different changes in rates of reactions leads to imbalances of biochemicals and ultimately to the collapse of the biochemical system that is an organism. Thermal impacts include outputs from power stations, outputs from dams which buffer temperature at levels that may differ from downstream rivers, and likewise changes in flow rates of rivers, impacting the rate of gain or loss of heat from the environment. Whilst it is recommended that water temperature be modelled from ambient air temperatures (DWAF, 2002; DWAF, 2008), it may be preferable to measure temperature directly to eliminate unaccounted confounding factors influencing model estimates. Temperature requirements of organisms are site-specific. Thus there is no universal baseline for temperature data as a measure of ecological impact. The expedient of using temperature *deviations* from optimal/natural conditions is effectively used.

Turbidity and/or water clarity

Turbidity/water clarity is the result of suspended particles in the river. The suspended particles may influence the river system by excluding light (implied by the "water clarity" description), or by directly occluding gill membranes of aquatic organisms. As with temperature and salinity, turbidity/water clarity is site-specific. Most aquatic scientists prefer to use clarity measures as opposed to turbidity measures. The advantage of this choice is that rapid measurements may be made under field conditions. The disadvantage is that measurements are related to individual observer optical functionality, and thus clarity is not a repeatable, fixed measure. Thus in this document turbidity is recommended as a measure, being reliably and accurately measurable in an analytical laboratory.

Toxic substances

Toxic Substances currently regulated by DWS. Toxic substances are chosen as those listed in the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996) (Table A2.6). This category includes unionised ammonia, toxic metal ions and toxic organic substances. Toxic substances identified as relevant to the current study are listed in Table A2.7.

Table A2.6: Toxic Substances (ecological) regulated by DWAF (1996)

Aluminium	Lead
Ammonia	Manganese
Arsenic	Mercury
Atrazine	Nitrogen (Inorganic)
Cadmium	pH (Acidity and Alkalinity)
Chlorine	Phenol
Chromium	Phosphorus (Inorganic)
Copper	Selenium
Cyanide	Temperature
Dissolved Oxygen	Total Dissolved Salts/Solids
Endosulfan	Total Suspended Solids
Fluoride	Zinc
Iron	

Table A2.7: Toxic Substances relevant to this study

Target	Type	Indicator	Reference
Human & ecosystem	Metal	Al	DWAF (2008) (Tables below)
Human & ecosystem	Metalloid	As	
Human & ecosystem	Pesticide	Atrazine	
Human & ecosystem	Metal	Cd hard	
Human	Algal Toxicants	Chl-a: phytoplankton	
Human, ecosystem & agriculture	Halogen	Chlorine (free)	
Wetland biota	Reductant	COD	
Human & ecosystem	Metal	Cr(VI)	
Human & ecosystem	Metal	Cu hard	
Human & ecosystem	Pesticide	Endosulfan	
Human & ecosystem	Halogen	F	
Human & ecosystem	Metal	Hg	
Human & ecosystem	Metal	Mn	
Wetland biota	Electron donor	Ammonia (unionised)	
Human & ecosystem	Metal	Cu hard	
Human & ecosystem	Metalloid	Se	This study
Wetland biota	Electron donor & acceptor	TIN-N	This study
River organisms	Electron donor	Total Ammonia	This study
Human & ecosystem	Metal	Uranium	This study
Human & ecosystem	Metal	Zn	This study

Selected toxic substances will be discussed in this section.

Ammonia (unionised)

Unionised ammonia is toxic. It readily enters cells through lipid cell walls (hydrophobic) due to being neutrally charged, not excluded as would be hydrophilic charged ions. Once within the cell, ammonia may ionise and change internal pH values, or it may overwhelm the mechanisms of excretion of toxic metabolic by-products. Ammonia is the principle form of nitrogenous excretion by fishes. At 25 degrees C at pH values of above 9.3, ammonia exists predominantly in the unionised form. The pH at which ammonia exists in the unionised form is dependent on temperature. Lookup tables may be used to determine the concentration of unionised ammonia from the concentration of total ammonia. This process is laborious and it is here recommended that total ammonia be analysed for as a screening value.

Hardness-sensitive toxic transition metals

As regulated as Toxicants, the toxic transition metals Cu, Cd and Pb have differential effects on biota as a function of water hardness. In the current study the RQOs corresponding to these toxic metals refer to the levels in hard water. This assumption was initially motivated by hardness levels appropriate to systems in which dolomite was dissolved by AMD, as occurs in the gold-mining areas of the Western Basin. At low levels of ambient hardness, high-hardness RQOs for these metals will be somewhat under-protective of aquatic life. It is a topic for future discussion as to whether the RQO values for the metal ions be adapted for current levels of hardness in the resource waters, or for future levels of hardness extrapolated by chemical speciation calculation from all RQOs for the resource under investigation.

Toxic ions of Mn, Se and Zn

Categorical concentration criteria for the toxic ions of Mn, Se and Zn are absent from the DWAF (1999) and DWAF (2008) guideline documents. Thus the levels of concentrations of these entities corresponding to resource water classes were derived using the method of assigning chronic toxicity values to the upper limit of "natural" class A, and acute toxicity values to the upper limit of "natural" class D.

Cyanobacterial blooms; algal Toxicants

Cyanobacterial blooms and other algal Toxicants are extremely dangerous if ingested. The Toxicants emitted by these organisms are very expensive to measure directly. Thus a useful surrogate is used, being measurements of Chl-a: phytoplankton.

Uranium

≤ 10 µg/L (Irrigation),
≤ 15 µg/L (this study)

Canadian Council of Ministers of the Environment. 2011. Canadian water quality guidelines for the protection of aquatic life: Uranium. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. Pp 1-9. Not much work has been done to establish uranium water quality guidelines for ecosystems. A notably consciencious study of this matter was conducted in British Columbia (CCME. 2011 in: CCME, 2011a). The method of determining Canadian Water Quality Guidelines for Uranium (Total recoverable, Unfiltered) for the Protection of Aquatic Life in ecological systems was the Species Sensitivity Distribution (SSD). The long-term water quality criteria were based on the SSD 5th percentile, as opposed to the SSD 5th percentile, 90% LFL (5%) = 9 µg/L, or the SSD 5th percentile, 90% UFL (95%) = 130 µg/L. Toxicity endpoints were lethality. Long-term exposure guidelines identify benchmarks in the aquatic ecosystem that are intended to protect all forms of aquatic life for *indefinite* exposure periods (≥ 7d exposures for fish and invertebrates, ≥ 24h for aquatic plants and algae). Long-term exposure levels toxic to a range of species was determined to be 15 µg/L uranium. "Long-term" exposure ranged from exposure periods of 7 days (*C. dubia*; reproduction) to 141d (*S. namaycush*; survival). The short-term water quality criteria were based on the SSD 5th percentile, as opposed to the SSD 5th percentile, 90% LFL (5%) = 8.5 µg/L, or the SSD 5th percentile, 90% UFL (95%) = 25 µg/L. Toxicity endpoints were non-viable embryos, survival and growth. "Short-term" exposure ranged from exposure periods of 24h (*C. latipinnis*) to 96h (*O. mykiss*). Short-term exposure levels toxic to species was determined to be 33 µg/L uranium. Toxicity endpoints were lethality. An example plot of long-term SSD is presented in Figure A2.4.

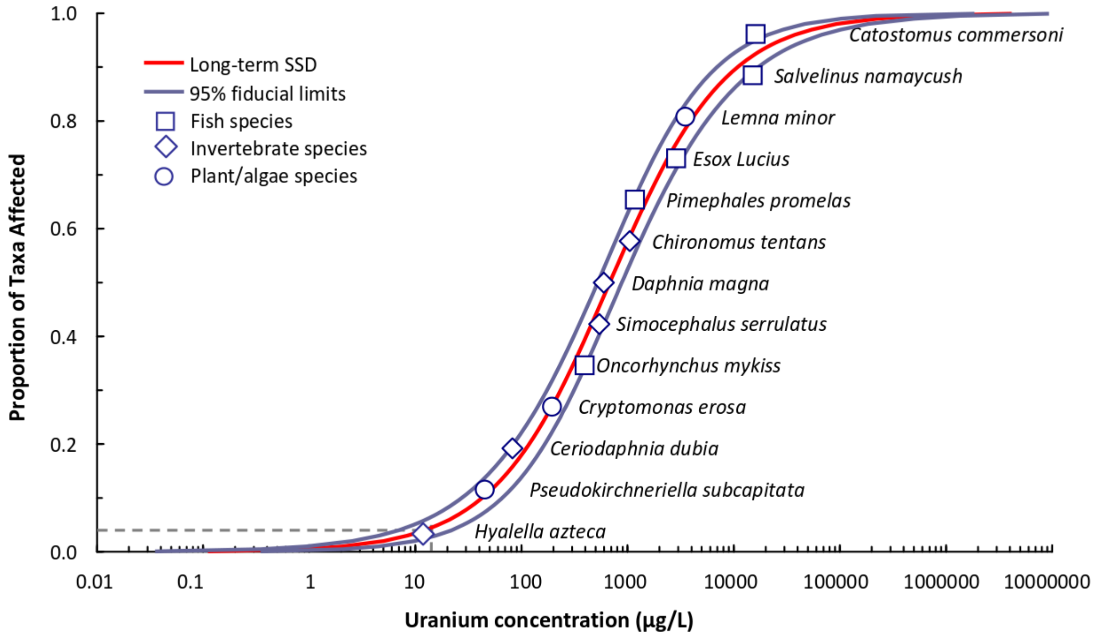

Figure A2.4: Long-term SSD for Uranium (Total recoverable, Unfiltered)

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SA RESERVE GUIDELINES

Water quality ranges corresponding to resource classifications are presented in Table A2.8 below:

Table A2.8: Water quality ranges corresponding to resource classifications

Natural – Poor categories		Natural	Good	Upper Fair	Lower Fair	Poor
PES rating		0	1	2	3	4
Deviation from reference condition		No change	Small change	Moderate change	Large change	Serious change
Water quality indicator	Units	Values				
EC	mS/m	0	30.1	55.1	85	-
pH	5th percentile Min	6.5	5.9	5.6	5	4
pH	95th percentile Max	6.5	6.5	5.9	5.6	5
pH	95th percentile Min	8	8	8.8	9.2	10
pH	5th percentile Max	8	8.8	9.2	10	11
Al	µg/L	20	62.5	105	150	192.5
Ammonia	µg/L	15	43.75	72.5	100	128.75
As	µg/L	20	57.5	95	130	167.5
Atrazine	µg/L	19	48.75	78.5	100	129.75
Cd soft	µg/L	0.2	0.7	1.2	1.8	2.3
Cd mod	µg/L	0.2	0.95	1.7	2.8	3.55
Cd hard	µg/L	0.3	1.63	2.95	5	6.33
Chorine (free)	µg/L	0.4	1.75	3.1	5	6.35
Cr(III)	µg/L	24	115	206	340	431
Cr(VI)	µg/L	14	67.5	121	200	253.5
Cu soft	µg/L	0.5	1.03	1.55	1.6	2.13
Cu mod	µg/L	1.5	3.03	4.55	4.6	6.13
Cu hard	µg/L	2.4	4.88	7.35	7.5	9.98
Cyanide	µg/L	4	32.5	61	110	138.5
Endosulfan	µg/L	0.02	0.08	0.13	0.2	0.26
Fluoride	µg/L	1500	2510	3520	2540	3550
Pb soft	µg/L	0.5	1.63	2.75	4	5.13
Pb mod	µg/L	1	3	5	7	9
Pb hard	µg/L	2	5.75	9.5	13	16.75
Hg	µg/L	0.08	0.53	0.97	1.7	2.15
Phenol	µg/L	60	200	340	500	640
DO	mg/L	8	8	6	6	4
PO4-P	mg/L P	0	0.01	0.02	0.03	0.13
TIN-N	mg/L N	0	0.25	0.7	1	4
Chl-a: periphyton (mg/m2)	mg/m^2	0	10	15	20	30
Chl-a: phytoplankton (µg/L)	µg/L	0	1.7	12	21	84

Data taken from DWAF (2008)

6.2 APPENDIX B: ADDITIONAL JUSTIFICATION OF SULPHATE SPECIFIC WATER QUALITY NUMERICAL LIMITS USED IN THE STUDY.

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There are a number of different guidelines or trigger values for sulphate concentration published by various regulatory agencies. Most of the guidelines and trigger values are based on species sensitivity distributions which are the "toxicology state-of-the-art" at the time of writing of this document. Many propose a guideline value for aquatic health in terms of sulphate concentration as around 500 mg/L sulphate. The current study assumes that the EC guideline values for aquatic health have been in use for a long period and are thus assumed to be provisionally non-contentious. Thus setting a sulphate guideline value as guided by EC relationships in a highly sulphate-polluted catchment would be appropriate until more site-specific methods were applied, such as whole effluent toxicity tests. Sulphate and EC values that were measured in tandem by DWA and published on WMS were downloaded and submitted to a rigorous data verification regime. The paired values were then plotted and a very large scatter was observed in the data. This scatter was enhanced when a log-log transformation was applied. Cluster analysis was applied to the dataset and three main clusters emerged. The most relevant cluster was fortunately the most linear. From this linear cluster of paired SO4 and EC values a direct least squares linear interpolation was performed, yielding a result with a high correlation coefficient. The interpolation of the least squares relationship to the EC value corresponding to a "D" class river water quality yielded a value of approximately 500 mg/L sulphate for a "D" class river. This value was set at the "D" level for sulphate concentrations and the "C", "B" and "A" values derived as were the values derived for use in the DWA Reserve Determination process.

INTRODUCTION

Sulphate is not usually considered a “Salt”. It is an anion, and usually a minor component of environmental water resources. In the regions of concern, however, acid mine drainage (AMD) is a significant concern downstream of large formal coal-mining operations, and intense informal coal-mining operations. In regions such as these, sulphate a good indicator, in combination with EC values, of the origin of water pollution contributing to adverse environmental conditions. In setting resource quality objectives for the Olifants and Upper Vaal catchments, the problem was encountered that there are no non-contentious guidelines available in South Africa for sulphate concentrations in highly impacted rivers. The problem reared its head in the above catchments in particular due to the great levels of sulphate loading emanating from coal- and gold-mining activities. There are no coherent internationally developed guidelines for sulphate concentrations in rivers, for the protection of aquatic communities. The procedure-based guidelines derived for sulphate utilised the techniques of Species Sensitivity Distributions, current "state of the art" for aquatic toxicology studies. In the absence of such studies in South Africa for sulphate and in particular for the catchments under study, in an explicitly site-specific undertaking such as resource quality objectives, an empirical approach was assumed. In the current study, guided by large values of internationally accepted guidelines, monitoring data were obtained from the DWA water quality monitoring programme database (WMS). This data was analysed with a view to establishing a provisional objective guideline based on sulphate/EC relationships. This current documentary is a summary of the above efforts.

Sulphate: Direct or indirect toxicity?

Sulphate toxicity as a direct phenomenon is somewhat contentious. The reason for the above is the fact that adverse health effects observed in organisms manifest at relatively high concentrations of sulphate. The contention is introduced at high sulphate concentrations due to concomitant high concentrations of the coupled cations, and of ionic strength, measured as electrical conductivity. Influences of these specific ions and system variables confound interpretation of laboratory toxicity tests, upon which most substance-specific guidelines are based.

Indirect toxicity: Chemically reducing environments.

Sulphate loading on a water resource containing a substantial reducing phase such as a wetland or a dam may exert indirect toxicity effects that are important to consider. Sulphate is also involved in problematic behaviour in anaerobic sediments. Sulphate is converted to sulphide, which interferes with the iron-phosphorous cycles. In addition, sulphate may competitively bind to anion-adsorption sites in sedimentary organic matter. By both mechanisms phosphate is expelled from sediments and becomes a problem in eutrophication. Indirect effects on these water resources originate from the conversion of sulphate to sulphide within sediments or other phases rich in organic matter. Sulphate reducing bacteria (SRBs) use the organic matter to reduce the sulphate. Sulphide is extremely toxic to oxygen-metabolising organisms. It binds to, and inactivates respiratory enzymes containing iron and copper several orders of magnitude stronger than does cyanide, a more charismatic toxin. The effect of concomitant increase of sulphate and organic matter has been observed to result in hyper-abundance of hydrogen sulphide in the sediments of the Loskop dam. Estimation of the loading of sulphate to create sulphide problems involves models more sophisticated than the ambit of the current study.

Confounding effects of other WQ variables

As mentioned above, specific coupled cations and system variables such as electrical conductivity may make assignation of toxicity to sulphate problematic. Some factors, e.g. hardness (concentrations of calcium and magnesium) and chloride concentrations confounding the establishment of direct sulphate toxicity have been recognised as persuasive enough to include in local water management legislation in the state of Iowa, USA.

Some sulphate guidelines implemented internationally

Many guideline values have been proposed and published and embedded as trigger values by various governing bodies. Much of the reasoning behind the derivation of the guidelines is opaque. Where the reasoning is not opaque, there is great discrepancy between values recommended. The following high guideline levels are presented in this light.

- USA: In the state of Wyoming, USA, the current level of permissible sulphate concentrations in fresh water resources is 3,000 mg/L SO4, and there is a petition underway to reduce this value to 500 mg/L. In the state of Iowa, based on toxicity test data and available toxicity data from a total of 11 species, to achieve aquatic life protection and livestock watering uses, concentrations for sulphate from 500 mg/L to 2,000 mg/L are not to be exceeded except in receiving waters for which mixing is allowed.
- Canada: In a Chronic Effects Benchmark study for the British Columbia (BC) government by Golder Canada (2013) based on toxicity test data, the hardness-level-adjusted sulphate environmental guideline for “moderately soft/hard to hard” water (76-180 mg/L $CaCO_3$) is between 309 mg/L sulphate and 743 mg/L sulphate. Meays and Nordin (2013) proposed a BC sulphate water quality guideline for moderately hard to hard water conditions, and recalculated benchmarks for hard water conditions, based on model-averaged sulphate toxicity endpoints from three direct investigations of sulphate toxicity in relation to water hardness. In a site-specific assessment for medium hard waters, sulphate concentrations were proposed to be set by TOTAL E&P Canada Ltd (2013) at alert levels of 309 to 430 mg/L.
- Australia: In a study involving actual site-specific toxicity testing and using the ANZECC guidelines “the concentrations of sulphate that would protect 95% of species would be 341 mg/L sulphate and the concentration predicted to be protective of 99% of species would be 123 mg/L” (Hydrobiology, 2012).

ESTIMATION OF SITE-SPECIFIC SULPHATE TARGET VALUES FOR THE OLIFANTS CATCHMENT

Method for estimating sulphate trigger values

The method for deriving interim target sulphate trigger values for the Olifants catchment and extrapolated to the Vaal catchments involves recognition of the high range of water quality standard values, and the operational assumption that electrical conductivity recommendations may guide estimations for a maximum value of sulphate recommended for various water quality classes.

Datamining: Clarifying EC-SO4 relationship

The main objective of analysing monitoring data for the Olifants River catchment is to derive a sulphate Resource Quality Indicator measurement. Sulphate was identified as an indicator of resource quality specific to sub-catchments of the Olifants River catchment. Managing operations such that sulphate concentrations fall below certain trigger values implies managing for sulphate toxicity, or managing for other environmental stressors for which sulphate may be a surrogate. Since EC is managed in the catchments, and SO4 is a contributor to EC, any “toxicity” of SO4 above the possible total contribution to EC by SO4 would be a useless endeavour.

Hazard Class risk method

The regions of the Olifants catchment under consideration are heavily impacted or soon to be heavily impacted by coal mining activities. When setting a RQO regulators are balancing long-term ecological health against short-term and necessary economic growth. Whilst in individual publications river classes are proposed correlated with percent species protected (as is the approach used in most first-world countries), this method has not as yet been comprehensively applied. In the current analysis it is estimated that a "D" class would represent a preservation of between 90% and 95% of the species in the ecosystem. The modifications are presented below (Table B1).

Table B1: Proposed hazard class values corresponding to water quality categories

HC_p	Water condition	Classification	Natural – Poor categories	Water Quality category	PES rating
<HC_1 (50)	Natural	Unmodified, or approximates natural condition.	Natural	A	0
HC_5 (5-25)	Good	Largely natural with few modifications.	Good	B	1
HC_5 (25-35)	Upper Fair	Moderately modified.	Upper Fair	C	2
HC_5 (36-50)	Lower Fair	Large change	Lower Fair	D	3
>HC_5 (50)	Poor	Largely modified.	Poor	E	4

In the absence of better information on the distribution of the sulphate concentrations and protection levels, an operational assumption was made in the current study that for a Level D ecosystem one may tolerate of the order of 10% of the data variance unassigned in the description of the HC5. This approximates to a sulphate concentration of 500 mg/L, as will be demonstrated below. It has been noted in many publications that the toxicity of sulphate to aquatic life is strongly dependent on water chemistry, not only hardness but chloride concentration and concentration of other constituents. It may well be that site-specific toxicity testing is required in the future.

ANALYSIS OF OLIFANTS WQ DATA

Considering the difficulty in finding coherent water quality guidelines from literature, the following operational approach was employed:

- The fundamental assumption was that sulphate may be acting in concert with other water quality constituents in a synergistic manner, possibly contributing to exhaustion of target organisms in their battles with metals or simple osmotic stress. Electrical conductivity (EC) was chosen as an indicator of osmotic shock for which there are already guideline values published (DWAF, 2008).
- Since EC values are not published for recommended limits to a D category water resource, the value of 110 mS/m was extrapolated to a PES of 3.0 from values published that corresponded to lower PES values and lower DWA classes.

UPPER LIMIT OF SULPHATE TRIGGER VALUE

Based on a limiting condition of 110 mS/m electrical conductivity, the maximum sulphate concentration recommended is calculated from limiting ionic conductivities. From CRC Handbook of Chemistry, and Physics, 91st Edition, Weast, R. C.,Ed., CRC Press, Boca Raton, FL, 1989 (Table B2).

Table B2: Electrical conductivity of sodium sulphate solutions

Mass % Sodium sulphate	0.5	1.0	2.0	5.0
EC (mS/m)	590	1120	1970	4270

Fitting curve of the form -10 x^3 -105 x2 +1235 x

Thus for a pure sodium sulphate solution in water, interpolation yields the mass fraction of 0.09% (m/m) to effect an EC of 110 mS/m.

A mass fraction of 0.09% corresponds to a concentration of 900 mg/L of sodium sulphate, which equals 6.34 mmoles/L of sodium sulphate. This equates to 6.34 mmoles/L of sulphate ion which corresponds to 608 mg/L sulphate.

This therefore is the maximum concentration of sulphate as a trigger to be derived in this study.

Please note that the above analysis only works for sodium sulphate in a pure solution because the electrical conductivities were *measured* for this system.

DERIVATION OF SULPHATE TRIGGER VALUE FROM WQ MONITORING DATA

All water quality monitoring data for all stations in the Olifant River catchment (Region B) were retrieved from WMS. There were 69,388 records retrieved. Of these data, records where both EC and sulphate were present were extracted and the highest 20% of EC value data retained (13,898 records). Within this data set the highest 10% of sulphate concentrations were retained, yielding 2,360 records. If there were some regularity between EC and SO4 at elevated concentrations of both, it would mean that SO4 dominates the ionic composition of the water and that some value of SO4 trigger may be derived from the EC regulation value. The figure below (Figure B1) shows the relationships between SO4 and EC in the dataset as derived above. A direct plot shows a great deal of scatter in the relationship between SO4 and EC in the Olifants River catchment which is expected.

In order to reveal more of the detail in the scatter at lower SO4 and EC values a log-log plot is used (Figure B1).

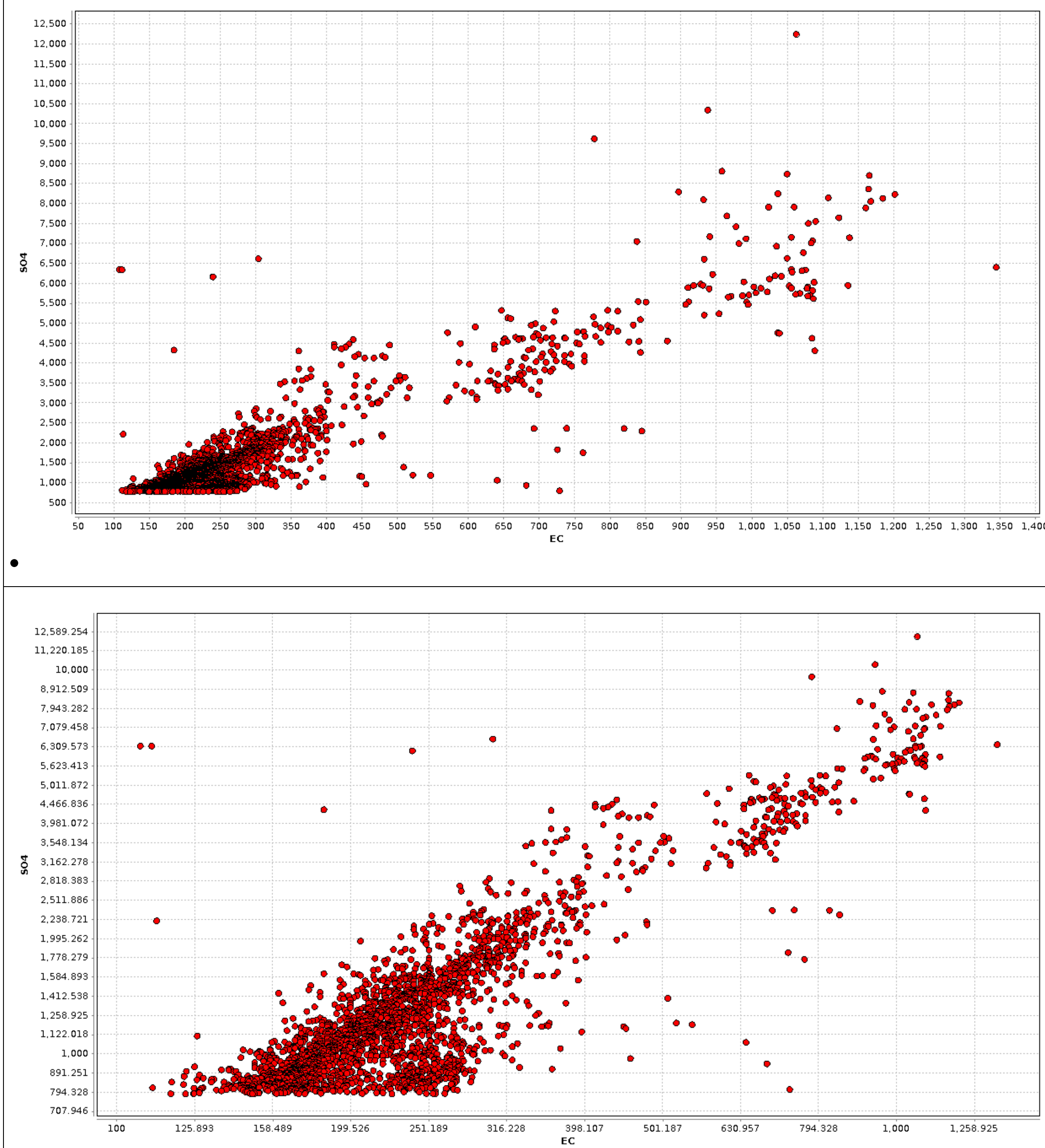

Figure B1 (a) Direct plot of SO4 vs EC; (b) log-log plot of SO4 vs EC

A direct linear regression on the EC and SO4 data produces the relationship:

[SO4 (mg/L)] = 6.4 x [EC (mS/m)] -190.

There is considerable scatter in the diagram. The intercept of the regression line is negative, implying that in the absence of sulphate the EC in general would be about 30 mS/m. This at least checks logically – were there to be a positive intercept it would imply that a non-zero concentration solution of sulphate could have zero EC.

When the SO4-EC relationship is explored in detail in the log-log plot (Figure (b)), three clusters appear. In order to find a useful relationship between EC and SO4 to base some limiting value on, a clearer picture needs to be formed describing the entire dataset. Simply stated, if one expects (or desires) a simple relationship between e.g. EC and SO4 and complexity arises in the projected relationship between the variables, it means that there is some additional factor or combination of factors that is causing the complexity. It is a useful assumption that the aforementioned factor(s) would be chemical in nature. Identifying the factor(s) would allow for their contribution to the complexity to be removed, yielding a clearer relationship between EC and SO4 in this case. The methods of data mining are used for this objective. Since the driving force of all chemical and biochemical reactions, the free energy, is directly proportional to the logarithms of concentrations, all water quality variables were represented as logarithms. The above statement is not strictly true, since it is the "activities" of the chemical constituents that are thus related to the free energy, and the activities vary with increasing concentration of salts in solution. There are in the system of interest considerably higher concentrations of salts than the "infinite dilution" that is required for use of concentrations as activities without transformation. Concentrations are presented as the molar form of the chemical constituent, as opposed to the mass per unit volume form most often used in water quality management. This transformation is performed in order to compare magnitudes of chemical constituents on the same level, the level at which the constituents would behave as molecular or atomic entities. It is noted that pH is already in a log form, being the negative logarithm of the concentration of free hydrogen ion. In order to compare pH with the other variables in the data mining exercise, it was used as the negative value of pH, denoted pH_neg. The reason to use data mining is to understand macro-dynamics in the higher salinity parts of the Olifants River system. Thus initially all water quality data are used in analysis.

Cluster analysis

To return to the original objective of the datamining activity, the monitoring data in the Olifants River catchment was analysed to establish workable relationships between the concentrations of sulphate and the physical water quality parameter Electrical Conductivity, the latter for which there exist trigger values for management of water quality to environmental and human health targets. The upper limit of EC characterising a water resource as a D-category resource in terms of water quality is 110 mS/m. A relationship between EC and the conductivity of a pure sodium sulphate solution was explored in a previous section. The work in this section aims to determine a relationship relating to the unique additional background salts of the region such that a water quality trigger value for sulphate may be provisionally established.

K-means clustering

The objective of cluster analysis is to establish similarities and difference between data points as viewed in groups. Thus clustering aims to group together points that are most similar, and to distinguish between groups so determined. K-means clustering is an *exclusive* method in that each point is assigned to one cluster only. The default analysis in Rapidminer was used, being clustering by squared Euclidean distances between points, and discrimination between clusters measured by this divergence parameter by the technique of Bregman Divergences.

Data integrity verification

Chemical analytical data is subject to the occasional mishap, such as entry into a database involving the misplacement of a decimal point, or in cases of high concentrations of a particular constituent, errors in dilution of the sample to levels acceptable to the analytical instruments. Whilst it is expected that the data used in the exercise of determining a convincing relationship between EC and SO4 will have significant scatter, modelling procedure of data verification is followed.

Mass balance calculations

The first test that should be applied to a chemical analysis is the mass-balance calculation. In the case of waters not heavily polluted and thus coming more under the heading of industrial water, an effective screen for bulk errors in chemical analyses takes the form of the mass balance. Mass balance involves adding up the individual concentrations per litre (usually expressed in milligrams per litre) and comparing the total to the "total dissolved solids" or TDS. The technique is relatively simple but has some minor problems associated with it. Carbonate and bicarbonate concentrations are not usually reported directly and need to be calculated from the Total Alkalinity and the pH values. There is the risk of making errors in calculating carbonate species concentrations in this way. In addition, TDS is often (usually) not determined directly, owing to the high costs of determining by dehydration. Usually TDS is derived from the EC measurement by multiplying by a scalar factor. This method may not be valid if the ionic composition of the samples deviates significantly from "natural", which would be the case in the Olifants and Vaal River catchments. In many cases, as appears to be the case with the WMS data, the TDS is actually derived as the sum of the analysed dissolved constituents. The WMS database explicitly quotes the DMS = "Dissolved mineral solids". A caution with respect to the concern of calculation of carbonate species mentioned above: The mass balance is much better effected after submitting the total analytical data to a chemical speciation calculation. This technique was used to verify the database of chemical analyses at the requisite coarse level.

Charge balance calculations

The program Phreeqci was used to calculate charge imbalances. A charge imbalance detected by a proper chemical speciation analysis refers to uncertainty in the concentrations of one or more of the water quality constituents analysed for, or in the worst case, a chemical species not analysed for. Chemical analyses featuring charge imbalances of less than 5% are acceptable for interpretation according to the ASTM "Standard Methods" (APHA), 1998). The dataset derived to represent resource waters of D-category or better was subjected to filtering by charge balance calculation.

DATA FILTERING

Sulphate data cleaning

All data points with sulphate concentrations less than 0.032 mmol/L SO4 were removed. The reason for this was that this is the maximum of the "instrumental detection limit" concentrations. Inclusion of these values in the analysis would skew the analysis towards unrealistically low concentrations of sulphate.

Sulphate data reduction

During exploratory clustering analysis the dataset clustered according to sulphate concentrations as seen in the figure below (Figure B2):

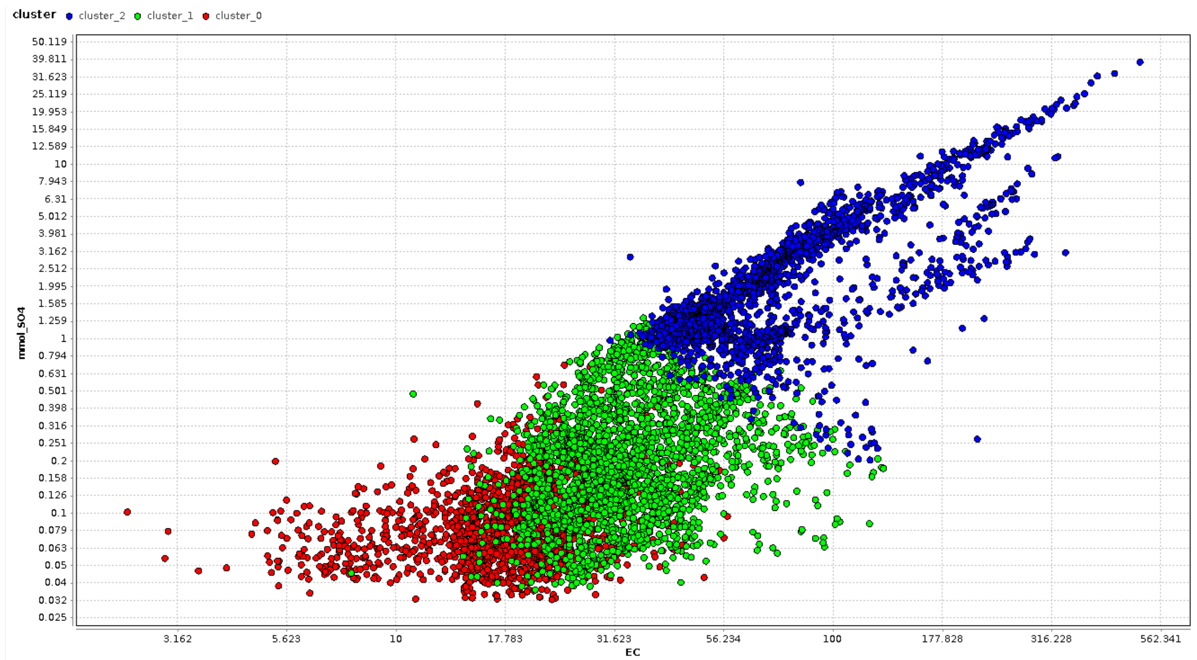

Figure B2 Preliminary cluster analysis of SO4-EC data for Olifants catchment

This was not a meaningful clustering as it did not achieve a linearity of a single cluster for analysis by linear regression. Thus all SO4 values below a concentration of 1 mmol/L were removed and the following clustering obtained (Figure B3).

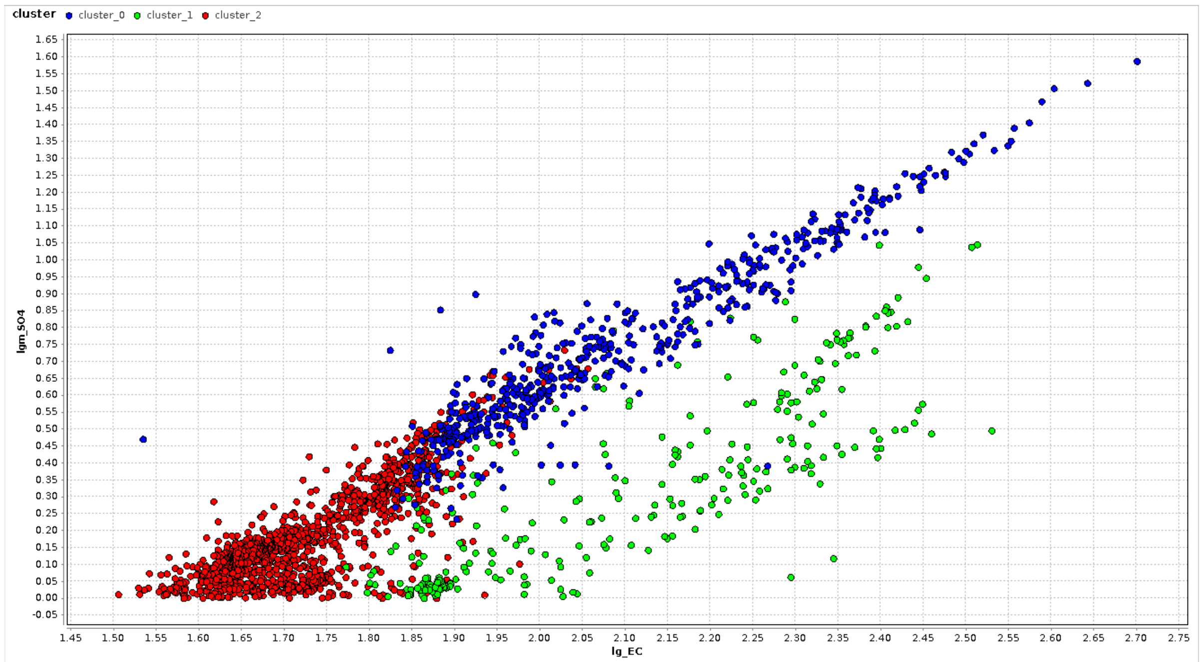

Figure B3: Cluster analysis of SO4-EC data with low values removed

The centroid plot of the clusters (Figure B4) shows the clustering driven mainly by the concentrations of chloride, sodium, phosphate, and then sulphate.

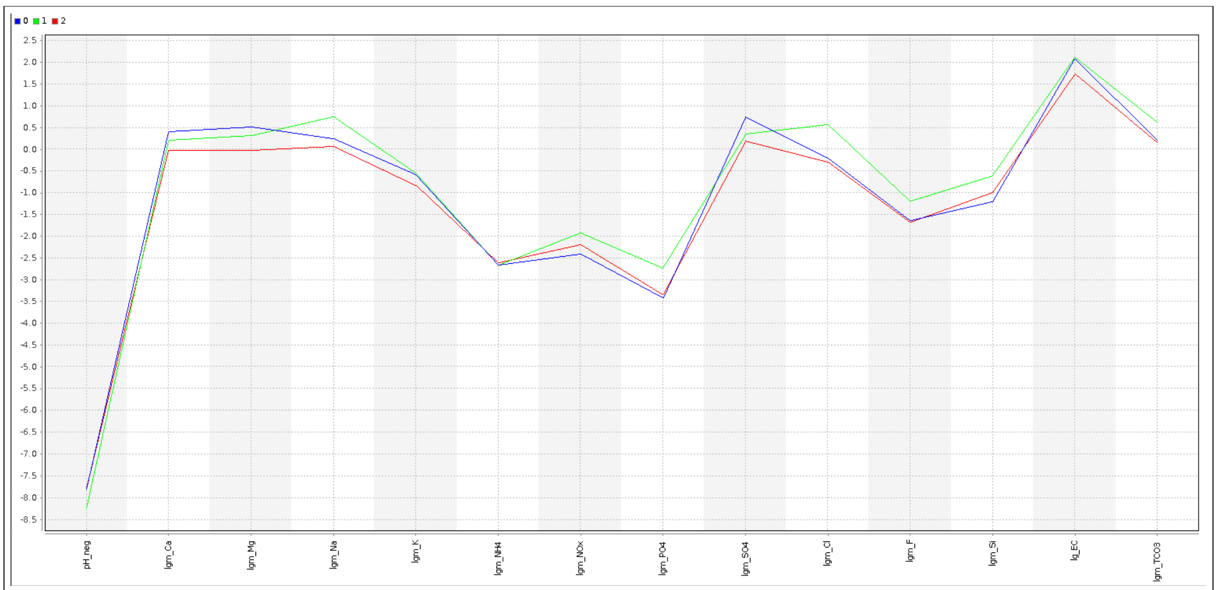

Figure B4: Centroid plot of clusters presented in Figure.

A parallel plot (Figure B5) demonstrates this separation.

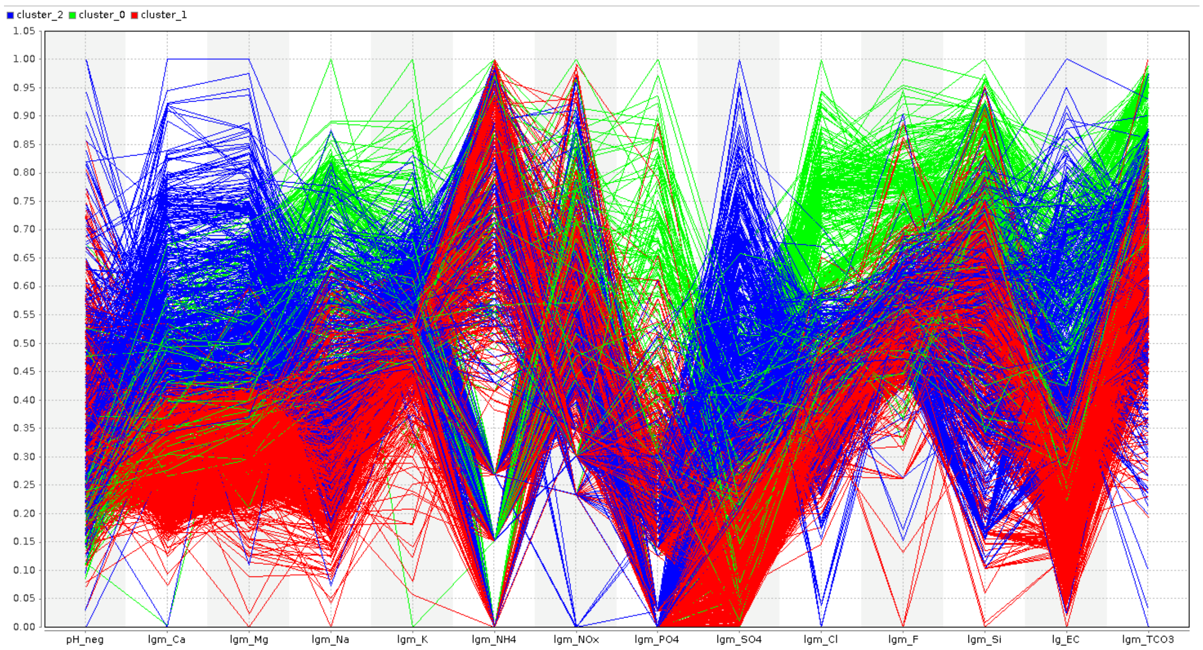

Figure B5: Parallel plot of clusters presented in Figure.

The separation of the clusters does reveal a relatively linear relationship between SO4 and EC in the combination of clusters 1 and 2. However the fact that clusters 1 and 2 still contain a sulphate-concentration component may be problematic. On the other hand, it may not. A further test was implemented in data exploration. The analysis was repeated with all data featuring SO4 concentrations less than 3 mmol/L removed (Figure B6).

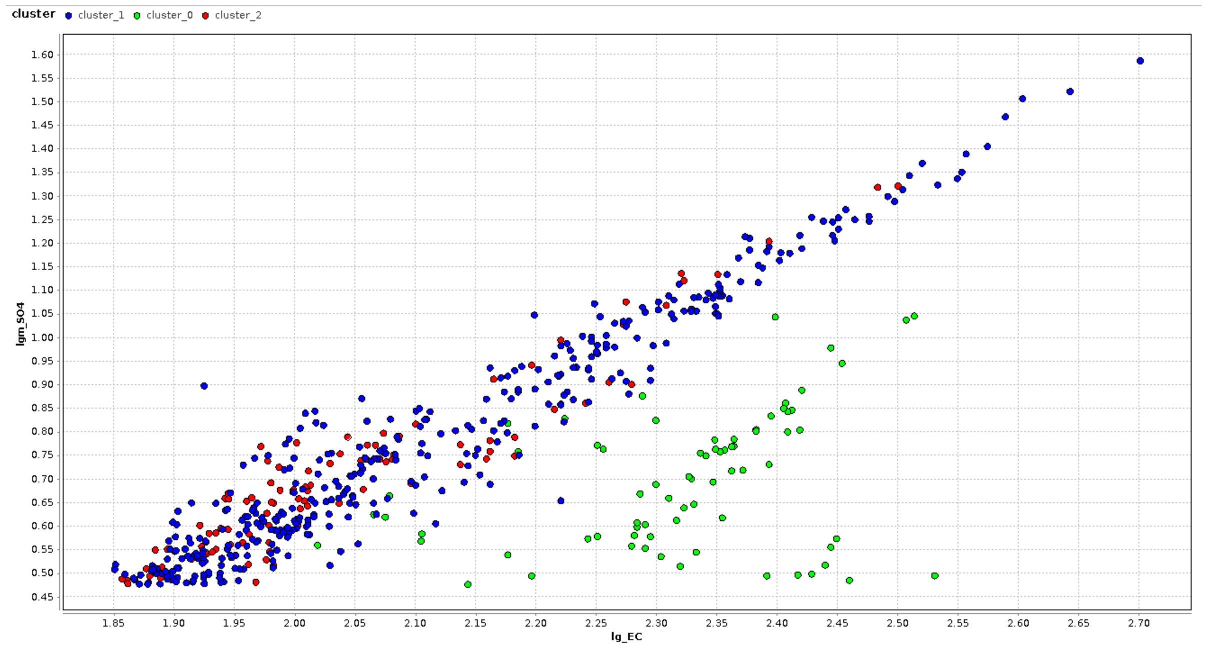

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Figure B6: Cluster analysis of SO4-EC data above 3 mmol/L.

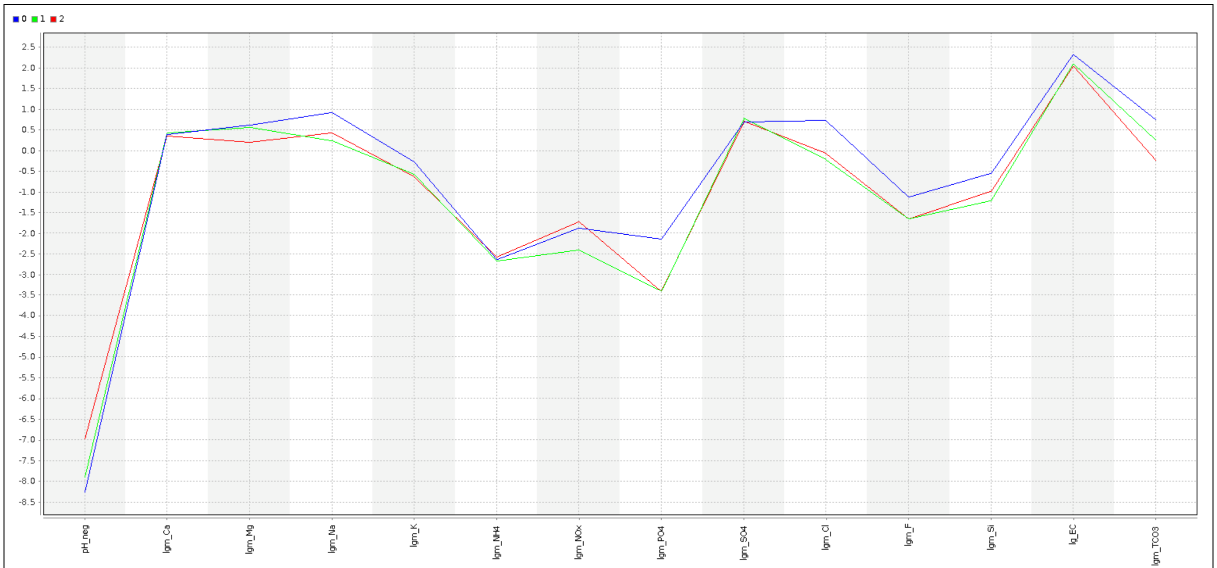

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Figure B7 Centroid plot of SO4-EC data above 3 mmol/L.

The linear regression on the lgm_SO4 vs lg_EC set defined by the combination of Clusters 1 and 2 reveal the following statistics:

lgm_SO4 = 1.28 x lg_EC -1.93; r^2 = 97%.

Interpolation of the maximum limit of EC for a water resource of Class D yields the information in the following table (Linear correlation = 96.5%):

EC (mS/m)	lg_EC	lgm_SO4	m_SO4 (mmol/L)	SO4 (mg/L)
110	2.04	0.70	5.05	495

FINAL RECOMMENDATIONS OF TRIGGER VALUES FOR SULPHATE

The value of 500 ("rounded up" from 495 mg/L) was set at the "D" level for sulphate concentrations and the "C", "B" and "A" values derived as were the values derived for use in the DWA Reserve Determination process (Table B3).

Table B3: Sulphate trigger values recommended

Water Quality category	Natural – Poor categories	PES rating	SO4 (mg/L)
A	Natural	0	50
AB		0.5	65
B	Good	1	80
BC		1.5	140
C	Upper Fair	2	200
CD		2.5	350
D	Lower Fair	3	500

CONCLUSION

The current study assumes that the EC guideline values for aquatic health have been in use for a long period and are thus assumed to be provisionally non-contentious. Thus setting a sulphate guideline value as guided by EC relationships in a highly sulphate-polluted catchment would be appropriate until more site-specific methods were applied, such as whole effluent toxicity tests. Sulphate and EC values that were measured in tandem by DWA and published on WMS were downloaded and submitted to a rigorous data verification regime. The paired values were then plotted and a very large scatter was observed in the data. This scatter was enhanced when a log-log transformation was applied. Cluster analysis was applied to the dataset and three main clusters emerged. The most relevant cluster was fortunately the most linear. From this linear cluster of paired SO4 and EC values a direct least squares linear interpolation was performed, yielding a result with a high correlation coefficient. The interpolation of the least squares relationship to the EC value corresponding to a "D" class river water quality yielded a value of approximately 500 mg/L sulphate for a "D" class river. This value was set at the "D" level for sulphate concentrations and the "C", "B" and "A" values derived as were the values derived for use in the DWA Reserve Determination process.

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6.3 APPENDIX C: WATER QUANTITY RULE TABLES INCLUDING MONTHLY FLOW PERCENTILES FOR APPLICABLE RQOS.

Lower Vaal RQOs (quantity)

Vaal River and Bloemhof Dam

IUA	LB
RU	8
EWR16	Low flows (river) and high flows (dam)

Desktop Version 2, Printed on 04/12/2009

Summary of EWR rule curves for : EWR16 based on Present Day Flows in C91A

Determination based on defined BBM Table with site specific assurance rules.

Regional Type : Vaal

ERC = D

Data are given in m^3/s mean monthly flow

% Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	16.340	16.245	16.082	15.801	15.325	14.534	13.253	11.268	8.434	5.413
Nov	58.826	27.261	25.814	25.289	20.153	15.592	14.218	12.088	9.047	7.032
Dec	20.282	20.203	20.077	19.873	19.535	18.966	17.983	16.230	12.948	7.004
Jan	65.676	53.430	39.792	28.049	23.165	22.490	21.325	19.245	15.354	8.305
Feb	87.040	52.687	39.063	37.211	35.793	34.553	33.205	32.077	30.268	13.982
Mar	65.974	62.813	28.655	27.856	26.800	25.721	24.783	23.215	20.038	12.605
Apr	25.344	23.526	20.471	19.518	18.507	17.897	16.308	15.139	13.291	10.965
May	16.614	16.327	16.103	15.946	15.479	15.128	14.438	13.295	10.606	5.737
Jun	13.724	13.671	13.585	13.447	13.219	12.834	12.169	10.982	8.762	4.739
Jul	13.585	13.547	13.472	13.320	13.132	12.728	12.046	10.871	8.673	4.691
Aug	11.507	11.441	11.325	11.128	10.793	10.236	9.333	7.935	5.939	3.812
Sep	14.532	14.470	14.311	14.091	13.639	13.087	11.835	10.021	7.501	4.814

Reserve flows without High Flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	16.339	16.244	16.081	15.800	15.325	14.534	13.252	11.267	8.434	5.413
Nov	17.528	17.427	17.251	16.950	16.440	15.591	14.217	12.087	9.047	5.806
Dec	20.281	20.202	20.076	19.872	19.534	18.965	17.983	16.229	12.947	7.003
Jan	24.051	23.957	23.808	23.565	23.165	22.490	21.325	19.245	15.354	8.305
Feb	39.479	39.369	39.063	37.211	35.793	34.553	33.205	32.077	30.268	13.982
Mar	32.097	32.022	28.655	27.856	26.800	25.721	24.783	23.215	20.038	12.605
Apr	25.344	23.526	20.471	19.518	18.507	17.897	16.308	15.139	13.291	10.965
May	16.614	16.327	16.103	15.946	15.479	15.128	14.438	13.295	10.606	5.737
Jun	13.723	13.670	13.584	13.446	13.218	12.833	12.168	10.981	8.761	4.739
Jul	13.585	13.532	13.448	13.311	13.085	12.704	12.046	10.871	8.673	4.691
Aug	11.506	11.439	11.324	11.127	10.792	10.234	9.332	7.935	5.939	3.812
Sep	14.532	14.448	14.302	14.053	13.630	12.926	11.787	10.021	7.501	4.814

Natural Duration curves

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	35.282	34.547	33.961	33.397	32.908	32.560	31.717	30.847	29.159	25.284
Nov	114.715	27.261	25.814	25.289	24.525	23.939	22.936	21.933	20.926	16.667
Dec	128.752	32.463	30.776	29.208	28.383	26.867	25.512	24.895	22.790	16.211
Jan	272.771	108.479	39.792	38.269	37.765	36.932	35.428	34.274	30.746	24.884
Feb	542.493	52.687	39.063	37.211	35.793	34.553	33.205	32.077	30.849	26.025
Mar	204.786	75.000	28.655	27.856	26.800	25.721	24.783	23.215	20.038	12.605
Apr	97.793	23.526	20.471	19.518	18.507	17.897	16.308	15.139	13.291	10.965
May	23.197	16.327	16.103	15.946	15.479	15.128	14.438	13.878	12.306	9.935
Jun	20.212	14.556	14.537	14.460	14.174	13.985	13.750	13.434	12.708	8.816
Jul	17.163	17.152	17.115	17.025	16.935	16.760	16.413	15.905	14.852	12.776
Aug	15.311	15.304	15.252	15.188	15.121	14.957	14.688	14.158	12.944	8.957
Sep	34.155	34.082	33.981	33.804	33.611	33.306	32.762	32.049	30.166	27.041

Harts River and Spitskop Dam

IUA LA4

RU 6

EWR17 Low flows for river and dam

- Desktop Version 2, Printed on 05/12/2009
- Summary of EWR rule curves for : EWR17 based on Natural Flows in C33C
- Determination based on defined BBM Table with site specific assurance rules.
- Regional Type : Lowveld
- ERC = D
- Data are given in m^3/s mean monthly flow
- % Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.46	0.545	0.175	0.019	0.019	0.004	0	0	0	0
Nov	5.508	0.437	0.437	0.437	0.437	0.228	0.127	0.073	0.008	0
Dec	4.238	2.41	0.347	0.03	0.03	0.03	0.03	0.03	0.03	0.015
Jan	5.38	4.095	1.554	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Feb	7.211	6.319	3.998	0.918	0.048	0.048	0.048	0.048	0.048	0.041
Mar	14.251	12.982	8.699	4.303	0.443	0.443	0.443	0.443	0.403	0.004
Apr	7.54	7.524	4.641	2.357	1.235	0.88	0.451	0.108	0.035	0
May	1.348	0.745	0.036	0.036	0.036	0.036	0.019	0.004	0	0
Jun	0.359	0.031	0.008	0	0	0	0	0	0	0
Jul	0.545	0.004	0	0	0	0	0	0	0	0
Aug	0.153	0.004	0	0	0	0	0	0	0	0
Sep	0.714	0.019	0	0	0	0	0	0	0	0

- Reserve flows without High Flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.46	0.545	0.175	0.019	0.019	0.004	0	0	0	0
Nov	2.182	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.008	0
Dec	4.238	2.41	0.347	0.03	0.03	0.03	0.03	0.03	0.03	0.015
Jan	5.38	4.095	1.554	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Feb	7.211	6.319	3.998	0.918	0.048	0.048	0.048	0.048	0.048	0.041
Mar	9.259	8.414	6.208	2.631	0.06	0.06	0.06	0.06	0.06	0.004
Apr	7.54	7.524	4.641	2.357	1.235	0.88	0.451	0.108	0.035	0
May	1.348	0.745	0.036	0.036	0.036	0.036	0.019	0.004	0	0
Jun	0.359	0.031	0.008	0	0	0	0	0	0	0
Jul	0.545	0.004	0	0	0	0	0	0	0	0
Aug	0.153	0.004	0	0	0	0	0	0	0	0
Sep	0.714	0.019	0	0	0	0	0	0	0	0

- Natural Duration curves

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.460	0.545	0.175	0.075	0.026	0.004	0.000	0.000	0.000	0.000
Nov	5.691	3.615	1.501	0.945	0.467	0.228	0.127	0.073	0.008	0.000
Dec	6.732	5.384	4.223	3.170	2.438	1.773	0.933	0.553	0.149	0.015
Jan	22.222	13.908	8.106	4.577	3.618	1.897	1.389	0.937	0.228	0.067
Feb	30.684	23.619	9.966	6.031	2.571	2.108	1.521	0.781	0.223	0.041
Mar	30.940	15.715	8.699	6.481	3.883	2.666	1.553	1.008	0.403	0.004
Apr	24.796	9.279	4.641	2.357	1.235	0.880	0.451	0.108	0.035	0.000
May	1.348	0.788	0.478	0.220	0.105	0.049	0.019	0.004	0.000	0.000
Jun	0.359	0.046	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.545	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.153	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.714	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000