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

WP10535

SUB-COMPONENT PRIORITISATION AND INDICATOR SELECTION REPORT

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Title: *Sub-Component Prioritisation and Indicator Selection Report*

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

Sub-Component Prioritisation and Indicator 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 sub-components were selected for RQO determination including:

- A total of 28 sub-components were selected to represent river resources from 5 prioritised RUs.
- A total of 37 sub-components were selected to represent groundwater resources from 11 prioritised RUs .
- A total of 29 sub-components were selected to represent dam resources from 6 prioritised ecosystems.
- A total of 24 sub-components were selected to represent wetlands resources from 8 prioritised ecosystems.

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

Sub-Component Prioritisation and Indicator Report

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Sub-Component Prioritisation and Indicator 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). RQOs 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 procedures includes the prioritisation of sub-components for RQOs, the select indicators for monitoring and proposes and the direction of change of these indicators (Step 4; DWA, 2011). Step 3 in the study included the prioritisation and selection preliminary Resource Units (RUs) and or ecosystems for the relevant resources for RQO determination. This sub-component prioritisation, indicator selection and direction of change step (Step 4) follows on from Step 3 and consists of two key objectives including:

- identification and prioritisation of sub-components that may be important to either users or the environment and,
- selection of those sub-components and associated indicators for which RQOs and Numerical Limits (NLs) should be developed.

This step in the RQO process bears particular relevance to the consideration of the impacts of land-based activities on the water resource and involves specialist water resource scientists, practitioners and water resource regulators.

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 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

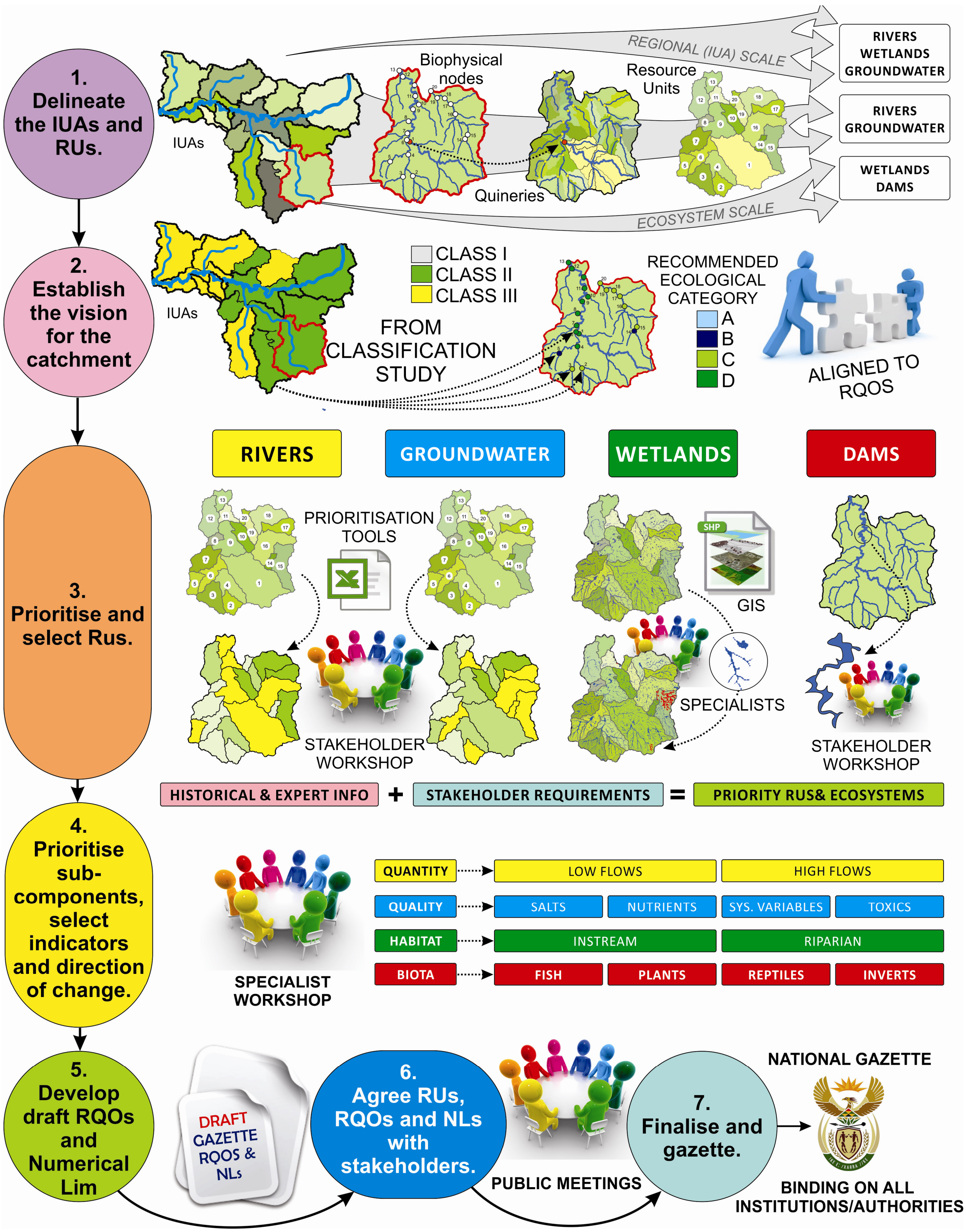

Figure 1: Schematic summary of the RQO determination procedure (adapted from DWA, 2011) which was implemented in this study.

3.2 SUB-COMPONENT AND INDICATOR SELECTION OVERVIEW

The prioritisation of sub-components for RQO determination and selection of indicators forms the fourth step of the RQO determination process (Figure 1). This step included 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.

3.3 RIVER COMPONENT

The river component of the prioritisation of sub-components for RQO determination and selection of indicators component involved the use of the existing Resource Unit Evaluation Tool for rivers that was developed by DWA (2011). The river Resource Unit Evaluation Tool has two primary functions including:

- determining the level of threat posed to each of the sub-components by impacting activities in the catchment and secondly,
- identifying which sub-components should be protected in order to support water resource dependent activities and/or maintain the integrity and ecological functioning of the water resource.

In this case study the river Resource Unit Evaluation Tool was implemented at a specialist workshop which included the relevant catchment managers and other key individuals with a good understanding of the area and also the ecosystem. The procedures involved in applying the tool are available in detail in the RQO determination procedure (DWA, 2011) and are summarised here.

Identify and assess the impact of current and anticipated future use on water resource components: The first sub-step in prioritising sub-components for RQO determination involves building an understanding of current impacts and future pressures on the RU using available data and specialist knowledge. This sub-step was undertaken using the 'Impacting activities' worksheet in the river Resource Unit Evaluation Tool.

Assess the importance of activities in driving resource change: Consideration was given to current users (existing and authorised water use) and anticipated future use (within next 5 years) within and upstream of each RU being evaluated. Those activities which were considered to have a considerable impact were rated as very important users irrespective of their contribution to the economy. The economic contribution of activities was then assessed in terms of their contribution to GDP, the number of jobs that they provide and whether they are a strategic water user. A brief description and rationale for the rating assigned to each user was provided.

Determine the anticipated level of impact on each sub-component: Each of the listed activities (*e.g.* irrigated agriculture, urban areas, rehabilitation, *etc.*) has the potential to impact the components and sub-components of the water resource in a variety of different ways. The purpose of this sub-step was to identify those sub-components which are threatened as a result of high levels of impact as such sub-components should be prioritised over those sub-components which are experiencing a low level of impact. The assessment was based on the scale, location and intensity of the current and future activities in the Resource Unit and/or catchment.

Determine the cumulative level of impact on each sub-component: The purpose of this step was to identify the cumulative effect of all of the impacting activities on each sub-component. Cumulative effects are commonly understood as the impacts which combine from different activities and which result in significant change, which is larger than the individual impacts. Based on a review of impact scores, a 'cumulative level of impact' score for each sub-component was selected using the impact rating guidelines. This information was used to automatically determine an Impact Class for each sub-component.

Determine the anticipated consequences of the impacting activities on each sub-component: Once an understanding of key impacts driving current and future impacts to the RU was assessed, this was used to help inform an assessment of the anticipated consequences of impacting activities on water resource quality. This is expressed as a projected trajectory of change for each sub-component and is informed by the 'cumulative level of impact' score.

Identify requirements of important user groups: The second sub-step in prioritising sub-components for RQO determination entails identifying which groups are using the resource, classifying the importance of these groups and determining which sub-components are important to them. This sub-step was undertaken using the 'User requirements' worksheet in the river Resource Unit Evaluation Tool.

Identify important user groups within the 'protection of the water resource' and 'water resource dependent activity' user group types: The purpose of this sub-step was to identify water users that need to be considered when setting RQOs. The relative importance of user groups was therefore assessed and recorded with a supporting rationale in the river Resource Unit Evaluation Tool.

Rate the importance of sub-components for the 'protection of the water resource' and 'water resource dependent activities: The purpose this sub-step was to determine which sub-components are important and / or of concern to different user groups. This was determined by rating the importance of sub-components for users who were identified as important or very important and was used to calculate an importance score for each sub-component. This helps to highlight sub-components of primary concern to different user groups, thus reflecting aspects of the water resource that they feel need to be closely monitored.

Summarise the aspirations of each important user group: Opportunity was provided to summarise relevant aspirations of conservation agencies and users dependent on the water resource. In the case of conservation agencies and users dependent on the water resource, stakeholders highlighted specific components or attributes of the water resource which are of concern to them. These aspirations effectively provide a justification for assigning a particular rating or score in the previous importance assessment.

Review Present State information: In this step the Present State information from the Reserve, WRC and from the recently completed assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity for the whole country (DWS, 2013) was used. This information was used to inform the desired direction of change for users and informed the situation from a protection perspective. For water resource dependent activities, the present state was expressed in terms of 'fitness for use' for those activities. When completing the information for the 'protection of the water resource' user group, the Ecological Category was recorded separately for each sub-component. The 'fitness for use' category for each sub-component for the 'water resource dependent activities' user group was then be recorded. The current trajectory of change for each component was also estimated. This was informed by the assessment of impacting activities but was sometimes over-written based on more reliable information.

Propose the desired direction and magnitude of change for each sub-component for important user-groups: For 'water resource dependent activities' and organisations responsible for protecting the natural environment, an assessment of the desired direction of change was undertaken to provide an indication of whether stakeholders would like a particular sub-component of the water resource to be improved or whether some level of degradation may be acceptable. Both the importance ratings for each of the sub-components and present state / fitness for use information was used to guide this assessment.

Selection of sub-components for RQO determination: In this sub-step the key sub-components for RQO determination and appropriate indicators to monitor them were selected.

Review the Ecosystem and User Prioritisation ratings: Two prioritisation ratings, one for the ecosystem and the other for users, are then automatically calculated in the Rivers RU Evaluation Tool. These prioritisation ratings are based on how important a sub-component is from an ecological or user perspective and whether this sub-component is threatened by anthropogenic activities occurring in the catchment. The overall prioritisation ratings range from very low to very high. Very high ratings highlight those sub-components which are both important from an ecological and/or user perspective and which are threatened by anthropogenic activities. This information was used to select the indicators and identify the 'UserSpec', 'EcoSpec' reason for the selection.

Select sub-components and associated indicators for RQO determination
The overall priority ratings were used to guide the selection of sub-components for RQO determination. Sub-components with high scores were selected first. A rationale for selecting each sub-component was provided. Based on the rationale for sub-component selection, the selection of a sub-component as a 'UserSpec', 'EcoSpec' and/or 'Integrated measure' was documented as this was later used to provide context information for the RQOs and to direct the NLs and monitoring requirements

Once sub-components have been selected, suitable indicators for monitoring should be identified. This was informed by the Ecosystem and User Prioritisation rating and the associated aspirations of the user group. The rationale for selecting the indicator was captured in the appropriate column in the Resource Unit Evaluation Tool.

Establish the desired direction of change for selected sub-components: Once sub-components and relevant indicators were selected, the level at which RQOs will be set were established. In this study the outcomes of the WRC were considered. Here the recommended Ecological Category (REC) scores were used to ensure that the RQO process and the classifications processes are aligned

The process of prioritisation ranked all of the RUs from high to low priority. Thereafter a decision had to be made on how many RUS to include in the list of priority RUs. This decision was based on the ability of the regulator (DWS) to manage the monitoring and implementation of RQOs in the selected priority RUs. In the absence of a detailed budgetary and capability assessment of DWS, the decision was made in conjunction with DWS staff who estimated how many RUs could be managed. This was partly driven by an estimation of the minimum number of RUs that would need to be monitored to ensure that there was adequate coverage of the entire WMA.

There are 5 RUs in the Lower Vaal WMA that were prioritised for the allocation of RQOs during the sub-component and indicator selection phase of the study. The methods described above were used to determine the sub-components and indicators for these RUs. Although it would have been ideal to workshop all of these RUs with stakeholders to select the sub-components and indicators, due to time constraints this could not be achieved. The sub-components and indicators were therefore determined using the following processes (Table 1):

- Workshop: Priority RUs were selected and the sub-components and indicators were selected during the workshop involving the specialists who attended the workshop and applied the Rivers Resource Unit Evaluation Tool.
- Protection: The stakeholders who attended the sub-component workshop justified the identification of additional RUs that were prioritised during the workshop for specific ecosystem protection components. Specialist knowledge of these protection requirements for these components nullified the need to use the Rivers Resource Unit Evaluation Tool.

Table 1: Sub-components and indicator selection procedures for the prioritised RUs considered in the study.

IUA	RU	Workshop	Protection
LA2	RU3	X	
LA4	RU6	X	
	RU7		X
LB	RU8	X	
	RU11	X	

After the completion of the sub-component and indicator identification phase the outcomes were aligned between RUs. The purpose of this alignment procedure at this stage of the study was to ensure that management decisions that affect downstream water resources were appropriate.

3.4 WETLAND COMPONENT

Wetland indicator selection for regional scale RQOs

At a regional level, selection of appropriate indicators was guided by the need to meet conservation targets for wetland ecosystems and to secure vital ecosystem goods and services that wetlands provide. Potential indicators were initially selected by the project team and then discussed with DWS and key wetland experts at a workshop held on the 20th and 21st of November 2013 to obtain input on the most appropriate approach to be followed. Additional wetland specialists who were not able to attend the workshop were also consulted.

The DWA (2011) resources unit evaluation tool developed for determining subcomponents and indicators was not designed to cater for regional scale RQOs. However we were able to adapt the tool in order to determine the potential indicators for the regional evaluation. The components and subcomponents were replaced with ecosystem services provided by wetlands (Table 2). The assessment of current and potential future impacts and the requirements of important users groups, with regards to ecosystem services highlighted the demand for services, under threat, at an IUA level.

Table 2: Ecosystem goods and services provided by wetlands

Regulating & Supporting Benefits									Provisioning Benefits			Cultural Benefits		
		Water Quality Enhancement												
Flood attenuation	Stream flow regulation	Sediment trapping	Phosphate assimilation	Nitrate assimilation	Toxicant assimilation	Erosion control	Carbon storage	Biodiversity maintenance	Provision of water for human use	Provision of harvestable resources	Provision of cultivated foods	Cultural heritage	Tourism and recreation	Education

Kotze, *et al.* (2007) preliminary rating of the hydrological benefits likely to be provided by a wetland based on its particular hydro-geomorphic type, was used to identify probable important wetland types at an IUA level (Table 3).

Table 3: Preliminary ratings of the hydrological benefits likely to be provided by a wetland based on its particular hydro-geomorphic type (Kotze, et al., 2007)

WETLAND HYDRO-GEO-MORPHIC TYPE	REGULATORY BENEFITS POTENTIALLY PROVIDED BY WETLAND							
	Flood attenuation		Stream flow regulation	Enhancement of water quality				
	Early wet season	Late wet season		Erosion control	Sediment trapping	Phos-phates	Nitrates	Toxicants[2]
1. Floodplain	++	+	0	++	++	++	+	+
2. Valley-bottom - channelled	+	0	0	++	+	+	+	+
3. Valley-bottom - unchannelled	+	+	+?	++	++	+	+	++
4. Hillslope seepage connected to a stream channel	+	0	+	++	0	0	++	++
5. Isolated hillslope seepage	+	0	0	++	0	0	++	+
6. Pan/ Depression	+	+	0	0	0	0	+	+

Notes: [1] The rationale for the rating of benefits is given in Section 3.6
[2] Toxicants are taken to include heavy metals and biocides.

Rating: 0 Benefit unlikely to be provided to any significant extent
\+ Benefit likely to be present at least to some degree
++ Benefit very likely to be present (and often supplied to a high level)

The outcomes from the specialist workshops provided the basis for determining ecosystem services in demand, and under threat, at an IUA level. The findings of this process informed the development of regional scale RQOs, which is part of the next step in the study.

Wetland subcomponents and indicator selection for ecosystem scale RQOs

Within this component of the study a Wetland Evaluation Tool was specifically developed for prioritised wetland ecosystems to assist in the rationalisation process. This tool has two primary functions (i) to determine the level of threat posed to each of the sub-components by impacting activities in the catchment and secondly (ii) to identify which sub-components should be protected in order to support water resource dependent activities and/or maintain the integrity and ecological functioning of the water resource. This information is then used to prioritise sub-components for RQO determination.

While the prescribed Wetland Evaluation Tool was used, not all of the attributes of the evaluation tool were used. Completing the entire tool was found to be cumbersome and time-consuming. Instead, the evaluation of sub-components and indicators focused primarily on the:

- Identification and assessment of current and potential future impacts (only cumulative impacts were scored); and
- Identification of the requirements of important users groups, both from a protection perspective and water resource dependent activity perspective.

This information provided suitable evidence to identify subcomponents. Potential subcomponents and indicators were initially selected by the project team and then discussed with DWS and key wetland experts at the workshop held on the 20th and 21st of November 2013 to obtain input on the most appropriate approach to be followed. Additional wetland specialists who were not able to attend the workshop were also consulted. The outcomes from the specialist workshops provided the basis for determining the subcomponents and indicators for priority wetlands. The findings of this process informed the development of ecosystem scale RQOs, which is part of the next step in the study.

3.5 DAM COMPONENT

The dams for the Lower Vaal catchment was prioritised in step 4 of the RQO procedures. A total number of 6 dams were seen as priority dams based on the criteria for selection. These criteria included (i) all DWS listed dams, (ii) smaller dams that are used for urban or community water supply, (iii) any request from stakeholders to include a specific dam. The following table shows the output of step 4 with some information on the selected dams (Table 4).

Table 4: Prioritised dams considered in this sub-component and indicator phase of the RQO determination procedure for the Lower Vaal Water Management Area.

IUA	Resource Unit	Dam Name	Quaternary	River	Year Established	FSC Mm³	Why it was built (Purpose)
LA2	3	Wentzel	C31E	Harts	1988	6.58	Irrigation, municipal - Schweizer Reineke
LA4	5	Taung	C31F	Harts	1993	58.9	Irrigation
	6	Spitskop	C33B	Harts	1992	56.6	Irrigation
LB	8	Bloemhof	C91A	Vaal	1987	1269	Irrigation
	9	Vaalharts Weir	C91B	Vaal	1987	48.7	Municipal, industrial, irrigation - Hartswater, Vryburg
	11	Douglas Weir	C92B	Vaal	1987	16.1	Irrigation, municipal - Douglas

To determine the subcomponents to be included per priority dam for which Resource Quality Objectives should be determined, the 'Resource Unit Evaluation' tool was developed. Evaluation criteria were included for quantity, quality, habitat and biotic requirements associated with dams. The specific indicators for each of these include:

- Quantity – low flows or maintenance flows and high flows, including freshets and 1:2 year floods. Note that this includes releases of water for the downstream river
- Quality – nutrients, salts, system variables, toxics, pathogens
- Habitat – riparian and in-dam habitats
- Biota – fish, aquatic and riparian plants, mammals, birds, amphibians, phytoplankton and aquatic invertebrates/zooplankton

The evaluation criteria for each of the above indicators are:

i. Cumulative level of impact - This is the anticipated level of impact of current and future use/activities in the upstream catchments on the inflows to the dam and the quality, habitat and biota in the dam. The 'impact rating' can be Very High: -1; High: -0.75; Moderate: -0.5; Low: -0.25; None: 0. Positive scores can be used where a positive impact on the resource quality is expected.
ii. Trajectory of change – These are indicated by arrows to show a positive (↑), negative (↓) or stable (→) trajectory.
iii. Confidence in the scoring indicated as 'very low' to 'high'.
iv. Rating of importance of components for the protection of the water resource, i.e. importance to releases water for downstream EWRs. Scores given are Very High:1; High:0.75; Moderate:0.5; Low:0.25; Not important:0.

v. Rating of importance of components for protection of the water resource for in-dam activities and releases of water for downstream use (irrigation, domestic/rural supply, etc). Scores given are Very High:1; High:0.75; Moderate:0.5; Low:0.25; Not important:0.
vi. Components with importance scores of 0.5 and higher for the ‘importance for protection’ or ‘importance for other water use’ are then selected to be included as an EcoSpec and/or UserSpec and will form part of the final set of RQOs for that specific dam.

3.6 GROUNDWATER COMPONENT

Unlike surface water where biota exists in the water and can be used as indicators, groundwater is very isolated in this regard. Very few records exist of groundwater biota, simply because this has not been studied extensively and because groundwater is a “hidden resource” that can only be accessed where a borehole has been drilled. Therefore only water quality, water level and abstraction could be used in the formulation of the RQOs. The approach taken to identify measurable sub-components and indicators for groundwater was to list groundwater related sites that may occur currently or in future in the study area. Suggestions on groundwater related sites originating from the groundwater sub-component workshop are listed in Table 5. All examples given were classified according to a site type which relates to the sub-components used in the RQO’s

Table 5: List of potential groundwater sites that could occur in the study area

Site Type	Example
Quantity	Production Borehole Well Fields Mines (Dewatering) Afforestation
Ecological	Springs Wetlands Baseflow (Groundwater)
Aquifer	Aquifer Dolomites Trans-boundary Aquifer
Quality	Mines (Decant, Fracking) Irrigation Water, WWTW Waste Sites / Landfill Burial Sites / Cemeteries Feedlots / Animal Dip Agricultural Areas (Pesticides / Fertilizer) Petrol Stations Sanitation Systems / Pit Latrines

Table 5 demonstrates that the examples are scale dependent, and for the purposes of this document the following definitions of scale were adopted:

- Local Scale – defines a site or point source e.g. a borehole or TSF
- Regional Scale – can be defined as the aquifer extent or that of the RU

All the components and examples that referred to aquifer were associated with the regional scale. The next step was to identify sub-components with associated indicators. Table 5 was extended to include parameters that can be measured for each of the site types and the resultant table is presented in Table 6.

Table 6: Site type with measurable parameters

Site Type (Components)	Example	Scale	Abstraction	Water Quality	Water Level
Quantity	Production Borehole	Local	X	X	X
	Well Fields	Local	#	#	#
	Mines (Dewatering)	Local	#	#	#
	Afforestation	Local	#	#	#
Ecological	Springs	Local		X	
	Wetlands	Local		X	
	Baseflow (Groundwater)	Local		#	#
Aquifer	Aquifer	Regional	#	#	#
	Dolomites	Regional	#	#	#
	Trans-boundary Aquifer	Regional	#	#	#
Quality	Mines (Decant, Fracking)	Local		X	
	Irrigation Water, WWTW	Local		X	
	Waste Sites / Landfill	Local		X	
	Burial Sites / Cemeteries	Local		X	
	Feedlots / Animal Dip	Local		X	
	Agricultural Areas (Pesticides / Fertilizer)	Local		X	
	Petrol Stations	Local		X	
	Sanitation Systems / Pit Latrines	Local		X	

Although, in theory, all the parameters marked with an X or # should be measurable or at least good estimates should be obtainable, however it is not practical to measure those situations marked with # as shown in Table 6. Various reasons exist for this and justification is provided in the next section.

4 FINDINGS

4.1 RIVER COMPONENT

The outcomes of the determination of the sub-component and indicator process for the RQO determination study for the Lower Vaal WMA includes a summary of the component, sub-component, rationale for sub-component choice, EcoSpec, UserSpec and Integrated Measure consideration and Indicator selection per RU within each IUA as follows:

- River sub-component and indicator selection for IUA LA2 is presented in Table 7
- River sub-component and indicator selection for IUA LA4 is presented in Table 8.
- River sub-component and indicator selection for IUA LB is presented in Table 9.

Table 7: River sub-component and indicator selection for IUA LA2: Lower Vaal Water Management Area

IUA	RU	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
LA2	RU3	Quantity	High Flows (Floods)	MC II, PES "D" REC "D". LF PES "D" Moderate flows important to provide ecological cues for ecosystem. Need to introduce variability as per EWR to maintain ecosystem in "D" state.	Y			EWR
		Quality	Toxics	WQ PES "D/E" improve to "D" Toxic PES unknown but OCs (pesticides) linked to Harts Scheme, content of the water concerning for irrigation and local communities who consume water and fish.	Y	Y		DEEEP and Fish Health Index for consumption and Ammonia.
		Habitat	Instream habitat	PES "C/D" REC "C/D". Important ecosystem template, NB for function and structure. Important for recreation. Impacts from flow alterations and abnormal growth of periphyton.	Y	Y		RHAM, consider periphyton affecting instream habitat state
			Riparian Habitat	PES "D" REC "D". Importance of the riparian zone for ecological processes, stabilisation of banks and cover/habitat for fish, frogs. Also NB for recreation and real-estate. Impacts associated with flows alterations and land use - agriculture.	Y	Y		VEGRAI may have conflicting requirements from users (recreational activities) and ecosystem.
		Biota	Fish	PES "D" REC "D". NB component of ecosystem, upstream barriers affect migrating cyprinids into Lower Harts. Quality of fish for consumption concerning.	Y	Y		FRAI, Population structures of targeted species for food (LCAP & LAEN).
			Aquatic Invertebrates	PES "C/D", REC "C/D". Important component of ecosystem and good indicator of water quality, quantity and habitat.			Y	MIRAI
			Diatoms	PES unknown REC "D". Important indicator of toxicants as a part of WQ.			Y	Diatom index.

Table 8: River sub-component and indicator selection for IUA LA4: Lower Vaal Water Management Area

IUA	RU	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
LA4	RU6	Quantity	Low Flows (Maintenance Flows)	MC II, PES "D" REC "D". LF PES "D" timing of releases in the Harts must be managed to reduce rapid daily fluctuations. Fluctuations are affecting habitat and response components incl. Riparian vegetation, affects cues and water quality.	Y			EWR
		Quality	Salts	PES "D/E" REC "D". Ecosystem intolerant to current high levels of salts. Affecting ecosystem function. Irrigation users require reduced salinity levels from Vaal-Harts scheme.	Y	Y		Electrical conductivity
		Habitat	Instream habitat	PES "D" REC "D". Important ecosystem template, NB for function and structure. Important for recreation. Impacts from flow alterations and abnormal growth of periphyton.	y			RHAM
		Biota	Aquatic Invertebrates	PES "D" REC "C/D". Inverts NB ecosystem component and indicator of quality, quantity and habitat.			y	MIRAI
			Diatoms	PES unknown. Good indicator of ecosystem state and measurement of toxics which are not being monitored.			y	Diatom index.
	RU 7	Biota	Fish	PES "C" REC "B/C". Fish communities should be improved so that they include viable populations of ecologically important species.	Y	Y		FRAI, Population wellbeing of *Labeobarbus kimberleyensis*.

Table 9: River sub-component and indicator selection for IUA LB: Lower Vaal Water Management Area

IUA	RU	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
LB	RU8	Quantity	High Flows (Floods)	MC III, PES "D" (but Reserve = "E") REC "D". PES "D", REC "D". Moderate flows important to provide ecological cues for ecosystem. Need to introduce variability as per EWR. Flow alterations associated with releases from Bloemhof Dam.	Y			EWR
		Quality	Toxics	Current toxics unknown, considered to contain metals and OCs, content of the water concerning for irrigation and local communities who consume water and fish.	Y	Y		DEEEP and Fish Health Index for consumption and Ammonia.
		Habitat	Instream habitat	PES "D" REC "D", Important ecosystem template, NB for structure and function. Important for recreation. Impacted on by flow releases and landuses.	Y	Y		RHAM, consider periphyton affecting instream habitat state
			Riparian Habitat	PES "E/F" REC "D" Importance of the riparian zone for ecological processes, stabilisation of banks and cover/habitat for fish, frogs. Impacts flows and land use, bank trampling by community. Also NB for recreation and real estate.	Y	Y		VEGRAI may have conflicting requirements from users (recreational activities) and ecosystem.
		Biota	Fish	PES "D" REC "D" NB component of ecosystem, Bloemhof acts as a barrier where migrating cyprinids in particular congregate. Targeted by local communities and other predators. NB FEPA. Quality of fish for consumption concerning.	Y	Y		FRAI, Population structures of targeted species for food (LCAP & LAEN).
			Aquatic Invertebrates	PES "D", REC "D". Important component of ecosystem and good indicator of ecosystem health (quantity, quality and habitat).			Y	MIRAI
			Diatoms	PES unknown suspected to be "D" REC "D". Important indicator of ecosystem health, NB toxics.			Y	Diatom index.
	RU11	Quantity	Low Flows (Maintenance Flows)	PES "C/D" REC "C" but PES/EIS PES is "D". LF "D (Reserve) and E (PES-EIS)" REC "C" maintain ecosystem but also to ensure provision of water for irrigation. Upstream flow alterations and excessive abstraction for Harts Scheme affecting state. During low flow period to minimise water quality impacts on Orange no flows released = 0 flows.	Y	Y		EWR

		Quality	Nutrients	WQ (Nutrients) "D (Reserve) and E (PES-EIS)" REC "C" excessive nutrients impact negatively on water treatment costs. Also negative for recreation, ecotourism and real estate. Also negative impact on ecosystem. Impacts water quality from Harts scheme and upstream Vaal.	Y	Y		P and TIN
			Salts	PES "D" REC "C" salinity concentrations must be managed to ensure WQ suitable for irrigated agriculture - Harts scheme and not affect Orange River.		Y		EC
			System variables	PES "D" REC "C" high temperatures and low DO resulting from low flows affect ecosystem health (REC "C"). Marginal turbidity for irrigation.	Y			Temperature
			Pathogens	PES unknown, microbial contamination must be minimised to reduce impact to irrigated crops - Harts scheme.		Y		E.coli
		Habitat	Instream habitat	Instream habitat PES "C" REC "B" (Reserve). Critical for maintenance of ecosystem and also for real estate and property and recreational angling. Impacted by flows and WQ.	Y	Y		RHAM with consideration of periphyton
		Biota	Fish	PES "C" REC "B" important component of ecosystem, recreational angling and maintenance of target species for angling and consumption.		Y		population structure of target species

4.2 WETLAND COMPONENT

The findings of an assessment of DWA (2011a) and DWA (2012), undertaken to determine the demand for wetland benefits and services at an IUA level, are included in APPENDIX A. This information was used to determine the key wetland benefits and services that are under threat at an IUA level (Table 10).

Table 10: Key wetland benefits and services that are under threat at an IUA level

IUA	Regulating & Supporting benefits									Provisioning Benefits			Cultural Benefits		
			Water Quality Enhancement												
	Flood attenuation	Stream flow regulation	Sediment trapping	Phosphate assimilation	Nitrate assimilation	Toxicant assimilation	Erosion control	Carbon storage	Biodiversity maintenance	Provision of water for human use	Provision of harvestable resources	Provision of cultivated foods	Cultural heritage	Tourism and recreation	Education
LA1				Y	Y				Y						
LA2			Y	Y	Y	Y	Y								
LA3			Y	Y	Y	Y	Y								
LA4			Y			Y	Y								
LB			Y	Y	Y	Y			Y						

Taking into consideration the findings from the above assessment, and following discussions with the project team and key stakeholders, a decision was taken to use the following indicators when setting regional scale RQOs:

- **Wetland condition:** Wetland condition is regarded as an appropriate surrogate and indicator for wetland functioning at a regional scale. This is also a useful measure against which management of priority wetland FEPAs can be evaluated.
- **Landuse compatibility:** In the case of FEPA wetland clusters, landuses that negatively affect hydrological or terrestrial connectivity are regarded as undesirable. As such the compatibility of landuses within a 500m buffer zone around these clusters was selected as an appropriate indicator.
- **Levels of wetland protection:** While maintaining wetland condition (and landuse compatibility in the case of FEPA wetland clusters) is regarded as important, it is essential that a sub-set of wetlands are formally protected to meet conservation targets. For this reason, levels of protection of wetland FEPAs (a sub-set of wetlands selected to meet conservation targets) was selected as an indicator to assess progress made towards meeting biodiversity protection objectives.

Wetland subcomponents and indicators for ecosystem scale RQOs in the Lower Vaal

Selection of subcomponents for prioritized wetland ecosystems was based on an evaluation of the relevance of each subcomponent in light of protection requirements and water resource dependant activities. A summary of the indicators selected per priority wetland and IUA is presented in Table 11.

Table 11: Summary of subcomponents and indicators selected for prioritized wetlands.

IUA	Wetland Code / Name	Quantity		Quality					Habitat		Biota								Indicators selected
		er in	uti on an	ie nt	Sa lts	m va	xic	og en	or ph	Ve ge	Fi sh	sp ec	m m	Bir ds	an s &	hy	ve rte	at o m	
LA1	**1.1 Leeupan**	**Y**					**Y**			**Y**				**Y**					• Water inputs • Toxics • Wetland vegetation • Lesser and Greater Flamingo populations
LA1	**1.2 Barberspan**	**Y**		**Y**			**Y**			**Y**				**Y**					• Water inputs • Nutrients • Toxics • Wetland vegetation • Lesser and Greater Flamingo populations
LA1	**1.3 Klein-harts**		**Y**						**Y**	**Y**									• Water distribution & retention patterns • Wetland vegetation • Wetland geomorphology
LA1	**1.4 Harts River**		**Y**	**Y**					**Y**	**Y**									• Water distribution & retention • Nutrients • Wetland vegetation • Wetland geomorphology
LA3	**3.1 Droe Harts**								**Y**	**Y**									• Wetland vegetation • Wetland geomorphology
LA4	**4.1 Harts River**	**Y**	**Y**						**Y**	**Y**									• Water inputs, and water distribution & retention patterns within the wetland • Wetland vegetation • Wetland geomorphology
LB	**5.1 SA Lombard**								**Y**	**Y**									• Wetland vegetation • Wetland geomorphology
LB	**5.2 Kamferpan**													**Y**					• Lesser Flamingo population

4.3 DAM COMPONENT

The following tables provide a summary of the findings for each of the priority dam for which numerical limits will be determined during step 6 of the RQO determination process.

- Dam sub-component and indicator selection for IUA LA2 presented in Table 12.
- Dam sub-component and indicator selection for IUA LA4 presented in Table 13.
- Dam sub-component and indicator selection for IUA LB presented in Table 14.

Table 12: Dam sub-component and indicator selection for IUA LA2: Lower Vaal Water Management Area

IUA	RU	Dam	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
LA2	RU 3	Wentzel Dam	Quantity	Low flow	The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation and urban use				EWR

Table 13: Dam sub-component and indicator selection for IUA LA4: Lower Vaal Water Management Area

IUA	RU	Dam	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
LA4	RU 5	Taung Dam	Quantity	Low flow	The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation				EWR
			Quality	Nutrients	The nutrient state of the dam must be improved and maintained in a mesotrophic state.				Phosphate, nitrates, nitrites
				Salts	Salinity concentrations must be maintained at levels acceptable for irrigation				Electrical conductivity
				Toxins	The numbers of cyanobacteria must be kept within mesotrophic levels				Chl-a: phytoplankton*
			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), fish health evaluation
	RU 6	Spitskop Dam	Quantity	Low flow	The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation				EWR
			Quality	Nutrients	The nutrient state of the dam must be improved and maintained in a mesotrophic state.				Phosphate, nitrates, nitrites
				Salts	Salinity concentrations must be maintained at levels acceptable for irrigation				Electrical conductivity
				Toxins	The numbers of cyanobacteria must be kept within mesotrophic levels				Chl-a: phytoplankton*

Table 14: Dam sub-component and indicator selection for IUA LB: Lower Vaal Water Management Area

IUA	RU	Dam	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
LB	RU 9	Vaalharts Weir	Quantity	Low flow	The dam must be able to provide EWR releases for the protection of ecosystem function downstream and for irrigation				EWR
			Quality	Nutrients	Nutrient levels must be improved and maintained in a mesotrophic state. Total inorganic nitrogen must be improved over present concentrations.				Phosphate, nitrates, nitrites
				Salts	Salinity concentrations must be maintained at levels acceptable for irrigation				Electrical conductivity
				Toxins	The numbers of cyanobacteria must be kept within mesotrophic levels				Chl-a: phytoplankton*
			Biota	Aquatic plants	Invasive aquatic plant population establishment must be prevented				Aquatic plant composition assessment. Methods to be developed.
	RU 11	Douglas Weir	Quantity	Low flow	Water should be released for the maintenance of the ecosystem in this last reach of the Vaal River				EWR
			Quality	Nutrients	Nutrient levels must be improved and maintained in a mesotrophic state.				Phosphate, nitrates, nitrites
				Salts	Salinity concentrations must be maintained at levels acceptable for irrigation				Electrical conductivity
				Toxins	The numbers of cyanobacteria must be kept within mesotrophic levels				Chl-a: phytoplankton*

IUA	RU	Dam	Component	Sub-component	Rationale for sub-component choice	EcoSpec	UserSpec	Integrated Measure	Indicator selection
			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), fish health evaluation

4.4 GROUNDWATER COMPONENT

Having considered the measurable parameters as per example listed in Table 6, some complexities were identified and can be summarised as follows (Table 15):

Table 15: Complexities with measurable parameters

Site Type	Description
Well Fields	Well fields are a collection of boreholes which can have a wide distribution in space leading to boreholes intersecting different geologies which may result in different water chemistries. In some instances it will be difficult to determine a representative water quality and water level for a well field. Furthermore abstractions rates of boreholes are not readily available and the WRMS database only reflects registered use.
Dewatering of mines	Mines need to pump to keep the workings dry. Pumping rates (if available) change with time as the mine develops and the groundwater ingress through various geologies can also lead major differences in chemistry especially considering oxidation that can take place. Groundwater levels can vary substantially in and around a mine lease area making it impossible to associate one water level with the mine.
Afforestation	Abstraction can be measured per tree using techniques such as sapflow, but in general abstractions are estimated through the use of a model and it is dependent on the age of the plantation. Water quality and groundwater level can be measured if boreholes are available, and could also vary spatially around the plantation footprint.
Groundwater contribution to baseflow	Water quality and groundwater level can only be measured at a point where a monitoring borehole intersects the groundwater contribution to baseflow and these parameters will vary significantly along a water course due to geological, streambed and topography differences. Hence a single point cannot be used to characterise the groundwater contribution to baseflow.
Aquifer Types	Due to the distributed and geological nature of aquifers, they cannot be characterised by a single water level and water quality. At best an estimation of available water can be done through modelling the system. Abstraction figures relate back to registered use and estimations from cultivated land can also be done through the use of crop models.

The methodologies to be used in setting up the RQO's as well as monitoring them should be practical and easily implementable; therefore detail modelling of complex systems is not an option. Cost implications should also be considered where specialist studies and borehole development are expensive.

The measurable parameters that can be used as sub-components are given as follows:

- *Quantity (Abstraction)* – this is done through metering, however a vast number of production boreholes are not metered and the WARMS database is not updated.
- *Aquifer (Water Level)* – groundwater water levels can be easily measured when access is available to a borehole

Quality (Water Quality) – field measurements of EC and pH is easy to carry out, but lab analysis of physical chemistry is costly. Due to the variations of geology in a RU and the fact that the water character of the groundwater will be associated with the geology through which it moves, no specific chemical constituent can be used as a general indicator of the water quality for a particular RU.

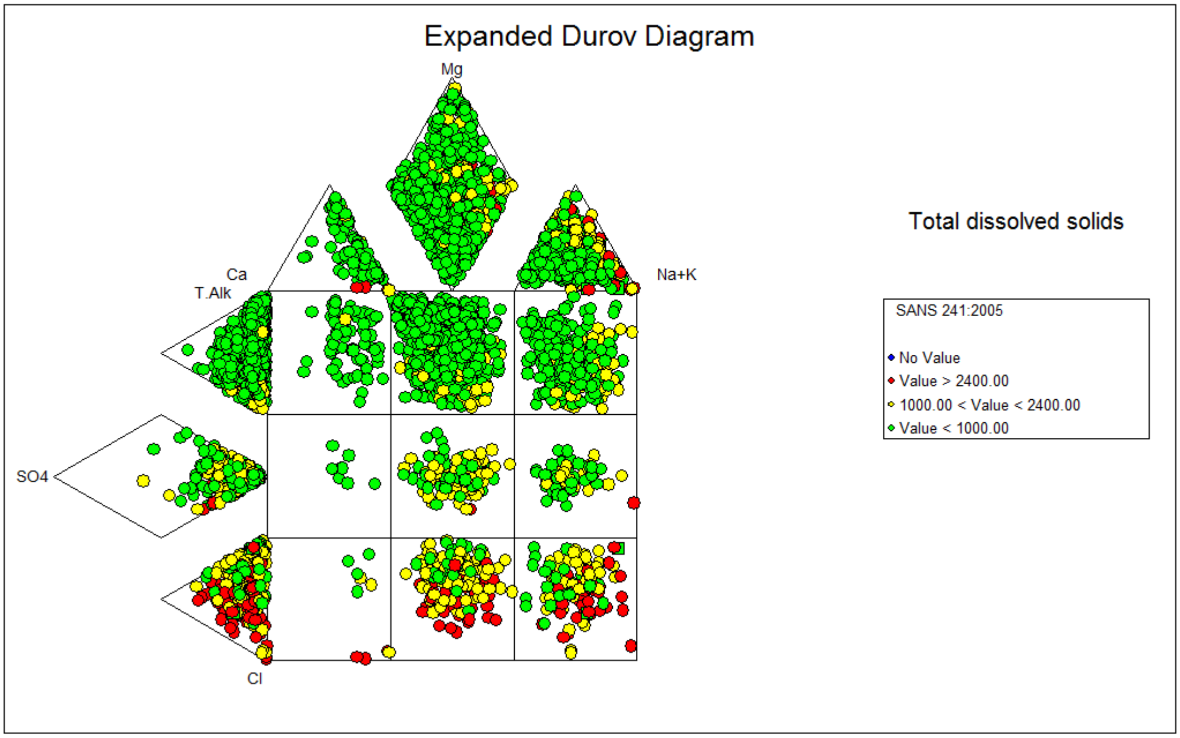

Figure 2: Expanded Durov diagram of available quality data

Protection Zones

According to The National Water Act (NWA) (Act No. 36 of 1998) there is a need to protect basic human need and the ecological reserve; therefore it is necessary to introduce RQO measures to do this. Due to a lack of information of sub-components in the groundwater system, protection zones have been introduced as a means of protecting the basic human need and ecological reserve. The four protection zones suggested with the concept of infringements are detailed in the following sections.

Radius of Influence:

The protection zone around a borehole (radius of influence) is calculated as follows (Parsons and Wentzel, 2005):

$$r = 1.5\sqrt{\frac{Tt}{S}}$$

where,

r = Radius of influence (m)
t = Time of pumping (days)
T = Transmissivity (m^2/d)
S = Storativity

Note: for wellfields a wellfield model is required to verify if protection zone are violated due to the cumulative effect of multiple boreholes.

Microbial Protection Zone:

Groundwater quality is for use and boreholes must be protected from microbial pollution. The protection zone around a borehole to avoid microbial pollution is calculated as follows (Parsons and Wentzel, 2005):

$$r = 2(0.28T) + 53$$

where,

r = Protection radius (m)
T = Transmissivity (m^2/d)

Wetland Protection Zone:
To protect ecological systems that are groundwater fed, it is important to maintain the groundwater gradient to these features. The groundwater gradient can be protected by specifying appropriate protection zones around wetlands (Parsons and Wentzel, 2005).

where,

d	=	Distance from wetland (m)
i	=	Groundwater gradient towards wetland
T	=	Transmissivity (m^2/d)
L	=	Wetland perimeter (m)
R	=	Groundwater recharge (mm/d)

River Protection Zone:
To protect ecological systems that are groundwater fed, it is important to maintain the groundwater gradient to these features. The groundwater gradient can be protected by specifying appropriate protection zones around rivers (Parsons and Wentzel, 2005).

where,

d	=	Distance from river (m)
i	=	Groundwater gradient towards wetland
T	=	Transmissivity (m^2/d)
R	=	Groundwater recharge (mm/d)

Zone Infringements:
The concept of RQO s based on infringements of a protection zone RQO's is proposed for existing infrastructure that will not comply due to their physical position. The RQO will be implemented including the protection zone, but will allow existing infringements. Monitoring of the protection zone will be done to ensure no further infringements are incurred with the introduction of new infrastructure.

Consider the wetland below where the protection zone of the wetland and the borehole overlap. The wetland RQO will be implemented allowing one infringement on the protection zone.

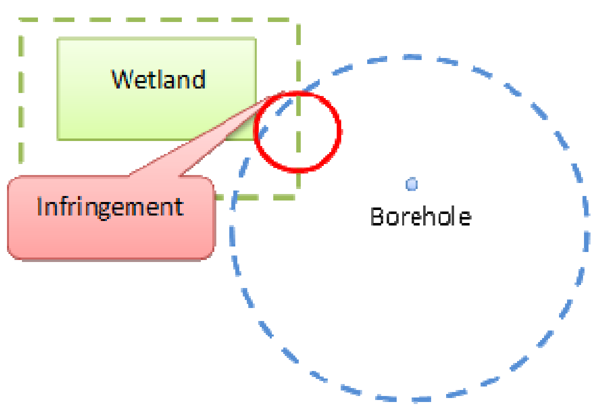

Figure 4: Graphical representation of an infringement area where the influence radius associated with use of a groundwater ecosystem is potentially impacting on a wetland ecosystem.

5 LIMITATIONS AND UNCERTAINITIES

5.1 RIVERS COMPONENT

The following limitations and uncertainties are relevant to the outcomes of this assessment:

- This assessment is largely based on the probability that the sub-components and indicators selected will be suitable indicators of the protection and or use requirements of the water resources considered. This probability consideration is largely based on qualitative information and expert solicitations. These outcomes should be monitored and updated using quantitative data where possible.
- Whilst a range of key stakeholders were involved in this assessment, there were a number of instances where the assessment was based purely on desktop information. There is therefore a risk that some important sub-components could have been omitted from the assessment.

5.2 DAMS COMPONENT

The following limitations and uncertainties are relevant to the outcomes of this assessment:

- This assessment is largely based on the probability that the sub-components and indicators selected will be suitable indicators of the protection and or use requirements of the water resources considered. This probability consideration is largely based on qualitative information and expert solicitations. These outcomes should be monitored and updated using quantitative data where possible.
- Whilst a range of key stakeholders were involved in this assessment, there were a number of instances where the assessment was based purely on desktop information. There is therefore a risk that some important sub-components could have been omitted from the assessment.

5.3 WETLAND COMPONENT

The following limitations and uncertainties are relevant to the outcomes of this assessment:

- The inaccuracy of the current NFEPA data is a concern that will need to be addressed if using this information for setting RQOs. As such, it is recommended that this information to reviewed and/or validated prior to being used to set specific RQOs.
- Stakeholders highlighted the fact that the diversity of pans is not adequately catered for in wetland typing used to set conservation targets for wetlands at a national level. As such, selection of wetland FEPAs does not adequately cater for this diversity and should be re-considered in future.
- Whilst a range of key stakeholders were involved in this assessment, there were a number of instances where the assessment was based purely on desktop information. There is therefore a risk that some important sub-components could have been omitted from the assessment.
- The implication of setting RQO's for groundwater is that individual sites will have to be considered together with prioritized Resource Units (see Figure 11) that can contain multiple sites. The purpose of this report is to identify sub-components and indicators for the groundwater RQO's while considering the complexity of the groundwater system. There will be a challenge implementing RQO's based on sub-components and indicators with respect to protection zones as each site will have its own parameters which cannot be expressed as regional RQOs. The associated numerical limits will need to be expressed in terms of the formulation of the protection zone, rather than the calculated protection zone.

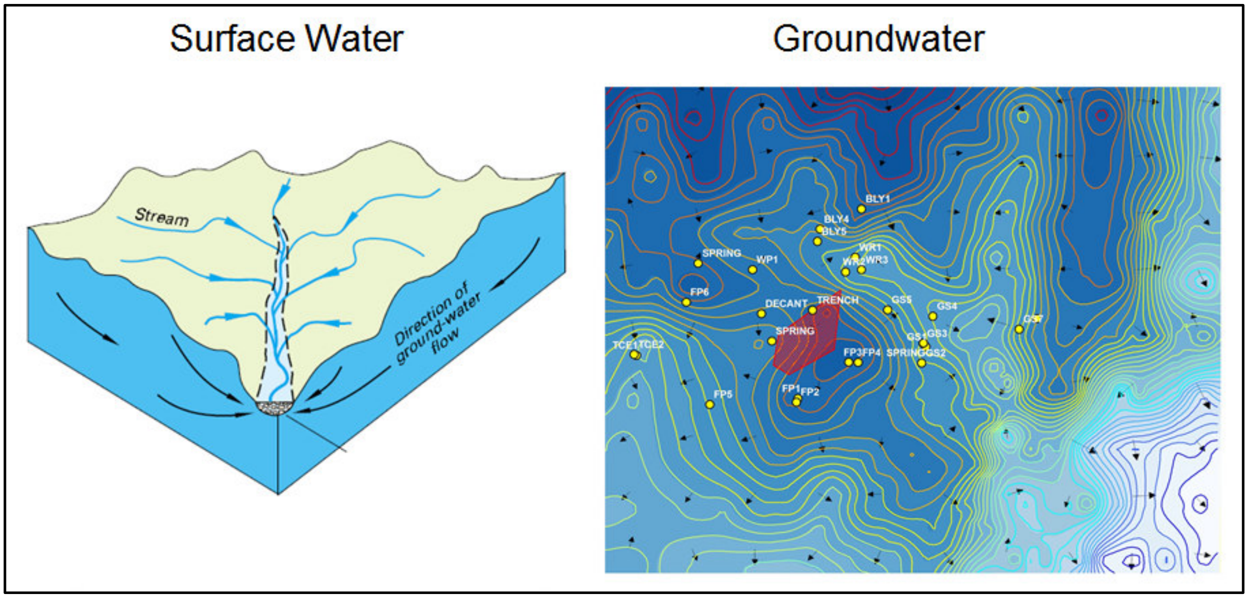

Figure 3: Surface water catchment flow dynamics and groundwater flow dynamics

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6 WAY FORWARD

The prioritisation of sub-components for RQO determination, select indicators for monitoring and propose the direction of change step (Step 4), has been successfully completed and has provided information required to develop draft RQOs and Numerical Limits.

7 ACKNOWLEDGEMENTS

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9 APPENDIX

APPENDIX B: LOWER VAAL – DETERMINING DEMAND FOR WETLAND GOODS AND SERVICES

IUA	DESCRIPTION OF RESOURCES	ECOLOGICAL ASSESSMENT	SOCIO-ECONOMIC ASSESSMENT	GOODS AND SERVICES ASSESSMENT
LA1	**Upper Harts River** The IUA includes the Upper Harts and Klein Harts systems. Sannieshof is the only urban area of any importance in the area. Most of the impacts are associated with agricultural activities (which includes dryland agriculture and livestock farming) and abstraction due to limited centre pivot irrigation.	Baberspan, a Ramsar site occurs in this IUA and is important for recreation in terms of bird watching. Additional areas were also evaluated and it was found that the C EC is representative of the larger area.	Grouped assessment for LA1-4 was undertaken. The area hosts the mining, manufacturing and irrigation agriculture sectors. The main urban centres are Schweizer-Reneke, Taung and Hartswater. The main contributor to GDP and employment opportunities is the mining sector.	The population density is low and overall the usage of G&S is likely to be low.
	Key Demand: Water quality enhancement (i.e. help mitigate the runoff from agricultural activities) **Key Wetland HGMs: Floodplains and Unchannelled Valley Bottom Wetlands**			
LA2	**Middle Harts River** This IUA includes the middle Harts River upstream of Wentzel Dam. Land use is primarily dryland agriculture and urban areas include Schweizer-Reneke and Delareyville.		Refer to LA1	The population density is low and overall the usage of G&S is likely to be low.
	Key Demand: Water quality enhancement (i.e. help mitigate the runoff from agricultural activities) **Key Wetland HGMs: Floodplains and Unchannelled Valley Bottom Wetlands**			
LA3	**Dry Harts River** This IUA represents the dry Harts River system. Vryburg is the only urban area of any importance in the area. Population density is low to very sparse. No regulation storage is present in this catchment and the flow is largely natural. The whole reach is characterised by extensive erosion (overgrazing). The upper reaches consist of settlements, e.g. Leshobo and Matlapaneng.		Refer to LA1	Goods and Services usage is limited in this area.
	Key Demand: Erosion control in the Dry Harts River system **Key Wetland HGMs: Floodplains, CVBs, UVBs, and Seeps**			
LA4	**Lower Harts River** The upper portions of the area are largely influenced by the Vaalharts Irrigation scheme which generates a significant base flow	It was observed that the main river is in a much more degraded state than the ephemeral tributaries.	Refer to LA1	Recreational fishing is limited, while subsistence fishing is limited throughout the IUA, but is of some

IUA	DESCRIPTION OF RESOURCES	ECOLOGICAL ASSESSMENT	SOCIO-ECONOMIC ASSESSMENT	GOODS AND SERVICES ASSESSMENT
	in the river due to irrigation return flows. The lower portion of the IUA, downstream of Spitskop Dam, is influenced by releases for irrigation abstracted along the river reach with little flow reaching the Vaal River. Dryland commercial agriculture is the most significant land use. The major towns are Hartswater and Pampierstad in the upper portion of the IUA, while the population of the lower portion of the area is negligible (**DWA, 2011c**). The irrigation return flows from Vaalharts Irrigation Scheme (increased base flows) in the upper reaches as well as the effect of Spitskop Dam (reduction in moderate flow events) in the lower reaches are the biggest impacts within the IUA.			importance to the residents of Pampierstad.
	Key Demands: Water quality enhancement (i.e. help mitigate the runoff from agricultural activities) and monitoring the impact of the irrigation scheme on wetlands along the main river **Key Wetland HGMs: Floodplains and Unchannelled Valley Bottom Wetlands**			
LB	**<u>Vaal River downstream of Bloemhof dam to Orange confluence</u>** The IUA includes the Vaal River downstream of Bloemhof Dam which serves as a conveyance conduit to supply water for irrigation and urban use in the lower reaches of the Vaal River (Kimberley, Christiana, Warrenton, Windsorton, Barkly West and Delportshoop). The Douglas Irrigation Scheme is supplied from the Douglas Weir and, in addition to the runoff entering Douglas Weir from the upstream incremental catchments, water is transferred (pumped) from the Orange River into the weir. The IUA has significant irrigation agriculture along the banks of the river and the river operating rule entails that no water from the Vaal River	The river stretch downstream of Douglas Weir is a very important migration corridor between the Vaal and Orange Rivers and therefore this area is of high Ecological (instream) Importance. Currently there are often zero flows in this river stretch. The key indicator species that would be potentially impacted by a change in flow regime would be *Labeobarbus kimberleyensis* (BKIM) which is a Red Data species. The recommendation was put forward to improve the PES of a C/D to a	The economic activity in the IUA consists of mining, manufacturing and irrigation agriculture sectors. The main urban centres are Bloemhof and Jan Kempdorp. The main contributor to GDP and household income is the manufacturing sector. The agricultural sector contributes the most to employment opportunities. The economic cost of providing the flow to achieve the recommended ecological category at the Douglas EWR site was estimated to be	Recreational fishing is of importance while subsistence fishing, although limited, may play some role for residents from the pooper parts of the towns in the area. Return flow dilution and assimilation as a function of the river is of some importance given that land use is primarily commercial agriculture particularly given the intensity of use.

IUA	DESCRIPTION OF RESOURCES	ECOLOGICAL ASSESSMENT	SOCIO-ECONOMIC ASSESSMENT	GOODS AND SERVICES ASSESSMENT
	reaches the Orange River. Outside of the riparian zone the most prominent land use is dryland commercial agriculture with very sparse populations.	C EC which could be attained by setting revised flows based on revised hydrology which was an improvement on the current zero flow durations.	between R511 million and R569 million and is as a result of the reduction in the available water in the Vaal River System (**DWA, 2012**).	
	Key Demands: Water quality enhancement (i.e. help mitigate the runoff from agricultural activities) **Key Wetland HGMs: Floodplains and Unchannelled Valley Bottom Wetlands**			