A PROCEDURE TO DEVELOP AND MONITOR WETLAND RESOURCE QUALITY OBJECTIVES

Ian Bredin, Adwoa Awuah, Catherine Pringle, Leo Quayle, Donovan Kotze, and Gary Marneweck

WATER RESEARCH COMMISSION

TT 795/19

A PROCEDURE TO DEVELOP AND MONITOR WETLAND RESOURCE QUALITY OBJECTIVES

Report to the
WATER RESEARCH COMMISSION

by

INSTITUTE OF NATURAL RESOURCES

in association with

UNIVERSITY OF KWAZULU-NATAL AND WETLAND CONSULTING SERVICES

Authors: Ian Bredin[1], Adwoa Awuah[1], Catherine Pringle[1], Leo Quayle[1], Donovan Kotze[2], and Gary Marneweck[3]

[1] Institute of Natural Resources, Pietermaritzburg, South Africa
[2] University of KwaZulu-Natal, Pietermaritzburg, South Africa
[3] Wetland Consulting Services, Pretoria, South Africa

WRC Report No. TT 795/19
ISBN 978-0-6392-0069-9

August 2019

OBTAINABLE FROM

Water Research Commission
Private Bag X03
Gezina 0031
South Africa

orders@wrc.org.za or download from www.wrc.org.za. Alternatively the report and all supporting information can be downloaded from https://sites.google.com/site/wetlandrqos

The publication of this report emanates from a project entitled: *The development of a refined procedure to develop and monitor wetland RQOs* (WRC Project No. K5/2547).

RECOMMENDED CITATION

Bredin, I.P., Awuah, A., Pringle, C., Quayle, L., Kotze, D.C. and Marneweck, G.C. 2019. A procedure to develop and monitor wetland resource quality objectives. WRC Report No TT 795/19. Water Research Commission, Pretoria.

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

There is a clear challenge with respect to the link between development and sustainable wetland management. The challenge is to maintain and reinstate the functions of South Africa's wetlands in order to ensure that the per capita ecosystem service levels provided by wetlands keep pace with a developing population and its growing demands on the resource base. This can only be achieved by giving effect to the National Water Act (No. 36 of 1998) (NWA) in co-operation with other relevant authorities and stakeholders.

The report provides an overview of the procedure to develop and monitor wetland Resource Quality Objectives (RQOs) in part one, and then a step-by-step technical guideline to implementing the steps of the procedure in part two. The approach focuses on determining primarily qualitative, or at best semi-quantitative, RQOs for priority wetland resources throughout Water Management Areas. The procedure is based on the need to balance practicality with sourcing wetland data at a suitable confidence level for the purposes of setting wetland RQOs.

The aim of the procedure is to provide a recommended standardized procedure for determining RQOs for wetlands. It should guide authorities of key departments, catchment managers, classification and RQOs consultants, and specifically wetland specialists through the recommended procedure to develop and monitor RQOs for wetlands. The recommended steps in the procedure include:

- Step 1: Identify potentially significant wetland resources;
- Step 2: Identify, verify and prioritize wetland resources to inform the delineation of Resource Units;
- Step 3: Desktop delineation, Present Ecological State and Importance and Sensitivity of Priority Wetland Resources to determine the Recommended Ecological Category and to inform the delineation of Resource Units;
- Step 4: Determine sub-components and indicators; and
- Step 5: Set Resource Quality Objectives, and numerical criteria, and provide implementation information

The first step in the procedure is to describe the broad wetland groups throughout the WMA, identify wetlands that are likely to be providing ecosystem services that are in demand, and wetlands that are likely to be significant from an ecological perspective. The National Wetland Map 5 (NWM5) or a best available wetland spatial layer, with the necessary attributes should be used as baseline data. The initial broad assessments provide an initial insight into the potential significant wetlands throughout the study area. Subsequent actions allow for the start of the collection of additional data and further interrogation of the data. A key component to the initial step in the procedure is a catchment tour, which will allow the project team the opportunity to get a better understanding of the catchment. It is an important step for developing a baseline for determining RQOs for wetland resources.

Step two of the procedure focuses on identifying and prioritizing significant wetland resources. The first phase should be a desktop verification of the outcomes from the initial rapid assessments. The second phase is then a more detailed verification of the significant wetland resources selected during the first phase. All available wetland resource information should be taken into consideration in the second phase. This may include information from specialists with a good understanding of the study area or information from available assessments, such as reserve studies.

Steps one and two have allowed for an iterative verification of the significant wetland resources and subsequent subset of priority wetland resources. However, further assessment is required to achieve a level of understanding of the priority wetland resources that will allow for the setting of RQOs.

Step three provides a process for developing an understanding of the extent of the wetland resource, the type or types of wetland HGM units that make up the wetland resource, and the Present Ecological State (PES) and the Importance and Sensitivity (IS) of the wetland resource. This is required because there is generally insufficient data, at a sufficient level of confidence, to set RQOs for wetland resources. Through following the actions in this step it is feasible to obtain sufficient information for determining the Recommended Ecological Category (REC) for the priority wetland resources, and embed the wetland resources into river or groundwater Resource Units (RUs).

Step four of the procedure has two key objectives. Firstly, to build an understanding of the impacts, and current and future pressures on priority wetland resources, and secondly identify sub-components and the associated indicators and numerical criteria (includes methodologies and monitoring requirements). During this process it is important to give consideration to the impacts of land-based activities on priority wetland resources.

Based on the indicators determined in Step four, RQOs can be developed for wetlands in Step five. Numerical criteria can be proposed, where applicable, for the RQOs recommended for the priority wetland resources. Numerical criteria translate the narrative RQOs into numerical values which can be monitored and assessed for compliance. However, given the approach to developing the majority of RQOs for the priority wetland resources, the RQOs will mostly be qualitative in nature. Step five also provides for the documenting of implementation information, with a specific focus on monitoring requirements. As part of the monitoring, a desktop monitoring method has been developed to assist with monitoring priority wetland resources in a more efficient and cost-effective way.

The procedure provides a step-by-step approach to develop and monitor qualitative RQOs for wetland resources, and where there is sufficient data it also allows for the determining of quantitative RQOs with numerical limits. It is based on the need to balance practicality with sourcing wetland data at a suitable confidence level for the purposes of setting RQOs. While the procedure allows for the development of RQOs, there is opportunity for improvement as we gain a better understanding of the country's wetland resources. Therefore, this procedure should be viewed as part of a process for enhancing how we identify and set key management objectives for South Africa's priority wetland resources.

Given that the procedure provides for the identification of priority wetland resources across the country, and the setting of objectives to sustainably manage priority wetland resources, there is an opportunity to contribute to the way South Africa reports on Sustainable Development Goal (SDG) 6, and specifically Target 6.6. In particular, there is a significant opportunity to utilize the recommended desktop monitoring method for not only monitoring the country's priority wetland resources from a RQOs perspective, but also from an SDG perspective.

ACKNOWLEDGEMENTS

The development of the procedure to develop and monitor wetland Resource Quality Objectives (RQOs) was funded by the Department of Water and Sanitation (DWS). Mr Bonani Madikizela and Ms Gerda Kruger from the Water Research Commission (WRC) are acknowledged for facilitating and giving invaluable advice on the administration of the project.

The Reference Group consisted of:

- Mr Bonani Madikizela (WRC);
- Dr Wietsche Roets (DWS);
- Ms Nancy Job (South African National Biodiversity Institute (SANBI));
- Dr Justine Ewart-Smith (Freshwater Consulting Group (FCG));
- Ms Mohlapa Sekoele (DWS);
- Dr Chris Dickens (IWMI);
- Ms Jacqueline Jay (DWS);
- Mr Dean Ollis (FCG);
- Ms Namhla Mbona (SANBI);
- Dr Piet-Louis Grundling (Department of Environmental Affairs (DEA));
- Dr Heather Malan (Freshwater Research Centre (FRC));
- Dr Gerhard Cilliers (DWS); and
- Mr Tumisho Ngobela (FCG)

Many different stakeholders contributed to the development of the procedure to develop and monitor wetland RQOs, and we wish to acknowledge their inputs. It is not possible to list everyone. However, we specifically wish to acknowledge the following contributors:

- Dr Justine Ewart-Smith (FCG) and Ms Louise Lodenkemper (Aurecon) for their valuable contributions to the case study, which guided the development of the procedure for determining wetland RQOs.
- Ms Simone Chetty, Ms Salona Reddy, Ms Samiksha Singh, and Mr Jarryd Gillham from the Institute of Natural Resources (INR) for their contributions throughout various stages of the project.
- Mr Perushan Rajah from the INR for is valuable contribution to developing the proposed wetland desktop monitoring method, which is recommended for desktop monitoring of priority wetland resources.

This page was intentionally left blank

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Climatic region	The climatic settings determined by the ratio of Mean Annual Precipitation (MAP) to Potential Evapo-Transpiration (PET) as defined by Schulze (2007) where: 1 = Arid (<0.2); 2 = Semi-arid (0.2-0.5); and 3 = Dry sub-humid to humid (>0.5).
Ecosystem Service Hot Spot	An area or wetland zone which is considered to have a high potential supply and demand of ecosystem services from a user perspective. A high potential supply and demand of ecosystem services is determined and described at an individual Water Management Area level and can differ for adjacent water management areas.
Importance and Sensitivity	The Importance of a wetland resource is a quantified expression of its importance to the maintenance of biological diversity and ecological functioning at a local and landscape level whilst its sensitivity refers to its fragility or the ability to resist or recover from disturbance.
Multipart feature	Multipart feature is defined as where multiple polygons or spatial features within a shapefile are linked to a single record in the attribute table.
Primary Drainage Region	Primary drainage regions are the broad hydrological catchment areas in South Africa.
Priority wetland	A significant wetland resource or cluster of wetlands which have been prioritized, or are a select subset of significant wetland resources based on ecological, socio-cultural and water resource use importance criteria and for which, Resource Quality Objectives could be set.
Recommended Ecological Category	The Recommended Ecological Category (REC) or future state of a wetland resource is determined by the PES and IS. Wetland resources which have PES categories in an E or F ecological category are deemed unsustainable by the DWS. In such cases the REC must automatically be increased to a D.
Required Management Scenario	An approved set of descriptive conditions provided as part of the Resource Quality Objectives which include: quantity, quality, habitat and biota indicators.
Significant water resource	Water resources that are deemed to be significant from a water resource use perspective, and/or for which sufficient data exist to enable an evaluation of changes in their ecological condition in response to changes in their quality and quantity of water. Water resources are deemed to be significant based on factors

	such as, but not limited to, aquatic importance, aquatic ecosystems to protect and socio-economic value (DWA, 2013).
Significant wetland resource	Significant Wetland Resources are wetland resources that are deemed to be significant from an ecosystem conservation perspective and/or a water resource use perspective, including both current and future use. This includes a variety of physical, biological and social factors such as size, location, wetland Importance and Sensitivity and ecosystem service use and non-use values.
Single part feature	Single part feature is defined as where each polygon within the shapefile has its own record and unique attributes.
Water Management Areas	Water Management Areas are the water administrative regions.
Water resource	Includes a watercourse, surface water, estuary, or aquifer
Watercourse	Includes: • a river or spring; • a natural channel in which water flows regularly or intermittently; • a wetland, lake or dam into which, or from which, water flows; and • any collection of water which the Minister may, by notice in the Gazette declare to be a watercourse.
Wetland	Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.
Wetland complex	Areas of wetland and upland terrain where the provision of ecosystem services and biodiversity value is enhanced due to the close proximity of the group of wetlands.
Wetland zone	An area within which a wetland resource is likely to occur. A wetland zone is spatially represented as the combined spatial extent of a low confidence delineated wetland and the area within a 200 m radius of the delineated wetland boundary. Used in the determination of hot spot areas.
Wetland zone of influence	The area within a 200 m radius of a delineated wetland covering a portion of the upslope catchment.

ACRONYMS

ALARM	Automated Land-based Activity Risk Assessment Method

BAS	Best attainable score
BHNR	Basic Human Needs Reserve
CMAs	Catchment Management Agencies
CR	Critically Endangered
CWBC	Coordinated Water Birds Counts
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitations
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EN	Endangered
EWR	Ecological Water Requirements
EWT	Endangered Wildlife Trust
FCG	Freshwater Consulting Group
FLD	Integrated score for flood attenuation
FRG	Freshwater Research Centre
GIS	Geographic Information System
HGM	Hydro-geomorphic
IBAs	Important Birding Areas
INR	Institute of Natural Resources NPC
IS	Importance and Sensitivity
IUAs	Integrated Units of Analysis
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
LT	Least Threatened
NAEHMP	National Aquatic Ecosystem Health Monitoring Programme
NFEPA	National Freshwater Ecosystem Priority Areas
NW&SMP	National Water and Sanitation Master Plan
NWA	National Water Act
NWM	National Wetland Map
NWMP	National Wetlands Monitoring Programme
NWRCS	National Water Resource Classification System
PES	Present Ecological State
RDM	Resource Directed Measures
REC	Recommended Ecological Category
REMP	River Ecostatus Monitoring Programme
RQOs	Resource Quality Objectives

RUs	Resource Units
SABAP2	South African Bird Atlas Project 2
SANBI	South African National Biodiversity Institute
SANSA	South African National Space Agency
SDGs	Sustainable Development Goals
SDMT	Integrated score for avoided sedimentation
STRM	Integrated score for streamflow regulation
SWSA	Strategic Water Source Areas
TEC	Target Ecological Category
UKZN	University of KwaZulu-Natal
VU	Vulnerable
WCS	Wetland Consulting Services (PTY) Ltd.
WMA	Water Management Area
WQ	Integrated score for water quality enhancement
WRC	Water Research Commission
WRCS	Water Resource Classification System

This page was intentionally left blank

PART 1: A PROCEDURE TO DEVELOP AND MONITOR WETLAND RESOURCE QUALITY OBJECTIVES

1. INTRODUCTION

1.1. Background

Wetlands are unique ecosystems in the landscape that play an essential role in the functioning of the hydrological cycle (DWA, 2014a). They vary in their characteristics and environmental role, depending on the nature of the landscape in which they occur. Different types of wetlands require different management and protection actions, and exhibit different levels of vulnerability to impacts and resilience to environmental change (DWA, 2014a).

In general people are uninformed of the importance of wetlands. This general lack of understanding has often resulted in improper use and management of these resources. As a result wetlands are prime examples of ecosystems that, despite their provision of important goods and services, have been extensively impacted by a range of anthropogenic activities (DWS, 2014a).

Consequently, a clear challenge has emerged with respect to the link between development and sustainable wetland management (DWA, 2014a).The challenge is to maintain and reinstate the functions of South Africa's wetlands in order to ensure that the per capita ecosystem service levels provided by wetlands keep pace with a developing population and its growing demands on the resource base (DWA, 2014a). This can only be achieved by giving effect to the National Water Act (No. 36 of 1998) (NWA) in co-operation with other relevant authorities and stakeholders.

1.2. Resource Directed Measures

Resource Directed Measures (RDM) consists of three major processes (DWS, 2016a):

- The Water Resource Classification System (DWAF, 2006);
- The determination of the Reserve (Louw and Hughes, 2002); and
- The determination of Resource Quality Objectives (RQOs) (DWA, 2011).

These processes were gazetted (Gazette No. 19182, Notice No. 1091) on the 17 September 2010[1]. This gazette provides procedures (in the format of steps) for each of the RDM processes, which are largely similar to the initially designed steps for the Reserve and Classification. However the steps for the determining of RQOs do not align with those proposed in the 'Procedure to develop and implement RQOs' (DWA, 2011). The DWA (2011) procedure to develop and implement RQOs was developed after the gazetted steps. A summary of these steps is provided in Annexure 1 for reference purposes.

According to DWS (2016a) each of the RDM processes therefore consists of gazetted steps, guidelines, methodologies and approaches and various methods and tools supporting the

[1] Regulations for the establishment of a water resource classification system. Published under Government Notice R 810 in Government Gazette 33541. Commencement date: 17 September 2010.

methodologies. There are inherent links, overlaps and complexities within all of the steps. This situation is further complicated by the fact that the study area for these assessments is usually large with many points of interest requiring varying levels of detail dependant on whether the study is undertaken at a desktop level and/or more detailed level. Issues regarding confidence, uncertainty and decision-making on various aspects such as where the areas of focus should be in study areas, adds to the complexity of inputs, outputs and the methodologies required to achieve these outputs.

1.3. Resource Quality Objectives

The National Water Act (No. 36 of 1998) (NWA) sets out to ensure that water resources are protected, used, developed, conserved, managed and controlled in an equitable, efficient and sustainable manner. In order to achieve this, the Act prescribes a series of measures which are intended to ensure the protection of water resources so that they can be used sustainably (DWA, 2011). The NWA states that these measures are to be developed progressively within the context of the National Water Resource Strategy and catchment management strategies. In particular, the Act provides for: the Classification of significant water resources, and determining a desired Management Class; the determination and implementation of the Reserve; and the determination and implementation of RQOs.

What are Resource Quality Objectives (RQOs)?
RQOs are defined in the National Water Act as "clear goals relating to the quality of the relevant water resources." The RQOs are numerical and narrative descriptors of quality, quantity, habitat and biotic conditions that need to be met in order to achieve the required management scenario (NWA, Act No. 36 of 1998).

Why are RQOs set?
The purpose of RQOs is to establish clear goals relating to the quality of the relevant water resources. In determining RQOs a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other (NWA, Act No. 36 of 1998).

Who are they set for?
RQOs are measurable management goals that give direction to water resource managers as to how the resources need to be managed (DWA, 2011). Determining RQOs forms a vital part of the water resources management cycle, as only when managers have clear objectives will protection of the resources become a reality.

Determining a management class, based on a degree of degradation, for a water resource informs the level of management required in order to maintain or improve its quality. Resource quality[2] of a watercourse means the quality of all the aspects of a water resource, which includes:

- The quantity, pattern, timing, water level and assurance of instream flow;
- The water quality, including the physical, chemical and biological characteristics of the water;

[2] Section 1(1) of the NWA (Act No.36 of 1998).

- The character and condition of the instream and riparian habitat; and
- The characteristics, condition and distribution of the aquatic biota.

According to the NWA (Act No. 36 of 1998), a Class and **RQOs are required to be determined for all or part of water resources considered to be significant.**

The NWA defines a water resource, watercourse and wetland as:
*"Water resource'" includes a **watercourse**, surface water, estuary, or aquifer.*
"watercourse" means-
- *a river or spring;*
- *a natural channel in which water flows regularly or intermittently;*
- ***a wetland**, lake or dam into which, or from which, water flows; and*
- *any collection of water which the Minister may, by notice in the Gazette declare to be a watercourse.*

"wetland" means land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.

NWA (Act No. 36 of 1998)

Significant Water Resources: *"Water resources that are deemed to be significant from a water resource use perspective, and/or for which sufficient data exist to enable an evaluation of changes in their ecological condition in response to changes in their quality and quantity of water. Water resources are deemed to be significant based on factors such as, but not limited to, aquatic importance, aquatic ecosystems to protect and socio-economic value."(DWA, 2013)*

Significant Wetland Resources: Significant Wetland Resources are wetland resources that are deemed to be significant from an ecosystem conservation perspective and/or a water resource use perspective, including both current and future use. This includes a variety of physical, biological and social factors such as size, location, wetland Importance and Sensitivity and ecosystem service use and non-use values.

Resource Quality Objectives are a set of criteria used to safe guard the integrity of water resources. They are clearly definable numerical or descriptive goals used to sustainably manage ecosystem goods and services. RQOs provide a means of monitoring ecological systems within a catchment by providing a bench mark or standard that a resource needs to be maintained to. The implementation and monitoring of RQOs is central to the longevity of water resources and the benefits they provide to all. The key to setting RQOs is creating a balance between the use and preservation of ecosystem goods and services. RQOs are measures intended to assist managers in achieving the vision set out for the resource. They enable action and provide a means of monitoring progress. RQOs are required to be developed for all water resources, i.e. dams, rivers, lakes, estuaries, wetlands and groundwater. RQOs are set for implementing agencies within each Water Management Area (WMA). These agencies can take the form of water resource managers within the Department of Water and Sanitation (DWS), regional officials, or Catchment Management Agencies (CMAs).

The DWS is the custodian of South Africa's water resources. The DWS's mandate is the protection, use, development, control and management of water resources. Therefore, the DWS strives to ensure that all South Africans gain access to clean water and safe sanitation, while aiming for effective and efficient water resources management to ensure sustainable economic and social development.

The role of RDM is to provide a framework to ensure sustainable utilization of water resources to meet ecological, social and economic objectives and to audit the state of South Africa's water resources against these objectives (i.e. audit the implementation of RDM and resource quality against the RQOs and the Reserve). As a result, the DWS gives effect to the NWA through the establishment and implementation of RQOs for all or part of significant water resources.

1.4. Wetland RQOs and Sustainable Development Goals

The Sustainable Development Goals (SDGs) represent an ambitious agenda to eradicate poverty and achieve sustainable development by 2030 (Ramsar, 2018). Wetlands are considered to be essential to human wellbeing, inclusive economic growth and climate mitigation and adaptation (Ramsar, 2018). This is due to the provision of multiple benefits and services. For this reason wetlands are considered to be essential in achieving the SDGs, and in particular SDG 6. The setting of RQOs for priority wetland resources complements SDG 6, specifically Target 6.6.

SDG 6: Ensure availability and sustainable management of water and sanitation for all.
Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
Indicator 6.6.1: Change in the extent of water-related ecosystems over time.
This indicator comprises four sub-indicators:
6.6.1.a. Spatial extent
6.6.1.b. Water quantity
6.6.1.c. Water quality
6.6.1.d. Ecosystem health

Dickens et al. (2017)

The key to setting RQOs is creating a balance between the use and preservation of ecosystems and the goods and services they provide. Resource Quality Objectives are measures intended to assist managers in achieving the vision set out for the resource. They enable action and provide a means of monitoring progress. South Africa intends adopting a 'No Net Loss' policy as a target for wetlands, in terms of a proposed National Wetland Policy. While wetland RQOs complement SDG 6, Target 6.6, they are currently not utilized for SDG report purposes. However, it is hoped that they will influence reporting in the future.

1.5. The challenge with setting RQOs for wetlands

Resource Quality Objectives have been determined or are in the process of being determined for over a third of the country's WMAs. However, while these assessments have covered significant water resources, including wetlands, generally only RQOs for rivers, dams, estuaries and groundwater have been established for gazetting. There are a number of challenges with determining RQOs for wetlands, which include:

- Data constraints;
- Existing methodology;
- National wetland monitoring programme; and
- Wetland heterogeneity.

1.5.1. Data constraints

The DWS acknowledge and understand that wetlands are critically important systems in the larger water cycle, that they provide valuable goods and services, and that they are also important from a biodiversity perspective. The DWS also acknowledge that in order to meet the requirements of the NWA, RQOs need to be set for wetlands, which are an integral component of a watershed. However, making the link between relevant wetland research information and the practical implementation for water resource management pertaining to wetlands is still relatively new in comparison to resource management of other water resources, e.g. rivers and dams. In particular, water resource management pertaining to rivers has developed substantially over the past three decades. This has largely been due to the River Ecostatus Monitoring Programme (REMP), previously known as the Rivers Health Programme.

The setting of wetland RQOs in principle is achievable. However, ensuring that the objectives can be audited is a major challenge. This is largely due to the lack of suitable wetland data and the level of understanding of the data. The robust and scientifically defensible process of determining RQOs for rivers has been made possible because of the level of data acquired through the REMP and the knowledge generated through this process. Unfortunately, this level of data and understanding is simply not available for wetlands at a scale that would allow for the same robust procedure followed for rivers.

There have been extensive efforts to map and provide essential wetland data on a national scale, i.e. The National Wetland Map 5 (NWM5) and the National Freshwater Ecosystem Priority Areas (NFEPA). The NFEPA project achieved a significant step in mapping and prioritising wetlands as part of the focus on freshwater ecosystems. However, the level of data accuracy is constrained (Mbona et al., 2015). Mbona et al. (2015) established that 75% of the extent of wetland area mapped for their project in the Mpumalanga Highveld was not captured in the NFEPA. They suggest that similar mapping inaccuracies could be found throughout the rest of the country. The NWM5 has contributed to improving the accuracy of wetland mapping. However, there is still a need to improve the quality of the National Wetland Map. These findings are also supported by anecdotal reports from wetland experts across the country.

1.5.2. Existing methodology – an emerging field

The procedure to develop and implement RQOs (DWA, 2011) was developed to guide practitioners through the process of determining and implementing RQOs for all significant water resources. A seven step procedure was provided for the determination of RQOs, with each of the steps having a detailed direction. In summary the procedure involves defining the resources, setting a vision, determination of RQOs and Numerical Limits, gazetting and then moving to implementation, monitoring and review before starting the process all over again. In addition, two Excel spreadsheet tools were provided to assist with decision-making. The tools included a resource unit prioritisation tool and a resource unit evaluation tool.

The RQO determination procedure detailed in DWA (2011) was designed for use across rivers, wetlands and estuaries. The process of determining RQOs was set up to remain constant, with the prioritization of components and indicators varying across the different water resources. The model thus comes in three variants for the different water resources but these are essentially very similar.

The development of the DWA (2011) procedure for determining RQOs provided a useful guideline to address some of the challenges with setting RQOs. It also provided a standardized method across the different water resources. However, for wetlands specifically the method required refinement. Anecdotal evidence supported by the findings from the recent analysis of wetland tools for the operationalization of RDM project (DWS, 2016b), suggests that users find the procedure to be cumbersome and time-consuming. As a result it has not been used to its full potential, even though many aspects of the procedure are robust. In applying it, we are of the opinion that components are still valid and users are encouraged to apply it, or components, for the setting of RQOs for water resources other than wetlands.

In addition to the DWA (2011) procedure, a host of other methods / tools have been applied throughout the various steps of the process undertaken to determine RQOs. These tools have been reviewed as part of the recent analysis of wetland tools for the DWS operationalising RDM project (DWS, 2016b). In essence some of the tools, or at least components of them, are sound. However, in general key challenges were identified with the majority of the wetland tools that have been applied. The analysis undertaken for the operationalisation of RDM project further highlights the need for a refined methodology for determining RQOs for wetlands.

A key challenge identified in both the development of the RQO methodology and subsequent application of the method, was the need to ensure sustainable use of large numbers of wetlands. Although various tools have been developed by the wetland community to facilitate management of wetlands, the majority of these are detailed and require in-field application.

1.5.3. National wetland monitoring programme

The setting of wetland RQOs is possible, however auditing is difficult. This is also largely due to the lack of a functioning wetlands monitoring programme. The WRC project K5/2269, resulted in the development of a National Wetlands Monitoring Programme (NWMP). The intention of the NWMP is to assess and monitor wetlands at three different spatial scales (Wilkinson et al., 2016):

- **Tier 1**: National Scale Assessment of Wetlands, largely using existing datasets and desktop assessment methods. Results from Tier 1 of the NWMP will allow the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) to report on the extent of wetlands in the country, land-cover and land ownership and their surroundings and the extent to which wetlands in the country are protected.

- **Tier 2:** Rapid Assessment of Prioritised Wetlands involves the prioritisation of certain wetlands for further investigation, followed by field assessors spending approximately 4-8 hours at each wetland. Results from Tier 2 will allow reporting of eight indicators, namely the extent of the wetland; the present state of hydrology, geomorphology, vegetation and water quality; present ecological state based on land use; scores for ecosystem services provided by the wetland; and a measure of the threats posed by listed invasive plants to the wetland.
- **Tier 3:** Detailed Monitoring of Selected Wetlands, most of which will have been selected from Tier 2. The purpose of Tier 3 is to build a body of knowledge of wetland ecosystems and to monitor wetlands assessed as being of concern for one reason or another. A suite of indicators and protocols are provided for monitoring wetlands at this level of detail. Not all indicators will necessarily be monitored at Tier 3 wetlands. A monitoring plan will need to be developed for each of these wetlands, the details of such a plan, including the indicators, will depend on the reasons for investigating the wetland.

While the planned NWMP may address the issue of the lack of a suitable monitoring programme, it still needs to be tested. Only once testing is complete will the programme be implementable. Hence currently, it is technically and legally difficult to set RQOs for wetlands without a way in which these RQOs can be monitored. It is critical that the DWS are able to determine if RQOs are being met and if not, they need to be able to identify the origin of the problem.

1.5.4. Wetland heterogeneity

Wetlands are transitional between aquatic and terrestrial systems and generally characterised by saturated soils and hydrophytic vegetation. The saturated soils can be permanently through to temporarily saturated (Ollis et al., 2013). Wetland features therefore make it difficult to set RQOs. For example, wetlands are a lot more heterogeneous than rivers in terms of water quality and the hydrogeomorphic setting. In addition, it is important to also understand that in comparison to rivers, wetlands are also less of a “public resource” and more of a “private resource”. This is largely due to a high proportion of wetland resources occurring on privately owned land.

1.6. Purpose of this report and user requirements

The aim of this report is to provide a recommended standardized procedure for determining RQOs for wetlands. It should guide authorities of key departments, catchment managers, classification and RQOs consultants, and specifically wetland specialist through the recommended procedure for determining RQOs for wetlands. Officials from the DWS RDM office and wetland specialists are anticipated to be the primary users of this procedure. It is important to highlight that in applying this procedure the user is required to have:

- A sound understanding of wetland resources and how they function at a landscape level;
- A sound understanding of the wetland resources that occur within the focus area of the proposed study; and

- A basic to intermediate understanding of Geographic Information System (GIS) software (e.g. GIS software like ArcGIS or QGIS), which is required for key steps within the procedure.

The procedure has been developed with the understanding that currently there is typically limited wetland data available for studies of this nature and to undertake the level of assessments required to acquire the required data are currently too costly and time consuming. An alternative approach to sourcing a sufficient level of understanding of significant wetland resources that will allow for the setting of RQOs was required. An approach that is practical yet robust enough to result in the setting of RQOs.

1.7. Scale of assessment

Before applying the procedure it is essential to understand the scale at which RQOs will be set for wetland resources. Wetland resources were considered at three levels: an individual wetland, a wetland complex, and wetlands throughout a region or regional wetlands. Only individual wetlands or wetland complexes are considered for the setting of RQOs. This is primarily due to the level of confidence in the data at these different scales. While a sufficient level of confidence is achievable for individual wetlands and wetland complexes, the same cannot be said for regional wetlands.

The procedure for determining wetland RQOs goes through a process of identifying potentially significant wetland resources, verifying and prioritizing wetland resources for which baseline assessments are conducted to determine the recommended ecological categories up to the drafting of the RQOs and where possible the numerical limits. For this procedure, wetland resources are considered to be either an individual wetland or a wetland complex (Figure 1). A wetland complex is defined as areas of wetlands and upland terrain where the provision of ecosystem services and/or biodiversity value is enhanced due to the proximity of the group of wetlands within the focus catchment.

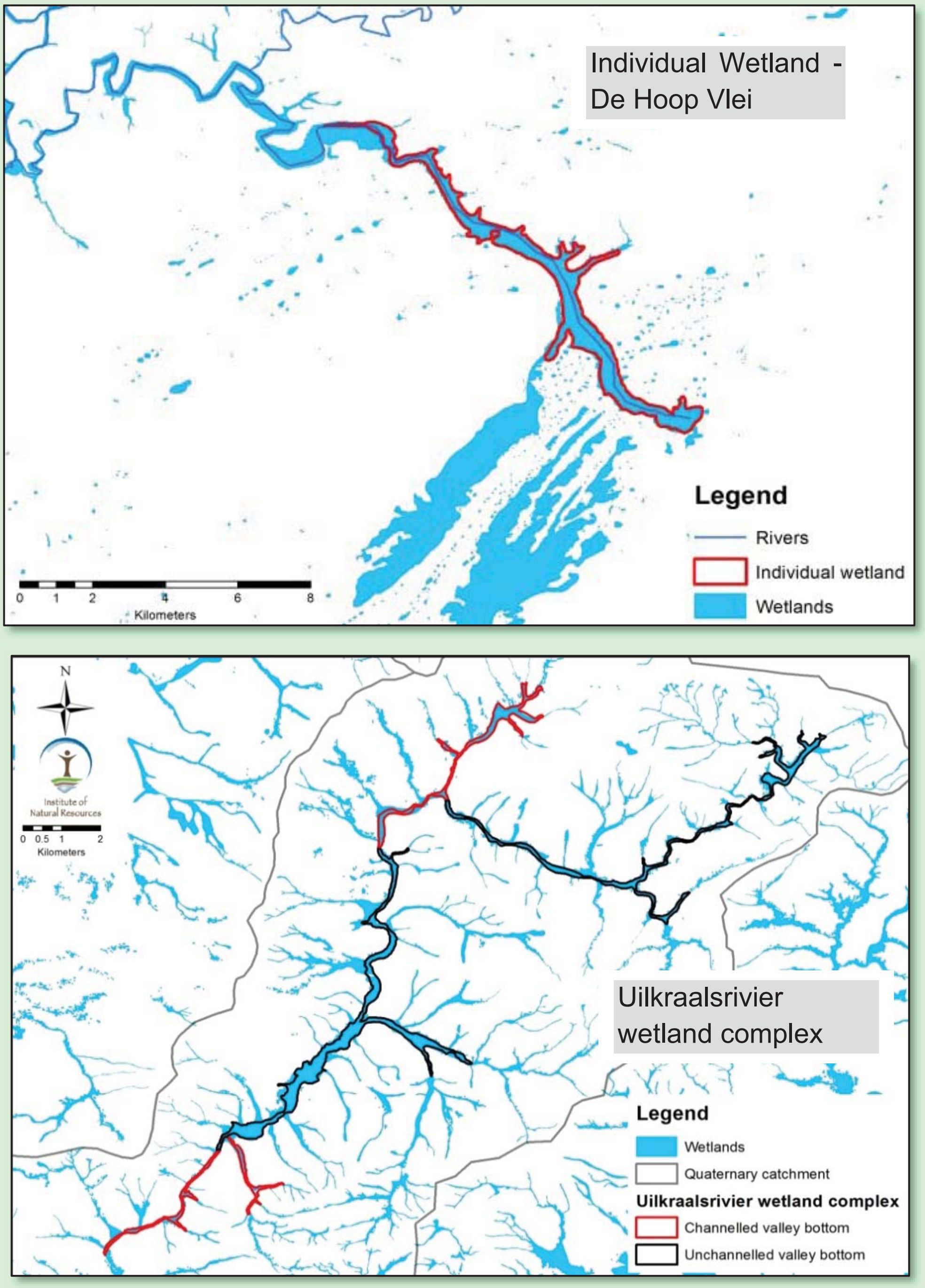


Figure 1: Examples of wetland resources at an individual wetland and wetland complex scale

2. PROCEDURE TO DEVELOP AND MONITOR WETLAND RQOS

The procedure to develop and monitor wetland RQOs is outlined below (Figure 2). It is important to highlight that given the challenges with determining RQOs for wetlands, particularly wetland data constraints, the procedure detailed in this section allows for an iterative process to gain an understanding of significant wetland resources throughout a study area. Best available wetland information is the starting point but as you progress through Steps 1-5 a greater understanding of the wetland resources will be acquired, which is essential for determining RQOs. It is envisaged that RQOs will be determined based on a sound understanding of the selected priority wetland resources (Bredin et al., in press).

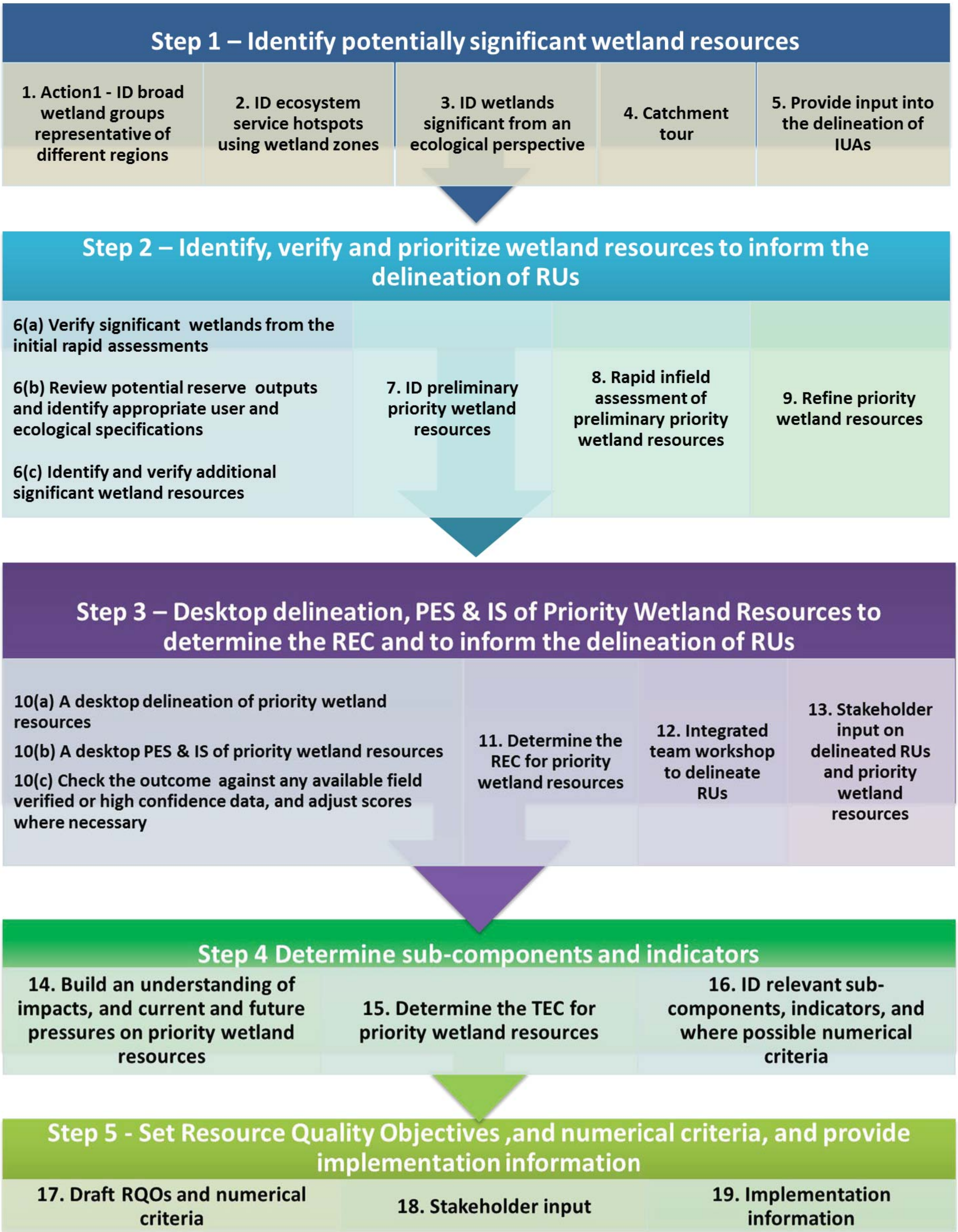


Figure 2: Summary of the procedure for determining wetland RQOs

2.1. Step 1 – Identify potentially significant wetland resources

The first step in the procedure is to describe the broad wetland groups throughout the WMA, identify wetlands that are likely to be providing ecosystem services that are in demand, and wetlands that are likely to be significant from an ecological perspective. This initial step in the procedure should typically be undertaken within a relatively short timeframe to allow for the information to be considered in the Classification process (e.g. to be taken into consideration when delineating Integrated Units of Analysis (IUAs)). The National Wetland Map 5 (NWM5) or a best available wetland spatial layer, with the necessary attributes (*refer to Action 2 & 3*) should be used as baseline data. The initial broad assessments will provide an initial insight into the potential significant wetlands throughout the study area. Subsequent actions will allow for the start of the collection of additional data and further interrogation of the data. A key component to the initial step in the procedure is a catchment tour, which will allow the project team the opportunity to get a better understanding of the catchment. It is an important step for developing a baseline for determining RQOs for wetlands. At this stage, best available data should be used to guide the initial / status quo assessment. While it is acknowledged that there are limitations with relying on existing national and provincial wetland data, subsequent steps in the procedure will provide an opportunity to refine the understanding of wetland resources within key focus areas.

The outcomes of Step 1 are the initial identification of broad wetland groups representative of different ecoregions, the identification of ecosystem service hotspots, and the identification of wetlands or wetland complexes of significance from an ecological perspective.

2.2. Step 2 – Identify and prioritize individual wetlands and wetland complexes throughout the study area

Step 2 of the procedure, which focuses on identifying and prioritizing significant wetland resources, should be conducted in two phases. The first phase should be a desktop verification of the outcomes from the initial rapid assessments (i.e. the verification process should be guided by the rapid ecological and ecosystem service assessment results). The second phase is then a more detailed verification of the significant wetland resources selected during the first phase. Additional significant wetland resources can be included during the second phase. All available wetland resource information should be taken into consideration in the second phase. This may include information from specialists with a good understanding of the study area or information from available assessments, such as reserve studies.

It is important to understand that the procedure is based on an iterative approach. This is largely due to the fact that we simply do not know enough about wetland resources to make informed decisions from the information currently available for wetland resources throughout the majority of WMAs in South Africa. We need to allow for an initial rapid assessment to gain an understanding of where significant wetland resources are located within a study area and then undertake a process of verifying the initial findings. This iterative approach allows for the building of understanding of the significant wetland resources and therefore an increased confidence in the delineated wetland resource, how it functions, and why it has been identified. This understanding is essential for formulating the RQOs late in the procedure. It is only after verification that significant wetland resources can be confirmed and a subset selected for RQOs determination. The subset of significant wetland resources should be referred to as the

Prioritized Wetland Resources. The prioritized wetland resources then need to be taken into consideration for the delineation of river and groundwater resource units (RUs).

The primary aim of Step 2 is to identify priority wetland resources through validating the findings of the rapid assessments undertaken for Step1 and undertaking further verification.

2.3. Step 3 – Assessment of priority wetland resources

The steps thus far have allowed for iterative verification of the significant wetland resources and subsequent subset of priority wetland resources. However, further assessment is required to achieve a level of understanding of the priority wetland resources that will allow for the setting of RQOs. Step 3 essentially provides a process for developing an understanding of the extent of the wetland resource, the type or types of wetland HGM units that make up the wetland resource, and the Present Ecological State (PES) and the Importance and Sensitivity (IS) of the wetland resource. This is required because there is generally insufficient data, at a sufficient level of confidence, to set RQOs for wetland resources.

Through following the actions in this step it is feasible to obtain sufficient information for determining the Recommended Ecological Category (REC) for the priority wetland resources, and embed the wetland resources into river or groundwater Resource Units (RUs).

It is important to note that developing a procedure that allowed for the determining of wetland data that has undergone both desktop and infield verification (albeit via a rapid infield assessment) was essential for the development of the procedure. Verified wetland data are required for the setting of RQOs. Given the acknowledged data constraints this approach allows for data gathering and the setting of limited RQOs (i.e. primarily for the habitat sub-component). Additional data, obtained through studies like intermediate reserve studies, are required to set RQOs for the other sub-components and for the setting of numerical limits (to be discussed in the subsequent Step).

2.4. Step 4 – Determine sub-components and indicators for priority wetland resources

Step 4 of the procedure for determining wetland RQOs has two key objectives. Firstly, to build an understanding of impacts, and the current and future pressures on priority wetland resources. During this process it is important to give consideration to the impacts of land-based activities on priority wetland resources. Secondly identify sub-components that may be important to either users or the environment, and select those sub-components and associated indicators for which RQOs, and where possible numerical criteria, should be developed.

2.5. Step 5 – Determine RQOs for priority wetland resources and provide implementation information

Based on the indicators determined in Step 4, RQOs can be developed for priority wetland resources. Where there is sufficient data numerical criteria may be proposed for the RQOs.

Numerical criteria translate the narrative RQOs into numerical values which can be monitored and assessed for compliance. However, given the approach to developing the majority of RQOs for the priority wetland resources at this stage, the RQOs will mostly be qualitative in nature (i.e. typically limited data are available for the setting of numerical criteria for the respective sub-components).

The basic approach to the drafting of RQOs for wetlands is outlined in Section 7. The drafted RQOs proposed will need to be reviewed, updated and refined based on stakeholder consultation.

The procedure for setting RQOs is finalized through the gazetting process. However, the process does not end once RQOs have been gazetted for priority wetland resources. The RQOs then need to be implemented, which includes monitoring and when legislation allows[3] a review of the RQOs. Therefore, an adaptive management cycle is required. Successful implementation may include: (adapted from King and Pienaar, 2011):

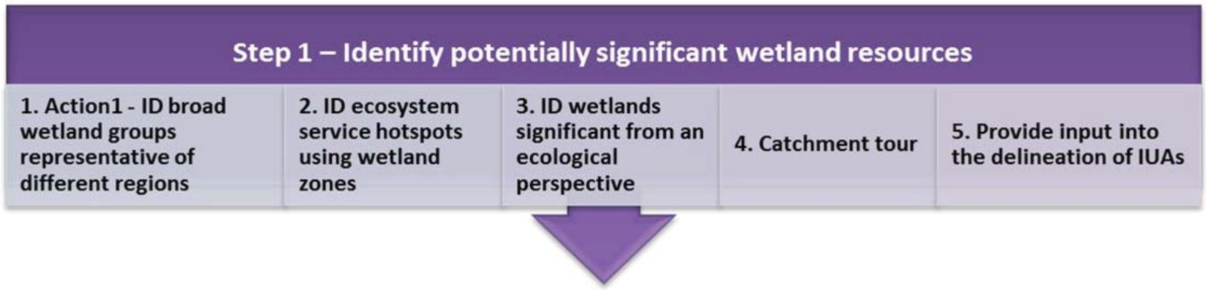
- Development of the appropriate policy, legislation and catchment management agreements;
- Re-organisation of water management institutions to meet the requirements of the NWA;
- Structured and continual engagement with stakeholders;
- Development of holistic wetland assessment methods;
- Management of the water quality, and the quality of the ecosystems that form the water resource base within the WMA;
- Development of catchment management strategies and regional regulatory mechanisms for the authorisation of water resource use;
- Creation of awareness among government and other stakeholders;
- Continual investment in research and capacity development; and
- Monitoring, enforcement and adaptive management.

The implementation of RQOs within a WMA is a complex process that should be undertaken across all priority water resources within the catchment/s of concern. The need for an integrated approach to implementing RQOs goes beyond the scope of this report. However, guidance on the desktop monitoring of priority wetland resources is provided in the technical guidelines to aid water resource managers in protecting priority wetland resources.

[3] Currently the NWA does not specify that RQOs should be reviewed. No timeframes are provided for a review of RQOs. However, through the proposed revision of the NWA there is an opportunity to incorporate a timeframe for which RQOs remain valid, and after which should be reviewed.

PART 2: STEP-BY-STEP TECHNICAL GUIDELINE FOR IMPLEMENTING THE PROCEDURE TO DEVELOP AND MONITOR WETLAND RQOS

3. STEP 1 – IDENTIFY POTENTIALLY SIGNIFICANT WETLAND RESOURCES



<u>Actions required to address this step include:</u>

1. Identify broad wetland groups representative of different ecoregions and process available wetland spatial data in the study area;
2. Conduct a rapid assessment of ecosystem services to identify ecosystem service hotspots for the provision of regulating and supporting services;
3. Undertake an initial rapid assessment to identify wetland or wetland complexes which are significant from an ecological perspective;
4. Undertake a catchment tour to broadly confirm occurrence, extent, type and condition of potentially significant wetland resources; and
5. As the wetland specialist on the project team participate in an integrated workshop to delineate IUAs.

3.1. Action 1 – Identify broad wetland groups and process available wetland spatial data in the study area

3.1.1. Identify broad wetland groups

In the ‘Development of Procedures to Operationalise Resource Directed Measures (RDM)’ (DWS, 2016b) it was suggested that broad wetland groups should be determined through an evaluation of criteria such as: wetland ecosystem types, ecoregions, geology, and ground water characteristics throughout a WMA. Developing an understanding of wetland resources throughout a WMA requires having an understanding of the broad / regional wetland groups, and thus an insight into key drivers of the relevant groups of wetlands. The rapid reserve determinations for wetlands (Rountree et al., 2013), lists specific information sources used to define wetlands at a regional scale. The status quo description of each broad wetland group follows on from the delineation of the different areas. Therefore, the information is generated as part of above action, which uses wetland type and broad biophysical characteristics to define wetland groups.

This step provides a broad overview of wetlands throughout the area of interest, which is not only important for developing an understanding of wetland resources in the WMA, but also useful for the subsequent action of determining potential ecosystem service hotspots (i.e. provides useful context). The broad scale / regional assessment should be viewed as a 'starting point' of the procedure, where a broad understanding of wetland resources can be determined and then refined throughout an iterative process.

Technical method: Broad wetland groups in the WMA are defined according to the Level I ecoregions, which are influenced by geological, vegetation, rainfall, soil and climatic controls (Kleynhans et al., 2005). The Hydrogeomorphic (HGM) unit, used for classification of wetland type, relates to location in the landscape, therefore it is important to consider the wetland groups as these provide an overview of the underlying controls of wetland type. Developing an understanding of the different characteristics of each of the wetland groups is important for determining key drivers of wetland functionality. The rapid reserve determination by Rountree et al. (2013) provides the necessary guidance on assessing broad wetland groups.

Example: The following example of level 1 ecoregions in the Breede-Gourtiz catchments is provided to help guide the recommended 'cleaning' process. As seen in Figure 3, the ecoregions do not align with the WMA boundaries resulting in the occurrence of relatively small ecoregions overlapping the peripheral areas of the WMA (i.e. small areas of the Nama Karoo and Western Fold Mountains in the Gouritz and South Western Coastal Belt in the Breede catchment).

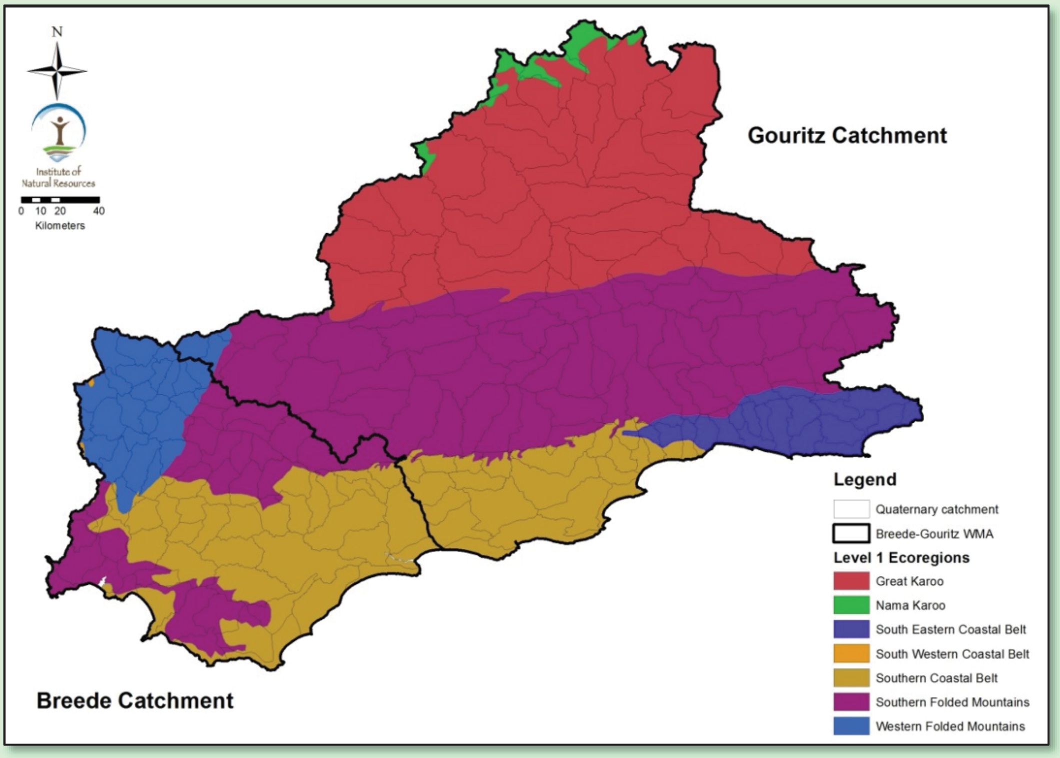


Figure 3: Breede-Gouritz wetland regions defined by the level 1 Ecoregions (Kleynhans et al., 2005)

For the purposes of selecting broad wetland groups it is impractical to select wetlands within a very small portion of an ecoregion within the study area. Therefore, the ecoregion map should be 'cleaned' to consist of the main primary ecoregions within the WMA. Ecoregions covering less than 1% of the WMA should be merged to the closest appropriate region (Figure 4).

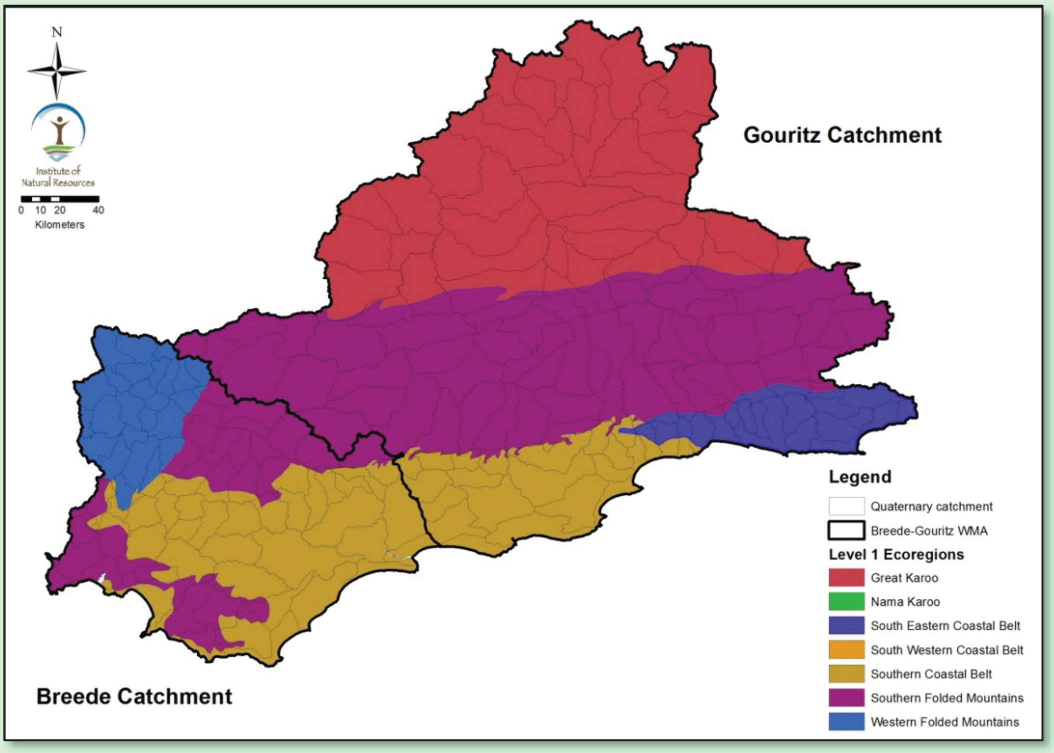


Figure 4: Example of simplified wetland regions defined by the DWS Level I ecoregions

Table 1: An example of a description of the broad wetland groups (typical wetlands), HGM types and characteristics within the Gouritz catchment (adapted from DWS, 2015)

Ecoregion	Typical wetlands type	NWM 5 HGM types	Characteristics of HGM
Great Karoo	Small seeps and river-linked wetlands with a likely high degree of direct and indirect groundwater dependence respectively.	Valley bottom	Saline, temporary to seasonal
		Seep	Groundwater-dependant, seasonal or permanent
		Depression	Saline, temporary to seasonal
		Depression	Seasonal to permanently saturated or inundated
Southern Folded	Small seeps and river-linked wetlands with a likely high degree of direct and indirect groundwater dependence respectively.	Valley bottom	Saline, temporary to seasonal
		Seep	Direct or indirect groundwater link, seasonal or permanent
South-East Coastal Belt	Channelled and unchannelled valley bottom wetlands.	Valley bottom	Seasonal or permanent
		Seep	Groundwater-dependant, seasonal or permanent

3.1.2. Process available wetland spatial data in the study area

The primary objective of this action is to process available wetland spatial data for the subsequent ecosystem service assessment. The initial broad scale identification of wetlands is based on best available wetland spatial data at a broad WMA scale (i.e. the study area). Fine scale spatial data may also be available for sections of the study area, and may be used instead of the national dataset. However it is anticipated that the national wetland spatial data will be the primary source of information for the initial identification of wetland distribution and extent (The best available national wetland spatial data currently is the NWM5).

It is acknowledged that assessments undertaken at a national level may have a limited level of accuracy. Through the testing of the procedure it was also acknowledged that the level of confidence of the national wetland spatial datasets is insufficient to describe wetland extent, type and condition for ROQ purposes (It is important to note that even provincial and /or regional wetland spatial layers were also found to be of too lower confidence level for RQO purposes). This is one of the key challenges wetland specialists face in the pursuit of developing wetland RQOs. Therefore the wetland spatial data should be used as a guide only. A guide, that allows for the identification of the presence of potential wetlands within the landscape. Wetland areas identified should include not only the potential wetland but also a zone of influence around the wetland, which has the potential to supply ecosystem services that are likely to be in demand. The zone of influence is defined by a 200 m zone around each wetland. The wetland areas identified will then need to undergo a validation process before wetland extent, type and condition can be determined for RQO purposes (i.e. subsequent steps in the procedure).

Technical method: The best available national wetland spatial data (i.e. NWM5) should be clipped to the study area to achieve a WMA wetland layer as a starting point for the required data cleaning process to develop the required wetland zones[4] (Figure 5).The data cleaning process to be undertaken should include the removal of the following:

- Dams and estuaries from the WMA wetland layer;
- Single part features where more than one polygon is linked to a single attribute;
- Single wetland polygons divided into multiple individual polygons; and
- Slivers and gaps between wetland polygons.

Polygon parts or holes within the wetland spatial data, which are less than 2ha, should be removed. The layer should then be buffered by 200 m to map the wetland zones of influence (Note: the dissolve type should be set to “all” to ensure no overlapping of buffer polygons).

[4] An area within which a wetland resource is likely to occur. A wetland zone is spatially represented as the combined spatial extent of a low confidence delineated wetland and the area within a 200 m radius of the delineated wetland boundary.

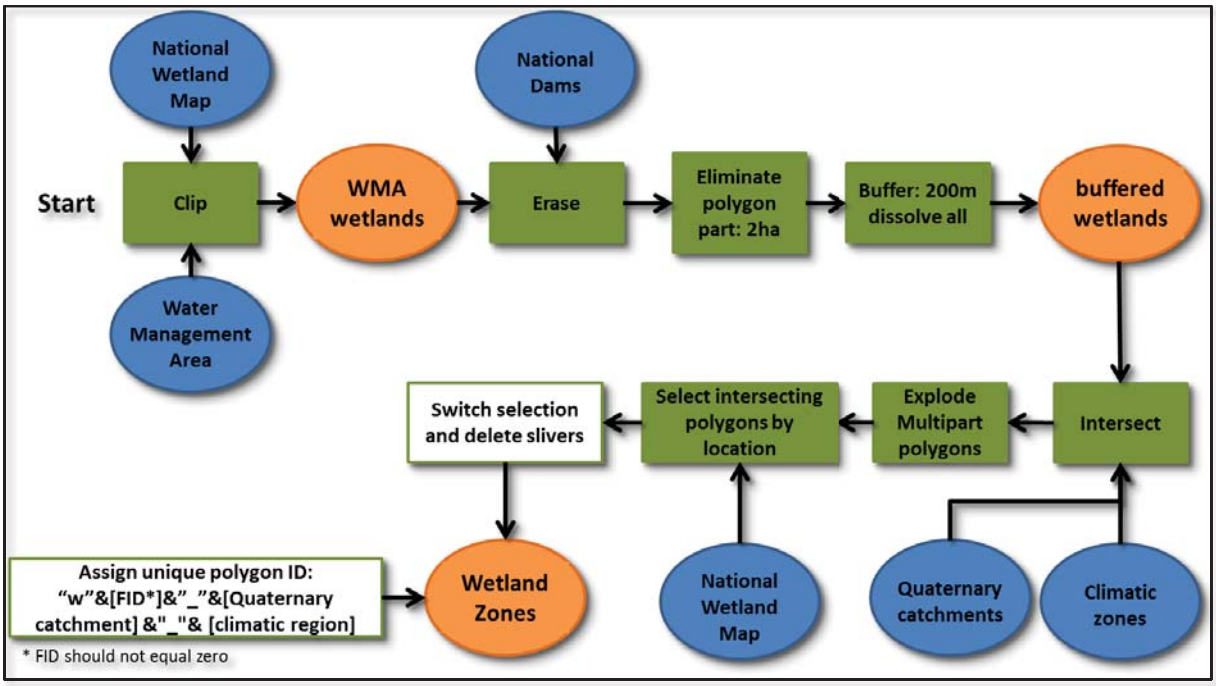


Figure 5: Schematic of the steps for developing the required Wetland Zones

The output layer (national wetlands layer buffered by 200 m) is then intersected with the quaternary catchment boundaries and the simplified climatic regions (spatial layer provided) to ensure the attributes of the wetland zones carries both the quaternary catchment name, as well as the climatic region within which it is located. This step also ensures that wetland zones are bounded by the quaternary catchment and do not extend continuously across numerous catchments. The multipart to single part tool can then be run to explode multi-part polygons[5] and ensure that for each polygon in the layer, there is a single record in the attribute table.

The buffering of the wetlands and intersection with the quaternary catchment boundaries can result in the presence of wetland zone slivers extending into the adjacent quaternary catchment. These wetland zone polygons do not intersect with the national wetlands map and should therefore be removed as they result in additional polygons which skew the results of the subsequent ecosystem services assessment. This can be done by using the select by location tool to select all wetland zone polygons which intersect with the national wetland layer. As we are interested in the polygons which do not intersect this layer, the selection can be switched / inverted to select all the polygons which do not intersect with the wetland layer. These slivers should be scanned (i.e. a rapid visual review) and then deleted from the wetland zone layer. The final step is to assign a unique ID to each wetland zone polygon. This allows for easy identification of features within the same quaternary catchment and as a safe guard against errors during the pre-processing stage. As the subsequent assessment of ecosystem services is applied with a combination of ArcGIS and Excel spreadsheets, a unique ID is required to link data across the different platforms.

[5] Multi-part feature is defined as where multiple polygons or spatial features within a shapefile are linked to a single record in the attribute table. Single part feature is defined as where each polygon within the shapefile has its own record and unique attributes.

The recommended formula to provide each polygon with a unique ID is:

“w”&[FID[6]]&”_”&[QuatName]&”_”&[ClimaticRegion[7]]

Example:

Quaternary catchment

w347_J12J_2

Field ID (wetland zone number)

Climatic region

The following figures of the Upper Breede wetland complex are provided to illustrate what the processed wetland zones look like in comparison to the initial wetland spatial layer (i.e. NWM5) (Figure 6 and Figure 7).

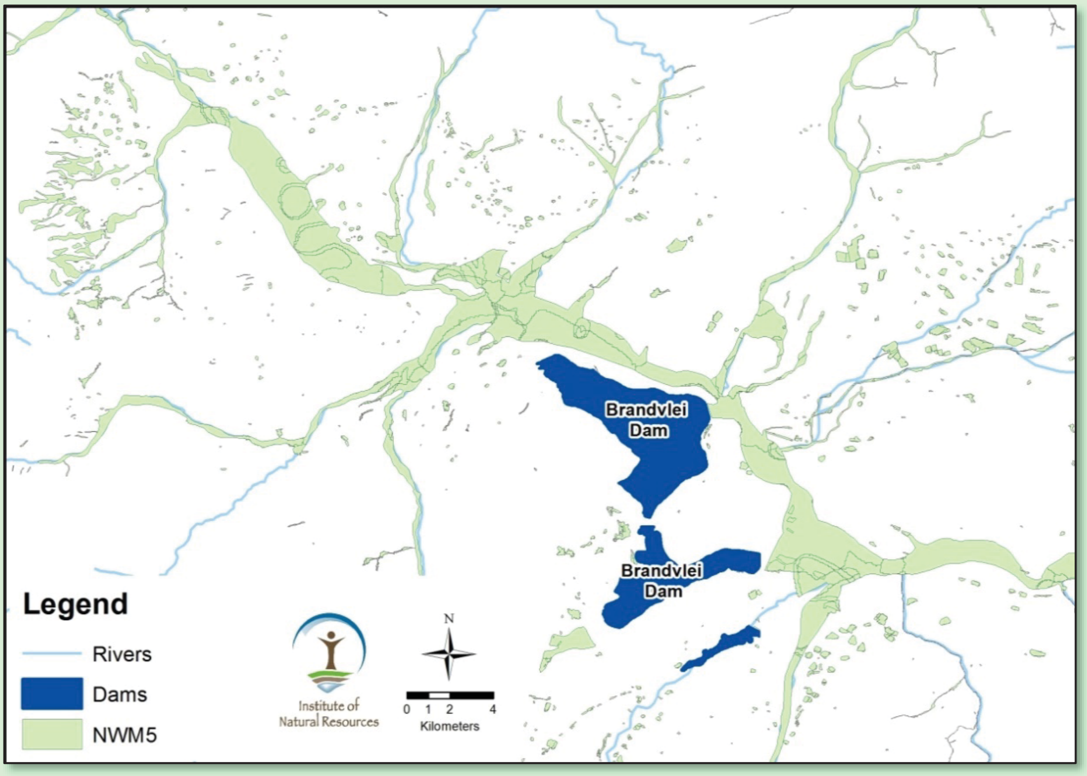


Figure 6: An example of the NWM5 wetlands spatial data where a large wetland system is divided into smaller units, largely as a result of digitising and wetland modelling procedures

---

[6] It is important to ensure the Field ID (FID) numbering in the attributes table begins with 1 and not 0.
[7] Climatic regions are represented as follows: 1 = Arid, 2= Semi-Arid and 3= Dry Sub-Humid to Humid.

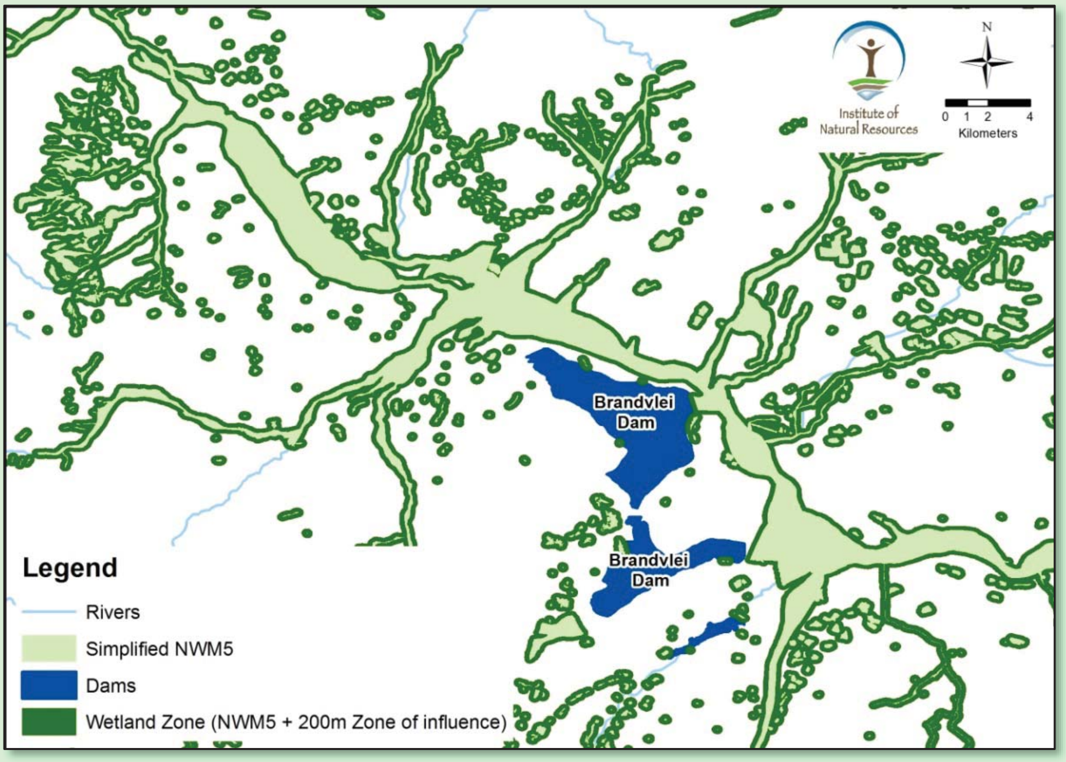


Figure 7: An example of Wetland Zones, which are defined as areas where wetland habitat is likely to occur

It is important to remember that the resulting 'wetland zone' layer that will be used in the subsequent actions of Step 1, to identify ecosystem service hotspots, comprises a likely wetland and a 200 m zone of influence. ***It is not a spatial layer representing wetland extent.*** The reasons for taking this approach were as follows:

- It was acknowledge from the onset that the National wetland layer must be considered as a low / medium confidence layer of wetland occurrence and extent.
- That it is not only the wetland / wetland cluster but the respective catchment, which needs taken into consideration for the assessment of the potential supply of ecosystem services. However, assessing entire catchments of wetlands at a WMA scale would not be practical. Therefore, the approach taken was to incorporate a 200 m zone of influence within the 'wetland zone' used to identify ecosystem service hotspots. The selection of a 200 m zone of influence was influenced by the current approach to assessing condition (i.e. Wet-Health).
- It allowed for fewer polygons for subsequent processing. Initially individual wetland polygons were used and it resulted in a very slow cumbersome process. Reducing the polygons to a clearer, simplified layer, allowed for a more efficient process to be undertaken.
- Finally, the primary factor to keep in mind is that this process is designed to '**highlight**' where ecosystem service hotspots occur at a coarse scale (i.e. quaternary catchment scale). It was not designed to automatically identify a significant wetland resource. Additional steps are required before the user is able to identify the significant wetlands Resource Units (RUs), which will require RQOs.

3.2. Action 2 – Rapid assessment of ecosystem services to identify ecosystem service hotspots using wetland zones

Ecosystem services refer to the benefits that people obtain from the environment. These services may be categorised as provisioning, regulating, cultural, habitat or supporting (Table 2). The aim of this action is to broadly identify hotspots of selected regulating services from wetlands across the study area. Hotspots are spatial areas of high supply of ecosystem service/s which coincide with areas of high demand. The demand for ecosystem services refers to ecosystem services which are currently used or consumed in a particular area over a specified period of time (Burkard *et al*., 2014).

Table 2: Classification of ecosystem services based on The Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2010)

Service type	Description and example of services
Provisioning	This service category describes the material outputs from ecosystems. They include food, water and other resources.
Regulating	These services are derived from ecosystems acting as regulators, e.g. regulating the quality of air and soil or by providing flood and disease control.
Habitat / Supporting	These services underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals.
Cultural	This service category refers to the non-material benefits people obtain from contact with ecosystems. They include aesthetic, spiritual and psychological benefits

In order to assess demand, data on actual use of ecosystem services is required. Gathering data to infer demand can be an onerous task particularly for provisioning and cultural services which typically occur at a local scale. For example, natural products from a specific wetland may be used by a nearby local community. In order to understand the demand for natural products across an entire study area, information on the use of natural products for each wetland in the study area is needed. This necessitates detailed field visits and interviews; an approach which is neither practical nor feasible when undertaking a rapid assessment.

The current methodology therefore limits the ecosystem services assessment, where supply and demand is taken into consideration, to four services (Bredin et al., in press):

- Flood attenuation;
- Water quality enhancement;
- Avoided sedimentation (i.e. a wetlands ability to trap sediment, which is important to downstream users); and
- Streamflow regulation.

These services have been selected for a number of reasons:

- Firstly, desktop data are available to infer demand for these services thereby enabling a rapid assessment approach;
- Secondly, these services are classified as regulating services which generally benefit large numbers of users; and
- Thirdly, evidence which supports the relationship between wetlands and these services is considerable and wide-spread.

This rapid assessment methodology builds on the supply-demand analysis framework described by Quayle and Pringle (2014). The method comprises two components. The first assesses the supply or capability of an ecosystem, in this case wetlands, to provide a particular level of ecosystem service. The second identifies areas of high demand. Figure 8 outlines a step-by-step guide for applying this method.

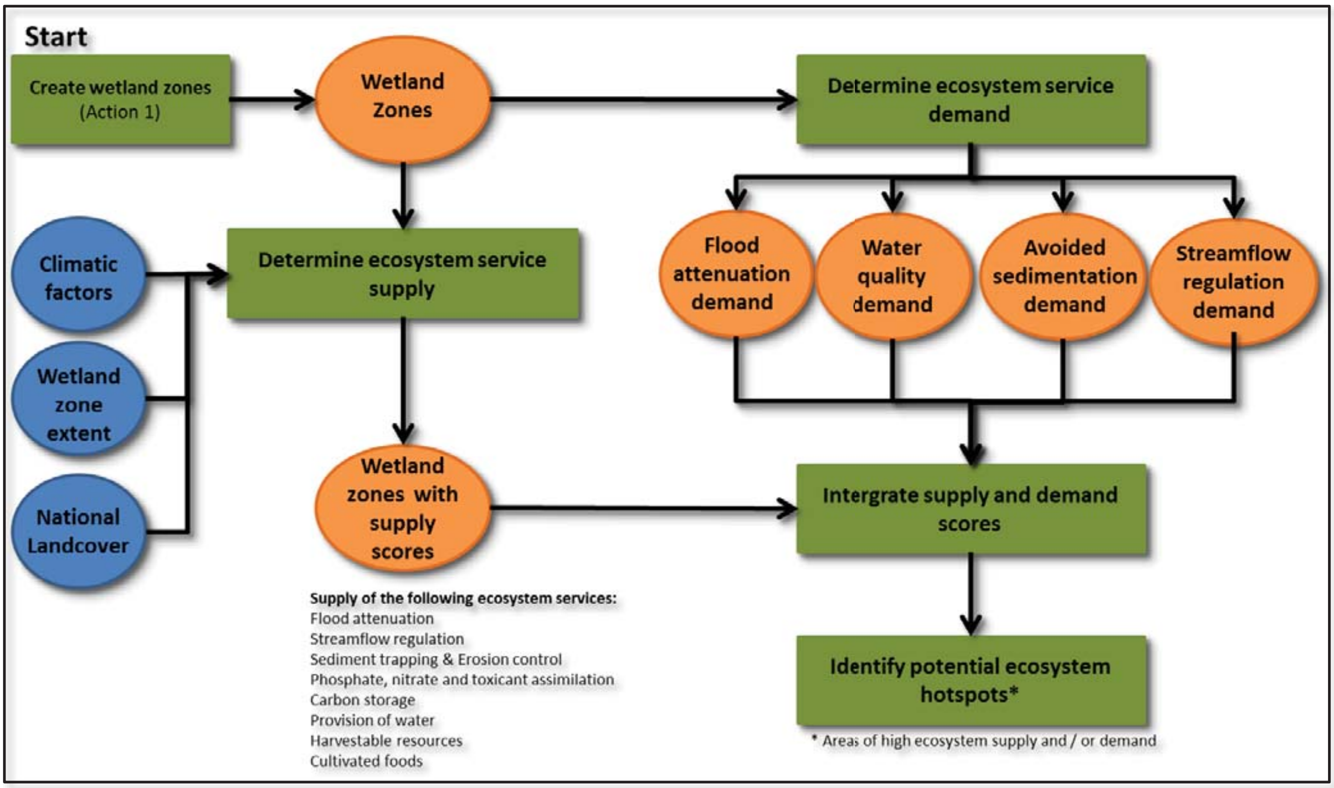


Figure 8: Schematic of the steps required to perform the rapid ecosystem services assessment

It is important to note that when a WMA comprises of two or more primary drainage regions, each of the respective **primary drainage regions** must be assessed separately. For example, the Breede and Gouritz catchments were considered as one WMA at the time of developing this procedure. However, the ecosystem service assessment was undertaken separately for each of the catchments. The assessment of ecosystem services at a primary drainage region is required to avoid the skewed selection of ecosystem service hotspots.

It is also important to note that while only four ecosystem services are assessed from a demand perspective, all services typically associated with wetlands are assessed (i.e. scored) from a supply perspective.

3.2.1. Determine the supply of ecosystem services from wetlands in the study area

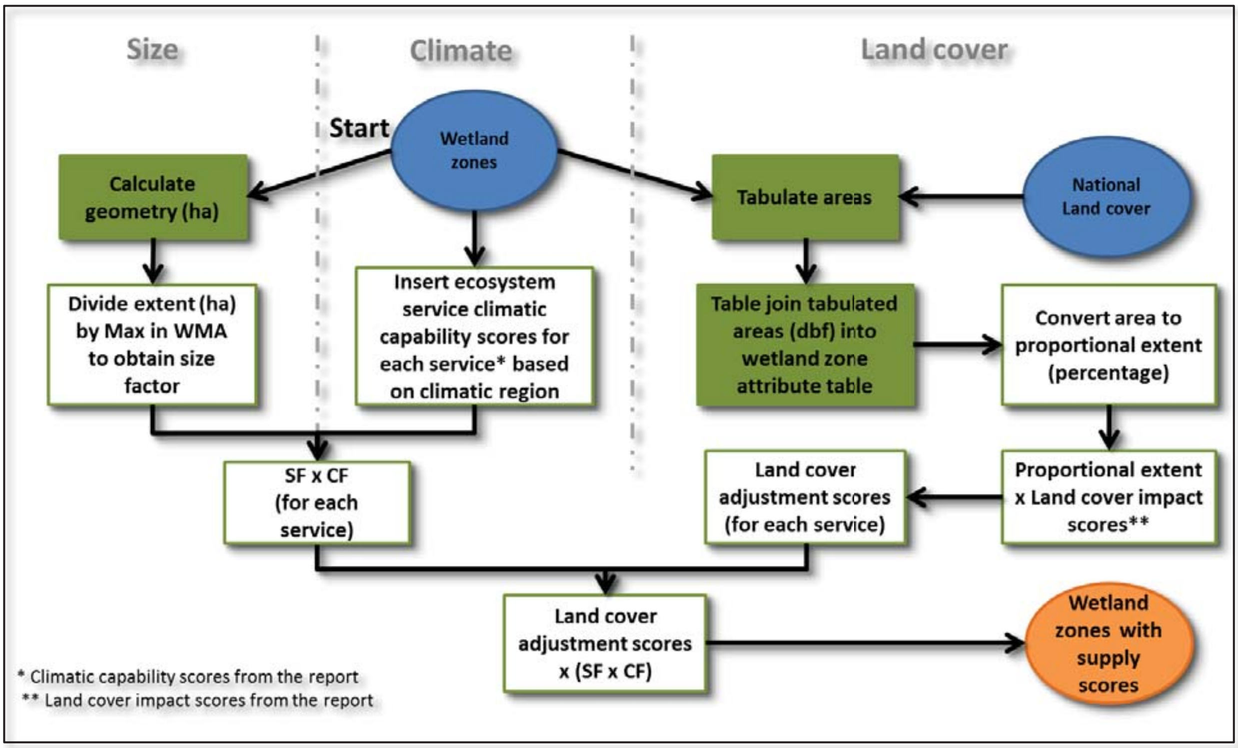


Figure 9: Schematic of the process for determining ecosystem service supply scores for wetland zones

3.2.1.1. Climatic factors

The first step in assessing the supply of the ecosystem services is to account for climatic factors impacting on the capabilities of wetlands to perform ecosystem services. A wetlands capability to supply specific services is influenced by climatic factors. For example, if a wetland is already flooded on arrival of a flood event then its capability to attenuate floods is lower than if it was in a dry state on arrival of the flood. Areas which remain flooded for prolonged periods are generally, most extensive in wetlands in humid climates and least extensive in wetlands in arid climates, which tend to be ephemerally flooded. However, climatic factors do not necessarily affect a wetlands ability to provide all ecosystem service. For example, the capability of a wetland to supply the service of sediment trapping does not vary based on climatic factors. This service is therefore supplied at a high capability across all climatic regions.

Technical method: Generic scores have been developed which indicate the capability of a wetland in different climatic settings to provide selected ecosystem services. The scoring system ranges from 1 (low capability) to 3 (high capability) and has been applied to three categories of climatic settings determined by the ratio of Mean Annual Precipitation (MAP) to Potential Evapo-Transpiration (PET) as defined by Schulze (2007) (Table 3). Therefore each wetland zone should receive a climatic factor for each of the eight listed ecosystem services in the layer attributes.

Table 3: Assumed general capability of wetlands under natural vegetation for supplying a range of ecosystem services based on the climatic region in which the wetland occurs

Ecosystem services	Capability for supplying the service based on MAP:PET ratio			Rationale
	Dry sub-humid to Humid (>0.5)	Semi-arid (0.2-0.5)	Arid (<0.2)	
Flood attenuation	2	3	3	If a wetland is already flooded on arrival of a flood event then its capability to attenuate floods is lower than if it was in a dry state on arrival of the flood, and areas which remain flooded for prolonged periods are generally most extensive in wetlands in humid climates and least extensive in wetlands in arid climates, which tend to be ephemerally flooded.
Streamflow regulation	2	1.5	1	A key factor limiting the extent to which a wetland sustains stream flows is evapo-transpirative loss, which is already potentially high in humid climates and increasing progressively with increasing aridity.
Sediment trapping & Erosion control	3	3	3	The capability of a wetland to supply the service of sediment avoidance does not vary based on climatic factors.
Phosphate, nitrate and toxicant assimilation	3	2	1.5	A variety of processes including chemical precipitation, adsorption and ion exchange contribute to the assimilative capacity of a wetland, and several of these required sustained reducing conditions, which are associated with prolonged saturation. Such conditions are most prevalent in humid climates and progressively declining in extent and duration with increasing aridity.
Carbon storage	3	2	1.5	Soil organic matter is promoted under sustained reducing conditions, which are associated with prolonged saturation. Such conditions are most prevalent in humid climates, and progressively decline in extent and duration with increasing aridity.
Provision of water	2.5	1.5	1	Besides the reduced volumes of water generally stored in wetlands under arid conditions, many such wetlands characteristically accumulate salts which impact negatively on the value of this water for human use.
Harvestable resources	2	3	2	Under humid conditions, the prolonged flooding of extensive areas of the wetland limits access to some of the potentially harvestable resources. In semi-arid climates resources are more accessible but tend to be present even in the dry season. However, in arid climates, excess water does not generally limit access to resources, but the presence of water for sustaining resources tends to be ephemeral and resource availability is therefore limited, especially in the dry season.
Cultivated foods	2	3	2	Similar to above, under humid conditions, the prolonged flooding of extensive areas of the wetland makes such areas difficult to cultivate.

A national spatial layer displaying the three climatic regions as defined by Schulze et al. (2007) was developed (Figure 10). Through an initial assessment of ecosystem services, the defined climatic zones were found to split across quaternary catchments and resulted in illogical breaks within the wetland zone areas. As the wetland zones are intersected with the climatic regions and quaternary catchments, within a number of quaternary catchments, wetland zones were further broken into many smaller polygons, leading to the assessment of multiple small polygon areas as opposed to a wetland zone unit as a whole.

To account for these errors in processing, the climatic regions have been aligned with the quaternary catchment boundaries calculating the mean MAP:PET ratio values with zonal statistics for each quaternary catchment (Figure 11). The relevant climatic adjustment factor for each ecosystem service is then applied based on the climatic region of the quaternary catchment.

The Climatic region of each wetland zone has been embedded into the naming convention detailed in the previous step where 1 = Arid, 2= Semi-Arid and 3= Dry Sub-Humid to Humid (i.e. as per the example provided in *Section 3.1.2*).

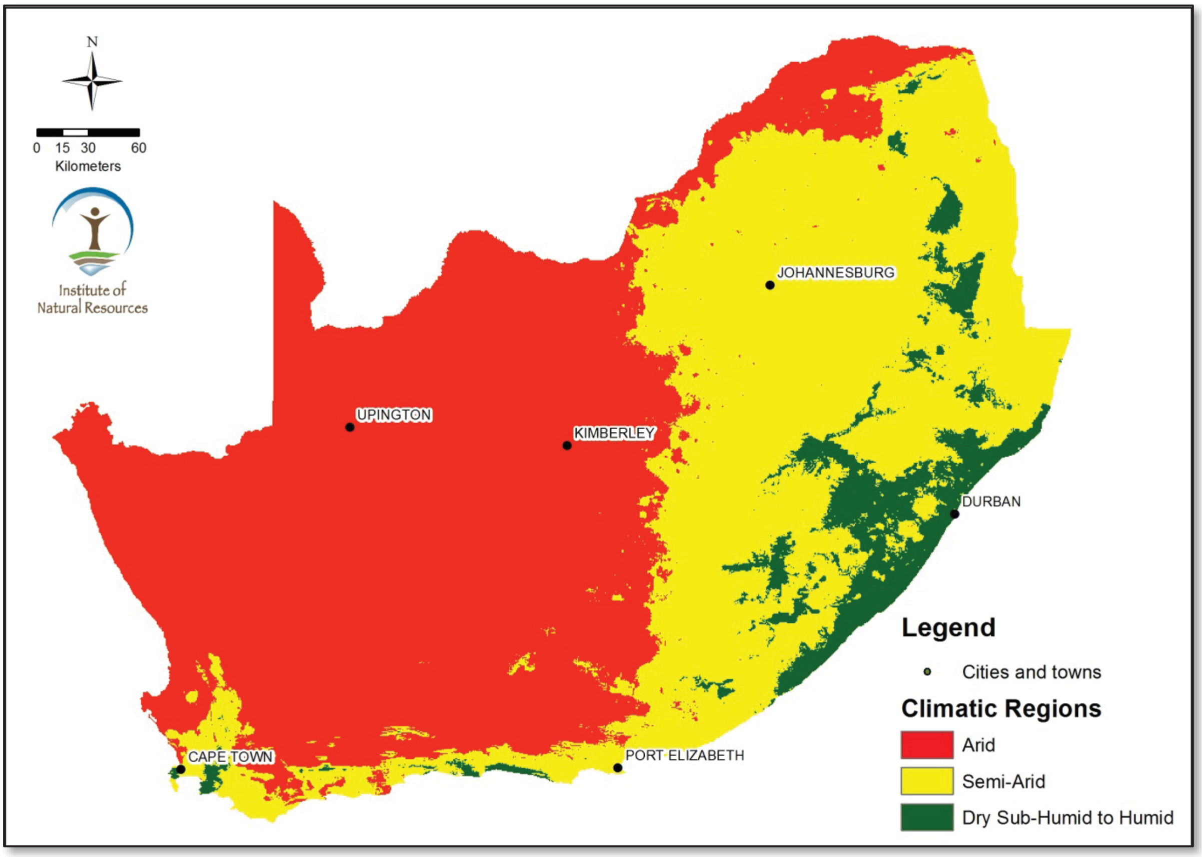


Figure 10: National climatic settings determined by the ratio of Mean Annual Precipitation (MAP) to Potential Evapo-Transpiration (PET) as defined by Schulze (2007)

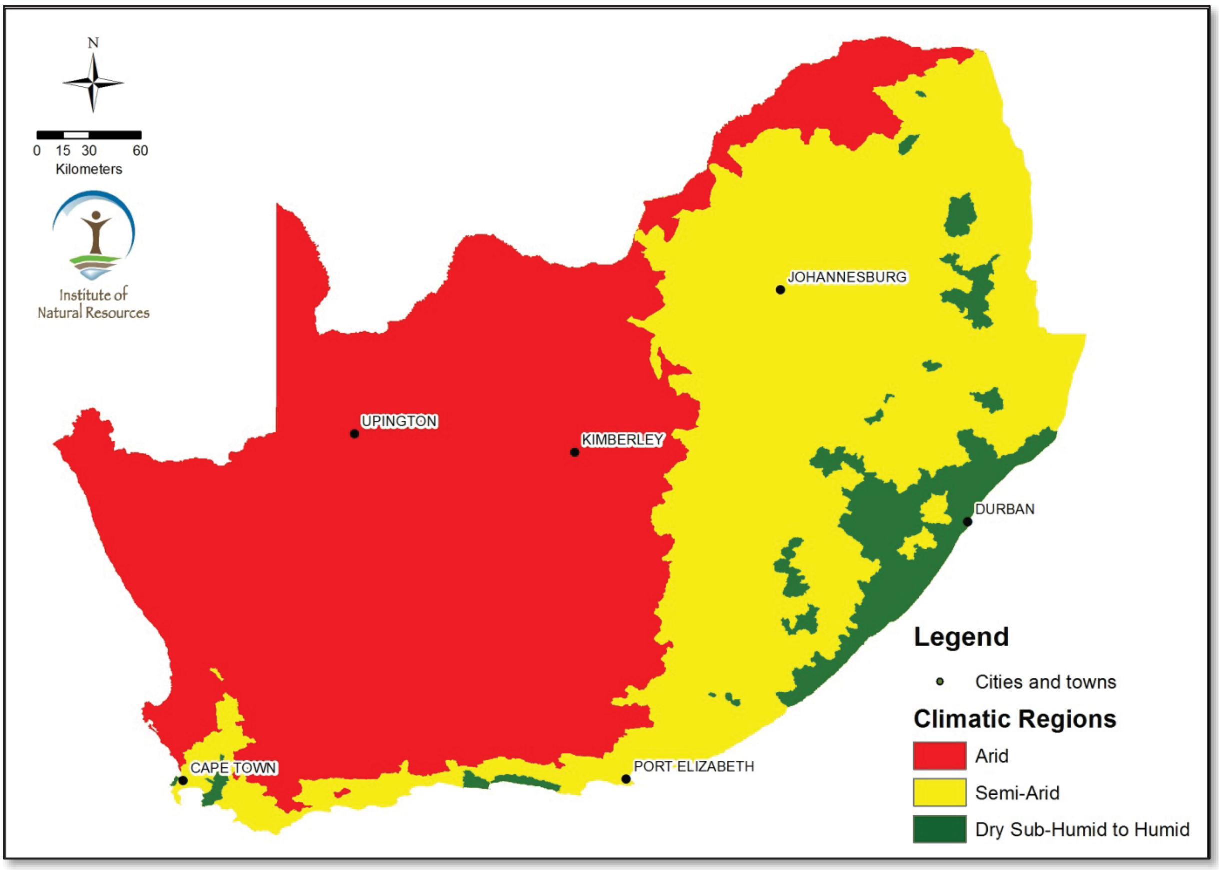
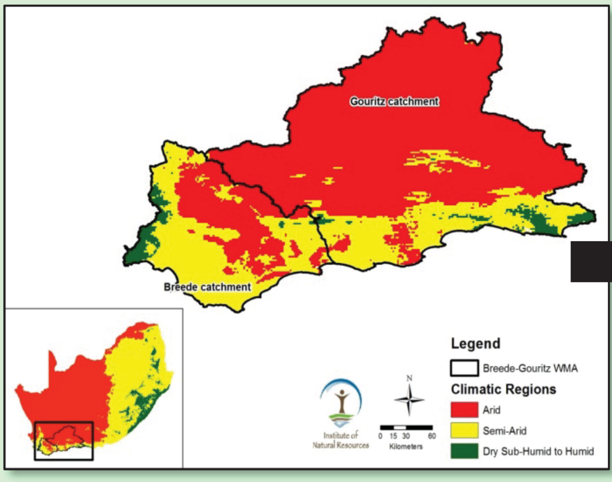


Figure 11: Simplified national climatic settings determined by the ratio of Mean Annual Precipitation (MAP) to Potential Evapo-Transpiration (PET) as defined by Schulze (2007) for each quaternary catchment

<u>Example:</u> Climatic regions for the Breede Gouritz catchments (Figure 12 & 13). The simplified climatic regions were intersected with the wetland zones and assigned a unique polygon ID.



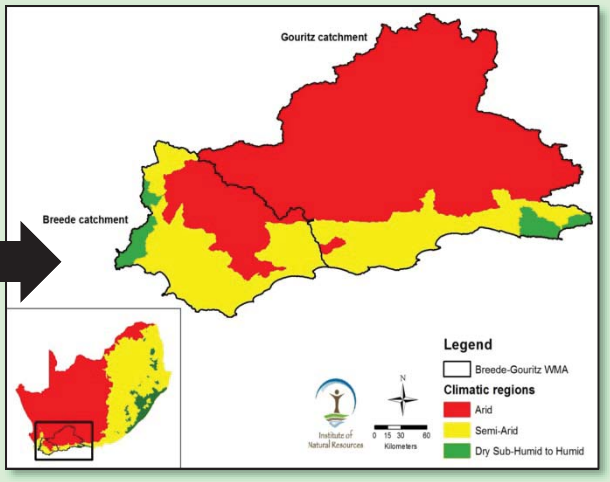


Figure 12: Climatic regions of the Breede-Gouritz WMA as defined by Schulze et al. (2007)

Figure 13: Simplified climatic regions aligned to quaternary catchments within the Breede-Gouritz WMA

3.2.1.2. *Size factor*

The supply of ecosystem services is also greatly influenced by the extent of a wetland and the impacts of surrounding land use on the system. A broad assumption is that the larger the wetland, the greater the provision of ecosystem services (Kotze et al., 2008). The importance of size on the delivery of benefits varies considerably between ecosystem services. For example, a five hectare wetland and a 500 hectare wetland may both score high for flood attenuation because of their climatic settings and features. Both wetlands may have a high surface roughness and a gentle slope which enable them to attenuate floods. However, it could be argued that the larger wetland is in order of magnitude more important for attenuating floods than the smaller system.

Technical method: The potential supply of ecosystem services from wetland zones in different climatic settings should therefore be adjusted according to its extent. It is recommended that a relative adjustment factor be applied on a scale of 0 to 1. The largest wetland zone in the study area should receive an adjustment factor of 1, with all other wetland zones receiving an adjustment factor relative to the largest one. This is achieved by identifying the largest wetland zone and then dividing the area of every wetland zone by the largest. Where more than one WMA or multiple primary drainage regions are being assessed, such as the Breede-Gouritz WMA, the process should be repeated per primary drainage region.

3.2.1.3. *Land cover*

The location and extent of different land cover types may also affect the capability of a wetland to supply ecosystem services. Some land cover types, such as commercial annual cops, may occur within a wetland and considerably diminish the ecological condition of the wetland and its ability to supply certain ecosystem services (Kotze, 2016a). Other land cover types may occur in the upslope catchment of a wetland with less direct impacts.

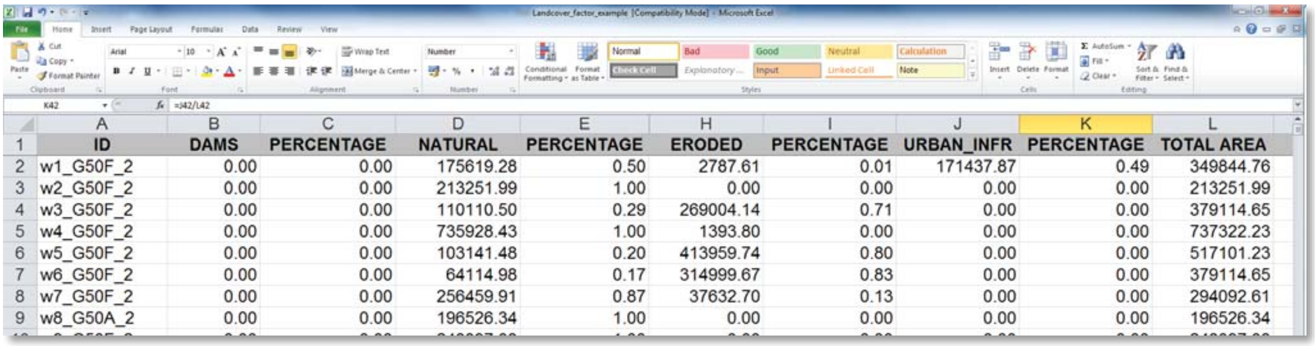
Technical method: The capability of a wetland to supply ecosystem services should therefore be adjusted based on the type and extent of land covers within the wetland zone. Generic adjustment factors which account for the influence of land cover types have been developed for seven broad land cover types (Table 4). These adjustment factors can be multiplied by the proportional extent of the identified land covers.

The National land cover dataset has been classified into 72 land cover classes. These classes should be reclassified to align with the broad seven land cover types defined by (Kotze et al., 2008) with the use of a summary table provided in Annexure 2. The tabulate areas tool of an appropriate geographic information system (GIS) package should be used to determine the extent of each land cover within each wetland zone. These values should be divided by the total area of the wetland zone to achieve a proportional area range between 0 to 1 (Figure 14).

Table 4: Adjustment factors to account for the influence of land-cover types on the capability of wetland zone to supply ecosystem services

Ecosystem service	Land-cover type						
	Natural	Dams	Crops	Alien trees[1]	Mining	Eroded	Urban infrastructure
Flood attenuation	1.0	0.8	0.4	1.1	0.3	0.4	0.0
Streamflow regulation	1.0	0.6	0.5	0.5	0.2	0.5	0.0
Sediment trapping & Erosion control	1.0	0.8	0.3	0.8	0.4	0.2	0.7
Phosphate, nitrate and toxicant assimilation	1.0	0.8	0.1	0.6	0.2	0.2	0.1
Carbon storage	1.0	0.6	0.2	0.6	0.0	0.2	0.2
Provision of water	1.0	1.1	0.2	0.2	0.0	0.4	0.0
Harvestable resources	1.0	0.5	0.2	0.3	0.0	0.3	0.0
Cultivated foods	0.0	0.0	1.0	0.0	0.0	0.0	0.0

[1] This includes tree plantations and dense infestations of invasive alien trees



ID	DAMS	PERCENTAGE	NATURAL	PERCENTAGE	ERODED	PERCENTAGE	URBAN_INFR	PERCENTAGE	TOTAL AREA
w1_G50F_2	0.00	0.00	175619.28	0.50	2787.61	0.01	171437.87	0.49	349844.76
w2_G50F_2	0.00	0.00	213251.99	1.00	0.00	0.00	0.00	0.00	213251.99
w3_G50F_2	0.00	0.00	110110.50	0.29	269004.14	0.71	0.00	0.00	379114.65
w4_G50F_2	0.00	0.00	735928.43	1.00	1393.80	0.00	0.00	0.00	737322.23
w5_G50F_2	0.00	0.00	103141.48	0.20	413959.74	0.80	0.00	0.00	517101.23
w6_G50F_2	0.00	0.00	64114.98	0.17	314999.67	0.83	0.00	0.00	379114.65
w7_G50F_2	0.00	0.00	256459.91	0.87	37632.70	0.13	0.00	0.00	294092.61
w8_G50A_2	0.00	0.00	196526.34	1.00	0.00	0.00	0.00	0.00	196526.34

Figure 14: An example of the tabulated areas output with the calculated proportional extent of each land cover type

As the wetland zones are defined by the national wetland layer and a 200 m zone of influence, the delineated wetland zones incorporate a portion of the adjacent upslope / catchment. This has been taken into consideration for the determining of the adjustment factors.

The adjustment factors are recommendations. Should there be clear scientific evidence to suggest an alternative adjustment factor then this should be used. However, motivation for the use of an alternative adjustment factor with the supporting evidence must be provided.

Example: Factoring in land cover into the assessment is the final component to identifying the potential for a wetland zone to supply the range of services outlined above. Figure 15 provides an example of the reclassified land cover types taken into consideration within a wetland complex in the Breede WMA.

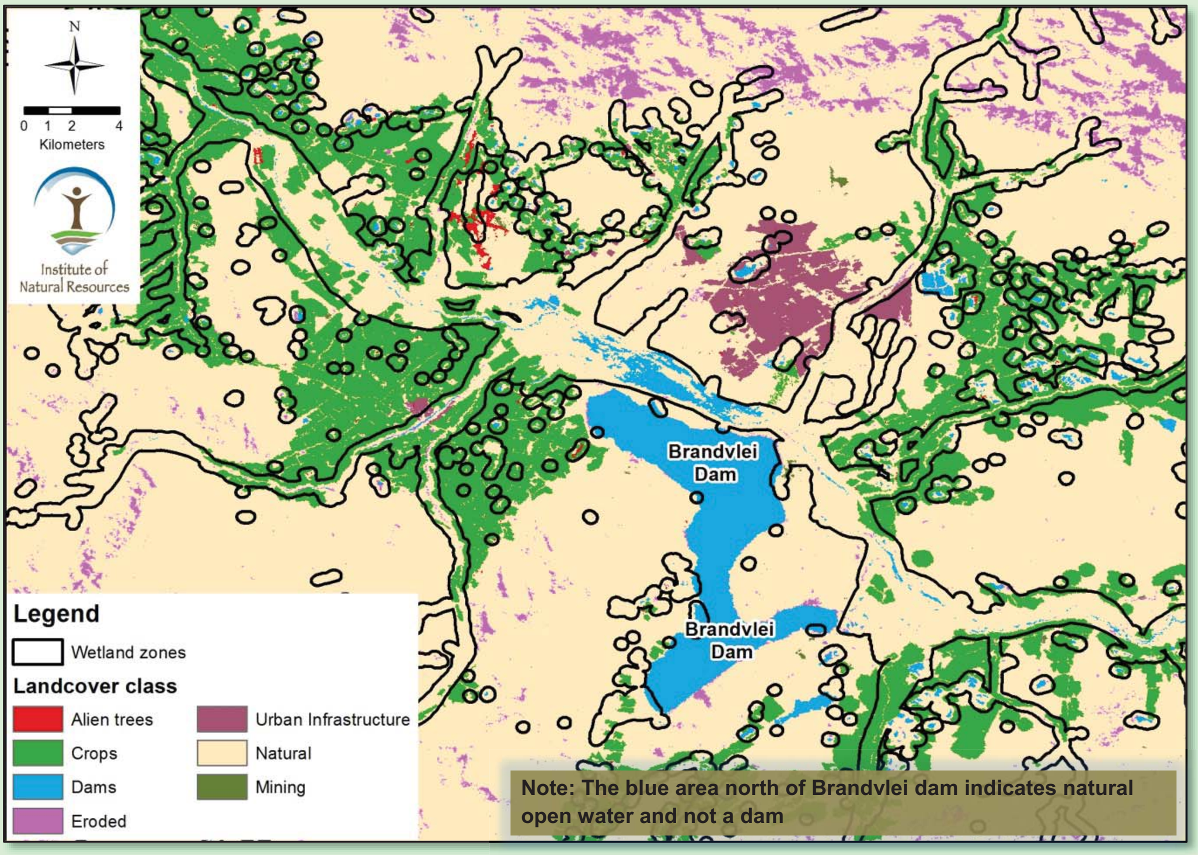


Figure 15: An example of the reclassified land cover classes within and adjacent to wetland zones

3.2.1.4. Calculating ecosystem service supply scores

Technical method: GIS software like ArcGIS, QGIS or equivalent is required to apply the supply methodology described in the previous sections. For each service, and each wetland zone, the climatic factor scores from Table 3 should be multiplied by the relative size adjustment factor which range between 1 and 0. For example, flood attenuation for a wetland zone which is in a semi-arid climate, and would therefore be assigned a score of 3. Let us assume that the largest wetland zone is 100 ha, and therefore receives an adjustment factor of 1. A 75ha wetland zone would receive a relative adjustment factor of 0.75, and a 50 hectare wetland zone a relative adjustment factor of 0.5. The adjusted score for flood attenuation (considering extent) for the 100 ha wetland zone would therefore be 3*1=3, and for the 75 ha wetland zone 3*0.75=2.25.

The resulting scores for ecosystem services in each wetland zone are then further adjusted to account for land-cover impacts within the zone. This entails determining the total extent of different land cover types within each of the wetland zones with the use of a tabulate areas tool. The proportional extent (ranging between 0 and 1) of each land cover is multiplied by the adjustment factor for each impact (

Table **4**). For example for flood attenuation, let us assume that 60% of a wetland zone is crops and 40% natural. The overall adjustment score for impacts in the wetland zone would be (0.6*0.4) + (0.4*1) = 0.64. If the wetland zone had 20% natural, 5% urban, 30% crops and 45% eroded the overall adjustment score would be (0.2*1) + (0.05*0.0) + (0.3*0.4) + (0.45*0.4) = 0.5

The final supply score for ecosystem services for each wetland zone is calculated by adjusting the climatic scores by both extent and land cover impacts. This is done by multiplying the climatic score adjusted by extent by the adjustment factors for land cover impacts within each wetland zone. For example, for the 100ha wetland zone in the semi-arid climate, the adjusted score was 3 and the adjustment score for impacts was 0.64. The total supply score for flood attenuation from the 100 ha wetland is therefore 3*0.64 = 1.92.

Example: Identifying significant wetland zones that are likely supplying the four focal ecosystem services is only half of the process to identifying potential ecosystem service hotspots throughout the WMA. However, it is still important to interrogate the supply layers separately, as they allow a better understanding / interpretation of the final integrated layer. Additionally, it is important to also remember that supply is assessed for the full range of ecosystem services (as per Table 4). Figure 16 below is provided as an example to illustrate an output for the assessment of one ecosystem service, sediment trapping.

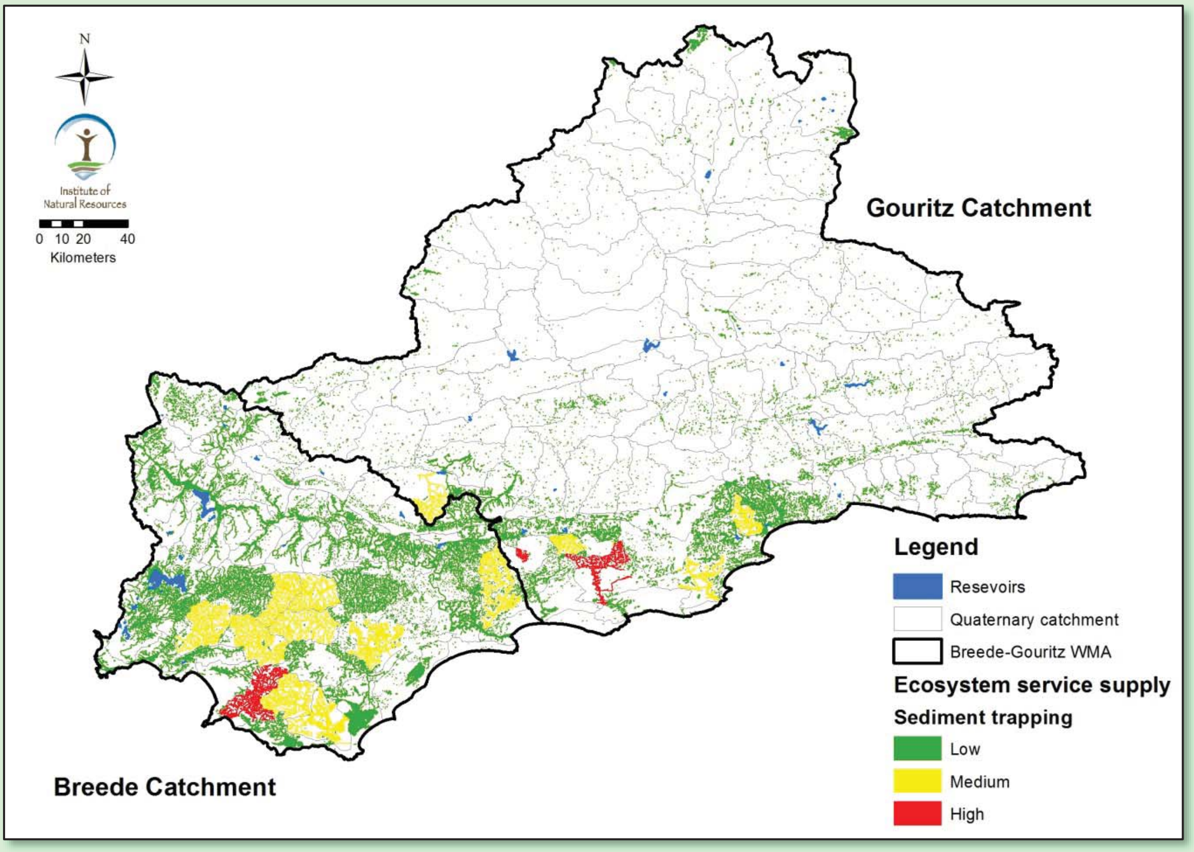


Figure 16: Wetland zones throughout the Breede-Gouritz WMA likely providing high, medium and low levels of sediment trapping

3.2.2. Determine the demand for ecosystem services

By definition, ecosystem services are only considered a service if there is a benefit to people. As such, there must be a level of demand for a service (Burkhard and Kroll, 2010). The following section outlines how demand can be determined for the selected services. The methodology should be applied using a GIS package such as ArcGIS, QGIS or something similar.

3.2.2.1. Demand for flood attenuation

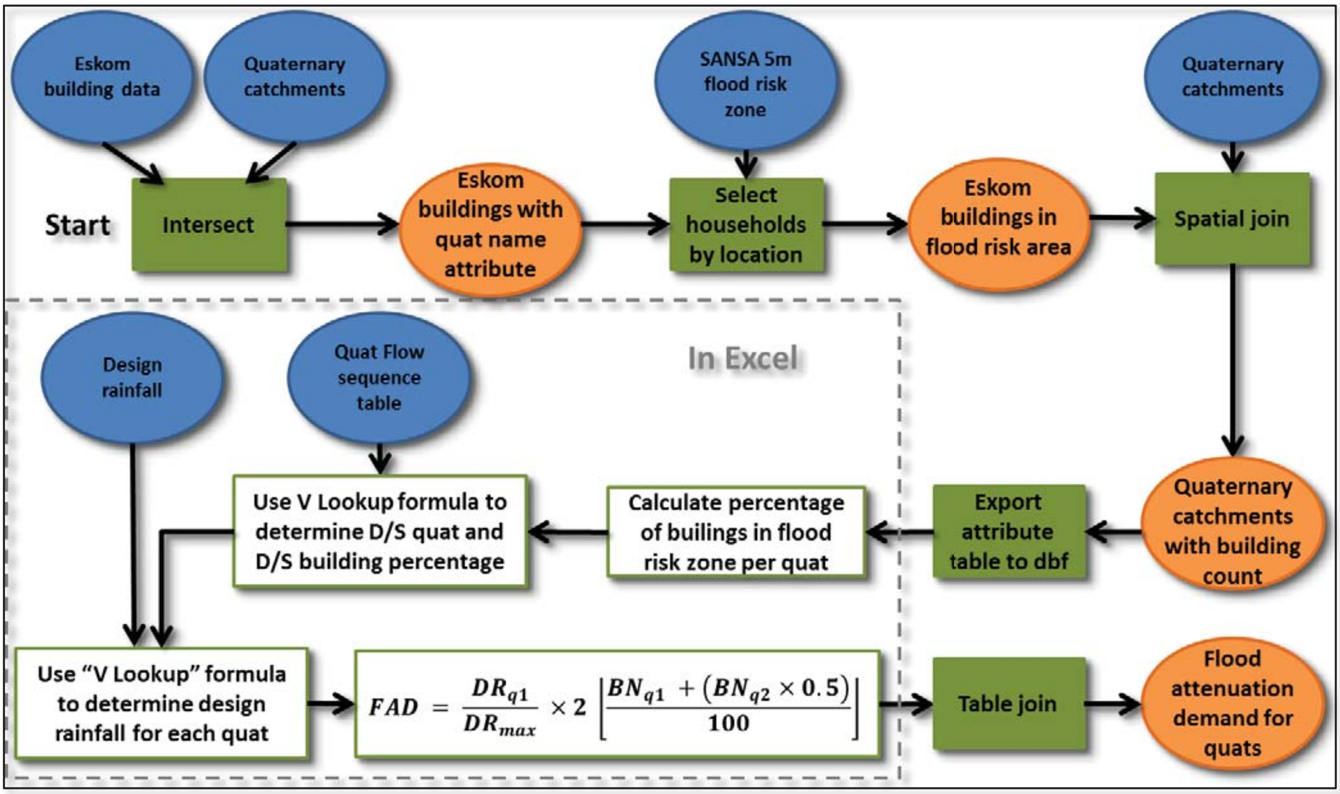


Figure 17: Schematic of the process for determining the demand for flood attenuation at a quaternary catchment scale within a WMA

The demand for flood attenuation is a function of the location of infrastructure (and therefore people) coupled with precipitation characteristics. The demand for flood attenuation is likely to be highest in areas where infrastructure is located close to water courses and which frequently experience short intense storms or long rainfall events.

The South African National Space Agency (SANSA) has developed a flood risk map for the major rivers of South Africa. This product has been developed for three water levels of 1, 3 and 5 meters above the river channel and can be used to identify areas vulnerable to flooding. This layer can be accessed at http://products.sansa.org.za/mapApp/SANSA.html . It is assumed that buildings located within the 5 meter flood zone benefit from the flood attenuation function offered by wetlands. Eskom Building Count data (available from Eskom) can be used to identify buildings (surrogate for infrastructure and people) most at risk to flooding.

Wetlands not only mitigate flood impacts in the quaternary catchment in which they occur but also mitigate flood impacts in downstream catchments. To determine the demand placed on wetlands in a particular quaternary catchment, the proximity of beneficiaries to these wetlands is considered. Beneficiaries are defined as any buildings which may be at risk from flooding.

Research has shown that floods are influenced by a combination of precipitation characteristics including the amount, intensity, duration and spatial distribution. Bracken et al. (2008) note that floods are produced by high intensity, short duration storms, or by longer duration, low intensity rainfall. Using rainfall data, the depth, duration and frequency of rainfall can be calculated. The amount of rainfall for a given duration and probability of recurrence (return period) is known as the 'design rainfall'. Schulze and Smithers (2007) have generated 'design rainfall' per quaternary catchment across South Africa. It is recommended that the one day 'design rainfall' with a 2 year return period be used in this rapid assessment.

Technical method: The Eskom building data should be intersected with the quaternary catchments to ensure the attributes of the Eskom building data contain the name of the catchment it falls within. The buildings can then be selected by location within the SANSA 5 meter flood area and made into a new layer. This layer should be spatially joined to the quaternary catchments which will automatically provide a count of the number of buildings located within the flood risk area for each catchment. These counts should then be converted to a percentage of the total number of buildings at risk for each primary drainage region within the WMA.

To determine the demand placed on wetlands in a particular quaternary catchment, the proximity of beneficiaries to the wetland zones is considered. The number of households within the flood area of the downstream catchment needs to be determined. To achieve this, the attribute table should be exported to Excel. A quaternary catchment flow sequence (DWA, 2014b) and **VLOOKUP** excel function should be used to identify the downstream catchment of each catchment within the study area where:

Lookup value = Primary quaternary catchment
Table array = Select the first two columns in the quaternary catchment flow sequence
Column index number= Column in which the downstream catchment is displayed (2)
Range lookup = False (as the equation is looking to find an exact match)

The same function can be used to determine the number and percentage of households located within the downstream catchment. Once the percentage number of households of each quaternary catchment and its downstream catchment have been determined, the excel table should be joined back to the attribute table in GIS by the quaternary catchment name.

A weighting factor of 1 should be applied to beneficiaries located in the quaternary catchment in which the wetland zones occur while a weighting factor of 0.5 applied to beneficiaries located in the quaternary catchment immediately downstream. The resulting scores should then be summed. For example, if quaternary catchment 1 contains 50% of the study area's beneficiaries and the catchment immediately downstream contains 20% of the study area's beneficiaries, then the weighted beneficiary percentage for quaternary catchment 1 is calculated as (1*50) + (0.5*20%) = 60%. This percentage should be converted to a score out of 2 by dividing by 100 and multiplying by 2. For example, the weighted beneficiary score for quaternary catchment 1 is calculated as (60/100)*2 = 1.2. Weighted beneficiary scores should be generated for each quaternary catchment in the study area.

The design rainfall for the relevant quaternary catchments should be extracted from the provided national two year design rainfall layer. A relative score out of 1 should then be calculated for each quaternary catchment by dividing the value for each quaternary catchment by the maximum value occurring in the WMA. Therefore, if the study area includes more than one WMA, these would have to be calculated separately.

The weighted beneficiary score and design rainfall score should then be multiplied to provide an indication of the demand exerted on wetlands in each quaternary catchment. For example, if the design rainfall score for quaternary catchment 1 is 0.6, then the demand exerted on wetlands occurring in quaternary catchment 1 is calculated as 1.2 * 0.6 = 0.72.

The flood attenuation demand score for wetlands in a given quaternary catchment is then calculated by the following equation:

$$\boldsymbol{FAD} = \frac{\boldsymbol{DR_{q1}}}{\boldsymbol{DR_{max}}} \times \mathbf{2}\left[\frac{\boldsymbol{BN_{q1}} + (\boldsymbol{BN_{q2}} \times \mathbf{0.5})}{\mathbf{100}}\right]$$

Where:

FAD = Flood Attenuation Demand
q1 = Quaternary catchment being assessed
q2 = Quaternary catchment immediately downstream of q1
DR_{q1} = Design Rainfall of q1
DR_{max} = Maximum Design Rainfall in study area
BN_{q1} = Beneficiary percentage of q1
BN_{q2} = Beneficiary percentage of q2

Demand scores should be calculated for each quaternary catchment in the study area.

Example: Demand scores for quaternary catchments in the Breede WMA were categorised into three classes to depict areas of high, moderate and low demand and scored as 2, 1 and 0, respectively (Figure 18). This was done by classifying the results into 10 equal quantiles, the top quantile (highest 10% of the dataset) was classed as high, the next 3 quantiles were classed as moderate, and the lowest 60% of the dataset were classed as low. The resulting classes provide an indication of the relative importance for flood attenuation services in the catchment rather than the absolute demand. It is therefore important to remember that this is an initial indication of flood attenuation function in the WMA, which is tested with stakeholders and/or specialists as part of the subsequent steps of the procedure.

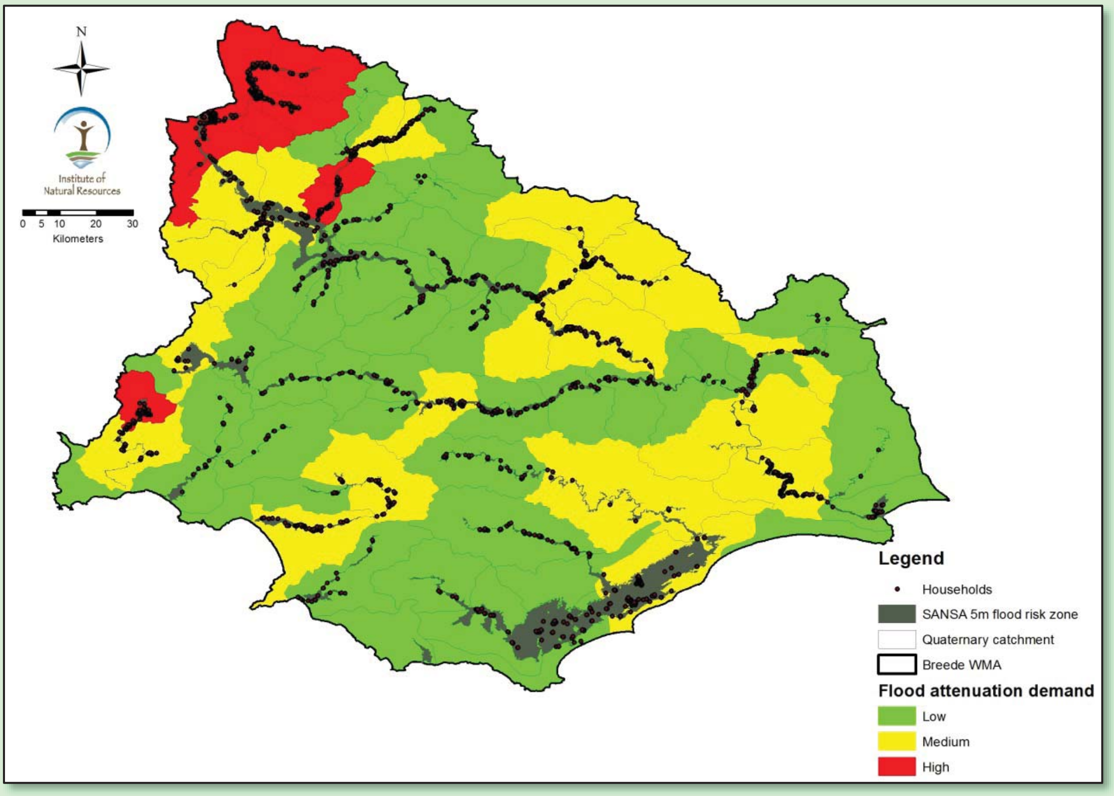


Figure 18: Flood attenuation demand for the Breede WMA based on the number of buildings located within the SANSA 5 m flood risk zone and the 2-year design rainfall for the WMA

3.2.2.2. Demand for water quality enhancement

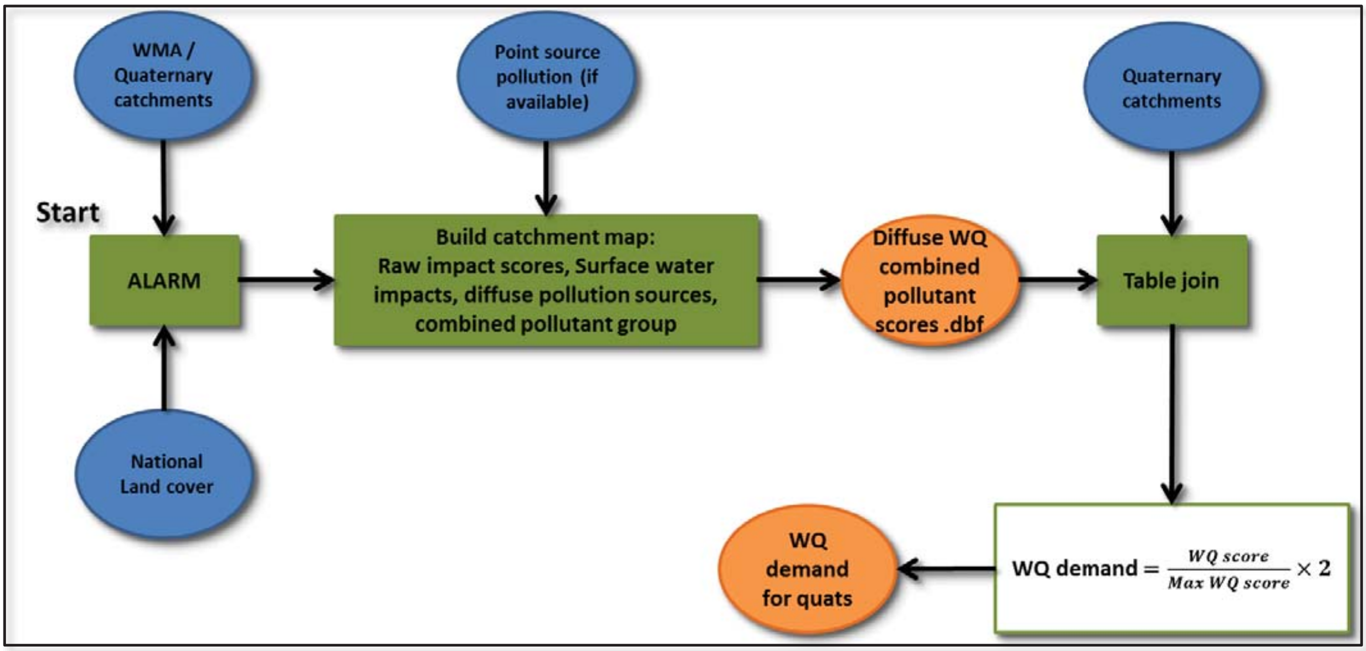


Figure 19: Schematic of the process for determining the demand for water quality enhancement at a quaternary catchment scale within a WMA

Every person requires water for drinking, washing and cooking. While the majority of South Africans utilise potable water, there are still a number of vulnerable communities who rely on unprotected water sources. These unprotected natural water sources are often polluted as a result of different land uses. Different economic sectors and land uses generate effluent and other outputs which decrease the quality of natural water resources. The demand for the water quality enhancement benefit offered by wetlands is therefore highest within catchments which have high water quality threats and the catchments directly downstream of these.

The Automated Land-based Activity Risk Assessment Method (ALARM) is an automated risk assessment method based on GIS and Excel spreadsheets which was developed for the Department of Water and Sanitation (DWA, 2014b). This tool is aimed at identifying likely diffuse or point source water quality impacts on water resources, and assesses the risk to vulnerable ecosystems and downstream users.

While the ALARM tool is very useful, there are limitations that need to be noted. These include:

- Output maps from the ALARM tool are hypotheses only. Verification of the outputs is required.
- Ambient water quality conditions have been excluded from the assessment as these do not constitute a land-based activity.
- Default input data for the assessment represent potential maximum values.
- For point-source pollution, water quality issues including buffering capacity, pH, water temperature and how this affects chemical pathways (e.g. carbonate chemistry) have not been included as these are regarded as modelling issues and beyond the scope of this tool.

Technical method: The ALARM framework is made up of four components to derive surface water risk scores for each quaternary catchment as shown in the Figure 20 below. A full explanation of the tool is not presented here as a detailed description of each of the components and formulae which run in the background are available in the user manual within the tool (https://sites.google.com/site/wetlandrqos).

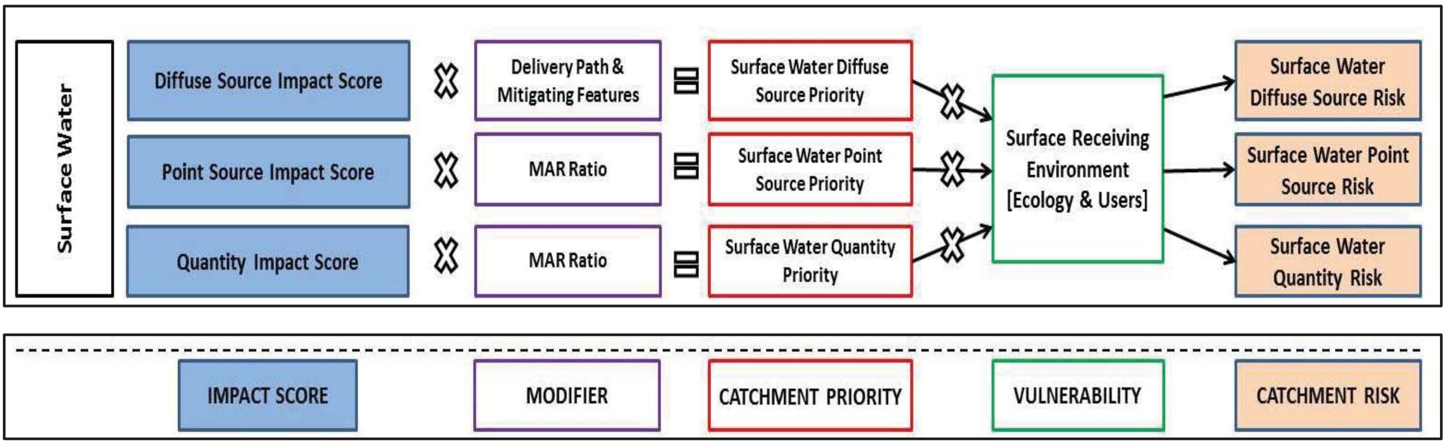


Figure 20: The four components of the ALARM framework used to derive surface water risk scores for quaternary catchments

Example: The ALARM user manual provides a step by step procedure on how the tool is used as well as detailed breakdown of the background processes factored into calculating the diffuse or point source impact scores and water quality risks for quaternary catchments.

Once the tool has been opened and a username and password created, a new ALARM can be entered. The default settings described below and illustrated in Figure 21 are recommended to determine the demand for water quality ecosystem service for each quaternary catchment within the WMA.

As RQOs are typically determined at a WMA level, the ALARM scale can be conducted at a WMA scale. The WMA being assessed can be selected in the drop down menu or alternatively each quaternary catchment can be selected manually. One of the main inputs to the tool is the land cover data. The type and extent of land cover within a quaternary catchment is used as a basis for calculating risk from the various pollutant groups. The most recent land cover data should therefore be used in this assessment. The default land cover can be selected, alternatively, if a recent updated version is available, the user manual should be consulted to convert this into a format that can be read by the tool.

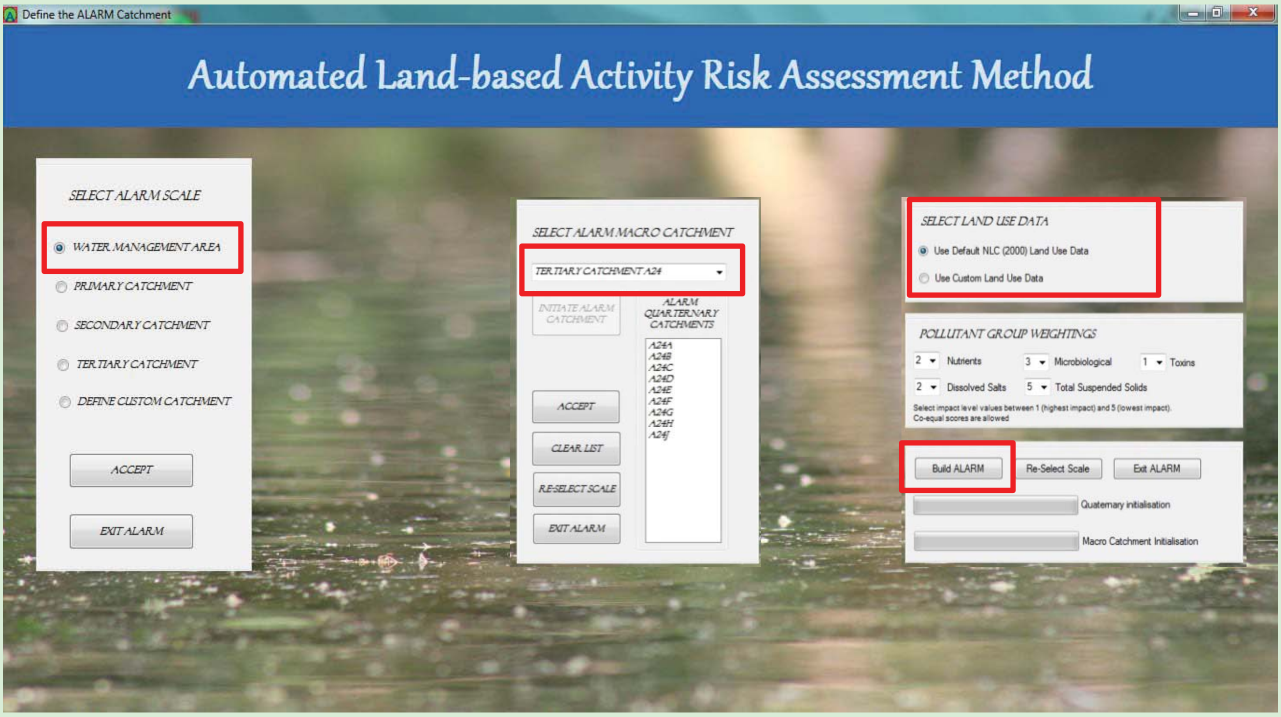


Figure 21: Recommended settings for using ALARM

The final input is the pollutant group weighting. It is recommended that the default pollutant group weightings be used. Where evidence can support an increase or decrease in any of the weightings, this can be done by the specialist. Once the tool has calculated the inputs the catchment risk assessment window is displayed (Figure 22).

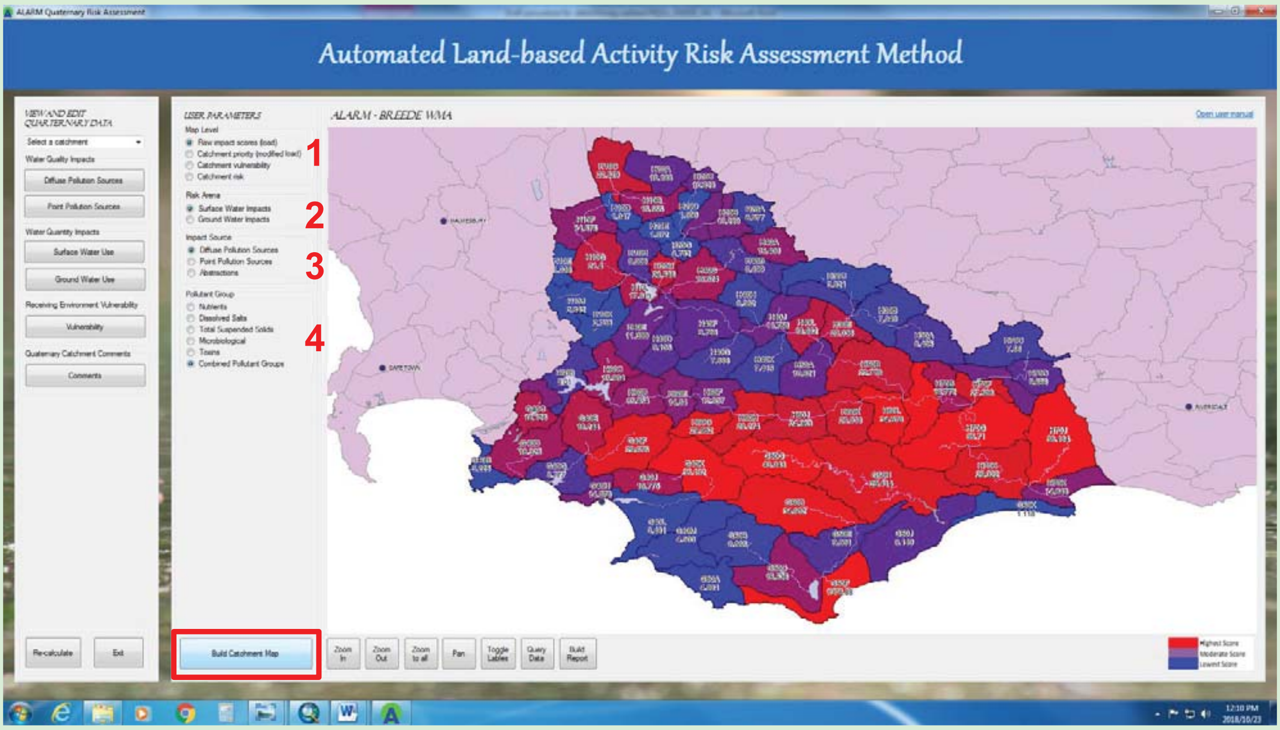


Figure 22: ALARM catchment risk assessment window

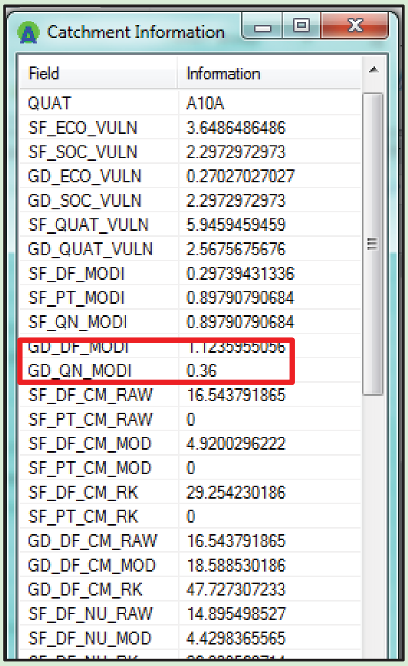
In the above window, the user can select which parameters are used to visually display the assessment outputs. The following user parameters are recommended:

1. The '**raw impact scores**' are used to indicate the water quality impacts at a quaternary catchment level.
2. '**Surface water impacts**' are the focus of this assessment.
3. '**Diffuse pollution sources**' is recommended as the default option. Where point source data and co-ordinates are available, these should be added in to supplement the results of the diffuse pollution sources. Due to limitations of the model, these two options cannot be run concurrently however the output of both processes can be extracted from the results attribute table.
4. Six pollutant group variables can be assessed. The '**combined pollutant groups**' is recommended as the default option which incorporates nutrients, dissolved salts, total suspended solids, microbiological and toxins into the combined score.

The catchment map in the display window provides a visual representation of the raw impact scores of surface water impacts from combined diffuse pollution sources. It is important to note that if the user has added in additional point pollution sources, the user must click on the 're-calculate' button and the 'build catchment map' button again. The point and diffuse source data must be done separately.

The output of this assessment is an excel spreadsheet. The resultant scores for raw impact surface water combined diffuse pollution (SF_DF_CM_RAW) can be extracted from the output results spreadsheet and table joined to the quaternary catchment boundaries in GIS software (if raw impact surface water combined point pollution (SF_PT_CM_RAW). The following table can be used to interpret the abbreviations for the column headings.

Abbreviation	Component
SF	Surface water arena
GD	Groundwater arena
DF	Diffuse pollution sources
PT	Point pollution sources
QN	Quantity impacts
NU	Nutrient pollutant group
ST	Total Dissolved Salts pollutant group
TS	Total Suspended Solids (TSS) pollutant group
MC	Microbiological pollutant group
CM	Combined
TX	Toxin pollutant group
RAW	Raw impact score
MOD	Modified impact score
RK	Risk score
VULN	Vulnerability
ECO	Ecological (vulnerability)
SOC	Social (vulnerability)
MODI	Modifier score



Field	Information
QUAT	A10A
SF_ECO_VULN	3.6486486486
SF_SOC_VULN	2.2972972973
GD_ECO_VULN	0.27027027027
GD_SOC_VULN	2.2972972973
SF_QUAT_VULN	5.9459459459
GD_QUAT_VULN	2.5675675676
SF_DF_MODI	0.29739431336
SF_PT_MODI	0.89790790684
SF_QN_MODI	0.89790790684
GD_DF_MODI	1.1235955056
GD_QN_MODI	0.36
SF_DF_CM_RAW	16.543791865
SF_PT_CM_RAW	0
SF_DF_CM_MOD	4.9200296222
SF_PT_CM_MOD	0
SF_DF_CM_RK	29.254230186
SF_PT_CM_RK	0
GD_DF_CM_RAW	16.543791865
GD_DF_CM_MOD	18.588530186
GD_DF_CM_RK	47.727307233
SF_DF_NU_RAW	14.895498527
SF_DF_NU_MOD	4.4298365565

The water quality scores then need to be converted to a score out of 2 to align with the demand scores of the other ecosystem services. This is achieved by applying the following formula:

$$\boldsymbol{Water\ Quality\ Demand} = \frac{\boldsymbol{Water\ quality\ score}}{\boldsymbol{Max\ water\ quality\ score}} \times \mathbf{2}$$

Although ALARM can assess the impacts of diffuse and point source pollution sources, it is recommended that the user run the ALARM with diffuse point source pollution and where applicable, use additional point data to modify the determined water quality demand scores. This approach is recommended due to the vast possible combinations of datasets. There will likely be more point source data for selected areas within the WMAs which creates a scoring bias when combined with the diffuse results. Additional point pollution source data which could be considered are:

- Wastewater works
- Mines; and
- Specialist data

3.2.2.3. *Demand for avoided sedimentation*

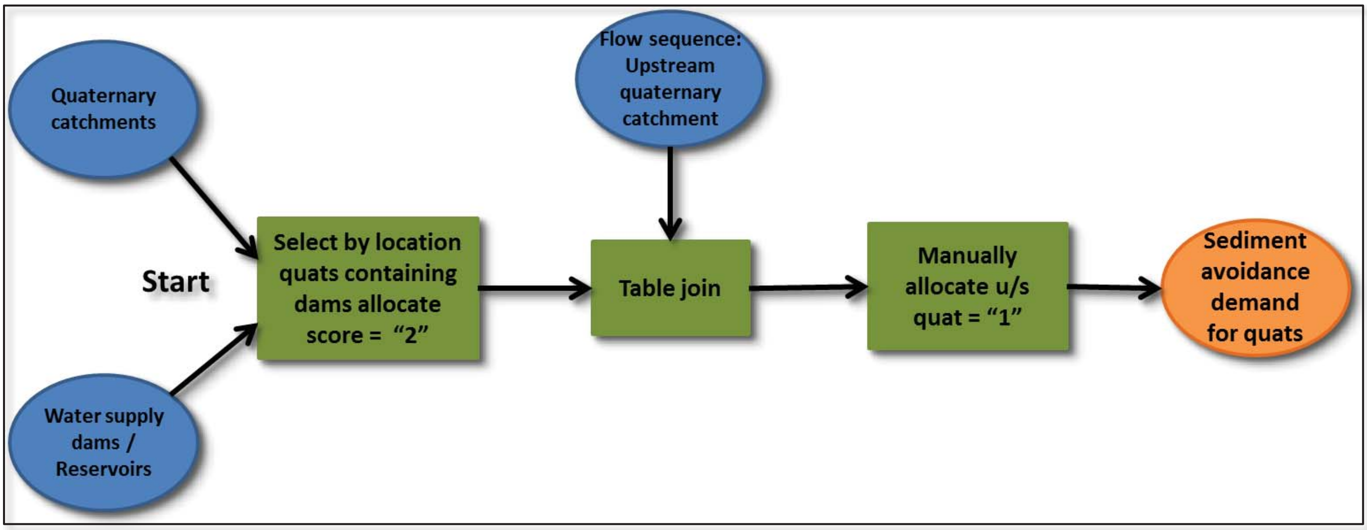


Figure 23: Schematic of the process for determining the demand for sediment avoidance at a quaternary catchment scale within a WMA

Wetlands play an important role in the maintenance of built infrastructure. These ecosystems trap sediment thereby maintaining the storage capacity of dams and prolonging their lifespan. This service is of direct benefit to large numbers of users who benefit from water from these dams. The demand for avoided sedimentation is dependent on the presence of water supply dams or reservoirs in the study area. Quaternary catchments containing large water supply dams of economic importance in the study area should be identified.

Technical method: Key water supply dams or reservoirs in the WMA should be identified by the surface water specialist on the team.

Where specialist input is not available, the national DWS dam spatial layer (showing dam extent and not point data) can be used as an alternative. The attributes of this spatial layer should be analysed and dams classified as reservoirs should be used in this assessment. The dams' layer should be further interrogated to establish the presence of functional dams within the catchments as the inclusion of recently decommissioned dams or saline lakes could lead to inappropriate prioritization. Island and natural dam types should not be considered as these consist of estuaries, land masses and water sources generally not utilised for water supply.

Once key water supply dams have been identified the 'select by location' tool (i.e. function of the GIS software used) can then be used to select quaternary catchments which are intersected by dams. This function will result in the selection of all quaternary catchments which intersect with a dam boundary. As the demand for wetlands which trap sediments is greatest in the wetlands directly upstream of the dam, the selected quaternary catchments are assigned a score of "2" (high demand for avoided sedimentation). With the use of the provided 'quat flow sequence' (DWA, 2014a), the upstream quaternary catchments can be determined, selected and scored a "1"[8] (medium demand for avoided sedimentation).

[8] Note that it is only necessary to consider those quaternary catchments located in the study area.

Example: All wetland zones located in the same quaternary catchment as a dam score a 2. Wetland zones that are located in the adjacent upstream quaternary catchment score a 1. All other wetland zones located upstream or downstream of these catchments score a 0.

As a number of dams are located near the bottom of the quaternary catchments, very small portions of the dam extent can overlap with the quaternary catchment downstream. A manual verification of this selection should be undertaken to ensure quaternary catchments which contain significant dam portions have been selected. Where quaternary catchments have been selected due to the intersection of small dam slivers, these quaternary catchments should be unselected and scored either a "1" if it is upstream of the dam or "0" if it is not as see in Figure 24. The resulting scores were categorised into three classes to depict areas of high, moderate and low demand and scored as 2, 1 and 0, respectively (Figure 25).

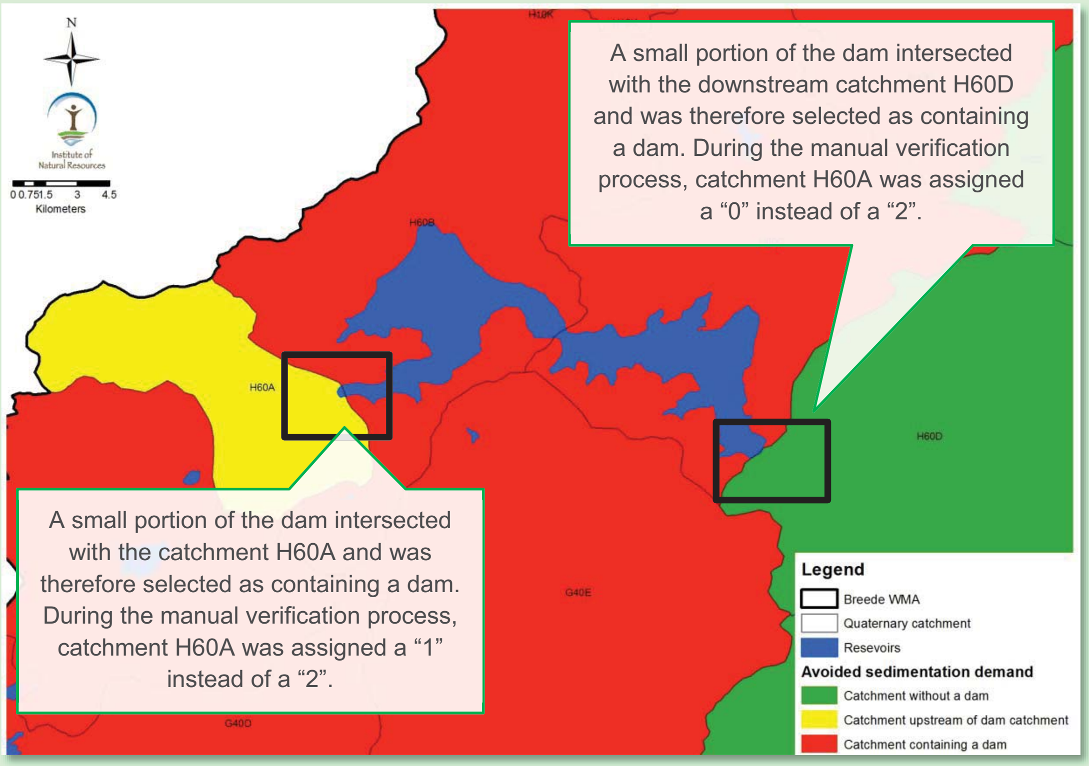


Figure 24: Example of where a dam intersects with upstream and downstream quaternary catchments and would need to be corrected manually

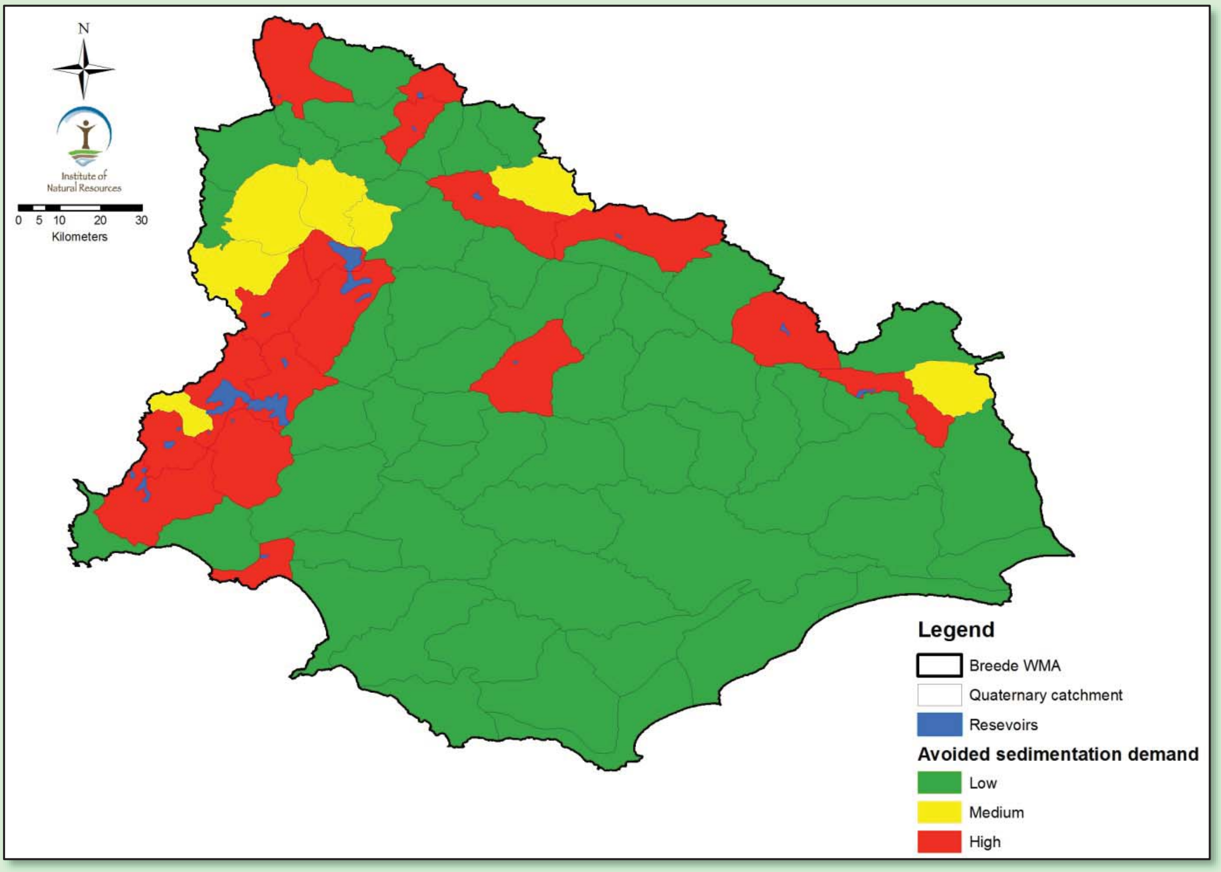


Figure 25: Water supply dams and the classified demand for sediment avoidance within the Breede-Gouritz WMA

It is important to identify where the dam is located within the quaternary catchment (i.e. top, middle or lower portion of the catchment) which has received the corresponding score. For example, where a dam is located in the upper reaches of a quaternary catchment, which would have score 2, the majority of the wetlands within the catchment are downstream of the dam and therefore do not provide a sediment trapping service that will benefit the demand at the relevant supply dam. A validation process is required to verify where there is demand within the quaternary catchment, or portion of the catchment.

It is also important to consider water transfer schemes where applicable. The scoring of avoided sedimentation demand should also account for catchments which source users in across transfer schemes. The primary and secondary catchments where there would be a high or medium demand for sediment avoidance should be determined in the source basin / WMA and scored accordingly. The surface water specialist on the team should be consulted when identifying catchment transfer schemes.

3.2.2.4. *Demand for streamflow regulation*

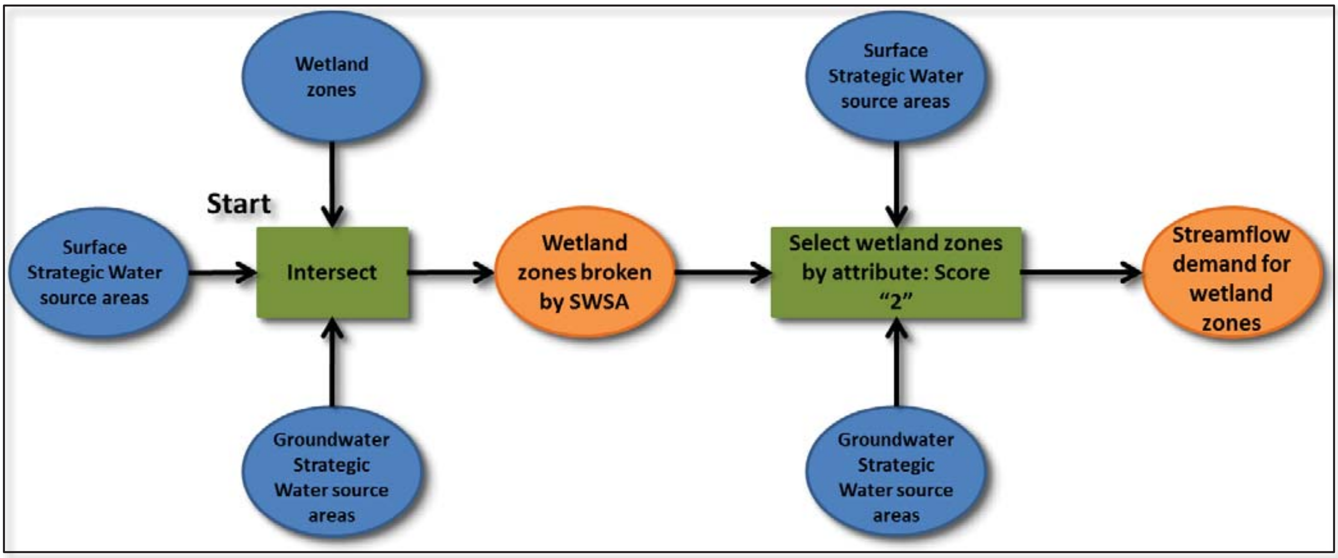


Figure 26: Schematic of the process for determining the demand for streamflow regulation at a quaternary catchment scale within a WMA

Water source areas are often relatively small areas where provisioning, regulating and cultural ecosystem services are provided. These areas are known to supply large amounts of water for the surrounding area. Increasing concerns about water scarcity and the increased occurrence of drought in South Africa led to the definition and delineation of Strategic Water Source Areas in South Africa (Figure 27). Strategic Water Source Areas (SWSA) have been defined as areas which (Le Maitre et al., 2018):

- Supply a disproportionate (i.e. relatively large) volume of mean annual surface water runoff in relation to their size and so are considered nationally important;
- Have high groundwater recharge and where the groundwater forms a nationally important resource; or
- Areas that meet both of the above criteria.

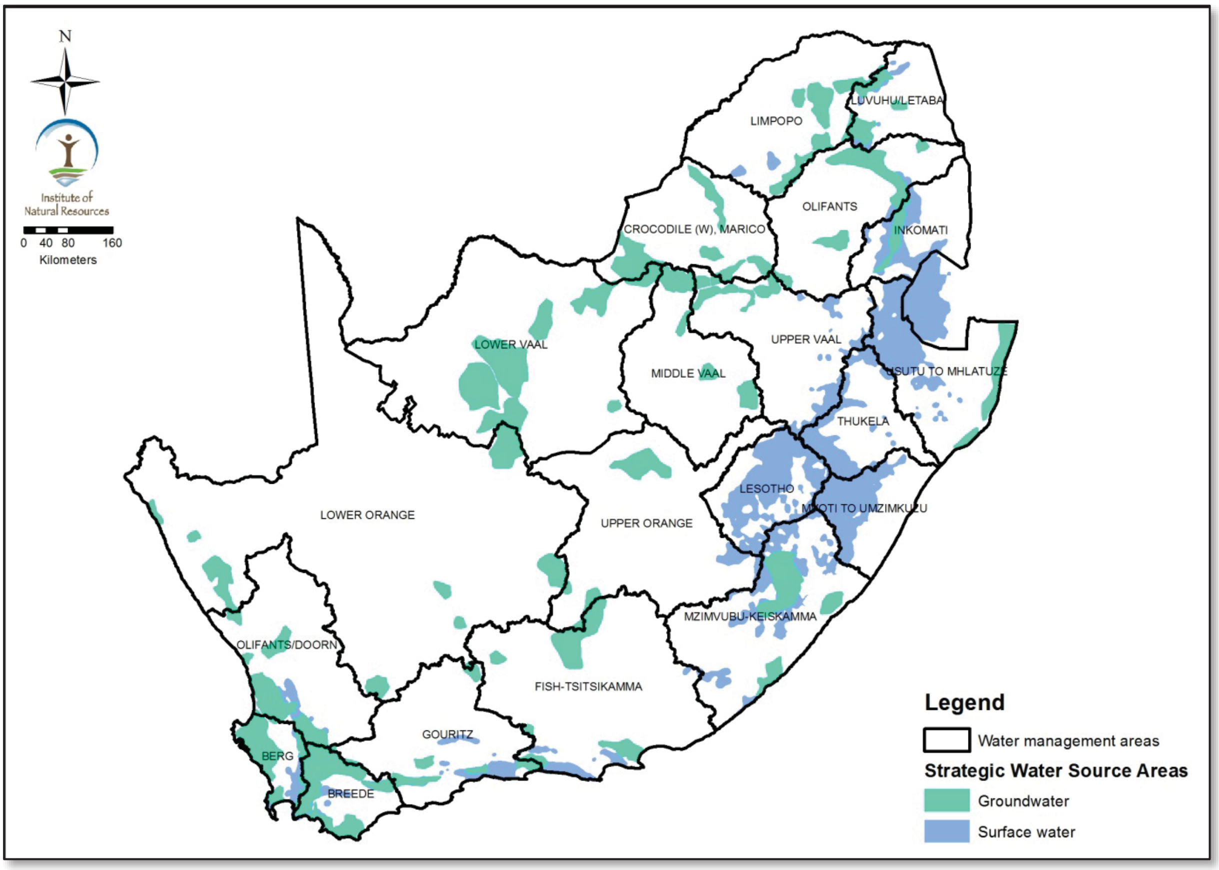


Figure 27: Strategic Water Resource Areas of South Africa showing national and surface ground water (Le Maitre et al., 2018)

Half of the water in South Africa, Lesotho and Swaziland is supplied by 8% of the land surface area (Nel et al., 2017; Le Maitre et al., 2018). However, one could then easily understand that a deterioration of these SWSA or water quality and quantity could have significant impacts at both a regional and a national level.

Wetlands are known to supply regulating and provisioning ecosystem services, particularly the provision of water and streamflow regulation. Wetlands in these SWSA contribute to the regulation of streamflows for the benefit of users directly downstream as well as regionally and nationally. Although this benefit is acknowledged, this assessment uses the SWSA to indicate areas of demand for streamflow regulation. The SWSA are used as a proxy / indicator for the demand for streamflow regulation services[9].

It is also acknowledged that not all wetlands within the SWSA provide the streamflow regulation. However, the assessment is used to broadly highlight potential significant wetlands in the SWSA and identify areas where there is a potential demand for the service. Further interrogation in the subsequent steps to determine if the wetlands found in this area actually perform the services is required.

Technical method: The demand for streamflow regulation is determined at a different scale compared to the other demand layers, i.e. it is conducted at the wetland zone level and not at

[9] The limitation of using SWSA as a proxy for demand is acknowledged. It is important to note that while SWSA are a good proxy for potential demand, they do not represent all areas of potential demand for streamflow regulation (For example: demand may also occur in areas with relatively low rainfall).

a quaternary catchment level. The surface water and groundwater SWSA should be intersected with the wetland zones. The wetland zones located within the surface water and groundwater SWSA are considered as wetland zones where there is a high demand for the streamflow regulation service and are therefore scored as high (2) for the demand of streamflow regulation. Wetland zones occurring outside of the SWSA should be scored as having a low (0) demand for the streamflow regulation service. While this approach allows for an identification of where there is potential demand for wetlands to contribute to streamflow regulation, a validation of the findings is required in order to confirm demand. Validation is undertaken in the subsequent step of the procedure. In terms of groundwater SWSA, the abstraction point (i.e. point of demand) from groundwater needs to be determined. If abstraction is directly from groundwater (i.e. via a borehole) then stream flow regulation is not required. However, where abstraction takes place downstream of an aquifers discharge point (e.g. a dolomitic eye), then wetlands may contribute to streamflow regulation and hence there may be demand.

Example: Figure 28 illustrates the intersected wetland zones in the Breede catchment with the surface water and groundwater SWSA.

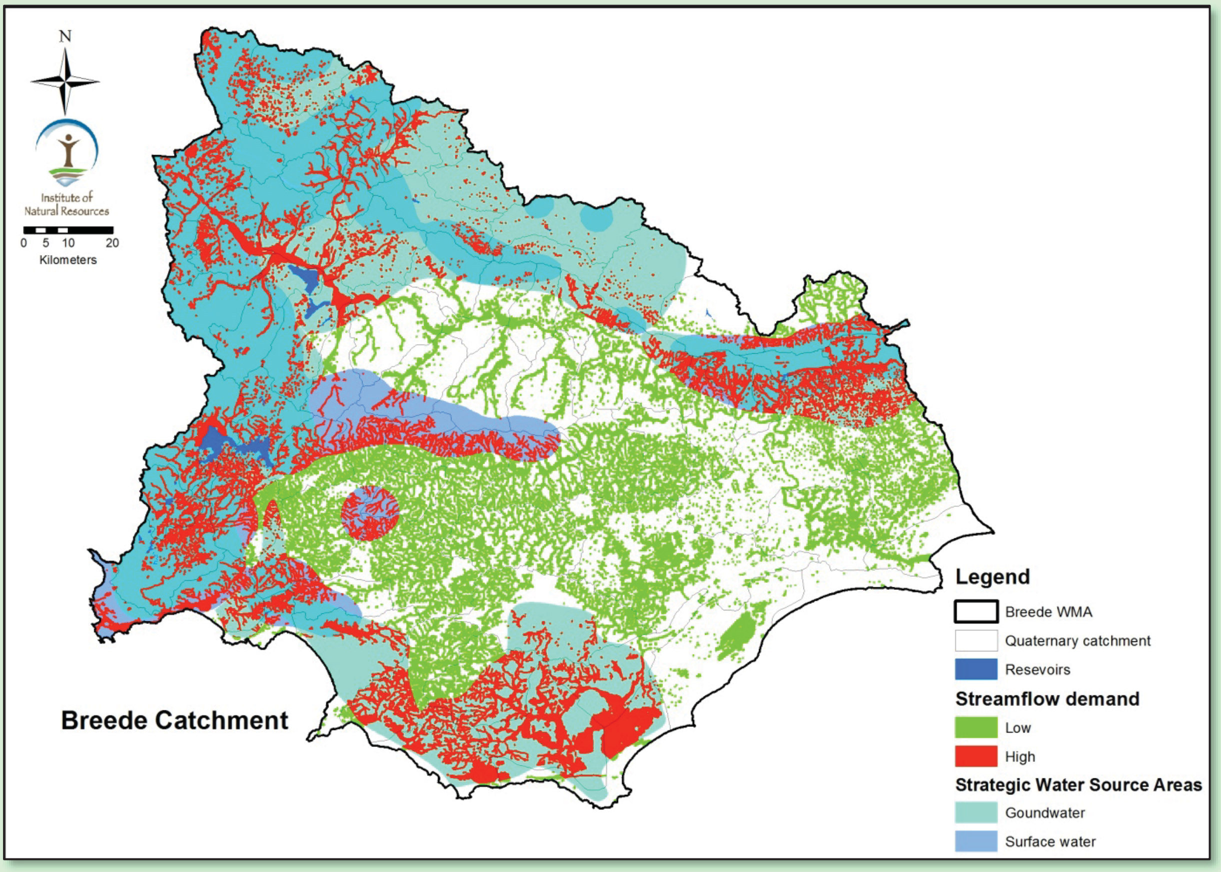


Figure 28: Breede surface water Strategic Water Source Areas (SWSA) and wetland zones where there is a potential demand for the streamflow regulation service

3.2.3. Classification of ecosystem services scores

The final process of determining ecosystem service hotspots, the supply and demand scores for flood attenuation, water quality, avoided sedimentation and streamflow regulation will be integrated. The classification of the integrated supply and demand scores for the above four services is an essential step in allowing for the identification of hotspot wetland zones within a WMA. The correct classification allows the user to determine the most important attributes that need to be taken into consideration to guide the selection of significant wetland resources.

The use of percentiles was identified as the preferred means for classifying the integrated ecosystem supply and demand scores. For each service, the integrated supply and demand scores should be sorted in descending order and the top 10% of the number of wetland zones is then selected as having a high potential for the provision of each of the services. Classifying by percentiles allows the use of set percentages.

Technical method: The following classification guide is used to identify wetland zones with relatively high integrated supply and demand scores (Table 5):

Table 5: Percentile classification guide for the integrated supply and demand of ecosystem services into high, medium and low categories

Class	Description
High	Top 10% of the data set for each respective service
Medium	Following 30% of the dataset for each respective service
Low	Bottom 60% of the dataset for each respective services

The parameters for the high medium and low classes provided in this section are a recommended guideline to flag high ecosystem service hotspot areas where significant wetlands are potentially located. It is acknowledged that results may vary across different WMAs and in WMAs where there is a high density of wetland zones, there can be a scoring bias towards larger wetlands. However, in Action 6, when the potential significant wetlands are identified, the attributes contributing to high ecosystem supply and demand scores are further interrogated as a process of elimination is undertaken.

3.2.4. Integrated assessment to identify ecosystem service hotspots

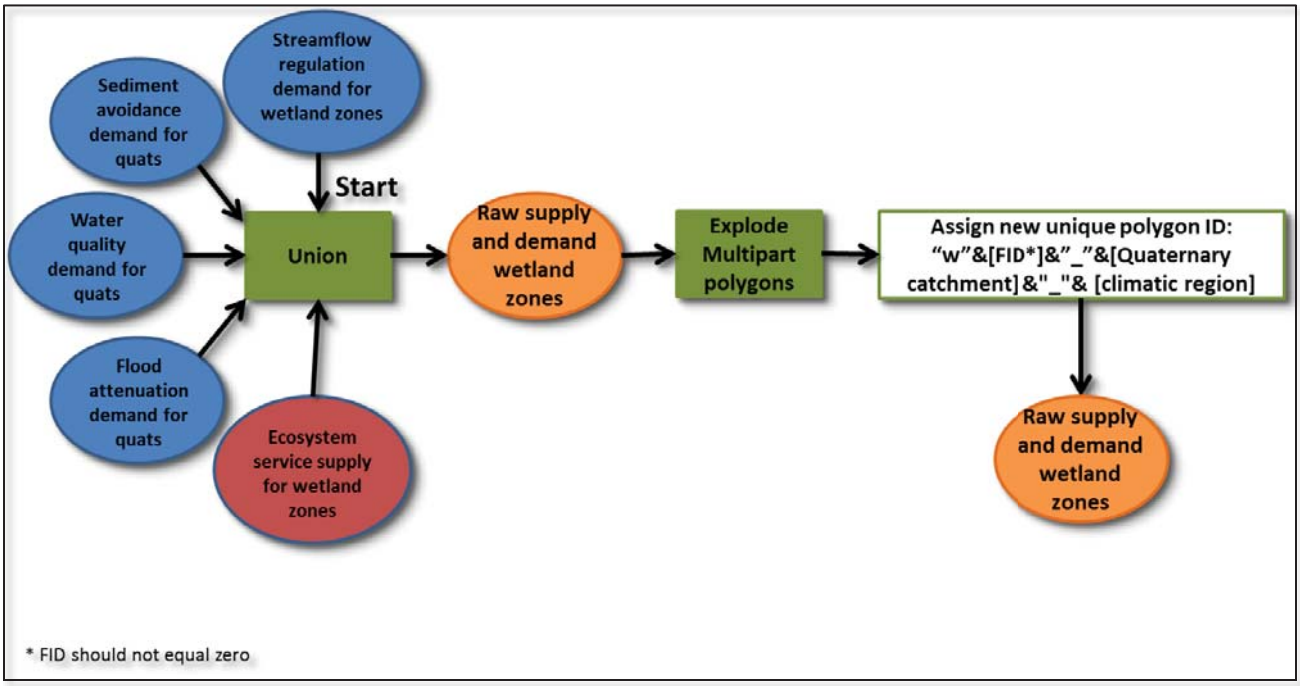


Figure 29: Schematic of the process for determining raw supply and demand wetland zones

Ecosystem service hotspots are defined as areas where high levels of service supply meet high levels of demand. Therefore, for each of the four services (flood attenuation, water quality, avoided sedimentation and streamflow regulation), the respective supply and demand scores should be multiplied to identify hotspot areas for each service by intersecting each of the supply layers with the respective demand layer. This integration process should be done at a wetland zone scale.

The integrated ecosystem service scores can then be analysed to identify ecosystem hotspot areas that could potentially be considered as significant wetland resources for the WMA. A combined approach of considering the integrated scores, as well as the delivery of specific services or combinations of services can be used to identify potential significant wetland resources.

Technical method: Using a GIS package such as ArcGIS, QGIS or something similar, the ecosystem services supply layer should be unioned with the flood attenuation, water quality, avoided sedimentation and streamflow regulation demand layers. The assessment is undertaken at wetland zone scale and not at a wetland scale, and allows the user to interrogate all the data within one spatial layer. The output of this process results in a raw supply and demand wetland zone layer.

The integrated supply and demand scores should be ranked in descending order for each service. The top 10% of polygons with the highest scores are then manually selected and classified as having a high potential to provide that particular service and assigned a “1” in a new Class field. For example, given a WMA that has 4500 wetland zones, in the attribute table, the supply scores for flood attenuation are sorted into descending order. The top 450 wetland zone polygons would then be classified as high and assigned a Class “1”. This is repeated for each of the four services that have been assessed (Figure 30).

The scores of each of the services can then be summed, and weighted by the number of times a service receives a ‘high score’ or classed as “1” as per the following equation (High= top 10 percentile).

Integrated Score = (FLD + WQ + SDMT + STRM) x (1 + count of High’s/4)

Where:
FLD = the integrated score for flood attenuation,
WQ = the integrated score for water quality enhancement and
SDMT = the integrated score for avoided sedimentation
STRM = the integrated score for streamflow regulation

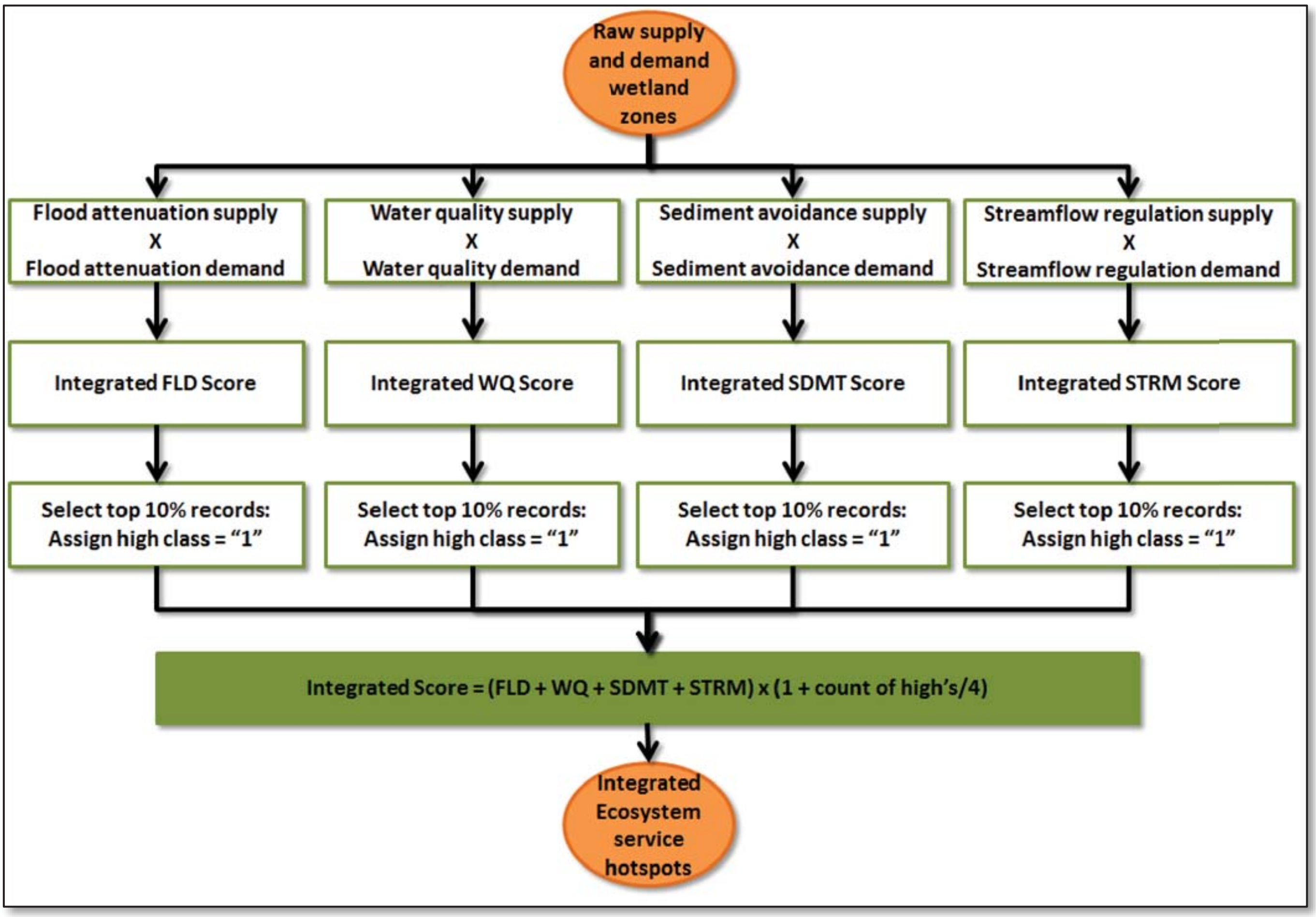


Figure 30: Schematic of the process for integrating supply and demand of select ecosystem services

The integrated ecosystem service scores should be classified into high medium and low classes using the guideline described in Section 3.2.3 as a guide. Although this is the recommended guideline, it is understood that the selection of significant wetland resources will most likely be driven by the number of systems that can practically be implemented. Therefore additional guidance is provided on selecting ecosystem service hotspots, which is based not only on the highest integrated ecosystem service scores but also on identifying wetland zones which scored high for two or more services.

Once ecosystem service hotspot areas have been identified in the WMA, these wetland zones should be used as a starting point to guide the identification of potential significant wetland resources in the WMA. A two pronged approach should be applied in identifying potential significant wetland zones. Firstly select high scoring wetland zones. Secondly select wetland zones based on the number of high scoring ecosystem services recorded for the wetland zone. Wetland zones that have scored high for all four or three of the assessed services must at least be considered. The attribute table of the integrated layer can then be interrogated to identify a 'practical' number of wetland zones, which is the number of wetland clusters / wetlands that can realistically be monitored from a RQOs perspective. A recommended starting point would be to select 50 potential significant wetland resources per WMA.

The integrated scores should be arranged in descending order so that the user can locate the high scoring wetland zones. The scores of each wetland zone can then be assessed in a descending order to understand why the wetland zone received the associated high score and also the number of services it scored high for.

These collective hotspot areas should be used in conjunction with other data layers to inform the delineation of significant wetland resources. This is the next step in the procedure. The scores for individual services should also be retained to enable RQOs to be set for specific ecosystem services should this be required.

3.3. Action 3 – Undertake an initial rapid assessment to identify wetland or wetland complexes which are potentially significant from an ecological perspective

It is widely acknowledged that wetlands are unique features in the landscape that not only provide a range of valuable services to society but may also be biodiversity significant (Dini & Everard, 2016). The focus of this initial rapid assessment is to identify wetlands or wetland complexes that are potentially significant from an ecological perspective. While the ecosystem service hotspot assessment was undertaken at a primary drainage level, this assessment should be undertaken at a broad ecoregion level (i.e. as per the example provide in Section 3.1). It is important to consider the ecoregions as these provide an overview of the underlying controls of wetlands, which determine key drivers of wetland functionality. The variation of wetlands across broad ecoregions may result in a bias to one region if an ecological assessment was undertaken at a primary drainage or WMA level. The focus on the ecoregions aims to avoid biasing the selection of significant ecological wetlands in any one area of the WMA, but instead selecting significant wetlands representative of the ecoregion and therefore of the typical wetland resources that occur under those conditions.

There is considerable variation in the level of ecological data available for wetlands across the country's WMAs. Therefore to standardize the approach to identifying wetlands likely to be significant from an ecological perspective, it is recommended that the best available national wetland spatial dataset, with the required attributes, be used to guide the initial rapid assessment. At the time of developing the procedure the NFEPA dataset and the National Vegetation Map 2012 were the best available. The user is encouraged to supplement these datasets with regional or fine scale data, or alternatively updated versions when available. It is important to remember that these datasets are being used for an initial rapid assessment and will be verified in a subsequent step.

A combined approach is considered, whereby a scoring and grouping system is used to identify potentially significant wetland resources from an ecological perspective. The distribution of likely significant wetland resources will vary considerably across ecoregions, which is why the approach considers overall high scoring wetlands and the highest scoring wetlands for each of the relevant broad ecoregions.

Technical method: Figure 31 highlights the rapid assessment process for determining wetlands that are likely to be significant from an ecological perspective.

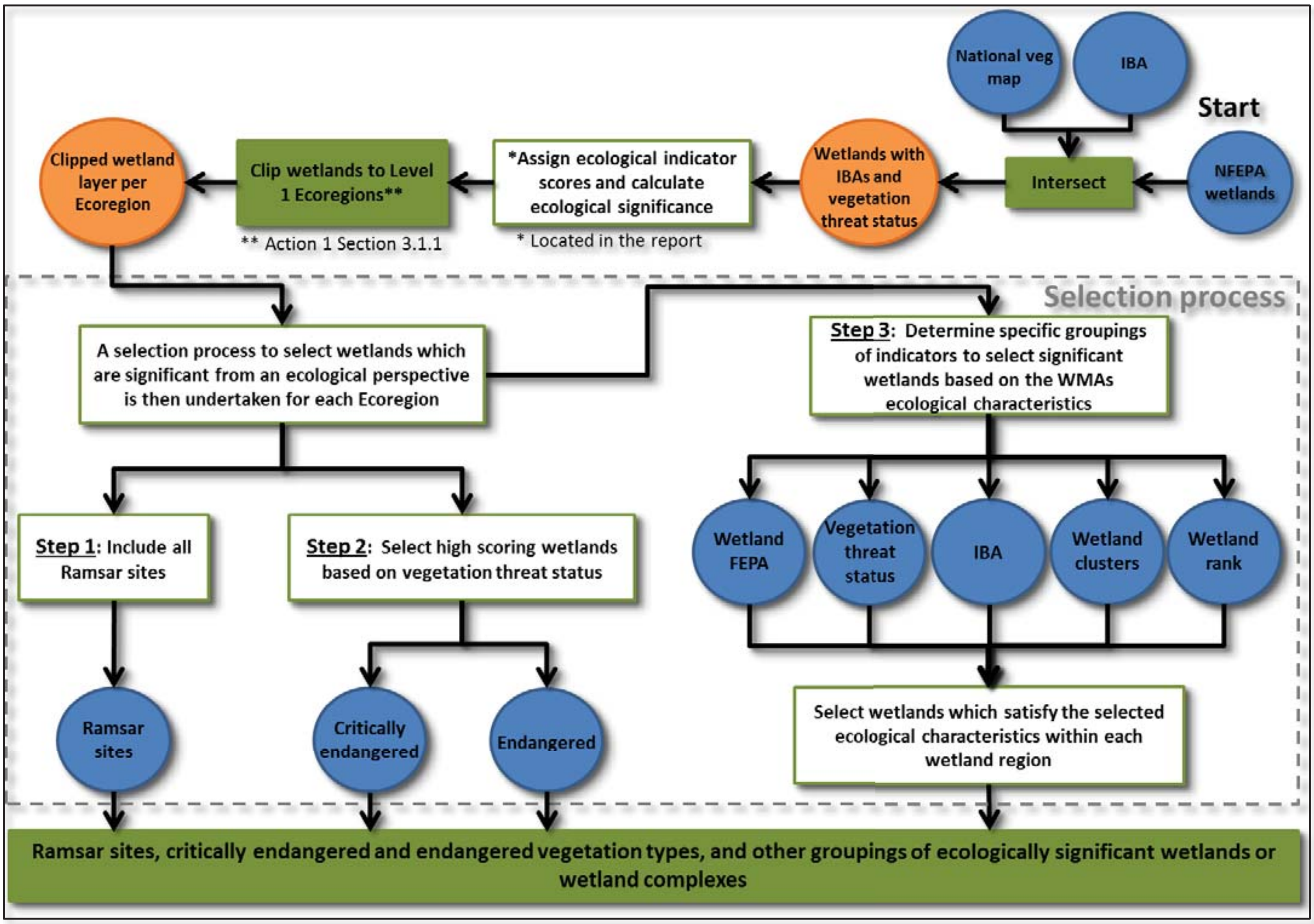


Figure 31: Schematic of the process for determining wetlands that are likely to be significant from an ecological perspective

Minimum spatial layers that need to be used for this assessment include: wetland polygons mapped for the NFEPA, the 2012 National vegetation map, and the Important Birding Areas (IBAs) layers. These spatial layers provide the attributes required to undertake a rapid assessment of potential significance from an ecological perspective. The spatial layers should be considered as a minimum and where possible improved or updated through the inclusion of additional regional or fine scale spatial layers with appropriate attributes, or replaced with updated versions. The NFEPA wetland polygons need to be intersected with the national vegetation spatial layer and the IBA layer. In the attribute table of the wetland layer, the adjustment factor scores in Table 6 are assigned for the following ecological indicators:

- Threatened vegetation status: The threat status of national vegetation layers as defined by the 2012 Vegetation Map of South Africa, Lesotho and Swaziland (SANBI, 2012).
- Important Bird Areas (IBAs): The purpose of the IBA Programme is to identify and protect a network of sites, at a biogeographical scale, critical for the long-term viability of naturally-occurring bird populations. Such sites are targeted for research and birding activities.
- Ramsar sites: Ramsar sites have been identified based on unique site attributes that emphasise their conservation value at both a National and International level.

- Wetland clusters: Wetland clusters are groups of wetlands within 1 km of each other and embedded in a relatively natural landscape. This allows for important ecological processes such as migration of frogs and insects between wetlands.
- Wetland rank 2: Wetlands were ranked in terms of their importance from an ecological perspective for NFEPA (Nel et al., 2011). This provided a useful basis for comparing the relative importance of wetlands in contributing towards biodiversity objectives. Wetland rank 2 specifically includes (Nel et al., 2011):
  - Wetlands within 500 m of a IUCN threatened frog point locality;
  - Wetlands within 500 m of a threatened water bird point locality;
  - Wetlands (excluding dams) with the majority of its area within a sub-quaternary catchment that has sightings or breeding areas for threatened Wattled Cranes, Grey Crowned Cranes and Blue Cranes;
  - Wetlands (excluding dams) within a sub-quaternary catchment identified by experts at the regional review workshops as containing wetlands of exceptional biodiversity importance, with valid reasons documented; and
  - Wetlands (excluding dams) within a sub-quaternary catchment identified by experts at the regional review workshops as containing wetlands that are good, intact examples from which to choose.
- Wetland FEPA: Wetland biodiversity targets (i.e. Wetland FEPAs). Wetland condition, largely modelled, was used primarily for the selection of wetland FEPAs.

Table 6: Adjustment factors to identify wetlands likely to be significant from an ecological perspective

Ecological Significance	Ramsar	CR	EN	VU	LT	Wetland FEPA	Wetland Cluster	Wetland Rank 2	IBAs
Ramsar	2								
Threat Status		2	2	1	0				
Wetland FEPA						0.5			
Wetland Cluster							0.5		
Wetland Rank 2								1	
IBAs									0.5

CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LT = Least Threatened IBAs = Important Birding Areas

The following formula is then applied to determine the ecological score:

Ecological Score = (Ramsar) + (Threat status) + (Wetland FEPA + Wetland Cluster + Wetland Rank + IBAs)

Once the scores have been determined, the wetland layer can then be clipped to each ecoregion occurring within the study area as defined in Action 1 Section 3.1.1., the output of this process is a wetland layer for each broad ecoregion occurring within the WMA. All wetland polygons scoring 2 or more should be considered as potentially significant from an ecological perspective. The adjustment factors ensure that all Ramsar sites, and CR and EN vegetation is automatically included as potentially significant from an ecological perspective. The additional attributes can score 2 or more through a variety of combinations.

It should be stressed that this action will need to be completed within a limited timeframe (i.e. a few days to a week) and therefore this should only be viewed as an initial identification of wetlands significant from an ecological perspective. The procedure affords the opportunity to verify identified wetlands through an iterative process. The calculated ecological scores, along with the groupings of key indicators, provide an initial indication of potential ecologically significance throughout the study area and is important as it provides guidance for the catchment tour in the next step.

It is recommended that data incorporated in this step have coverage for either the entire WMA study area or the entire ecoregion which is being assessed. However, it is acknowledged that this may not always be the case. The team should then identify individual or groups of ecological characteristics which are considered important within the WMA and select wetlands or wetland complexes based on ecological characteristics which the team deems important.

3.4. Action 4: Undertake a catchment tour to broadly confirm distribution, extent, type and condition of wetlands

A rapid visual catchment tour allows the specialists on the RQOs project team the opportunity to learn more about the WMA as a whole, while specifically focusing on their respective resources or aspects of interest. The identified ecologically important wetland areas and ecosystem service hotspots will guide where in the catchment the wetland specialist would ideally need to visit. The catchment tour affords the opportunity to undertake an initial verification process. The extent, type, condition, and identified ecosystem service hotspots can be broadly confirmed for those wetlands and wetland complexes that can be visited during the catchment tour. The tour also provides the opportunity for the wetland specialist to learn about the other water resources and important aspects (e.g. socio-economic component) from the project members. Thus the catchment tour should be seen as the first step in an interactive process that will lead to the determining of both IUAs (if not already delineated) and Resource Units (RUs).

Technical method: A rapid tour of the catchment should be conducted. The tour should include all of the specialists working on the RQOs team. The extent, type, condition, and identified ecosystem service hotspots can be broadly confirmed for those wetlands and wetland complexes that can be visited during the catchment tour. While the focus will be on rapidly assessing accessible wetlands or wetland complexes, it is important to remember that the tour is the perfect opportunity to learn about other water resources within the study area from the other specialists.

The value of the catchment tour involving all specialists on the RQOs project team cannot be stressed enough. There may be a tendency by project teams to omit this action to try and save on costs. This should be avoided. If defensible RQOs are to be determined for wetlands, then it is essential that a sufficient level of infield assessments, albeit rapid assessments, be undertaken.

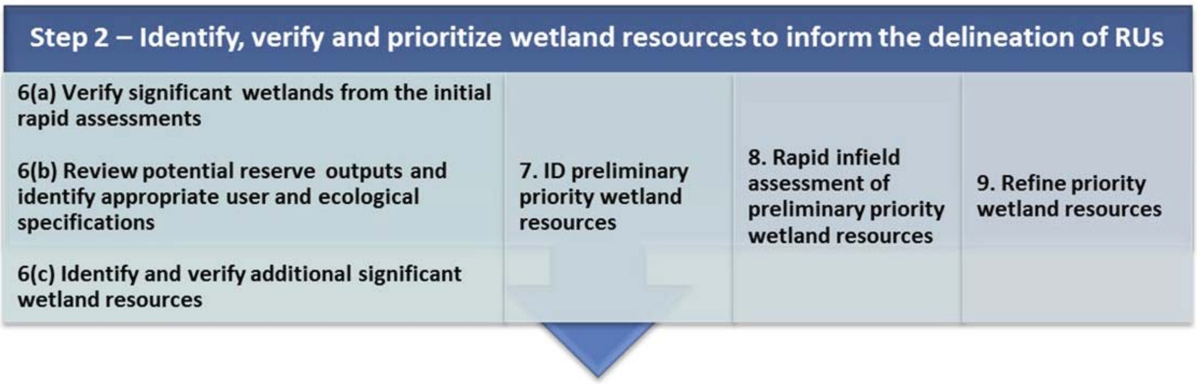
3.5. Action 5 − As the wetland specialist on the project team participate in an integrated workshop to delineate IUAs

The DWA (2011) identified Integrated Units of Analysis (IUAs) as finer-scale units aligned to watershed boundaries, in which socio-economic activities are likely to be similar. These homogeneous units provide a useful indication of similar impacts in different areas of the catchment which need to be taken into consideration for the determination of RQOs. The purpose of defining IUAs is to establish broader-scale units which may be subjected to similar anthropogenic impacts. Essentially the IUAs are a combination of socio-economic zones and watershed boundaries, within which ecological information is provided at a finer-scale (DWA, 2011). The IUA delineation process is undertaken for the Water Resource Classification process, which precedes the RQO determination process. Integrated Units of Analysis are therefore an important baseline for determining RQOs, as they provide the broader socio-economic context, which needs to be taken into consideration for the determination of Resource Units (RUs). Resource Units are typically nested within IUAs and should align, where possible, with IUA boundaries (DWA, 2011).

The RQO process is currently undertaken as an integrated process, which starts with the classification of water resources and leads into the development of RQOs for significant water resources. There is a level of overlap when applying an integrated process. The need to delineate IUAs is one such overlap. IUAs are required for the classification process and therefore Step 1 of this procedure should be undertaken for the classification process. It also needs to be undertaken within a short timeframe, which is why the initial phase of the proposed approach is a rapid one.

Technical method: The IUAs should be determined through an interactive process involving team specialists assessing the various water resources and the socio-economic component. A workshop is likely to be the most effective way of determining the IUAs. While wetland information is not essential for determining IUAs, it certainly adds value to the process. The outputs from at least Step 1 of the procedure, and any additional wetland information, should be presented at an integration workshop for determining IUAs.

4. STEP 2 – IDENTIFY AND PRIORITIZE INDIVIDUAL WETLANDS AND WETLAND COMPLEXES THROUGHOUT THE STUDY AREA



<u>Actions required to address this step include:</u>

6. Select individual wetlands and wetland complexes that are considered to be significant wetland resources;
7. Identify the preliminary priority wetland resources;
8. Undertake a rapid infield assessment of the selected priority wetland resources; and
9. Refine the priority wetland resources.

4.1. Action 6 – Select individual wetlands and wetland complexes that are considered significant wetland resources

4.1.1. Phase one – desktop verification of ecosystem service hotspots and wetland resources identified to be significant from an ecological perspective

Significant wetland resources, which can be either individual wetlands or wetland complexes, can be selected based on water resource use, socio-cultural and ecological values. These resources are often areas of high ecological importance where water resources are stressed or may be stressed in future. The verification process acts as a filter to allow one to select resources that are significant and exclude those that are no longer considered to be significant after verification. The first phase is to identify both significant wetland resources within the ecosystem service hotspots identified and the wetland resources identified to be significant from an ecological perspective.

<u>Technical method</u>: The outputs from Step 1, i.e. the 'ecosystem service hotspots' and wetland resources likely to be significant from an ecological perspective, are used as a baseline to identify significant wetland resources (Bredin et al., in press). The highest scoring wetland zones and also the wetland zones that score high for four or three of the ecosystem services, where both supply and demand were assessed, should be verified. This process involves interrogating the attributes that lead to the overall score and then undertaking a desktop assessment using Google Earth, or best available satellite imagery, to find evidence to support the findings of the rapid assessment. For example, if a wetland zone was flagged as having a high demand for sediment avoidance then the following should be verified:

- The supply dam that triggered the demand for sediment retention is located downstream of the wetland zone; and

- The wetland resources that provide effective sediment retention, such as unchannelled valley-bottom systems, can be found within the wetland zone.

The threshold for the verification process will and for the foreseeable future be based on how many wetland resources can practically be considered for RQOs. As a guideline the top scoring wetland zones, according to the integrated scores, which include the wetland zones that scored high for all four or three of the assessed ecosystem services, should undergo verification. Thereafter if additional significant wetland resources can be considered the next highest scoring wetland zones should be considered for verification.

From an ecological perspective, the attributes of the ecological assessments should be investigated with a similar approach. The ecological scores for each of the ecoregions assessed should be arranged in descending order which allows for the selection of wetlands or wetland complexes (i.e. selection to consider representatives of specific types or representatives of an ecoregion). All wetland polygons that scored 2 or more should be verified. This will include all Ramsar sites, all sites with Critically Endangered (CR) and Endangered (EN) vegetation threat statuses, and sites scoring 2 or more for a combination of Vulnerable (VU) vegetation threat status, IBAs, Wetland Rank 2, Wetland Clusters, and Wetland FEPAs. Equally the top scoring wetland polygons from each of the ecoregions assessed should be verified (As a guide, it is suggested that the top 5-10 wetlands from each ecoregion be included in the verification process).

The interrogation of the outputs from Step 1 should be supported by any available additional wetland data (e.g. fine scale data) to help verify the wetland resource and the demand for the service/s it is providing. A key part of the interrogation of the data is to delineate the significant wetland resources, which include both individual wetlands and wetland complexes. Available fine scale data will also assist delineation. Alternatively a rapid visual assessment of satellite imagery can be undertaken to gain a better understanding of the extent (Note: a digitizing exercise, as per Mbona et al. (2015), will be carried out for the selected priority wetland resources in Action 10. This is to ensure an appropriate level of accuracy for the purposes of setting RQOs).

Example: Figure 32 illustrates an example of wetland zones identified as ecosystems service hotspots and wetland polygons identified to be significant from an ecological perspective across the Breede catchment.

Examples of the process undertaken to identify significant wetland resources and the delineation of the resources include:

- De hoop vlei (Ramsar site – G50H &J) – an example of a wetland system selected according to its significance from an ecological perspective;
- Botrivier wetland complex (G40E) – an example of a potential significant wetland cluster from an ecosystem service perspective that was not selected; and
- Uilkraalsrivier wetland complex (G40M) – an example of a wetland complex that was selected on the grounds of being significant from an ecosystem service perspective.

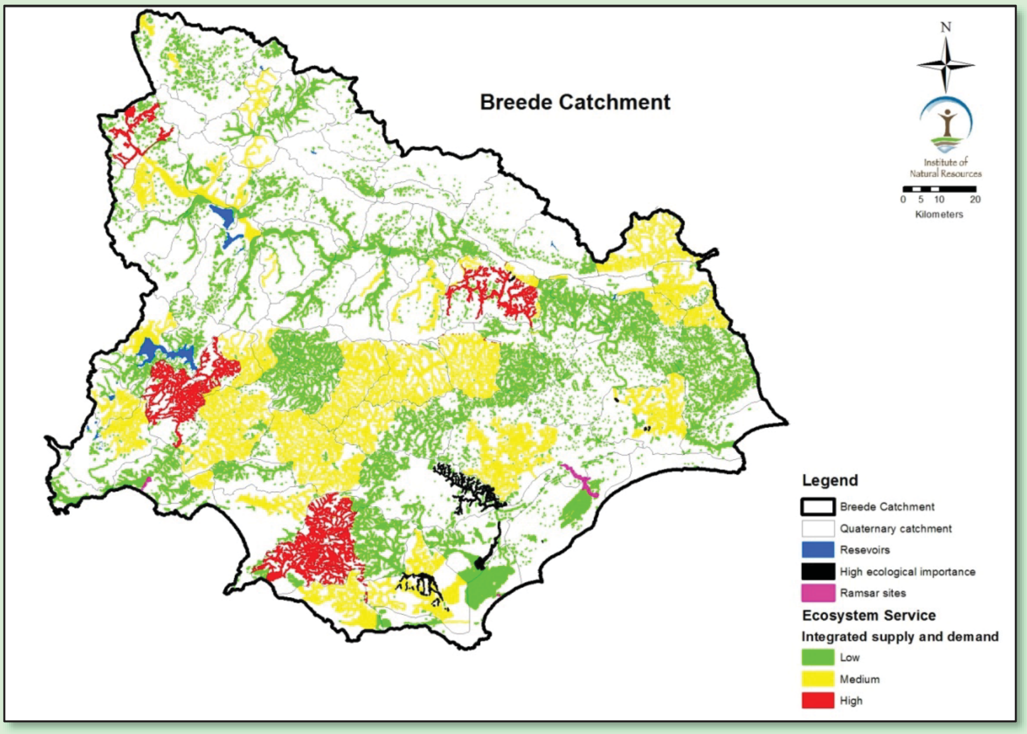


Figure 32: Potential ecosystem service hotspots and ecological significant wetland areas within the Breede catchment requiring verification

De hoop vlei is a Ramsar site and therefore automatically considered as a significant wetland resource, i.e. due to its national / international importance. Portions of the wetland were also identified as important from an ecological perspective due to the presence of critically endangered habitat. De hoop vlei is also an important birding area. It should be selected as a significant wetland resource and delineated according to the Ramsar site (Figure 33).

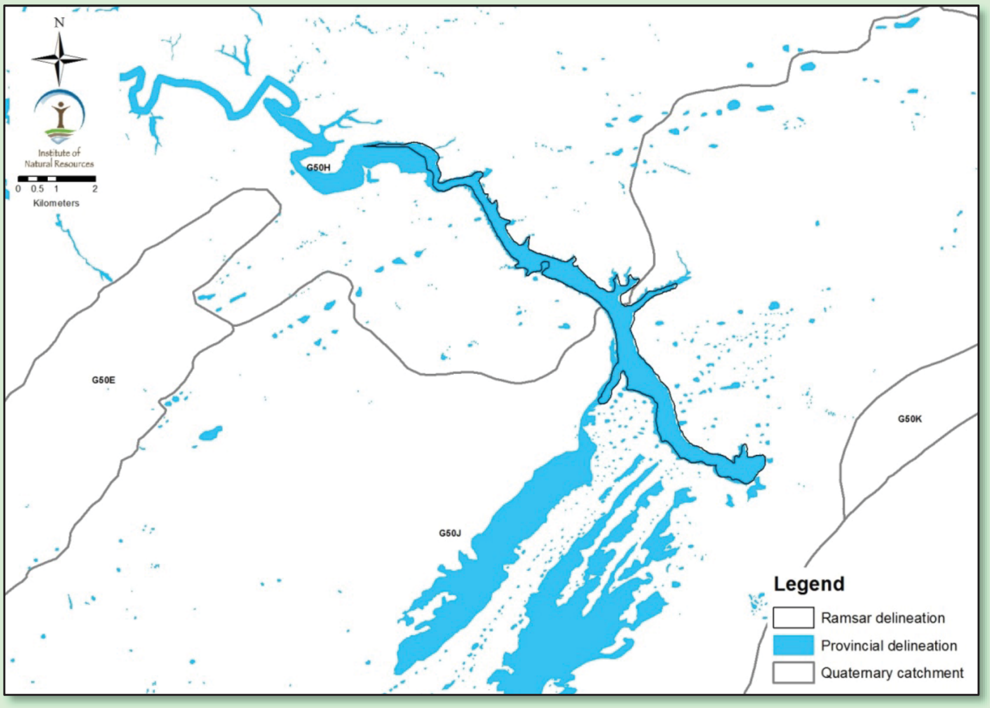


Figure 33: De Hoop Vlei Ramsar site – a significant wetland resource

The Botrivier wetland complex is largely surrounded by agriculture along the central and eastern portion of the system. The western and south western portions of the wetland are located in nature reserves: Hottentots Holland Mountain Catchment area, Groenlandberg Nature Reserve and Nuweberg Staatsbos. It was identified as a potentially significant wetland resource for its ability to provide the function of sediment trapping upstream of a key water supply dam. However, on interrogating the ecosystem service hotspot it was determined that the dam is actually an agricultural dam that is located at the top of the catchment, and therefore the downstream wetland complex is not able to provide sediment trapping. The verification process resulted in this wetland complex being excluded.

The Uilkraalsrivier wetland complex is a significant wetland resource in the southern fold mountains, due to:

- Flood attenuation – Moderately high integrated supply and demand scores. Franskraal, as well as a smaller settlement, is located directly adjacent to the estuary downstream of the main body of the wetland (i.e. a valley bottom system). Location of households with the flood risk area would suggest a moderately high demand for flood attenuation within the catchment.
- Water quality – The high integrated water quality is due to a moderately high supply score and a high demand score. Due to the agricultural activity within the catchment, the presence of Franskraal in the lower end of the catchment an the high risk of diffuse surface flow pollution, the ALARM tool calculated that the catchment (G40M) had a high combined pollutant water quality risk score and therefore a high demand for water quality ecosystem services. There are also a high number of households dependent on non-potable water within this catchment which results in an increased demand for water quality enhancement.
- Sediment avoidance – Initial scoring for this wetland was low for sediment avoidance demand as the national dams' layer showed that there were no dams present within the catchment. Upon further interrogation a supply dam was discovered to be within the quaternary catchment and linked to the wetland. This resulted in an increase of the sediment avoidance score from low to high.
- Streamflow regulation – The wetland complex has an overall moderate score for streamflow regulation as the lower half of the complex is within a SWSA and had a relatively high score whilst the top half of the received a low score. Due to the importance of the SWSA the entire system is considered as being important from a streamflow regulation perspective as opposed to just a portion of the wetland.

It is also worth noting that from an ecological perspective within the wetland complex is a vegetation type that is considered Endangered. The wetland has also been highlighted as an important cluster on the NWM5 layer.

The high value from an ecosystem service perspective was the primary reason for selecting this wetland complex Figure 34 illustrates the delineation of the wetland complex, where desktop mapping was undertaken to refine the delineation of the wetland complex.

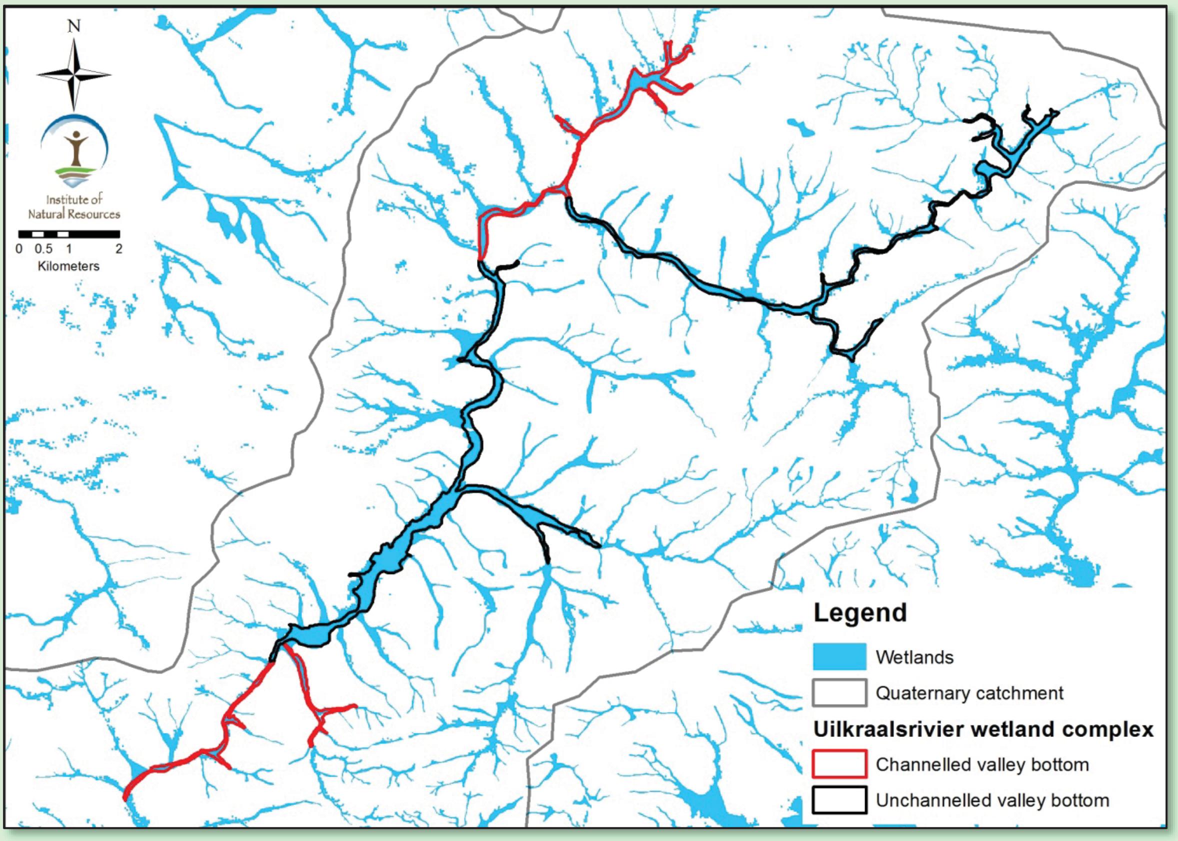


Figure 34: The Uilkraalsrivier wetland complex comprising of channelled and unchannelled valley bottom wetlands

4.1.2. Phase two – review potential reserve outputs and identify appropriate ecological specifications

Available reserve studies should be consulted to identify wetland resources, which have ecological specifications (i.e. Eco Specs). For more detailed reserve studies this level of data could potentially allow for more detailed RQOs to be set (i.e. numeric limits could potentially be considered for these specific wetland resources if there is sufficient data)

Technical method: Engage the relevant authorities and key stakeholders to determine what reserve studies have been undertaken in the study area. Wetland resources included in reserve studies, particularly intermediate studies, should for considered significant wetland resources. Data generated for a reserve study may provide the best opportunity to set RQOs for a range of sub-components and at a level of detail that would include numerical limits.

4.1.3. Phase three – selecting individual wetlands and wetland complexes considered to be significant wetland resources

The third phase of the Action 6 is to interrogate additional data layers from both an ecological and user perspective to identify significant wetland resources that would not have necessarily been detected through the initial rapid assessments undertaken.

This step builds on to the initial list of potential significant wetlands compiled through interrogating the ecosystem service hotspots and the wetlands considered to be significant from an ecological perspective. Further available information and specialist knowledge of the area should be consulted to identify additional wetlands and wetland complexes, which may also be significant wetland resources. Best available wetland spatial data should be used but as with the first phase, each potentially significant wetland resource needs to be validated.

Technical method: Interrogation of available datasets is generally not automated and thus can be time consuming, requires reasonable GIS experience, and is dependent on expert interpretation and some local knowledge of the area being considered. Generally, unless more detailed delineations are available, all potentially significant wetland resources require additional desktop mapping using the most recent available imagery. It is recommended that wherever possible, this is done at a scale of 1: 5 000 or as close as possible to this. In some cases significant wetland resources may not be captured on existing wetland databases and will need to be mapped as part of the verification process. Despite mapping at a desktop level, it is important to try to capture the wetland resource boundaries as accurately as possible.

Additional potential significant wetland resources should be considered for inclusion based on consideration of the aspects such as but not limited to:

- Whether there is a strategic use requirement for wetland resources within sections of the WMA that may elevate the importance of wetland systems;
- Whether there are any known vulnerable uses of wetland resources within the WMA;
- Whether or not there are high demand areas for ecosystem services not considered in the rapid ecosystem service assessment;
- Whether or not the system occurs within a conservation area;
- Whether or not the system is recognised as having cultural significance or supporting livelihoods through providing provisioning ecosystem services;
- Whether or not the system occurs in a database, regional, local or other (fine scale), that indicates it as being an important wetland. Aspects such as the Vegetation Group and Threat Status of the wetland are considered as is whether the system forms part of a Threatened Ecosystem (according to GN 1002, National List of Ecosystems that are Threatened and in need of Protection) (Note: this is largely covered in the first phase but it is worth double checking);
- Whether or not the system is known to support rare or threatened species (in addition to the data and / or species considered in the first phase). For example: Pickersgill's Reed frog and Wattled Cranes (CR species), known breeding sites for rare or threatened species, and crane species distributions which can be accessed through the South African Bird Atlas Project 2 (SABAP2) or the Endangered Wildlife Trust (EWT). The distribution of threatened bird species that are known to utilize wetland habitat can be drawn from the Coordinated Water Birds Counts (CWAC) or the SABAP2;
- Systems known to contain peat (Refer to the peatlands map for South Africa for an initial guide to identifying the location of peatlands);
- Systems thought to be important in terms of the hydrology, geohydrology and/or the biogeochemistry of a particular area or sub-catchment;
- Whether or not the system forms part of a biodiversity or landscape corridor that is considered important for a particular area or region or a particular species;
- Fish sanctuaries or sites which are important for protecting threatened freshwater fish or provide fish migration corridors between certain habitats;
- Whether or not the system is associated with important rivers, aquifers (groundwater linked) or estuaries; and

- Expert knowledge of potentially significant wetland resources from either a user or ecological perspective.

This approach allows the use of coarse data / low accuracy wetland spatial data to inform the initial rapid assessment followed by a verification process, using available data and input from experts. The follow-on assessments will allow for additional criteria to be assessed, and then verified, which will lead to additional significant wetland resources being identified and mapped. This is not a once-off activity but an iterative process.

The above additional criteria need to be considered in the context of the health or state of the wetland systems and their likely trajectory of change given the current land uses in the area or whether or not it is considered to be at risk from proposed new water uses in the area. Expert opinions form a vital part of the assessment and as such a combination of additional desktop mapping and field verification is required.

Where additional ecosystem services are identified as potentially being important, the ecosystem supply outputs from the ecosystem service hotspot assessment can be used to identify likely areas of high supply of each service. It is important that other water resources are taken into consideration during these ecosystems service assessments.

4.2. Action 7 – Identify the preliminary priority wetland resources

Thus far the procedure has allowed for an iterative process to identify significant wetland resources throughout a WMA. For the purposes of setting wetland RQOs a select group of the significant wetland resources needs to be identified. This is primarily due to the practical limits of implementing RQOs for wetland resources. A preliminary group should be selected for further verification. The subset of the significant wetland resources are referred to as the *Priority Wetland Resources*.

***Technical method*:**
At this stage a list of verified significant wetland resources, which may include both individual wetlands and wetland complexes, selected from an ecological and ecosystem service perspective should be drafted. Evidence for the selection of the significant wetland resources should be documented. The extent of each of the priority wetland resources should be verified through a visual inspection of satellite imagery or through the use of available fine-scale wetland spatial data (Note: extent will be verified for priority wetland resources in Action 10). The preliminary priority wetland resources are the initial selected wetland resources for the setting of RQOs. The number of wetland resources to be selected will be guided by how many resources can be practically managed / monitored. The preliminary priority wetlands will undergo further verification during the next action, which is a rapid infield assessment.

Priority Wetland Resources are a subset of identified significant wetland resources. The wetland resources would have been identified as significant for the following reasons (more than one of these may be applicable) (Figure 35):

- Significant from an ecosystem service perspective;
- Significant from an ecological perspective, which includes wetland resources with ecological specifications (i.e. determined through a reserve assessment); and
- Wetlands connected to significant river or groundwater resources, where overlapping RQOs may occur.

The level of threat posed to the wetland resources was not directly considered as part of the initial rapid assessment for identifying significant wetland resources. Therefore, threat should be taken into consideration when selecting the Priority Wetland Resources. Emphasis should be placed on selecting wetland resources most likely to be impacted by high risk activities and which could therefore have serious implications for users and the environment if not effectively managed (DWA, 2011). Potential priority wetland resources located within catchments where there is unlikely to be significant threat (both current and future) should be excluded, with clear reasoning.

The level of threat should be guided by the level of transformation within the quaternary catchment where the wetland resource is located. Essentially where there is greater transformation the wetland resources is likely to be under greater threat. Where required, this level of assessment of transformation can be refined. However, its primary purpose is to provide an indication of the likely threat, which can be used to assist in the selection on Priority Wetland Resources. Figure 36 illustrates the transformation layer that has been determined from the categorising of the National Land Cover layer into either transformed or untransformed categories (Annexure 4). The spatial data illustrated in Figure 36 should be used to guide the broad threat assessment.

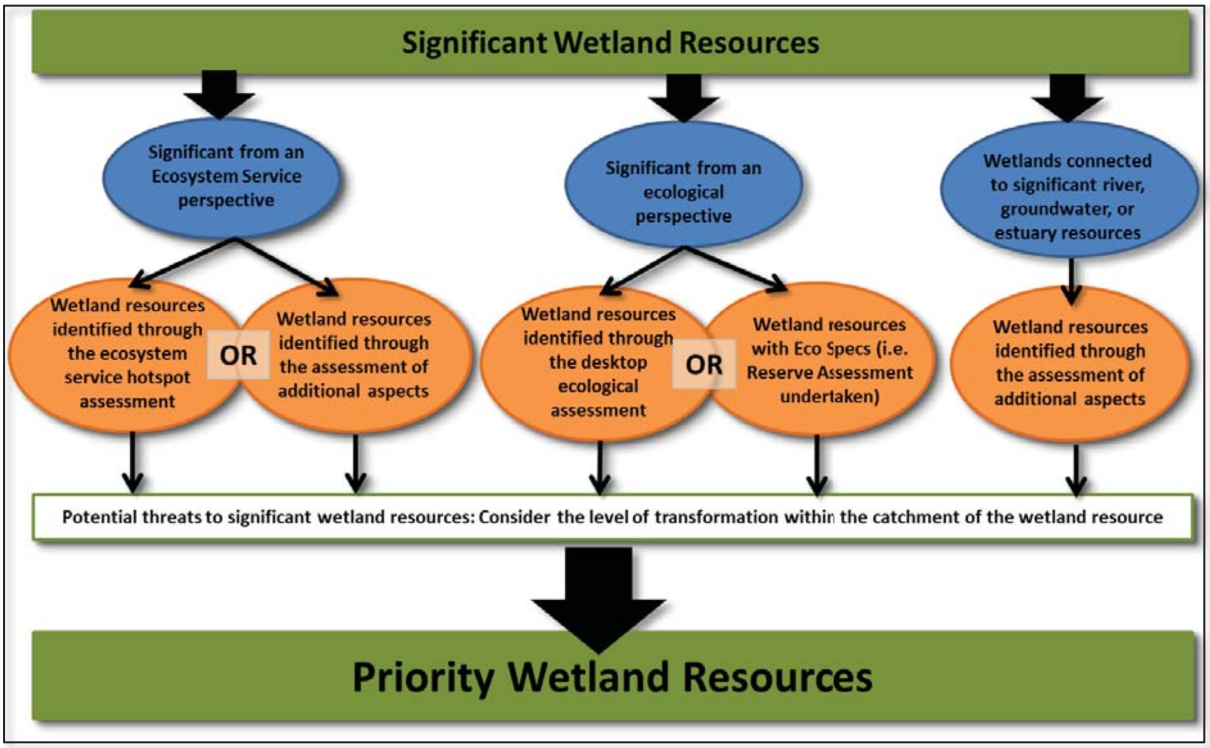


Figure 35: Schematic of the process for selecting Priority Wetland Resources

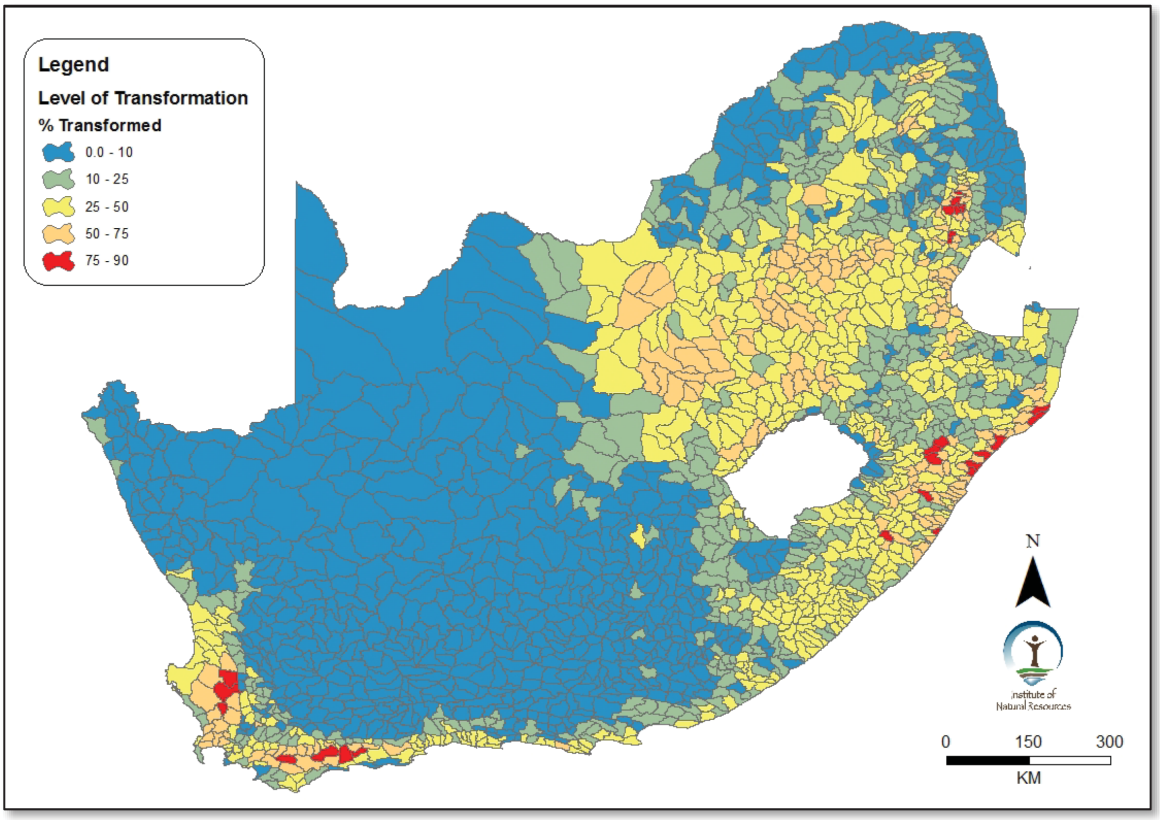


Figure 36: An illustration of an approximate level of transformation based on an assessment of the National Land Cover at a quaternary catchment scale

It is important to note that at this point in the procedure there is an opportunity to tailor the assessment according to the available budget. While it is hoped that consideration of the full procedure will be taken into consideration for the budgeting of the wetland component of RQOs projects, it is acknowledged that in some instances the wetland specialist may be required to develop wetland RQOs on a reduced budget. If this is the case, fewer significant wetland resources can be selected during the verification process. However, this would need to be in agreement with the DWS.

4.3. Action 8 – Undertake a rapid infield assessment of the selected priority wetland resources

The initial catchment tour afforded the opportunity to get a better understanding of the catchment in general, and to visit a limited number of wetlands to undertake some infield verification. A follow-up infield assessment of the preliminary priority wetlands and wetland complexes is essential. The focus of the assessment will be to verify the desktop assessment of the preliminary prioritized wetland resources. As a guideline, the infield assessment is anticipated to be a visual assessment with limited sampling over a period of approximately a week.

Technical method: Undertake an infield rapid visual assessment of the preliminary priority wetland resources. The assessment will largely be a visual assessment, either from a vehicle or by foot (where access allows) of the priority wetland resources and the catchment areas. It is important to remember that the majority of the wetland resources are likely to be on private land and therefore accessibility could be limited. The visual assessment will likely be conducted from accessible observation points along public roads throughout the study area. The focus of the visual assessment should be to, as best as possible:

- Verify the desktop assessment of the prioritized wetland resources, in terms of extent and HGM type;
- Document any impacts within the wetland resources, the adjacent 'zone of influence' and the wetland's catchment;
- Document different land cover types within the wetland resource and an approximate 200 m zone of influence;
- Document evidence to suggest the Importance and Sensitivity of the wetland resource; and
- Where possible, document any evidence of rare or threatened species.

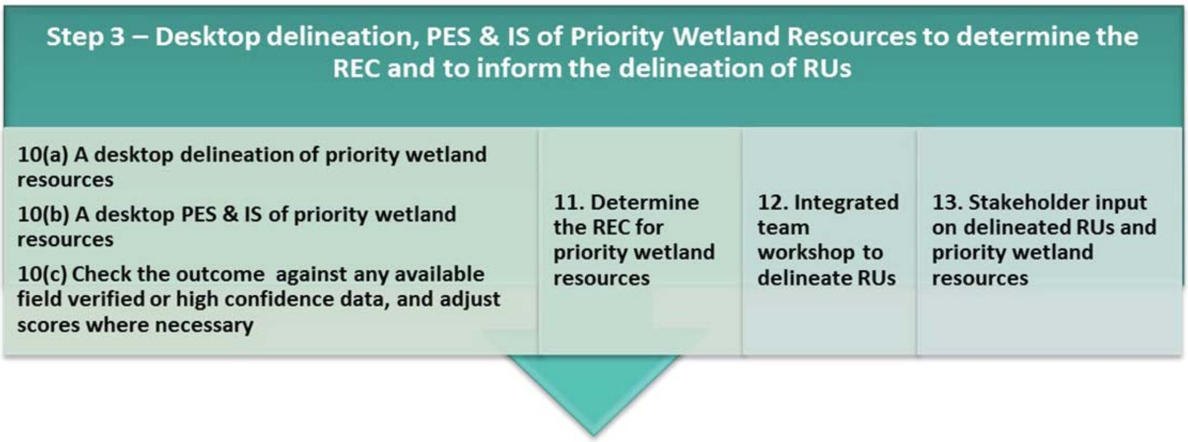
4.4. Action 9 – Refine priority wetland resources

The rapid infield assessment of the preliminary priority wetland resources should provide the evidence required to make a final decision on the selection of the priority wetland resources. The infield verification is an essential action for confirming, based on best available information, the inclusion or exclusion of the preliminary wetland resources.

Technical method: Use the outcomes of the rapid infield assessment of the preliminary wetland resources to select the priority wetland resources for RQOs. It is important to share the proposed priority wetland resources with the other water resource specialists on the RQOs project team and the RDM representative from the DWS.

The priority wetland resources will inform the delineation of Resource Units (RUs). While this process is covered in Action 12 it is important to note that all water resource RUs should be delineated through an integrated process (i.e. refer to Action 12). However, alignment with the other water resource specialists on the RQOs project team can be challenging and there may be a need to contribute to the delineation of RUs prior to completing Actions 10 and 11. Therefore, a level of flexibility is required when delineating RUs (i.e. embedding priority wetland resources into river or groundwater RUs, or alternatively identifying separate wetland RUs where applicable).

5. STEP 3 – ASSESSMENT OF PRIORITY WETLAND RESOURCES



<u>Actions required to address this step include:</u>

10. A desktop delineation of priority wetland resources; a desktop PES & IS of priority wetland resources; and the checking of outcomes of these process with available field verified or high confidence data, and adjust scores where necessary;
11. Determine the REC for priority wetland resources;
12. Participate in an integrated team workshop to delineate RUs; and
13. Obtain stakeholder input on the delineated RUs and priority wetland resources.

5.1. Action 10: Undertake a desktop delineation, desktop PES and IS assessment of priority wetland resources and check the outcomes against high confidence data

For all priority wetland resources, the following approach is recommended for the determination of relevant measurable indicators:

- Determine a baseline (i.e. undertake a desktop delineation process);
- Undertake an assessment of 'cleaned' land cover categories within the wetland resources and the zone of influences; and
- Calculate the ecological condition categories (i.e. PES) and importance and sensitivity (IS).

5.1.1. Phase one – Undertake a desktop delineation of the priority wetland resources

It is widely acknowledged that the current level of mapping of wetlands throughout WMAs is not at a sufficient level to adequately inform the RQOs process. While some initial refinements to wetland resource extent would have been made during the previous verification processes, which would have included the use of available fine-scale wetland data, it is nevertheless important to remember that the delineation of the priority wetland resources was based primarily on low confidence spatial data (e.g. NFEPA and NWM5). Therefore, a desktop delineation process is required to ensure the delineations of the priority wetland resources are refined as best as possible.

Technical method: Reference should be made to Mbona et al. (2015) and van Deventer (2016)[10], to guide the desktop delineation of priority wetland resources.

Mbona et al. (2015) outline a process for mapping wetlands at a desktop level (i.e. desktop delineation of wetlands using appropriate remote sensing imagery) that allows for a significant improvement in the mapping of wetland extent. The desktop determination of wetland extent should consider:

- Visible patches of open water;
- Visible signs of the presence of vegetation clumps or patterns indicative of periodic soil saturation and indicator communities/species (i.e. vegetation colour, pattern and texture);
- Location within the landscape;
- Contour lines which indicate watersheds; and
- River lines which indicate the direction of water flow.

Mbona et al. (2015) highlighted that in general wetland resources often appear different in colour and texture from the surrounding dryland areas when interrogating satellite imagery. In addition, wetlands are typically found in low-lying regions in the landscape as channelled or unchannelled valley bottoms or in seepage areas at higher elevations as valley head or hillslope seeps. It is also important to remember that there is often connectivity between hillslope seeps and valley bottom wetland areas. Wetlands can also appear slightly differently depending on the soil and vegetation. For example, wetlands often appear darker than the surrounding dryland and have a more “blotchy texture” when considering the vegetation layer. These differences can be particularly evident in the summer rainfall regions of South Africa where soils tend to be darker in water-logged areas. Lastly, wetlands in certain regions of the country are often difficult to farm and therefore often appear as unfarmed areas in a highly transformed agricultural landscape (i.e. this is not always the case, such as in the Western Cape where wetlands have been extensively farmed). In addition, the presence of dams on a farm is also a good indicator of where wetlands may be or where they may have once occurred.

Undertaking a desktop interrogation of a combination of Google Earth satellite imagery, contour data and river lines (plus any other layers deemed to be useful for determining extent of wetlands), is the rapid procedure that should be followed for improving the accuracy of mapped wetland resources throughout the WMA. This will provide the required ‘baseline’ for assessing wetland extent, PES and IS, and impacts to the wetland resource.

5.1.2. Phase two – Undertake a desktop Present Ecological State (PES) and Importance and Sensitivity (IS) assessment of priority wetland resources

When evaluating a wetland resource and providing recommendations for the future management or REC, the NWA requires consideration of the PES (i.e. health or integrity of the wetland resource relative to the natural or close to the natural reference condition) and the IS, which includes (Rountree et al., 2013):

[10] The efforts to update the NWM include the WRC Project K5/2546: Enabling more responsive policy and decision-making in relation to wetlands through improving the quality of spatial wetland data in South Africa.

- Ecological Importance (ecosystems and biodiversity);
- Ecological functions, and
- Basic human needs (especially for rural people who rely directly on ecosystem goods and services for their livelihoods and wellbeing).

According to Rountree et al. (2013) wetland resources which have high values for one or more of these criteria may thus be justifiably managed with greater care due to their ecological importance (for instance, due to biodiversity support for endangered species), their hydrological functional importance (where water resources provide critical functions upon which people may be dependent) or their role in providing direct human benefits (such as meeting some of the basic needs of rural people who depend directly on the water resource). Therefore, a PES and IS assessment are required to be undertaken for priority wetland resources.

A desktop PES and IS also provide an opportunity to gather data for the priority wetland resources, which would unlikely have been available. This essentially will allow for the setting of RQOs for the wetland resources, albeit limited RQOs (to be discussed in the next steps).

Technical method: A major challenge with any catchment-scale study, particularly where access to priority wetland resources and time is limited, is determining the Present Ecological State (PES) of the systems. The revised WET-health tools (Macfarlane et al., 2018) address these issues and allows for the determination of PES across a range of spatial scales. Two levels are provided for desktop-based assessments which have been modified from the semi-quantitative desktop method "A method to assess wetland ecological condition based on land-cover type", Water Research Commission Project K5/2350 (Kotze, 2016a and 2016b). Level 1A is aimed at national and regional assessments which are based entirely on existing land cover data. Level 1B is aimed at regional to local scale assessments which is based on refined land cover classes as well as a 'heads-up' digitising and verification process which results in an increased confidence level in the results. The level 2 assessment is conducted at a site based scale with a high confidence level (Macfarlane et al., 2018).

For the assessment of the PES of the priority wetland resources, the Wet-Health Level 1B assessment should be applied (Macfarlane et al., 2018). The Wet-Health manual should be consulted. The bullets below, and the schematic in Figure 37, outline key requirements for consideration when applying the Wet-Health Level 1B tool:

- The first step to determine the PES of the delineated priority wetland resources is to define the HGM unit types for the wetland resources. Each HGM unit should then be buffered by 200 m to achieve a layer which contains the priority wetland resources and the HGM's 200 m zone of influence. The national land cover data must be classified into 29 classes as described by the Level 1B WET-Health assessment (Annexure 3). The classified land cover should then be clipped by the buffered priority wetland resource layer.
- The clipped land cover layer may be 'cleaned' (Note: GIS and desktop mapping experience is required for this task). This is done by overlaying the land cover layer with a true colour Sentinel image or most recent similar satellite imagery and manually checking the land cover categories align with the activities occurring on the ground. Polygons which have been mis-categorised may be merged with the adjacent correctly classified polygon. In addition, some classes typically do not align perfectly with the

original classes of the national land cover and therefore manual classification of these, based on specialist knowledge and visual evidence from the satellite imagery, is required. These classes include:

  - Deep flooding from impoundments
  - Shallow flooding from impoundments
  - Aquaculture dams/ponds
  - Semi-natural (undrained)
  - Semi-natural (drained)
  - Dense infestations of alien plants;
  - Quarrying (sand, stone, diamonds)
  - Coal mining
  - Ore mining
  - Livestock feedlots (cattle and pigs)
  - Chicken farms
  - Planted pastures
  - Infilling (incl. infrastructure)
  - Sediment deposits
  - Areas where water supply has become more sustained (e.g. from irrigation return flows, or seepage downslope of dams or embankments)

- A tabulate areas tool can then be run to determine the extent (ha) of each land cover class in each HGM unit and respective zone of influence. The results of the tabulate areas can be table joined to the wetland attribute table and the calculated land cover extents converted to a percentage. These areas can then be used to apply the Level 1B WET-Health assessment tool located within the first portion of the WET-Health Level 2 spreadsheet (Macfarlane et al., 2018).
- Impact intensity score have been generated for each land cover category within the wetland and within the zone of influence. The proportional extent of each land cover and the intensity scores are used to derive an impact score, PES score and Ecological Category (EC).
- The WET-health Level 1 B tool assesses each HGM unit as an individual and therefore generates an impact score, PES score for each unit. Where a large number of wetlands are within a wetland complex, the area of each wetland may be used to generate an overall area weighted score for the entire wetland complex (Note: this will be required for the setting of an RQO for a wetland complex with a large number of wetlands).

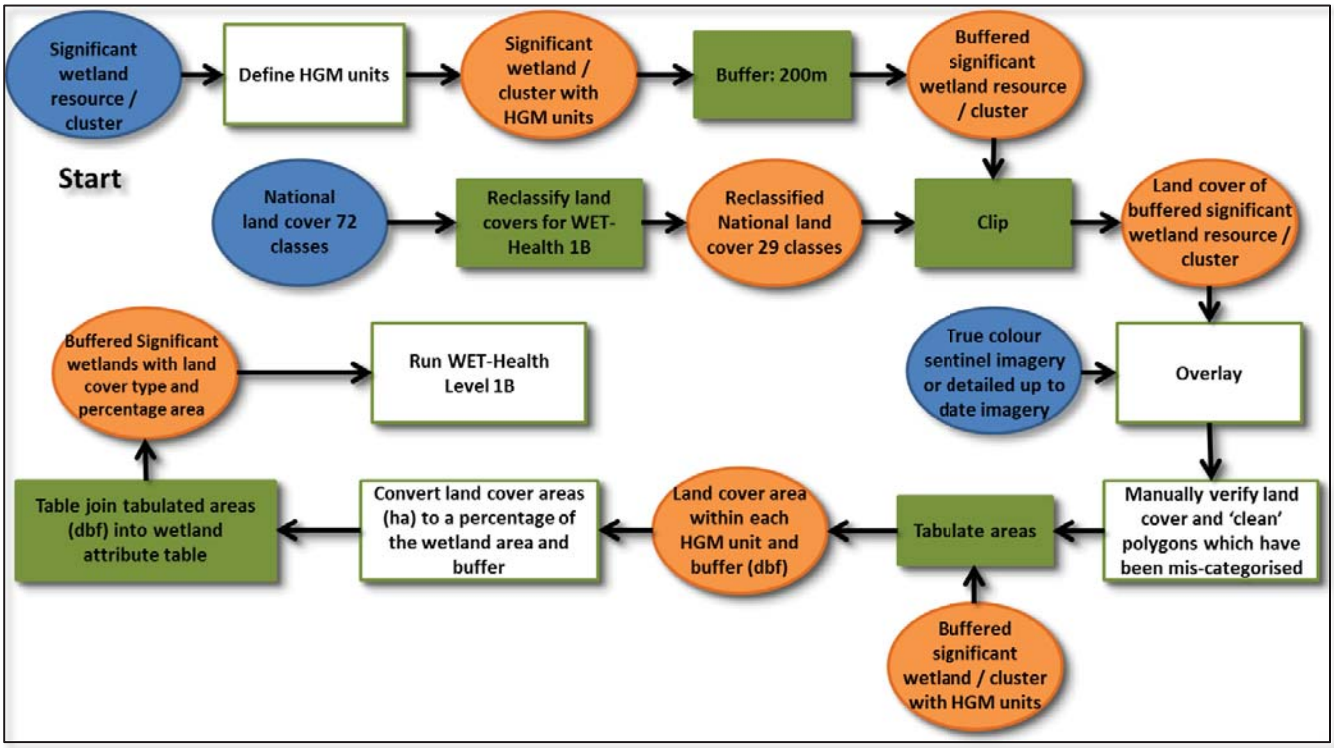


Figure 37: Schematic of the process for cleaning the national land cover and preparing the spatial data for the Wet-Health Level 1B assessment

It is important to note the importance of the 'cleaning' of the land cover within the wetland resource and the zone of influence. It is anticipated that the cleaned land cover layer will be used as the baseline for monitoring the change in condition of the wetland resource. Hence it is a critical action in the procedure that must not be overlooked.

The Importance of a wetland resource is a quantified expression of its importance to the maintenance of biological diversity and ecological functioning at a local and landscape level whilst its sensitivity refers to its fragility or the ability to resist or recover from disturbance (Rountree et al., 2013). The IS assessment developed by Rountree et al. (2013) is a rapid scoring system which evaluates three aspects of importance and sensitivity:

- Ecological importance and sensitivity (biodiversity support, landscape scale and sensitivity of the wetland);
- Hydrological functions (regulating and supporting ecosystem services); and
- Direct human benefits (Cultural and subsistence benefits).

These aspects are scored on a scale ranging from 0 to 4 and the overall importance and sensitivity is dictated by the highest score (Table 7) (Rountree et al., 2013). The IS assessment should be undertaken during a one-day workshop with a small group of specialists who are ideally familiar with the priority wetland resources (An example of a useful table that can be used for the workshop is present in Table 8).

Table 7: Importance and sensitivity categories and the interpretation of median scores for biota and habitat determinants (Rountree et al., 2013)

Importance and Sensitivity categories	Range of IS scores
Very high: Wetlands that are considered ecologically important and sensitive on a national or even international level. The biodiversity of these systems is usually very sensitive to flow and habitat modifications. They play a major role in moderating the quantity and quality of water of major rivers.	>3 and <=4
High: Wetlands that are considered to be ecologically important and sensitive. The biodiversity of these systems may be sensitive to flow and habitat modifications. They play a role in moderating the quantity and quality of water of major rivers.	>2 and <=3
Moderate: Wetlands that are considered to be ecologically important and sensitive on a provincial or local scale. The biodiversity of these systems is not usually sensitive to flow and habitat modifications. They play a small role in moderating the quantity and quality of water of major rivers.	>1 and <=2
Low/marginal: Wetlands which are not ecologically important and sensitive at any scale. The biodiversity of these systems is ubiquitous and not sensitive to flow and habitat modifications. They play an insignificant role in moderating the quantity and quality of water of major rivers.	>0 and <=1

The one-day workshop for the IS assessment is a good opportunity to also verify the PES scores calculated for the wetland resources, using the Wet-Health Level 1B tool. In the workshop, the team should go through each of the priority wetland resources, and based on the specialist knowledge and individuals within the workshop, complete the IS assessment and verify the PES scores. The aim of the workshop is to get as much specialist input as possible to inform the baseline assessments of the PES and IS assessments. The table provided as an example (i.e. Table 8) should be used as a template to capture the outcomes from the specialist workshop.

Table 8 is an example of a table that can be used to workshop the IS of the priority wetland resources, as well as verify the PES scores with specialist. The table is based on the Rountree et al. (2013) method and was designed by Collins (pers. comm. 2018). An example of the PES and IS table and scores from wetland resources identified in the Breede catchment are presented below:

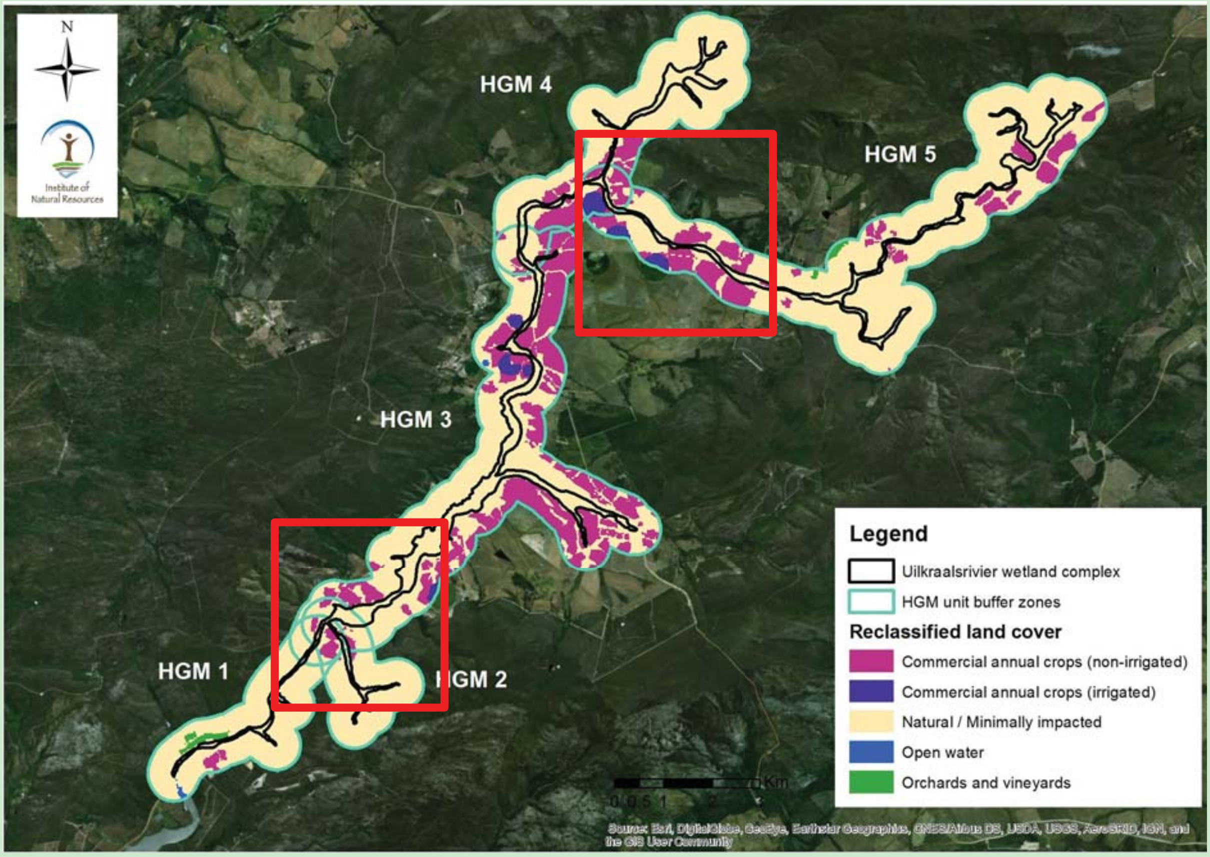
Table 8: An example of the IS and PES assessment table (Rountree et al., 2013)

WMA	Wetland resource name	HGM	Lat	Long	Assess the extent of modification (0-10)					NB & Sensitivity (0-4)	NB for hydrological functions (0-4)	Extent of use (0-4)	Max	IS	Expert Knowledge (0-1)	Comment
					Hydrology	Geomorphology	Vegetation	Average	PES	Ecological importance and sensitivity	Hydro-functional importance	Direct human benefit				
Breede	De Hoop Vlei	UCVB								1	3	1	3	High	1	Specialist knowledge of the Ramsar Site.
Breede	Uilkraals-rivier wetland complex	CVB								1	2	1	2	Moderate	0	
Breede	Uilkraals-rivier wetland complex	UCVB								1	2	2	2	Moderate	0	

UCVB = Unchannelled Valley Bottom; CVB = Channelled Valley Bottom

The specialist team should go through the list of priority wetland resources in a workshop setting and verifying the assigned scores. A confidence rating must be provided as part of the table to indicate if the data has been based on expert knowledge by individuals who are familiar with the wetland resources, or if a 'best educated estimate' has been provided based on specialist opinion and general knowledge of the area.

Example: The Uilkraalsrivier wetland complex was buffered by 200 m and with assistance of satellite imagery the reclassified land cover data was “cleaned” as seen in Figure 38.



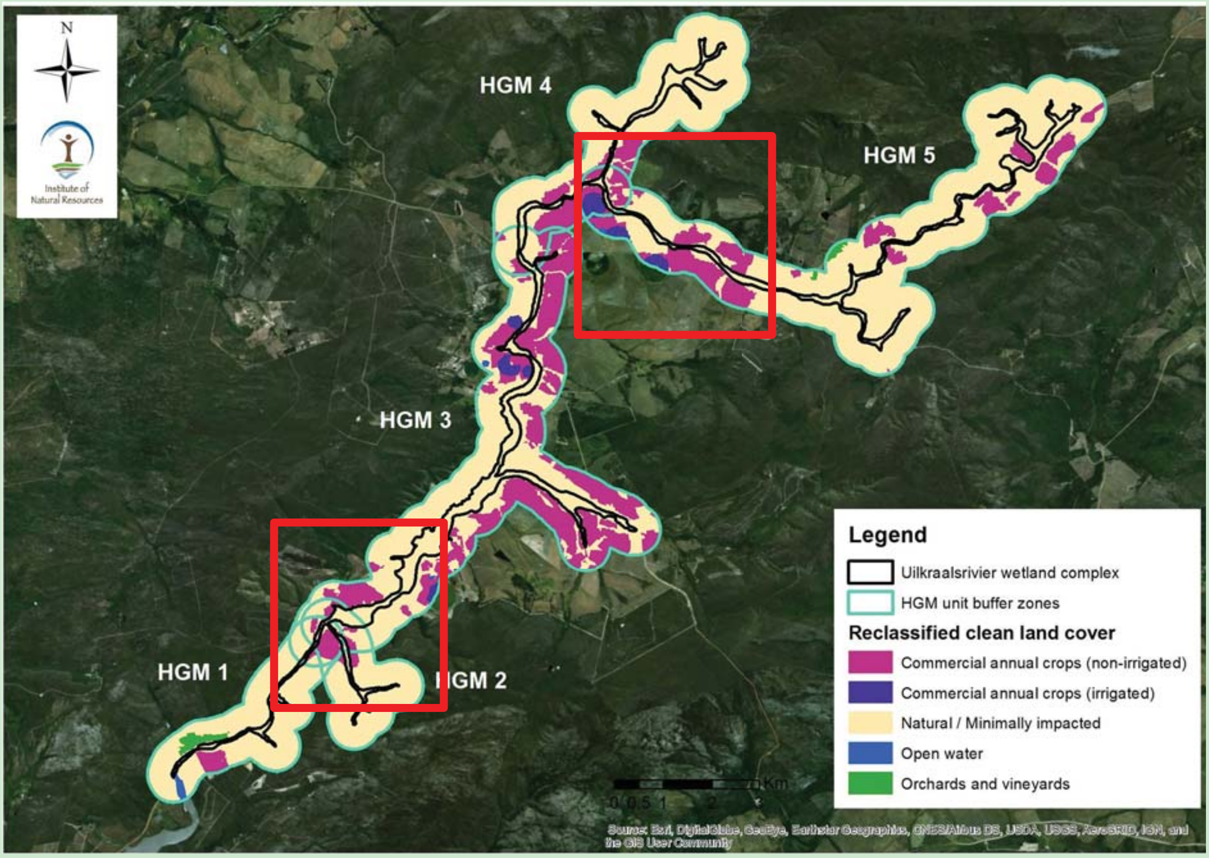


Figure 38: An example of land cover data ‘cleaning’

The area of each land cover type was then calculated with the tabulate areas tool and converted to a percentage of each wetland HGM unit and 200 m zone of influence to account for upslope impacts. The percentage area of each land cover class was then inserted into the WET-Health Level 1B assessment tool. The tables below provide examples of the condition scores for each HGM unit as well as if a weighted average approach is to be taken (Table 9):

Table 9: Uilkraalsrivier wetland complex – area weighted condition score

HGM	In-wetland condition	Zone of influence condition	Overall Condition score	Condition category	Area (%)
HGM 1 Unchannelled valley bottom	**1,3**	**1,1**	2,3	C	28%
HGM 2 Channelled valley bottom	**1,2**	**0,6**	1,7	B	16%
HGM 3 Unchannelled valley bottom	**2,1**	**3,8**	5,1	D	47%
HGM 4 Channelled valley bottom	**1,2**	**0,2**	1,4	B	4%
HGM 5 Channelled valley bottom	**1,2**	**0,5**	1,6	B	6%
Total area					**100%**
Area weighted condition			**3,5**	**C**	

5.1.3. Phase three – Check the outcome against any available field verified or high confidence data, and adjust scores where necessary

Available field verified or high confidence data results in an increased level of confidence in the applicable data. In addition, high confidence data can also lead to more detailed RQOs being set (i.e. numeric limits could potentially be considered for these specific wetland resources if there is sufficient data)

Technical method: Engage the relevant authorities and key stakeholders to determine what field verified or high confidence data are available for the study area. Data generated for an assessment that includes field verified or high confidence data may provide the best opportunity to set RQOs for a range of sub-components and at a level of detail that would include numerical limits.

5.2. Action 11: Determine the Recommended Ecological Category (REC) for the priority wetland resources

The Recommended Ecological Category (REC) is the desirable future state for the wetland resources. The Present ecological State (PES) or condition, and the Importance and Sensitivity (IS) of the wetland resource is taken into consideration for determining the REC (Kleynhans & Louw, 2007; Rountree et al., 2013). Where the IS is high or very high, the ecological aim should be to improve the condition of the wetland (Rountree et al., 2013); Weston *pers. comm.,* 2017). However, the causes related to a particular PES should also be considered to determine if improvement is realistic and attainable. This relates to whether the problems in the catchment can be addressed and mitigated. If the IS evaluated as moderate or low, the ecological aim should be to maintain the wetland in its PES. However where the Ecological Category is an E or F PES, then this is regarded as ecologically unacceptable and remediation is required (i.e. increased to a D category, or higher if feasible).

Technical method: Using the outputs from Action10 apply the rules in Table 10 to determine the REC for each of the wetland resources. It is recommended that the Weston *pers. comm.* (2017) rules are adopted as the preferred approach. However, this should be confirmed with the RDM office at the time of undertaking the assessment.

Table 10: Rules for determining the REC for wetland resources as per Rountree et al. (2013) and Weston *pers. comm.* (2017)

PES	IS	REC (Rountree et al., 2013)	REC (Barbara Weston *pers. comm.*, 2017)
A, B, C or D	Very High	At least 1 category higher (if feasible)	1 category higher (if feasible)
A, B, C or D	High	At least 1 category higher (if feasible)	0.5 category higher (if feasible)
A, B, C or D	Moderate	Current PES (unless improvement feasible)	Current PES
A, B, C or D	Low/Marginal	Current PES (unless improvement feasible)	Current PES
E or F	Any category	D (or higher if feasible)	D (or higher if feasible)
A or B (but improvement not possible)	Any category		Best Attainable State (BAS) or maintain PES

5.3. Action 12: Participate in an integrated team workshop to delineate Resource Units (RUs)

The RUs should be determined through an interactive process involving specialists on the project team assessing the various water resources and other aspects such as the socio-economic drivers in the catchment. Essentially RUs need to take into consideration all types of water resources within the study area to ensure that there is alignment across the selection and delineation of the water resources. Resource Units should be delineated according to the most appropriate biophysical boundary. In this way RUs can be selected for a specific resource, while taking cognisance of other water resources. The nature of wetland resources requires that they are embedded within the RUs of either rivers or, where relevant, groundwater units. Wetlands form part of the hydrological catchment and therefore should be aligned with other water resources as best as possible. It is possible for a priority wetland resource to be identified as a RU but this would typically be the exception rather than the norm. The process of embedding wetland resources into river or groundwater RUs must therefore be an interactive one, where key specialists on the team workshop the most appropriate way to delineate the RUs based on the requirements for their respective water resources.

Technical method: Participate in a one day integration workshop with the water resource specialists on the project team to delineate RUs. Figure 39 provides a simplified illustration of how individual wetlands and wetland complexes could be embedded within a river RU. It is not essential for wetland resources to be confined to any one RU for a river or groundwater unit, and may span several RUs if this is determined to be the best option for delineating the water resources within the WMA.

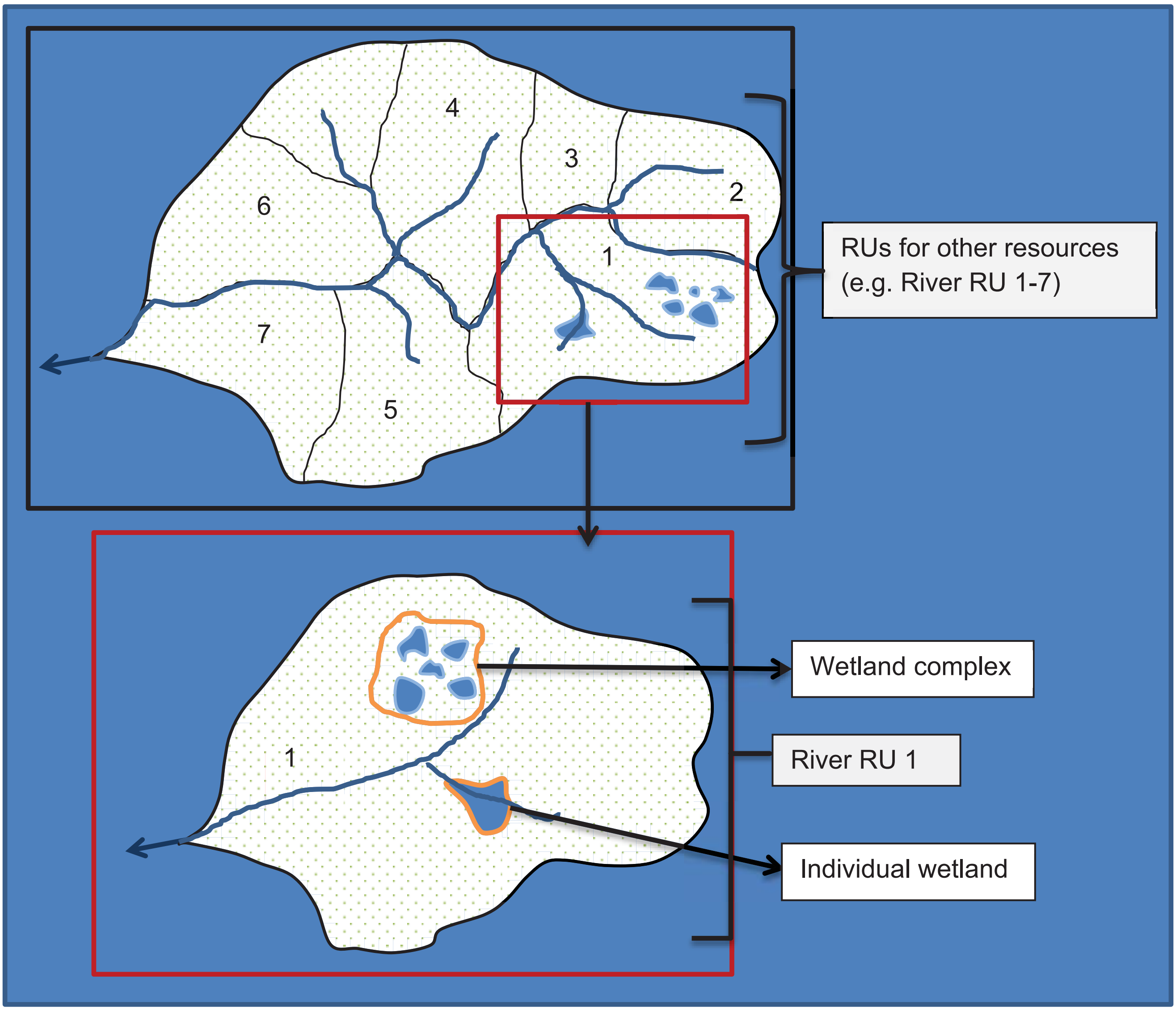


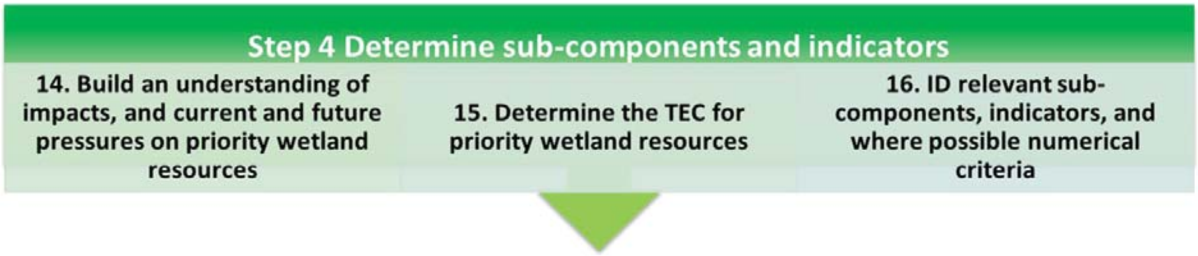
Figure 39: Simplified illustration of how wetland resources can be embedded within a river RU

5.4. Action 13: Obtain stakeholder input on the delineated RUs and priority wetland resources

At this stage it is essential to obtain input from stakeholders on both the delineated RUs and the priority wetland resources. A stakeholder workshop should be held to afford key stakeholders the opportunity to comment and make recommendations.

Technical method: While stakeholder engagement is included as a specific action for the procedure it is important to note that this will be guided by the project team managing the entire RQOs project. Stakeholder engagement is required for all the water resources and not just wetlands. As such, when there is a planned stakeholder meeting the delineated RUs and priority wetland resources should be presented, either by the wetland specialist or the RQOs project manager.

6. STEP 4 – DETERMINE SUB-COMPONENTS AND INDICATORS FOR PRIORITY WETLAND RESOURCES



<u>Actions required to address this step include:</u>

14. Build an understanding of impacts, and current and future pressures on priority wetland resources;
15. Determine the Target Ecological Category (TEC) for priority wetland resources; and
16. Identify relevant sub-components, indicators, and where possible numerical values

6.1. Action 14: Build an understanding of impacts, and current and future pressures on priority wetland resources

As part of determining relevant subcomponents and associated indicators, there is a need to determine relevant importance, which also requires consideration of the impacts of land based activities on the priority wetland resources. Determining indicators involves building an understanding of impacts, and current and future pressures on priority wetland resources (DWA, 2011).

<u>Technical method</u>: Impacts and current and anticipated future pressures are required to be considered for the priority wetland resources selected. The following aspects should be taken into consideration (adapted from DWA, 2011):

- Key drivers of the wetland resource. Understanding how the wetland resources function within the landscape is essential for developing an understanding of current impacts and future pressures (Note: this understanding should largely have been determined in pervious steps)
- Identify and assess the impact of current and anticipated future use on the priority wetland resources:
    - Assess the importance of activities in driving resource change;
    - Determine the anticipated level of impact on each relevant sub-component;
    - Determine the cumulative level of impact on each relevant sub-component; and
    - Determine the anticipated consequences of the impacting activities on each relevant sub-component
- Identify requirements of important user groups:
    - Identify important user groups of the priority wetland resources and the activity types;
    - Identify important user groups for the protection of the priority wetland resource;
    - Rate the importance of relevant sub-components for the protection of the priority wetland resource and the water resource dependent activities;
    - Review present state information; and
    - Propose the desired direction and magnitude of change for each relevant sub-component for important user-groups.

- Identify whether the problems can be addressed in the current state or if there are opportunities for improving the wetland resource in the future.

The process of building an understanding of impacts, and current and future pressures on priority wetland resources is an intensive and time consuming process, and is based largely on specialist judgement. It is recommended that the necessary supporting data and spatial layers be acquired first (refer to example), and then undertake the work on the aspects highlighted above systematically to determine an understanding of impacts and pressures. These should be clearly documented and then presented in a workshop with the other specialists on the RQOs project team (i.e. it is important to understand the linkages across the different water resources within the WMA when assessing impacts and pressures).

It is important that the project team, in collaboration with the DWS, provide an overview of impacts and a short to medium-term outlook on pressures within the WMA, but more specifically within the catchments where the priority wetland resources may occur.

Examples of potential sources of supporting data may include:

- The DWS have a database of existing Water Use Licences (WUL's) and WUL applications. This may provide a first step in identifying pressures on a priority wetland resource.
- Stakeholders such as irrigation boards for example may have certain information that relates to potential future stresses. Future water demand scenarios (whether surface or groundwater), even in catchments that currently are not stressed, may have already been considered by the DWS or stakeholders and it may be useful to consider these in the assessment. Some of this information may emerge in earlier steps in the prioritisation process but sometimes some additional or other information is provided by stakeholders during the stakeholder meetings.
- Local stakeholder knowledge may also either serve to verify future concerns or highlight additional ones in a particular area. These may however not be specific to a particular priority wetland resource, but may result in scenarios with regards to surface and groundwater in an area or region that could potentially affect a particular priority wetland in the future.
- Specialist judgement is definitely important but this should ideally be supported by information that is available, or information that the project team collects during the course of the study. For example, the groundwater specialist on the project team may have information on groundwater use/stress/recharge where groundwater fed wetlands occur.
- Again integration between the different disciplines on the RQOs project team is essential. Where data are limited then it is important that the wetland specialist has a general understanding of the pressures on water resources across the focus areas. An understanding of the general pressures is likely to emerge as the project develops, when there is interaction among the different specialist disciplines on the team.
- A general understanding can also be gained by considering the categorisation of, and future threats to other water resources. For example, it may be important to consider the categorisation of, and threats to, other water resources in the proximity to, or possibly linked to a priority wetland. These may provide some guidance when assessing possible future pressures on priority wetland resources.

6.2. Action 15: Determine the TEC for priority wetland resources

The Target Ecological Category (TEC) or Best Attainable State (BAS) is the ecological category that is determined to be achievable after taking into consideration the current impacts and future pressures on the priority wetland resource. It provides a realistic target for the management of a wetland resource, in comparison to the determined REC. Understanding the causes of change, the source of the impact/s and the trend, allow for a trajectory of change to be determined. This is essential for developing a clear understanding of whether or not an RQO is achievable and what is required to maintain or improve the wetland resources condition.

Technical method: With an understanding of the PES, IS, REC, and current impacts and future pressures on the priority wetland resources, the TEC can be set. The procedure to develop and implement RQOs (DWA, 2011) identifies key principles, which should be taken into consideration. Essentially the process requires an interrogation of available information to determine the achievable / desired ecological category or BAS taking into consideration current and anticipated anthropogenic drivers of change that will result in impacts affecting the ecological integrity of the wetland resource. Figure 40 illustrates the connectivity across ecosystem drivers, responses, and external impacts and future pressures, all of which need to be taken into consideration when determining the TEC.

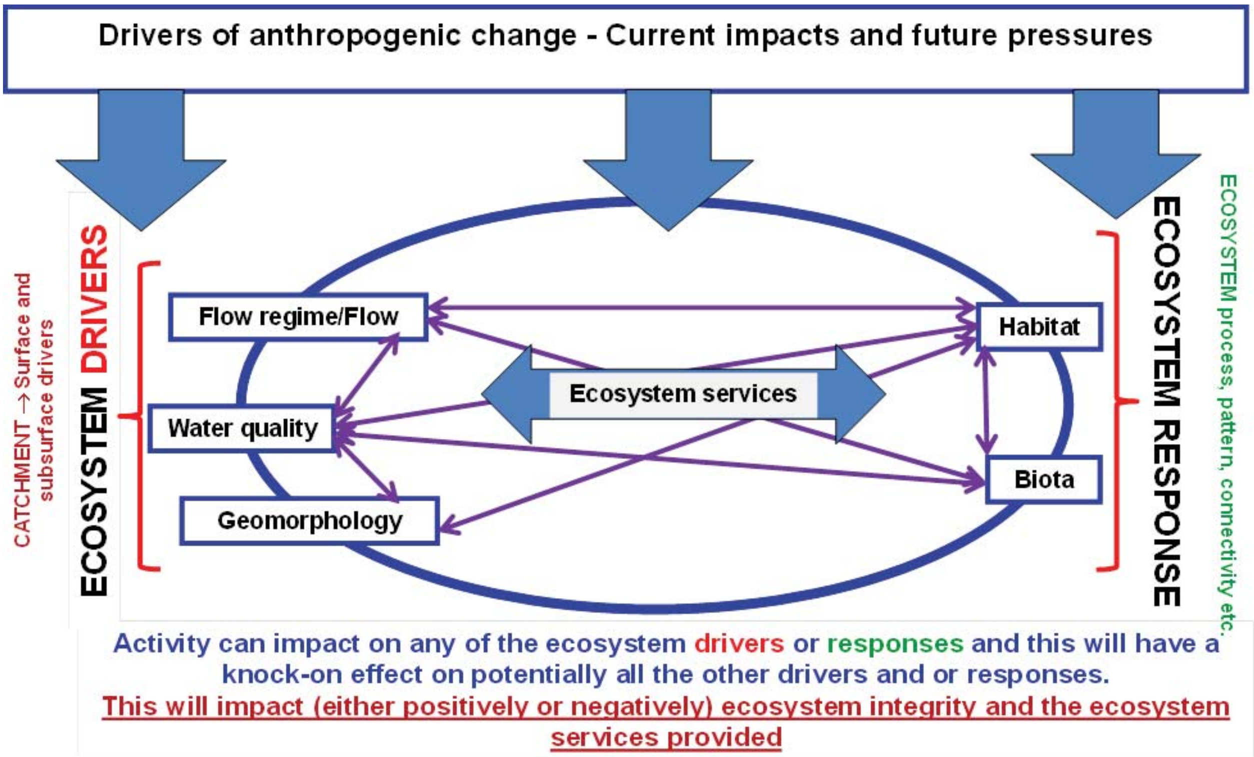


Figure 40: Schematic illustrating the relationship between ecosystem drivers, responses, and external impacts and future pressures (adapted from Roets *pers. comm.,* 2018)

In order to determine the TEC the following should be considered:

- The PES, IS and current and future impacts;
- The scenarios developed for the classification process;

- The trajectory of change and the cause of the change;
- The user groups and activities impacting or likely to impact the wetland resources; and
- The important user groups / stakeholders likely to contribute to the protection of the wetland resource.

The TECs should be shared with the specialist who contributed to the setting of the PES and IS for the priority wetland resources for their inputs. If impacts or future pressures are likely to be too server then careful consideration should be given to the selection of the priority wetland resource for the setting of RQOs (i.e. if the anticipated RQO for the wetland resources appears to be unachievable due to current impacts or future pressures, then consideration should be given to how it could be adjusted).

6.3. Action 16: Identify relevant sub-components, indicators, and where possible numerical values

According to DWA (2011), RQOs should be quantifiable, measureable, verifiable, and enforceable and ensure protection of all components of the resource, which make up ecological integrity. Although there is a wide range of sub-components (Table 11) for which RQOs can be set, it is not necessary or practical to set RQOs for all sub-components. The setting of RQOs is dependent on data, with a relatively high level of confidence. Where data are insufficient for the setting of an RQO for certain components, clear justification should be provided as to why an RQO will not be set.

The principals of the process for prioritizing sub-components for RQO determination, in the procedure to develop and implement RQOs (DWA, 2011), are valid and should be taken into consideration. However, this level of detailed interrogation to prioritize sub-components and associated indicators is required when there is suitable data available for the water resource. This typically is not the case for most wetland resources.

Technical method: Sub-components, indicators, and where possible the respective numerical criteria need to be extracted. These will vary according to the level of data available for each of the priority wetland resources. Indicators and numerical criteria for wetlands considered in Reserve studies could be based on the ecological specifications determined. These could vary between wetland systems. Table 11 identifies the sub-components for wetlands identified in the DWS procedure for determining RQOs (DWA, 2011).

Table 11: Wetland components and examples of possible sub-components (adapted from DWS, 2011)

Components	Sub-components
Quantity	Water inputs
	Water distribution and retention patterns
Quality	Nutrients
	Salts
	System variables
	Toxics
	Microbial determinands
Habitat	Present Ecological State (PES)
	Geomorphology
	Wetland Vegetation
Biota	Fish
	Plant species
	Mammals
	Birds
	Amphibians & reptiles
	Periphyton
	Aquatic Invertebrates
	Diatoms

Given our current limited understanding of the majority of wetland resources, a likely scenario will be that RQOs will only be set for a few sub-components. As mentioned, this will be due to insufficient data or low confidence data typically being available for priority wetland resources. The procedure provides an opportunity to at least determine RQOs for habitat, using PES primarily. This provides a ‘starting point’ to manage priority wetland resources in the absence of data that would allow for the setting of RQOs across a range key sub-components. Therefore, the indicators for the majority of priority wetland resources will likely be limited to wetland condition with a PES score, extent (hectares determined for the wetland systems), or a change in the impact score that is used to determine the wetland condition. Figure 41 outlines the opportunities for setting RQOs, across the broader components, for wetlands when there is limited data available for priority wetland resources.

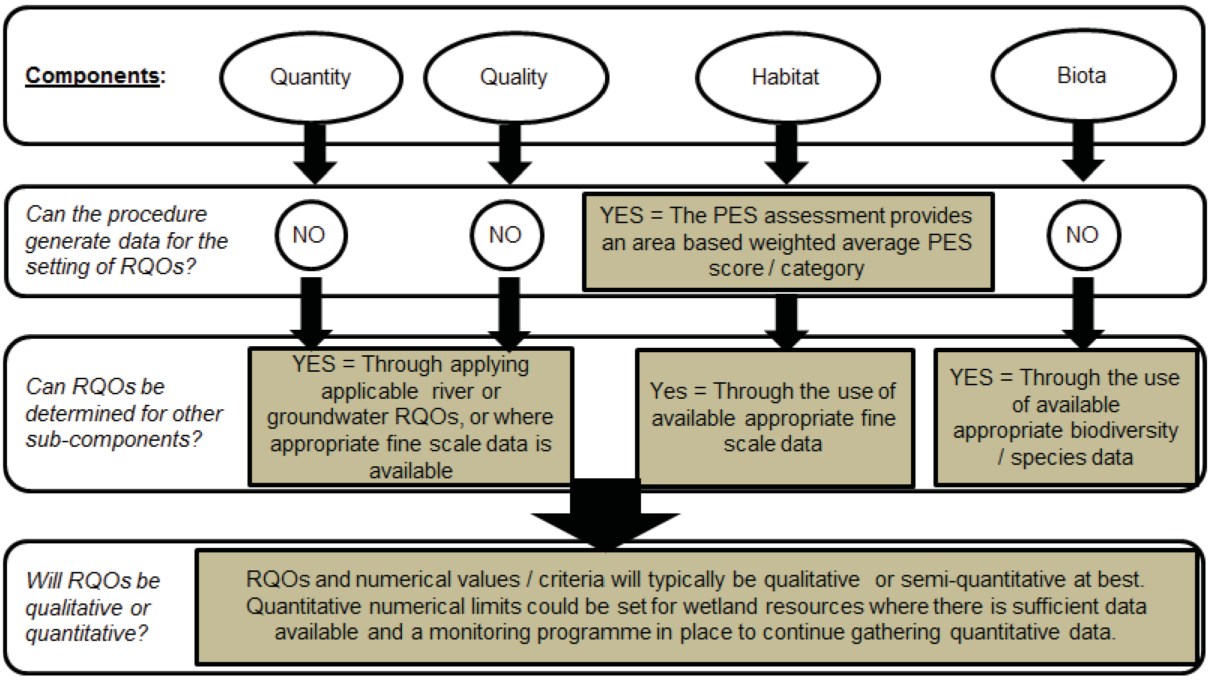


Figure 41: A flow diagram illustrating the opportunities for determining RQOs for wetlands, given the level of data typically available

As indicators will need to be determined for wetland condition it may be useful to consider the key criteria for identifying suitable indicators of ecosystem condition (refer to the box below).

Suitable indicators of ecosystem condition (Adapted from Uys, et al., 1996; CSIRO Division of Water Resources 1992; Department of Environment, Sport and Territories 1994; Hohls 1995) should:

- be sensitive to a range of changes/stresses and allow for the detection of trends, while being stable in response to natural variability;
- generate information that can be easily understood;
- be easy to measure;
- be representative of the overall state of the environment;
- be acknowledged by experts to measure or represent important aspects of wetland condition;
- be appropriate for measurement at a wetland resource scale;
- be cost-effective;
- be sensitive to management intervention (i.e. show change as a· result of management activities);
- integrate environmental effects over time and space;
- be unambiguously related to an identified issue;
- provide an early warning of widespread change; and
- be capable of being measured using skills available to resource managers.

7. STEP 5 – DETERMINE RQOS FOR PRIORITY WETLAND RESOURCES

Step 5 - Set Resource Quality Objectives ,and numerical criteria, and provide implementation information		
17. Draft RQOs and numerical criteria	18. Stakeholder input	19. Implementation information

Actions required to address this step include:

17. Draft appropriate RQOs and numerical criteria / limits, where feasible, stipulating methodologies and frequencies for monitoring;
18. Obtain stakeholder input; and
19. Document implementation information.

7.1. Action 17: Draft appropriate RQOs and numerical limits stipulating methodologies and frequencies

A practical approach should be applied to determining wetland RQOs. Wetlands considered in Reserve studies would have likely been assessed at a suitable level to determine Eco and User Specs. These could form the basis for drafting RQOs for the relevant wetland resources. The focus for all other priority wetland resources will be to draft RQOs that will be set for wetland condition, extent or change in impact score. These will largely be narrative RQOs.

Technical method: Determining RQOs for priority wetland resources is dependent on a number of factors, such as:

- Wetland Categorisation. The RQO must consider the categorisation (PES, IS, REC or TEC category) determined for the priority wetland. Most importantly, it must consider the TEC, which is the ecological category determined to be achievable after taking into consideration the current impacts and future pressures on the priority wetland resource. Whether a numeric limit or qualitative descriptor, the RQO for the component prioritised has to consider limits applicable to achieving the TEC. This may relate to either improving or maintaining the ecological state determined for the priority wetland, depending on whether or not the TEC is one category (or half a category – see Table 10 in Section 5.2) higher than, or the same as, the PES respectively;
- Links to other water resources. Priority wetlands linked to rivers for example, are likely to be directly influenced by RQOs set for the adjoining river reach. Detailed numerical limits could potentially be set for such RQOs, assuming the data are available for the particular stretch of river influencing the priority wetland. Note that while this may be suitable for a particular priority wetland resource, it may not always be the case that the river RQO's will be adequate to protect another priority wetland resource. For example, a flow requirement for baseflow in a river system may not be adequate to ensure maintenance of a floodplain system which requires high flow flood events for its maintenance. In such cases, and particularly where no high flow data exists, the wetland specialist may be required to set a qualitative objective to maintain high flows at a particular frequency and distribution. Alternatively, where high flow data are available, these could be assigned with a numeric limit;

- Similarly wetlands linked to groundwater discharge points may be directly influenced by RQOs set for the groundwater resource or aquifer. Detailed numerical limits may be able to be set for such RQOs, assuming the data are available for the particular aquifer. In some cases these may be related to a protection zone, being a groundwater component that is prioritised, around the wetland where, for example, groundwater abstraction is limited or prohibited;
- Where detailed assessments may have been undertaken for the wetland resource because of its importance from a conservation perspective or to users. The available data may allow for both narrative and numerical RQOs to be set.

The level at which RQOs are set is largely based on the desired direction of change for selected sub-components, which is determined in consultation with stakeholders and specialists. Wetland RQOs are generally set by converting aspirations into qualitative statements. The setting of numeric limits on the other hand is far more challenging and requires considerable knowledge of the wetland system. It will, for example, need to take into consideration the availability of data suitable for determining such, and whether or not such data can be translated into meaningful limits for the relevant components, sub-components and indicators. In addition, when setting numeric quantity limits for example, consideration may also need to be given to the level of variability in the hydrological regime of the wetland and how this can be expressed as part of the RQO. This will all be dependent on the level of data available or collected and its suitability for setting an RQO for a particular sub-component. Consideration also needs to be given to suitability (accuracy and time related) to allow for the monitoring of change. While a general assumption is that where a low variability in, for example, the components quantity and quality, occurs, numeric limits should be easier to set. In contrast where there is a high level of variability in these components then RQOs will likely need to be limited to narrative RQOs only (Note: at this stage where there is such limited data available for wetlands in general, this is likely to be the case for most wetland resources).

Table 12 and Table13 below provide examples of wetland RQOs set across different components and a template for information required for gazette purposes. Additional information should be provided in the supporting technical report (e.g. feasible methodologies, frequency of monitoring, etc.). A template with notes is provided in Annexure 5.

Table 12: Examples of wetland RQOs across the different components and different wetland types (DWS, 2017)

Component	Indicator	RQO	Numerical Criteria*
Habitat (for a priority pan complex for example)	Desktop PES Category (based on a semi-quantitative area based weighted average score for all the pans units in the wetland complex).	Area based weighted Average Ecological Category of C/D (Ecological category determined by REC or TEC).	Undertake a desktop PES assessment and determine the area based weighted average score for the wetland complex – see the method of Macfarlane et al. (2018). Repeat every 3 to 5 years and assess and report on this with a view to assess if there have been any changes in the state of the system (increase or decrease in the PES category). Verify by undertaking a rapid field-based PES assessment of selected pans and take fixed point photographs of key features.
Biota (for a priority pan for example)	Breeding population of Giant Bullfrogs.	Maintain a viable breeding population of Giant Bullfrogs in the pan.	Verify from monitoring records and recorded sightings adult bullfrogs in the pan basin, catchment or surrounding area, and recorded breeding events in the pan basin. Determine whether the population is stable, increasing or declining from the monitoring records. Report on this every 3 to 5 years.
Quantity(for a priority floodplain for example)	Extent and frequency of flooding of floodplain habitat in relation to rainfall in the catchment.	Floods are necessary to inundate the floodplain thereby providing the wetting regime required for supporting the floodplain vegetation, particularly the facultative hydrophytic grasses, sedges and forbs that are dependent on flooding for their life cycles.	Using available remote imagery, estimate the extent and frequency of inundation/flooding in relation to rainfall for the wetland. Repeat the above every 3 to 5 years and assess and report on this with a view to assess if there are any measurable changes in the relationship between flooding extent and rainfall events. (For example, if a rainfall event of a certain magnitude, which in the past resulted in flooding of the entire floodplain habitat, now only inundates 40% of the floodplain habitat, then it would be reasonable to conclude that there is a change in the relationship between the extent of flooding and rainfall. This

Component	Indicator	RQO	Numerical Criteria*
			in turn would translate into a potential deterioration in the ecological state of the floodplain).
Quality (for a priority channelled valley bottom wetland for example)	River indicators apply (see river indicators).	River RQO's apply (see river RQO's).	River numerical limits apply (see river numerical limits). (Note: here reference is made to the numeric limits indicated for this river system in the river RQO tables for the specific sub-components indicated for quality).
Biota (for a priority floodplain for example)	Maintenance of a structurally and species diverse riparian zone.	The overall structural and species diversity of the riparian zone must be maintained.	Using a rapid field-based assessment monitor the structure and species diversity of the riparian zone at selected sites along the floodplain. Determine using a suitable repeatable botanical sampling technique whether the structure and species diversity of riparian trees and shrubs is stable, increasing or declining. Similarly, determine using a suitable repeatable botanical sampling technique, whether the population of at least 3 of the key indigenous riparian tree species is stable, increasing or declining. Take fixed point photographs of key riparian features. Report on this every 3 to 5 years.
Biota (for a priority pan for example)	Reporting rates for aquatic/wetland dependent bird species.	Overall diversity and populations of aquatic/wetland dependent bird species must be maintained.	Verify from monitoring records and recorded sightings from available avifaunal reporting data whether the numbers of key aquatic/wetland dependent bird species are stable, increasing or declining. Report on this every 3 to 5 years.

** = Monitoring information is provided as context. Note this level of information would be included in the technical report and not the table for gazetting.*

Table13: Example of a template for RQO gazetting purposes

IUA	RU	Wetland / Site	Component prioritised	Indicator	RQO	Numerical criteria
IUA/s within which the wetland/s occur.	RU/s within which the wetland/s occur. RUs to be delineated based on surface and groundwater (in some circumstances wetlands may have stand-alone RUs).	Name of individual wetland or wetland complex	Quantity	Indicators for the following subcomponents can be determined: Water inputs, Water distribution and retention patterns	The Resource Quality Objective (which can be linked to river or groundwater objectives)	Numerical criteria for which the RQO can be monitored
			Quality	Indicators for the following subcomponents can be determined: Nutrients Salts System variables Toxics and Pathogens	The Resource Quality Objective (which can be linked to river or groundwater objectives)	Numerical criteria for which the RQO can be monitored
			Habitat	Indicators for the following subcomponents can be determined: Geomorphology and Wetland Vegetation	The Resource Quality Objective (which can be linked to river or groundwater objectives)	Numerical criteria for which the RQO can be monitored
			Biota	Indicators for the following subcomponents can be determined: Fish, Plant species, Mammals, Birds, Amphibians & reptiles, Periphyton, Aquatic Invertebrates and Diatoms	The Resource Quality Objective (which can be linked to river or groundwater objectives)	Numerical criteria for which the RQO can be monitored

7.2. Action 18 – Obtain stakeholder input

It is essential to obtain input from stakeholders on the draft RQOs that have been determined. Stakeholder workshops are normally held at selected venues within the project study area (WMA for example). This affords key stakeholders the opportunity to comment and make recommendations on the RQOs. It is always very useful to invite stakeholders who have wetland knowledge, or who are either directly or indirectly responsible for wetland management or aspects of wetland management, in a particular region within the study area, to attend. In cases where key wetland stakeholders cannot attend the workshops, it may be informative to contact them directly to get their inputs and comments on the draft RQO's.

Technical method: While stakeholder engagement is included as a specific action for the procedure it is important to note that this will be guided by the project team managing the entire RQOs project. Stakeholder engagement is required for all the water resources and not just wetlands. As such, when there is a planned stakeholder meeting the RQOs for the priority wetland resources should be presented, either by the wetland specialist or the RQOs project manager. If stakeholder comments or inputs are received, either at the workshops or via targeted stakeholder engagement, then the wetland specialist will need to consider whether to incorporate these into the RQO's, amend the RQO's to reflect these, or alternatively not to incorporate these into the RQO's. It is important that stakeholder feedback is provided by the wetland specialist or project team to motivate or justify the final decision. The draft RQO's are then finalised. Additional opportunity is provided to stakeholders to comment on the RQO's during the comment period provided during the gazetting process. It may be the case that further amendments may be required based on stakeholder comments during this process prior to finalising the Gazette Notice.

7.3. Action 19 – Document implementation information

Prior to gazetting of RQOs there is a need to develop an approach to implementation, which includes monitoring and reviewing of the RQOs (i.e. an adaptive management cycle is required). DWS, 2016(b) identified that an integrated approach, where all water resources are taken into consideration, is required for the development of an implementation report. The implementation report therefore needs to consider all priority water resources within the catchment/s of the WMA and address a range of aspects, with a primary focus on monitoring requirements. While an integrated approach to implementing RQOs goes beyond the scope of this report (refer to Section 2.5), guidance is provided on the monitoring of priority wetland resources. Monitoring of RQOs set for priority wetland resources need to be clearly documented and made available for review prior to finalizing the gazetting process.

Technical method: The selection of sub-components for RQO determination and suitable indicators, outlined in Action 16, provide the baseline for the monitoring of wetland RQOs. The selection of appropriate indicators, which are quantifiable, measureable and verifiable are essential for monitoring purposes. The practicality of the recommended monitoring should also be taken into consideration (i.e. Can the recommended monitoring requirement be practically implemented given data and resource availability?).

Monitoring requirements for each of the selected indicators across the respective sub-components should be clearly documented in the technical report for the gazetted wetland RQOs. Table 12 provides some examples of typical monitoring requirements for a select number of indicators. The array of wetland assessment, and inland aquatic assessment, methods available to users can be used to inform the monitoring requirements for each of the selected indicators. In addition, Tier 2 or 3 monitoring outlined for the NWMP should be reviewed to allow for alignment between the recommended monitoring of select indicators and the NWMP. A key aspect of the monitoring is the timeframe for which monitoring should take place. Typically a timeframe of 3-5 years is recommended (Table 12).

There are a number of challenges with the current approach to monitoring suitable indicators. Firstly, simply trying to practically implement the recommended monitoring of wetland indicators is a huge challenge for the DWS, and secondly the acceptable timeframes for which monitoring should take place allow for extensive periods between monitoring, which makes it difficult for water resource managers to ensure RQOs are being met. These challenges resulted in the need for another level of monitoring to complement the existing approach. Monitoring that is cost-effective, rapid, and of a sufficient level of confidence to allow for decision making. With this in mind, a desktop monitoring method has been developed and is provided in Annexure 6. The method complements the NWMP. It is a desktop monitoring method that allows water resource managers a way of monitoring change within a wetland resource, and a zone of influence. The desktop monitoring method is viewed as a mechanism to monitoring priority wetland resources regularly (i.e. annually) for detection of potential changes in land use activities that may lead to non-compliance. In the event of detecting significant change (i.e. where there is risk of the RQOs not being met) the desktop monitoring should be used as a trigger for the monitoring requirements for each of the selected indicators. In this way, more detailed monitoring can be undertaken when required. Thus a more flexible approach to monitoring is achievable through the inclusion of the recommended desktop monitoring method, which is anticipated to not only allow for more frequent cost-effective and practical desktop monitoring but also a more cost-effective and efficient monitoring of selected indicators.

8. CONCLUSION AND RECOMMENDATIONS

The procedure provides a step-by-step approach to develop and monitor qualitative RQOs for wetland resources, and where there is sufficient data it also allows for the determining of quantitative RQOs with numerical limits. It is based on the need to balance practicality with sourcing wetland data at a suitable confidence level for the purposes of setting RQOs. While the procedure allows for the development of RQOs, there is opportunity for improvement as we gain a better understanding of wetland resources. Therefore, this procedure should be viewed as part of an iterative process for enhancing how we identify and set key management objectives for the country's priority wetland resources.

The report has been separated into two parts, with the first part providing the user with an overview of the procedure in reference to key information, which provides the context. The second part to the procedure is the step-by-step technical approach to develop and monitor wetland RQOs. This part contains extensive information on the proposed actions to be undertaken for each of the respective steps. In particular, significant effort has been placed on developing a method that allows for the determining of priority wetland resources from both an ecological and user perspective. The assessment of ecosystem service demand and supply provided the basis for determining priority wetland resources from a user's perspective. While advancements were made in this respect, there is still a need to improve on how more ecosystem services can be considered in the prioritization of wetland resources, particularly non-valued services.

The procedure deals with the approach to develop and monitor RQOs for priority wetland resources. It does not address the full complement of criteria that would allow for successful implementation. The implementation of RQOs within a WMA is a complex process that should be undertaken across all priority water resources within the catchment/s of concern. As a result, the need for an integrated approach to implementing RQOs goes beyond the scope of this report. However, a key component of implementation is monitoring. A third component of the procedure is the recommended monitoring of indicators for respective sub-components, and the proposed desktop method for monitoring wetland resources. The desktop monitoring method complements the monitoring requirements that need to be specified for the indicators selected for the respective sub-components. A method for monitoring wetland resources at a desktop level is provided in the technical guidelines to guide water resource managers in their efforts to monitor priority wetland resources (Annexure 6).

The desktop monitoring method allows for the detection of changes in land use taking place within priority wetland resources or the respective zones of influence. The method aims to provide the user with a step-by-step process that will allow them to detect significant change timeously and provide guidance on how to respond accordingly. The desktop monitoring method is intended for use by water resource managers either at a national or catchment scale, but can also be used be a range of other parties.

It was noted in DWA (2011) that through the practical implementation of adaptive management in water resources management, there should be allowance for the review of RQOs after not more than five years. In addition, there may be situations that trigger a need for a review within a shorter timeframe. Such triggers may include:

- Substantial changes to the activities in the catchment which will pose an increased threat to the water resource;
- The RQOs determined for the water resource are failing to protect it; and
- A substantial change to the information available for the water resource.

The need for adopting an adaptive management approach to managing priority wetlands is a challenge given that the NWA currently does not stipulate a timeframe for the review of RQOs. The proposed approach to monitoring priority wetlands, has been developed with the aim of providing water resource managers with a way of detecting change over a relatively short timeframe so that they can respond accordingly. While an adaptive management approach is still advocated, the proposed monitoring of priority wetland resources will allow for desktop monitoring of priority wetland resources, thereby providing an opportunity to respond timeously to potential threats to the priority wetland resources. At the time of developing the procedure it was understood that consideration will be given to introducing a timeframe for reviewing RQOs, which may be included to the revised NWA.

While the aim of the procedure was to provide an approach to develop and monitor wetland RQOs at a confidence level that supports the gazetting of wetland RQOs, key challenges were identified during the development of the procedure. These challenges should be taken into consideration when there is an opportunity to revise the procedure. The key challenges included:

- The PES of the priority wetland resources were assessed using a semi-quantitative desktop method. This method utilizes calculations of within wetland and surrounding wetland land-uses as a proxy to determine wetland impacts, and consequently wetland ecological integrity. The method allows for the calculation of the percentages of various types of land-uses both within the wetland boundaries and within a 200 m zone of influence outside of the wetland boundaries. There are several ways to improve upon the method, including using better field verified delineation of the wetland boundaries associated with high-level field PES verification as well as more detailed desktop mapping of the surrounding land uses based on high resolution aerial imagery. This could further be supported by field verification of the land-use categorization within the zone of influence. The zone of influence could also be extended to include the local catchment. However, even if time and budget allowed, such field verification would likely be limited by access. Even in cases where there is access to a particular wetland or part of a wetland, the areas being accessed and visited may not always represent the general conditions throughout the wetland and the zone of influence across the entire system. These are some of the challenges that any method for remotely determining the PES of wetlands would have when the wetlands extend over such large areas and where many of the systems form wetland complexes comprising of different HGM units. It is thus important to point out that the application of this type of method for remotely determining the PES of wetlands at the scales appropriate here is still in its early stages. Thus, creating an opportunity for improving the approach, through ongoing testing and verification. It nevertheless represents a robust and detailed method to develop and monitor wetland RQOs.

- Besides the limitations related to the wetland mapping and PES assessments undertaken as part of this study, it should also be noted that there may be other wetlands that were not identified or covered as part of the RQO study due to the level of investigation undertaken, the extent of the study area, the limited nature of field verification, and accuracy and level of detail of the information used to derive the wetland coverage. Some of these 'excluded' wetlands could also potentially be priority wetland resources. The prioritisation provided for the purpose of this RQO study cannot therefore be considered finite but rather part of an on-going process where new systems may be identified and prioritised in future as more information becomes available or as the wetland coverage of the study area improves.

- Limited data are available for wetland resources. This is particular evident in the later part of the procedure, when sub-components need to be identified for the purpose of setting RQOs. The method has been developed to allow for data to be gathered that would, at the very least, allow for the setting of an RQO from a habitat perspective. Wetland data constraints are widely acknowledged, and as a result the setting of RQOs for most of the components is reliant on other available data sources (i.e. other water resource data, like applicable river or groundwater data, etc.). The data constraints for wetland resources are evident in the fact that very few wetland RQOs have been incorporated into gazetted RQOs for water resources. Hence it would be useful to acknowledge that for the foreseeable future a reflection on those that have been set is required in order to learn and improve.

Effective implementation of RQOs is essential for the management of South Africa's priority wetland resources. Guidance for monitoring, a key component of implementation is provided. However, further implementation guidance is still required. As discussed, an integrated approach to implementation is required. Some criteria for successful implementation have been listed in Section 2.5.

While the procedure forms part of an iterative process for enhancing how we identify and set key management objectives for the country's priority wetland resources, its development also provides an opportunity. Given that the procedure provides for the identification of priority wetland resources across the country, and the setting of objectives to sustainably manage priority wetland resources, there is an opportunity to contribute to the way South Africa reports on SDG6, and specifically Target 6.6. While currently not utilized, wetland RQOs for priority wetland resources could contribute to reporting on SDG 6 in the future. In addition, there is also a significant opportunity to utilize the desktop monitoring method (Annexure 6) to monitoring indicators 6.6.1a and 6.6.1d of SDG 6. A follow-up project is recommended to investigate this opportunity as it may serve a vital role in not only reporting on but also monitoring the country's priority wetland resources.

9. REFERENCES

Bracken, L.J., Cox, N.J. and Shannon, J. (2008). The relationship between rainfall inputs and flood generation in south-east Spain. Hydrological Processes, 22:683-696,

Bredin, I.P., Rajah, P., Awuah, A., Pringle, C., Quayle, L., Kotze, D.C. and Marneweck, G.C. (2019). A manual for monitoring wetland resource quality objectives. WRC Report No (tbc), Water Research Commission, Pretoria.

Burkhard, B. and Kroll, F. (2010). Maps of ecosystem services, supply and demands. In: Cleveland, C. J. (Ed.), Encyclopedia of Earth, Environmental Information Coalition, National Council for Science and the Environment, Washington, D.C

Burkard, B., Kandziora, M., Hou, Y. and Müller, F. (2014). Ecosystem service potentials, flows and demands – concepts for spatial localization, indication and qualification. Landscape Online, 34: 1-4.

Crafford, J., Naidoo, N., Harris, K., Mulders, J. and Maila, D. (2016). Development of a methodology and decision support system to determine appropriate protection levels of water resources using ecosystem services and socio-economic tools. Deliverable 4: Draft Revised Socio-Economic Report. WRC Project K5/2465

CSIRO (Australia) Division of Water Resources. (1992). Towards healthy rivers. A report from CSIRO to the Honourable Ros Kelly, Minister for Arts, Sport, the Environment and Territories. CSIRO, Division of Water Resources, Consultancy Report no. 92/44. 1 03pp.

Department of Environment, Sport and Territories. (1994). State of environment reporting: a framework for Australia. Commonwealth of Australia.

Dickens, C., Rebelo, L-M., and Nhamo, L. (2017). Guidelines and indicators for Target 6.6 of the SDGs: Change in the extent of water related ecosystems over time. Report by the International Water Management Institute. CGIAR Research Program on Water, Land and Ecosystems (WLE). 44p.

Dini, J & Everard, M. (2016). National Wetland Policy: South Africa. Chapter in “The Wetland Book”, C.M. Finlayson et al. (eds.), Springer Science + Business Media Dordrecht 2016.

DWA (2011). Procedures to develop and implement resource quality objectives. Department of Water Affairs, Pretoria, South Africa

DWA (2013). CLASSIFICATION OF SIGNIFICANT WATER RESOURCES IN THE CROCODILE (WEST), MARICO, MOKOLO AND MATLABAS CATCHMENTS: Ecologically Sustainable Base Configuration (ESBC) Report. Directorate Water Resource Classification. Department of Water Affairs, South Africa. Report No: RDM/WMA1, 3/00/CON/CLA/0412

DWA (2014a). Assessing the Impact of Land-based Activities on Water Resources: User Manual for the Automated Land-based Activity Risk Assessment Method. Version 1.01. Directorate: Water Resources Information Programmes, Department of Water Affairs, South Africa. Report No: WP 10255.

DWA (2014b). Draft position paper for the protection, use, development, management and control of wetlands. Department of Water Affairs, Pretoria. South Africa

DWAF (2007). Manual for the assessment of a Wetland Index of Habitat Integrity for South African floodplain and channelled valley bottom wetland types by M. Rountree; C.P. Todd, C. J. Kleynhans, A. L. Batchelor, M. D. Louw, D. Kotze, D. Walters, S. Schroeder, P. Illgner, M. Uys and G.C. Marneweck. Report no. N/0000/00/WEI/0407. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWS (2016a). Development of Procedures to Operationalise Resource Directed Measures. Integrated Framework Milestone Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/0316.

DWS (2016b). Development of Procedures to Operationalise Resource Directed Measures. Wetland tool analysis and standardisation Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/0616.

DWS (2017). Determination of Resource Quality Objectives in the Mokolo, Matlabas, Crocodile West and Marico Catchments in the Limpopo North West Water Management Area (WMA01): Resource Quality Objectives and Numerical Limits Report. Final. Report No: RDM/WMA01/00/CON/RQO/0516

European Commission (2012). The Multi-functionality of Green Infrastructure. Science for Environment Policy Series: European Commission, Directorate-General Environment, Bristol, United Kingdom.

Hohls, O. (1995). Design framework for a national programme to monitor the health of aquatic ecosystems. CSIR report: Aquatic Ecosystems Monitoring Project.

Job N., Walters, D. and Kotze D. (2015). A desktop assessment of wetland condition in the Upper Mooi, Upper uMngeni and Upper Mvoti catchments. Prepared for WWF South Africa.

King, J. and Pienaar, H. (editors) (2011). Sustainable use of South Africa's inland waters. A situation assessment of Resource Directed Measures 12 years after the 1998 National Water Act. WRC Report Number TT491/11. Water Research Commission, Pretoria.

Kleynhans, C.J., Thirion, C and Moolman, J. (2005). A Level I river ecoregion classification system for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria.

Kleynhans, C.J., Louw, M.D. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report.

Kotze, D.C. (2016a). A method to assess wetland ecological condition based on land-cover type. Part 1: User manual. A simple Citizen Science tool to assess the ecological condition of a wetland, Version 1.3 (May 2016). WRC Project number K5/2350. Water Research Commission, Pretoria.

Kotze, D.C. (2016b). A method to assess wetland ecological condition based on land-cover type. Part 2: technical background. A simple Citizen Science tool to assess the ecological condition of a wetland, Version 1.3 (May 2016). WRC Project number K5/2350. Water Research Commission, Pretoria.

Kotze, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S. and Collins, N.B. (2007). WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report No TT 339/08, Water Research Commission, Pretoria.

Le Maitre, D.C., Seyler, H., Holland, M., Smith-Adao, L., Nel, J.A., Maherry, A. and Witthüser. K. (2018). Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater. Final Integrated Report on Project K5/2431, Water Research Commission, Pretoria.

Macfarlane, D.M., Kotze, D.C., Ellery, W.N., Walters, D., Koopman, V., Goodman, P. and Goge, C. (2007). *WET-Health: a technique for rapidly assessing wetland health*. Version 1.0. Water Research Commission, Pretoria.

Macfarlane, D.M., Ollis, D.J. and Kotze, D.C. (2018). WRC Project K5/2549: Wet-health (Version 2.0) tools for assessing the present ecological state of wetland ecosystems. Draft report submitted to the Water Research Commission.

Mbona, N., Job, N., Smith, J., Nel, J., Holness, S., Memani, S. and Dini, J. (2015). Supporting better decision-making around coal mining in the Mpumalanga Highveld through the development of mapping tools and refinement of spatial data on wetlands (WRC Project No. K5/2281).

Millennium Ecosystem Assessment (MA) (2005). Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Nel, J.L., Le Maitre, D.C., Roux, D.J., Colvin, C., Smith, J.S., Smith-Adao, L., Maherry, A. and Sitas, N. (2017). Strategic water source areas for urban water security: making the connection between protecting ecosystems and benefiting from their services. Ecosystem Services, 28(B): 251-259.

Nel, J.L., Murray, K.M., Maherry, A., Petersen, C.P., Roux, D.J., Driver, A., Hill, L., Van Deventer, H., Funke, N., Swartz, E.R., Smith-Adao, L.B., Mbona, N., Downsborough, L. and Nienaber, S. (2011). Technical Report for the National Freshwater Ecosystem Priority Areas project. *Water Research Commission Report No. 1801/2/11.* Water Research Commission, Pretoria.

Ollis, D.J., Snaddon, C.D., Job, N.M. and Mbona, N. (2013). Classification System for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria.

Quayle, L & Pringle, C. (2014). A guide for assessing ecosystem services at the catchment scale. INR Report No 497/14. Report Prepared for the African Wildlife Foundation: Nairobi, Kenya.

RAMSAR (2018). Wetlands and the SDGs: Scaling up wetland conservation, wise use and restoration to achieve the Sustainable Development Goals. RAMSAR CONVENTION ON WETLANDS, July 2018.

Rountree, M.W., H. Malan and B. Weston (editors). (2013). *Manual for the Rapid Ecological Reserve Determination of Inland Wetlands* (Version 2.0). Joint Department of Water Affairs/Water Research Commission Study. Report No. 1788/1/13. Water Research Commission, Pretoria.

Schulze, R.E. (2007). South African Atlas of Climatology and Agrohydrology, WRC Report 1489/1/06, Water Research Commission. Pretoria.

Schulze, R.E. and Smithers, J.C. (2007). One Day Design Rainfall. In: Schulze, R.E. (Ed). 2007. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 6.8.

South African National Biodiversity Institute (2012). 2012 Vegetation Map of South Africa, Lesotho and Swaziland [vector geospatial dataset] 2012. Available from the Biodiversity GIS website.

TEEB (2010). The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.

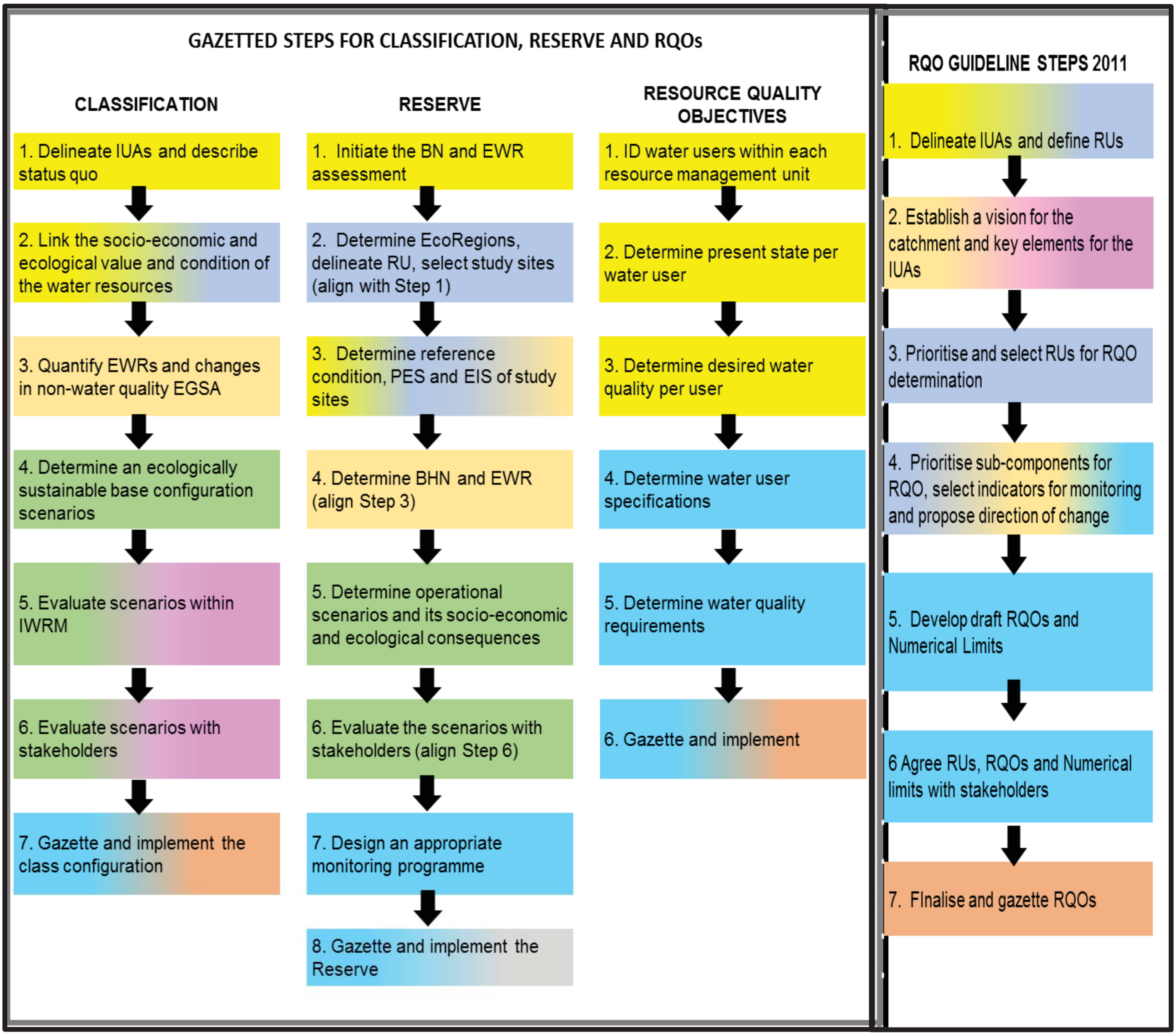
Uys, M.C., Goetsch, P.A. & O'Keeffe, J.H. (1996). National Biomonitoring Programme for Riverine Ecosystems: Ecological indicators, a review and recommendations. NBP Report Series No 4. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Wilkinson, M., Mulders, J., Mitchell, S., Malia, D. and Danga, L. (2016). The design of a National Wetland Monitoring Programme, Implementation Manual, Volume 2. WRC Report No. 2269/2/16.

10. ANNEXURES

10.1. Annexure 1 – Steps for Classification, Reserve and RQOs

Below is a flow diagram illustrating the gazetted steps for Classification, Reserve and RQOs, and the RQO steps in the DWA 2011 guideline (adapted from DWS, 2016a).



10.2. Annexure 2 – Reclassified land cover classes for Action 2

Land cover classes in the National land cover dataset and reclassified classes for the RQO procedure.

Value	Land Cover Classes	Reclassified Classes
0		Ocean
1	Water seasonal	Dams
2	Water permanent	Dams
3	Wetlands	Natural
4	Indigenous Forest	Natural
5	Thicket /Dense bush	Natural
6	Woodland/Open bush	Natural
7	Grassland	Natural
8	Shrubland fynbos	Natural
9	Low shrubland	Natural
10	Cultivated commercial fields (high)	Crops
11	Cultivated commercial fields (med)	Crops
12	Cultivated commercial fields (low)	Crops
13	Cultivated commercial pivots (high)	Crops
14	Cultivated commercial pivots (med)	Crops
15	Cultivated commercial pivots (low)	Crops
16	Cultivated orchards (high)	Crops
17	Cultivated orchards (med)	Crops
18	Cultivated orchards (low)	Crops
19	Cultivated vines (high)	Crops
20	Cultivated vines (med)	Crops
21	Cultivated vines (low)	Crops
22	Cultivated permanent pineapple	Crops
23	Cultivated subsistence (high)	Crops
24	Cultivated subsistence (med)	Crops
25	Cultivated subsistence (low)	Crops
26	Cultivated cane pivot – crop	Crops
27	Cultivated cane pivot – fallow	Crops
28	Cultivated cane commercial – crop	Crops
29	Cultivated cane commercial – fallow	Crops
30	Cultivated cane emerging – crop	Crops
31	Cultivated cane emerging – fallow	Crops
32	Plantations / Woodlots mature	Alien trees
33	Plantation / Woodlots young	Alien trees
34	Plantation / Woodlots clear felled	Alien trees
35	Mines 1 bare	Mining
36	Mines 2 semi-bare	Mining
37	Mines water seasonal	Mining
38	Mines water permanent	Mining
39	Mine buildings	Mining

Value	Land Cover Classes	Reclassified Classes
40	Erosion (donga)	Eroded
41	Bare none vegetated	Eroded
42	Urban commercial	Urban Infrastructure
43	Urban industrial	Urban Infrastructure
44	Urban informal (dense trees / bush)	Urban Infrastructure
45	Urban informal (open trees / bush)	Urban Infrastructure
46	Urban informal (low veg / grass)	Urban Infrastructure
47	Urban informal (bare)	Urban Infrastructure
48	Urban residential (dense trees / bush)	Urban Infrastructure
49	Urban residential (open trees / bush)	Urban Infrastructure
50	Urban residential (low veg / grass)	Urban Infrastructure
51	Urban residential (bare)	Urban Infrastructure
52	Urban school and sports ground	Urban Infrastructure
53	Urban smallholding (dense trees / bush)	Urban Infrastructure
54	Urban smallholding (open trees / bush)	Urban Infrastructure
55	Urban smallholding (low veg / grass)	Urban Infrastructure
56	Urban smallholding (bare)	Urban Infrastructure
57	Urban sports and golf (dense tree / bush)	Urban Infrastructure
58	Urban sports and golf (open tree / bush)	Urban Infrastructure
59	Urban sports and golf (low veg / grass)	Urban Infrastructure
60	Urban sports and golf (bare)	Urban Infrastructure
61	Urban township (dense trees / bush)	Urban Infrastructure
62	Urban township (open trees / bush)	Urban Infrastructure
63	Urban township (low veg / grass)	Urban Infrastructure
64	Urban township (bare)	Urban Infrastructure
65	Urban village (dense trees / bush)	Urban Infrastructure
66	Urban village (open trees / bush)	Urban Infrastructure
67	Urban village (low veg / grass)	Urban Infrastructure
68	Urban village (bare)	Urban Infrastructure
69	Urban built-up (dense trees / bush)	Urban Infrastructure
70	Urban built-up (open trees / bush)	Urban Infrastructure
71	Urban built-up (low veg / grass)	Urban Infrastructure
72	Urban built-up (bare)	Urban Infrastructure

10.3. Annexure 3 – Reclassified land cover classes for Action 12

Refined land cover categories for the level 1B WET-Health assessment

No.	Refined Land-cover Categories (Level 1B)	Grid code	Original Land-cover Categories	Additional spatial data required
1	Open Water – Natural	1	Water seasonal (Excluding artificial)	Excluding artificial water bodies from DEA/NFEPA layer
		2	Water permanent (Excluding artificial)	
2	Deep flooding from impoundments			Consider artificial water bodies from DEA/NFEPA layer
3	Shallow flooding from impoundments			
4	Aquaculture dams/ponds			
5	Natural / Minimally impacted	3	Wetlands	Excluding SANBI layer
		4	Indigenous forest	
		5	Thicket/Dense bush	
		6	Woodland/Open bus	
		7	Grassland	
		8	Shrubland	
		9	Low shrubland	
		41	Bare non vegetated	
6	Semi-natural (undrained)			SANBI layer
7	Semi-natural (drained)			
8	Orchards and vineyards	16 17 18	Cultivated orchards (low, medium & high)	
		19 20 21	Cultivated vines (low, medium & high)	
9	Sugar cane	26 27	Cultivated cane pivot (crop and fallow)	
		28 29	Cultivated cane commercial (crop and fallow)	
		30 31	Cultivated cane emerging (crop and fallow)	
10	Commercial annual crops (irrigated)	13 14 15	Cultivated comm pivots (low, medium & high)	Only with irrigation – DoA layer

No.	Refined Land-cover Categories (Level 1B)	Grid code	Original Land-cover Categories	Additional spatial data required
11	Commercial annual crops (non-irrigated)	10 11 12	Cultivated comm fields (low, medium & high)	Excluding irrigation – DoA layer
		22	Cultivated permanent pineapples	
12	Subsistence crops	23 24 25	Cultivated subsistence (low, medium & high)	
13	Tree plantations	32 33 34	Plantations / woodlots (young, mature, clear felled)	
14	Dense infestations of invasive alien plants			
15	Quarrying (sand, stone, diamonds)	35 36 37 38 39	Mines	
16	Coal mining			
17	Ore mining			
18	Eroded areas	40	Erosion	
19	Urban Industrial/Commercial	42	Urban commercial	
		43	Urban industrial	
20	Urban Informal	44 45 46 47	Urban informal	
21	Urban Residential – high density	48 49 50 51	Urban residential	
		61 62 63 64	Urban township	
		69 70 71 72	Urban built-up	
22	Urban Residential – low density	53 54 55 56	Urban smallholdings	
		65 66 67 68	Urban village	
23	Urban Open Space	52	Urban school and sports ground	
		57 58 59 60	Urban sports and golf	
24	Livestock feedlots (cattle and pigs)			
25	Chicken farms			
26	Planted pastures			
27	Infilling (incl. infrastructure)			
28	Sediment deposits			
29	Areas where water supply has become more sustained (e.g. from irrigation return flows, or seepage downslope of dams or embankments)			

Categories highlighted in green are only applicable within the wetlands and not within the buffer or pseudo catchments.
Categories highlighted in grey need to be identified and classified during the land cover data cleaning step.

10.4. Annexure 4 – Land cover categories summarised into broad transformed and untransformed layers

Untransformed vs. Transformed	Broad Land-cover Categories	Refined Land-cover Categories (Wet-Health Level 1B)	Grid code	Original Land-cover Categories
Largely Untransformed / Minimally Impacted	Natural / Minimally impacted	Natural / Minimally impacted	3	Wetlands
			4	Indigenous forest
			5	Thicket/Dense bush
			6	Woodland/Open bus
			7	Grassland
			8	Shrubland
			9	Low shrubland
			41	Bare non vegetated
Transformed	Open Water*	Open Water	1	Water seasonal
			2	Water permanent
	Cultivation	Orchards and vineyards	16 17 18	Cultivated orchards (low, medium & high)
			19 20 21	Cultivated vines (low, medium & high)
		Sugar cane	26 27	Cultivated cane pivot (crop and fallow)
			28 29	Cultivated cane commercial (crop and fallow)
			30 31	Cultivated cane emerging (crop and fallow)
		Commercial annual crops (irrigated)	13 14 15	Cultivated comm pivots (low, medium & high)
			10 11 12	Cultivated comm fields (low, medium & high)
		Commercial annual crops (non-irrigated)	10 11 12	Cultivated comm fields (low, medium & high)
			22	Cultivated permanent pineapples
		Subsistence crops	23 24 25	Cultivated subsistence (low, medium & high)
		Tree plantations	32 33 34	Plantations / woodlots (young, mature, clear felled)
	Mining	Quarrying (sand, stone, diamonds)	35 36 37 38 39	Mines
		Coal mining		
		Ore mining		
	Eroded areas	Eroded areas	40	Erosion
	Urban	Urban Industrial/Commercial	42	Urban commercial
			43	Urban industrial
		Urban Informal	44 45 46 47	Urban informal
		Urban Residential – high density	48 49 50 51	Urban residential
			61 62 63 64	Urban township

Untransformed vs. Transformed	Broad Land-cover Categories	Refined Land-cover Categories (Wet-Health Level 1B)	Grid code	Original Land-cover Categories
			69 70 71 72	Urban built-up
		Urban Residential – low density	53 54 55 56	Urban smallholdings
			65 66 67 68	Urban village
		Urban Open Space	52	Urban school and sports ground
			57 58 59 60	Urban sports and golf

10.5. Annexure 5 – Suggested template for capturing key information in the supporting technical report

IUA	RU	Wetland /Site	Wetland Type	PES & IS	REC	TEC	Component prioritised	Sub-component	Indicator	RQO	Numerical criteria	Monitoring Requirements

Notes:

- Integrated Unit of Analysis (IUA) → It is important to indicate which IUA the wetland resource is located in.
- Resource Unit (RU) → RU/s within which the wetland/s occur. The natural of wetland resources requires that they are embedded within the RUs of either rivers or where relevant groundwater units. Wetlands form part of the hydrological catchment and therefore should be aligned with other water resources as best as possible. It is possible for a priority wetland resource to be identified as a RU but this would typically be the exception rather than the norm.
- Wetland Site → Name of wetland resource (i.e. either the individual wetland or wetland complex).
- Wetland Type → Wetland HGM unit.
- Present Ecological State (PES) & Importance and Sensitivity (IS) → The PES = the health or integrity of the wetland resource relative to the natural or close to the natural reference condition, and the IS = Ecological Importance (ecosystems and biodiversity), ecological functions, and direct human benefit.
- Recommended Ecological Category (REC) → The desired future state for the wetland resources.
- Target Ecological Category (TEC) → The achievable future state for the wetland resource taking into consideration current and anticipated future impacts and drivers of change. Best Attainable State / Score (BAS) is a key component of the TEC.
- Component prioritised → Quantity, Quality, Habitat, and Biota.
- Sub-component → As per Table 11
- Indicator → Indicators should be appropriate, measurable, sensitive, representative, and cost-effective.
- RQO → A qualitative statement that clearly defines the objective.
- Numerical criteria → Supporting qualitative information that details what data are required and how the data should be collected (i.e. feasible methodology). Where quantitative data are available, numerical limits can be set.
- Monitoring Requirements → Monitoring methods and timeframes should be clearly outlined.

10.6. Annexure 6 – A desktop method for monitoring wetland resources

EXECUTIVE SUMMARY

The aim of this annexure is to assist water resource managers, and other parties, in monitoring wetland resources at a desktop level. Specific focus is given to monitoring priority wetland resources. The report is an annexure of the "Procedure to Develop and Monitor Wetland Resource Quality Objectives" (Bredin et al., 2019). It is intended as an initial desktop monitoring method for water resource managers to monitor priority wetland resources, to determine when further monitoring of the select indicators for the relevant sub-components is required. Therefore, the report aims to offer water resource managers a desktop method for monitoring potential change in land use activities, which may lead to a change in the condition of priority wetland resources. Where the change in condition results in increased risk to achieving the respective wetland Resource Quality Objectives (RQOs), the outcomes of the desktop monitoring should be used as a 'trigger' to undertake more detailed monitoring of the relevant indicators.

Importantly it is not a comprehensive manual for monitoring wetlands at different levels, nor is it an implementation manual, or though as indicated in Action 19 of the Procedure to Develop and Monitor Wetland Resource Quality Objectives, monitoring does form a key part of the required implementation of wetland RQOs. More specifically the monitoring that is outlined in this report is an initial 'flagging' method that will allow water resource managers the ability to detect significant changes taking place within priority wetland resources and the respective zone of influence around the wetland resources. It is a complementary desktop method to the monitoring requirements that will be set for the selected indicators for each of the respective sub-components.

The primary focus of this report is a step-by-step approach to guide the user through a process that will allow them to detect significant change timeously and provide guidance on how to respond accordingly.

Users of this report are encouraged to use the "Procedure to develop and monitor wetland RQOs" (Bredin et al., 2019) to gain an understanding of the approach taking to determining priority wetland resources and the relevant terminology associated with the setting of RQOs.

In developing the approach to monitor priority wetland resources at a desktop level, it became apparent that there is enormous potential to improve on the 'simple change detection' proposed, as such recommendations for improving the method are provided.

ACKNOWLEDGEMENTS

The development of a manual for monitoring wetland Resource Quality Objectives (RQOs) was funded by the Department of Water and Sanitation (DWS). Mr Bonani Madikizela and Ms Gerda Kruger from the Water Research Commission (WRC) are acknowledged for facilitating and giving invaluable advice on the administration of the project.

The Reference Group consisted of:
- Mr Bonani Madikizela (WRC);
- Dr Wietsche Roets (DWS);
- Ms Nancy Job (South African National Biodiversity Institute (SANBI));
- Dr Justine Ewart-Smith (Freshwater Consulting Group (FCG));
- Ms Mohlapa Sekoele (DWS);
- Dr Chris Dickens (IWMI);
- Ms Jacqueline Jay (DWS);
- Mr Dean Ollis (FCG);
- Ms Namhla Mbona (SANBI);
- Dr Piet-Louis Grundling (Department of Environmental Affairs (DEA));
- Dr Heather Malan (Freshwater Research Centre (FRC));
- Dr Gerhard Cilliers (DWS); and
- Mr Tumisho Ngobela (FCG)

TABLE OF CONTENTS

LIST OF FIGURES

ACRONYMS USED IN THIS ANNEXURE

DEM	Digital Elevation Model
DWS	Department of Water and Sanitation
ESA	European Space Agency
GDAL	Geospatial Data Abstraction Library
GIS	Geographic Information System
GUI	Geographical User Interface
HGM	Hydrogeomorphic unit
IHI	Index of Habitat Integrity
INR	Institute of Natural Resources
LSWI	Land Surface Water Index
MSI	Multi-spectral Instrument
NAEHMP	National Aquatic Ecosystem Health Monitoring Programme
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NLC	National Land Cover
NW&SMP	National Water and Sanitation Master Plan
NWA	National Water Act
NWMP	National Wetland Monitoring Programme
PES	Present Ecological State
RDM	Resource Directed Measures
RQOs	Resource Quality Objectives
SARVI	Soil and Atmosphere Resistant Vegetation Index
SDGs	Sustainable Development Goals
UKZN	University of KwaZulu-Natal
VRT	Virtual Raster Tile
WCS	Wetland Consulting Services
WMA	Water Management Area
WRC	Water Research Commission

11. INTRODUCTION

11.1. Background

A key component of implementation is monitoring. The setting of Resource Quality Objectives (RQOs) includes recommended monitoring of indicators for respective sub-components. This monitoring is typically undertaken every three to five years.

People are generally uninformed of the importance of wetlands. This lack of understanding typically results in improper use and management of these important and valuable ecosystems, which play an essential role in the functioning of the hydrological cycle. As a result there is a critical need to supplement the current acceptable monitoring of wetland RQOs with a monitoring method that allows for more regular monitoring to reduce the possibility of improper use and management of the countries priority wetland resources.

11.2. Purpose of the report

The purpose of this report is to describe a desktop method that has been developed for the monitoring of priority wetland resources at a national level or within separate Water Management Areas (WMAs). The report is available on the following website: https://sites.google.com/site/wetlandrqos

While the focus of the this report is on providing water resource managers with a complementary desktop wetland monitoring method, it is also acknowledged that the method may have relevance to a range of parties (e.g. conservation bodies, private consultants, etc.) who deal with monitoring wetlands at a catchment scale.

The aim of this report is to assist water resource managers in monitoring priority wetland resources. A lot of emphasis has been placed on a procedure to develop and monitor wetland RQOs (Bredin et al., 2019) (hereafter referred to as the Procedure). The Procedure allows for the determining of significant wetland resources and then a subset of priority wetland resources, for the purpose of setting RQOs. However, very little emphasis has been placed on offering water resource managers guidance on how to monitor the priority wetland resources to ensure that the legislated objectives are being achieved. The monitoring for select indicators for respective sub-components are guided by existing methodologies and the National Wetland Monitoring Programme (refer to Action 19 in the Procedure). However, given the current challenges faced by water resource managers a need has arisen for a complementary cost-effective and efficient way of monitoring.

This report aims to offer water resource managers a desktop method for monitoring potential change in land use activities, which may lead to a change in the condition of priority wetland resources. Where the change in condition results in increased risk to achieving the respective wetland RQOs, the outcomes of the desktop monitoring should be used as a ‘trigger’ to undertake more detailed monitoring of the relevant indicators.

Importantly it is not a comprehensive manual for monitoring wetlands at different levels, nor is it an implementation manual, or though as indicated in Action 19 of the Procedure, monitoring does form a key part of the required implementation of wetland RQOs. More specifically the monitoring that is outlined in this report is an initial 'flagging' method that will allow water resource managers the ability to detect significant changes taking place within priority wetland resources and the respective zone of influence around the wetland resources. It is a complementary desktop method to the monitoring requirements that will be set for the selected indicators for each of the respective components/sub-components. The primary focus of this report is a step-by-step approach to guide the user through a process that will allow them to detect significant change timeously and provide guidance on how to respond accordingly. It is important to highlight that in applying this method the user is required to have:

- A sound understanding of wetland resources and how they function at a landscape level;
- A sound understanding of the wetland resources that occur within the focus area for monitoring purposes; and
- A basic to intermediate understanding of Geographic Information System (GIS) software (e.g. GIS software like ArcGIS or QGIS), which is required for key steps within the procedure.

Users of this report are encouraged to first review the Procedure (Bredin et al., 2019) to gain an understanding of the approach taken in determining priority wetland resources and the relevant terminology associated with the setting of RQOs.

12. APPROACH TAKEN TO DEVELOP THE DESKTOP MONITORING METHOD

The approach to developing this desktop monitoring report has largely stemmed from the development of the procedure to develop and monitor wetland RQOs (Bredin et al., 2019). The procedure outlines a method that allows for a baseline condition to be set for priority wetland resources by taking into consideration land cover impacts within the wetland resource and an appropriate zone of influence. It is the setting of this baseline that led to the investigation of methods that allow for the detection of change which may indicate a change in condition of the wetland over time. This led to the testing of the concept of regular assessments of change will allow for the detection of change in wetland condition. The key was to find a way to compare one aerial image with another taken at different intervals (i.e. one year apart), which would allow for change to be detected and used to assess if a change in condition of the wetland resource has occurred.

Wetland RQOs can be set for priority wetland resources in terms of the quantity, quality, habitat and biota (refer to Section 1.3 of the Procedure). The timeframes typically indicated for the monitoring of these RQOs are every 3-5 years. However, change in wetland condition can occur within a much shorter timeframe. This was a key criterion taken into consideration for the development of a way to monitor priority wetland resources. Essentially the approach taken was to develop a desktop based method that allows for a water resource manager to detect if change is going to have a detrimental impact to a priority wetland resource and respond accordingly. The approach took into consideration what practical measures could be implemented to allow for an early detection of change in condition so that water resource managers can respond before a wetland RQO is no longer achievable.

The approach taken to develop the desktop monitoring report was to first draft an initial method based on the concepts stemming from the work undertaken for the Procedure, and then to run a workshop to obtain input from the project team and key stakeholders.

Finally, in developing an approach it became apparent that there is considerable potential to improve on the 'simple change detection' proposed in this report. Therefore, the approach was to develop an initial method to illustrate its advantages so that it can be improved on through potential follow-on projects.

13. FRAMEWORK FOR DEVELOPING THE DESKTOP MONITORING METHOD

Four key focus areas were taken into consideration for the development of the desktop monitoring method. The focus areas provided the context for the development of the method. They included:

- The outputs from the procedure to develop and monitor wetland RQOs;
- The National Wetland Monitoring Programme;
- The revised Wet-Health Method (Macfarlane et al., 2018); and
- The use of Sentinel remote sensing imagery.

13.1. Outputs from the wetland RQOs procedure and existing wetland RQOs

Resource Quality Objectives are determined for quantity, quality, habitat and biota. Where data exists RQOs can be quantitative, with specific numerical criteria. Alternatively where data is limited, RQOs are typically aspirations converted into qualitative statements with broader numerical criteria. Additionally, the possible RQOs for significant wetlands can vary considerably.

The procedure to develop and monitor wetland RQOs (Bredin et al., 2019) requires that an assessment of wetland condition be undertaken through the use of land cover within the priority wetland resource and a zone of influence. This assessment provides the opportunity to not only determine likely wetland condition but also operate as a platform for long-term regular monitoring (i.e. annual wetland monitoring). The semi-quantitative desktop method utilizes calculations of within wetland resource and surrounding wetland land-uses as a proxy to determine wetland impacts, and consequently wetland ecological state / condition. The method allows for the calculation of the percentages of various types of land-uses both within wetland boundaries and within a 200 m zone of influence outside of the wetland boundaries (clip to the wetlands catchment). This is achieved by utilizing existing land cover data, which has been refined through a 'cleaning process'.

> It is important to note that the use of the land cover based wetland condition assessment has not been applied for all existing wetland RQO assessments. If this monitoring method is to be used retrospectively for WMAs where RQOs have already been determined then a baseline wetland condition assessment, using the land cover assessment (i.e. Wet-Health Level 1B assessment, Macfarlane et al., 2018) would need to be undertaken for the selected priority wetland resources.

13.2. National Wetland Monitoring Programme

According to Wilkinson et al. (2016), the National Wetland Monitoring Programme (NWMP) adopts the DWAF (2004); Finlayson et al. (2001) and Ramsar Convention (2002) definition of monitoring, which is the collection of specific information for management purposes in response to set objectives derived from assessing the wetlands of interest. Monitoring results are then used for implementing management. Hence for an effective monitoring programme it is necessary for water resource managers to have an understanding of what changes may, or may not, be taking place so that they can respond accordingly.

The intention of the NWMP is to assess and monitor wetlands at three different spatial scales. These scales include:

- **Tier 1**: National Scale Assessment of Wetlands, largely using existing datasets and desktop assessment methods. Results from Tier 1 of the NWMP will allow the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) to report on the extent of wetlands in the country, land-cover and land ownership and their surroundings and the extent to which wetlands in the country are protected.
- **Tier 2**: Rapid Assessment of Prioritised Wetlands involves the prioritisation of certain wetlands for further investigation, followed by field assessors spending approximately 4-8 hours at each wetland. Results from Tier 2 will allow reporting of eight indicators, namely the extent of the wetland; the present state of hydrology, geomorphology, vegetation and water quality; present ecological state based on land use; scores for ecosystem services provided by the wetland; and a measure of the threats posed by listed invasive plants to the wetland.
- **Tier 3**: Detailed Monitoring of a Sub-set of Wetlands, most of which will have been selected from Tier 2. The purpose of Tier 3 is to build a body of knowledge of wetland ecosystems and to monitor wetlands assessed as being of concern for one reason or another. A suite of indicators and protocols are provided for monitoring wetlands at this level of detail. Not all indicators will necessarily be monitored at Tier 3 wetlands.

The proposed desktop monitoring of priority wetland resources does not fit within any one of the three tiers of the NWMP. However, it is viewed as a method the complements Tier 1 and 2 of the NWMP by combining components of the two tiers. This is largely due to the referenced use of the land cover based method for determining wetland condition (Kotze, 2016a and b). This method has subsequently been taken into consideration and revised for the updating of the Wet-Health method (Macfarlane et al., 2018). The revised method is proposed for the monitoring of priority wetland resources.

13.3. Revised Wet-Health Method

Present Ecological State (PES) of wetland ecosystems is a central concept for wetland-related management and decision-making in South Africa. The Wetland Index of Habitat Integrity (Wetland-IHI, after DWA 2007) and WET-Health (Macfarlane et al., 2009) have been widely applied across the country. However, there has been some confusion regarding which of these tools to use under what scenarios. In an attempt to address this Ollis et al. (2014) develop a decision-support tool to guide the assessment of wetland PES. A gap analysis was also undertaken by Ollis & Malan (2014), and it highlighted strengths and weaknesses with both approaches. The framework developed for the NWMP identified the need to address the gaps and limitations of the existing wetland PES assessment methods amongst the high-priority needs for the implementation of the NWMP (Wilkinson et al., 2016). As such, a current WRC project aims to address the clear need that has been identified to produce a refined suite of tools for the assessment of the PES of wetland ecosystems in South Africa. The ultimate goal is to provide a robust, rigorously tested suite of tools that can be used to categorise the present ecological condition of all HGM wetland types (Macfarlane et al., 2018).

The proposed 'Level 1B' Wet-Health assessment (Macfarlane et al., 2018) for regional- to local-scale assessments based on refined land-cover classes is the proposed method for assessing the condition of priority wetland resources. The approach represents a modification of the land-cover-based method that Kotze (2016a and 2016b) developed for the rapid assessment of wetland condition by non-specialists, using land-cover types based on the National Land Cover 2014 (NLC- 2014) dataset as the starting point. The approach focuses on the relative extent of various land cover types estimated within the wetland resources that need to be assessed and in an area surrounding the wetlands, and this information is then used to derive modelled PES scores (and Ecological Categories) for the four components of wetland condition taking the HGM type into account (Macfarlane et al., 2018).

13.4. The use of Sentinel remote sensing imagery

There has been a steady increase in the use of GIS and Remote Sensing in wetland applications. Remotely sensed data such as freely available Google Earth satellite imagery and other geospatial data have proven to improve desktop wetland delineations (Kaplan and Avdan, 2017). Multispectral imagery has been used internationally to classify wetlands through indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Land Surface Water Index (LSWI) and Soil and Atmosphere Resistant Vegetation Index (SARVI) (Kaplan and Avdan, 2018).

The Sentinel-2 Multi-spectral Instrument (MSI) sensor was launched in June 2015 and is considered to be a follow up mission to the SPOT and Landsat instruments. Sentinel 2 is part of the European Copernicus program created by the European Space Agency (ESA) (Kaplan and Avdan, 2017). Sentinel-2 offers satellite images with a resolution from 10 m to 60 m and when compared to Landsat Sentinel-2 has better spatial resolution and spectral resolution in the near infrared region, and three Vegetation Red Edge bands with 20-meter spatial resolution (Kaplan and Avdan, 2017; 2018).

The Sentinel 2 satellite imagery will provide the platform for assessing change within wetland resources and their zones of influence.

14. PROPOSED METHOD FOR DESKTOP MONITORING OF PRIORITY WETLAND RESOURCES

The steps outlined in this section aim to provide a practical and cost-effective method for monitoring priority wetland resources throughout the country's WMAs[11]. The proposed desktop monitoring focuses on detecting changes in land use in the wetland and the zone of

[11] It is important to note that the monitoring can only be undertaken for wetland resources that have had a baseline land cover derived wetland condition assessment.

influence, which provides an opportunity to detect change in wetland condition (Bredin, in press).

14.1. Change detection workflow

The proposed GIS workflow provides initial findings of a semi-automated attempt at change detection using freely available GIS software[12] and new age satellite imagery (Sentinel-2). The workflow is explained via a step by step process where all spatial analysis and image interpretation and downloads are conducted within QGIS.

QGIS download is available at: https://qgis.org/en/site/forusers/download.html

14.1.1. Prerequisite checklist

- QGIS installed (version 2.18.15 and higher)
- Plugins:

Sentinel Hub
The Sentinel Hub QGIS-plugin allows for the efficient download and utilization of various Sentinel-2 band combinations (layers). Certain band combinations prove to be more suitable for analysing changes across different sectors. For example, the Sentinel Hub provides 8 pre-packaged layers that are best suited for specific monitoring tasks. The Sentinel Hub plugin transforms any layer created in Sentinel Hub Configuration Utility into QGIS layers. It allows exploration, customization and image download. To install the Sentinel Hub QGIS-plugin, go to “Plugins” in the menu tool bar and select “Manage and Install Plugins”. Search for “Sentinel Hub” and click install plugin. An icon with an “S” should appear.

Sentinel Hub by SINERGISE account
Simply go to https://apps.sentinel-hub.com/configurator/#/ where if you already have an account you log in using the “Login” tab. If you do not have one, it is straight forward to do, select the “Don’t have account yet?”. Once you have logged in, you will see an ID code which you will use to access the imagery in the first step.

GDAL (Geospatial Data Abstraction Library)
The GDAL Tools plugin offers a Geographical User Interface (GUI) to the collection of tools in the Geospatial Data Abstraction Library, http://gdal.osgeo.org. These are raster management tools to query, re-project, warp and merge a wide variety of raster formats. Also included are tools to create a contour (vector) layer, or a shaded relief from a raster DEM (Digital Elevation Model), and to make a Virtual Raster Tile (VRT) in XML format from a collection of one or more raster files. These tools are available when the plugin is installed and activated. Select “View” on the toolbar menu, select “Panels” and then turn on the processing toolbox. In the search box type “GDAL” and the GDAL tools will become visible. Within these tools, locate the raster calculator which will be used in the change detection process.

[12] The proposed software was free at the time of developing the desktop monitoring method. However, Sentinel Hub currently charges a nominal fee for the use of the software.

14.1.2. Step 1: Sentinel Hub plugin

Open the Sentinel Hub plugin in order to explore available Sentinel-2 imagery. Note the plugin may not be located in the same location as seen in the screenshot below. If this is the case simply look for the tab with a large “S” symbol on it.

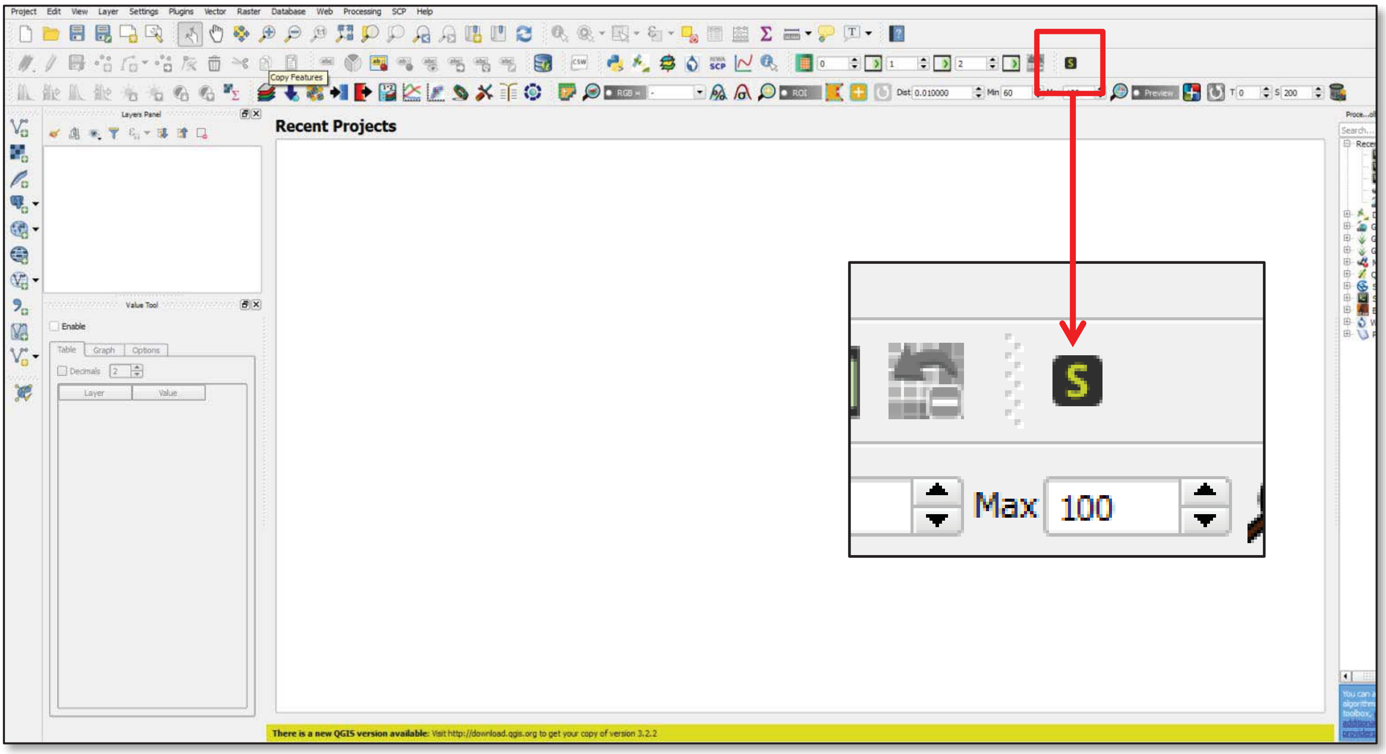


Figure 42: Sentinel Hub plugin screen shot

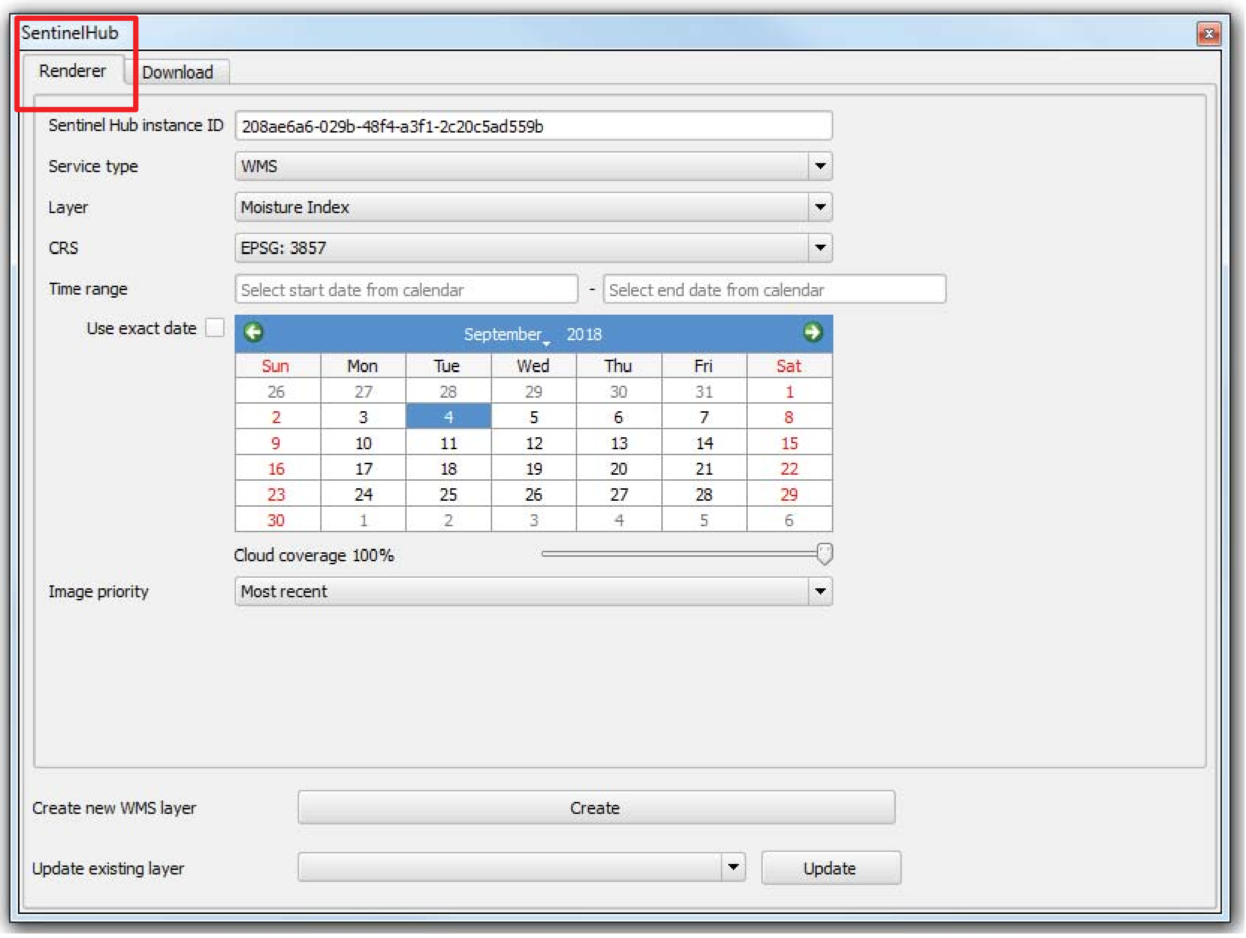


Figure 43: Sentinel Hub Rendering page screen shot

Follow the steps below:

- Select the "Renderer" tab
- Enter the unique Sentinel Hub Instance ID from SINERGISE account
  If you don't already have an existing account – create a Sentinel Hub SINGERISE account at: (https://apps.sentinel-hub.com/configurator/#/)
- Select WMS as service type

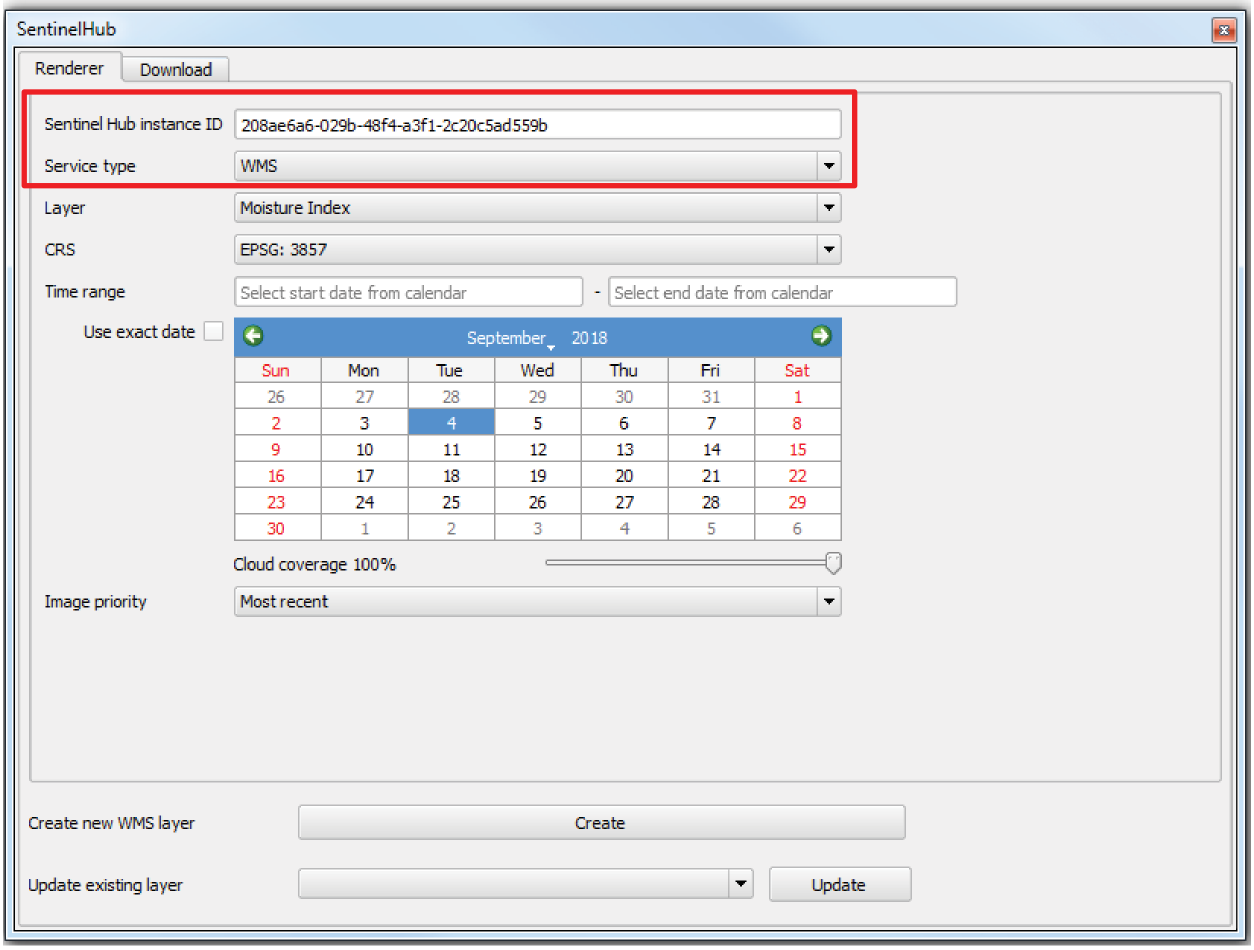


Figure 44: Sentinel Hub Rendering page screen shot showing the inputting of the unique Sentinel Hub Instance ID from SINERGISE

- Choose layer from available options (Agriculture, NDVI, False colour, etc.). Natural colour (true colour) is recommended as the default layer.

- Select the dates that you would like to acquire imagery for. Dates that have imagery available will appear greyed in the calendar. The first image that will be downloaded will be the reference image when the baseline assessment was conducted. The second image is the monitoring image.

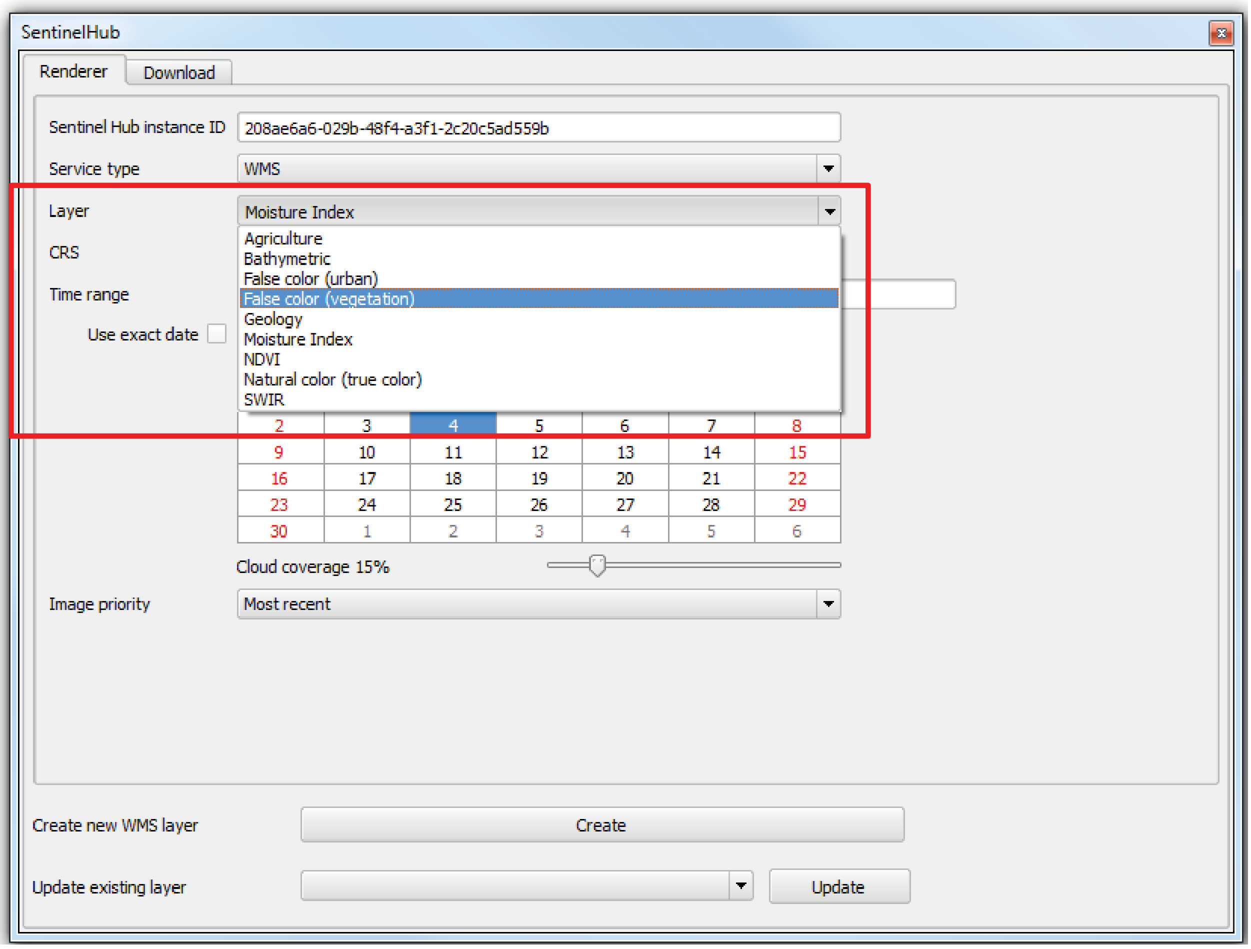


Figure 45: Sentinel Hub Rendering page screen shot showing the selection of the required layers

The proposed timeframe for detecting change is annually (Note: the assessment should be undertaken at approximately the same each year, i.e. within the same season each year). This is because it will help eliminate seasonal changes. Imagery should be selected for the same month of each year to be assessed.

- Cloud coverage should be set to less than 15%. The number of greyed dates (dates with available images) will reduce as you reduce the cloud cover percentage. Sentinel-2 imagery is available at approximately 10 day intervals however cloud cover could result in a reduced availability of imagery.

- Select create to initiate search. Once you have selected update, the layer should display in the current extent window of QGIS.

- A screenshot of what should appear within the QGIS interface is illustrated below. The example shows a false colour vegetation layer (Figure 6).

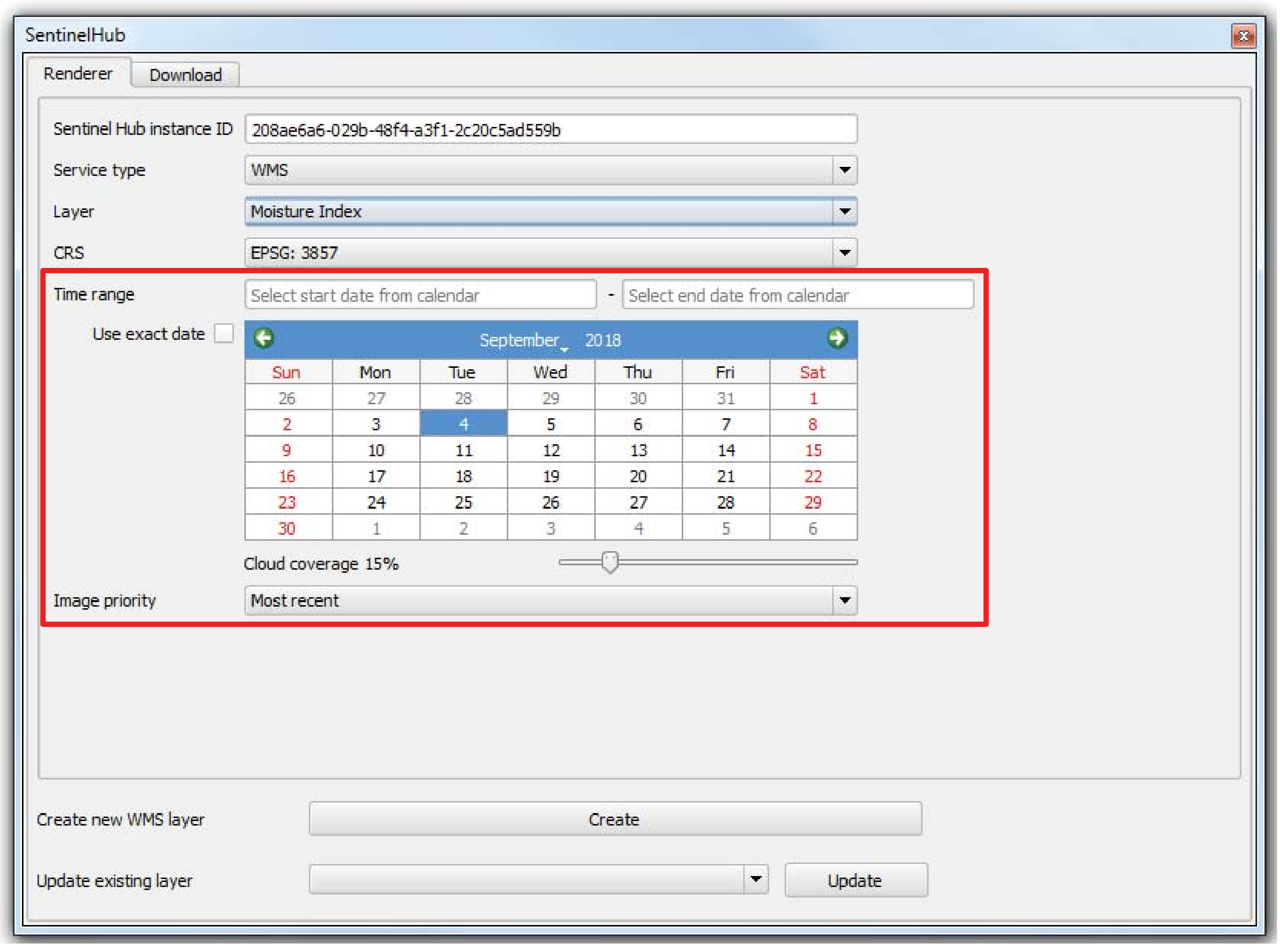


Figure 46: Sentinel Hub Rendering page screen shot showing time ranges and cloud coverage selections

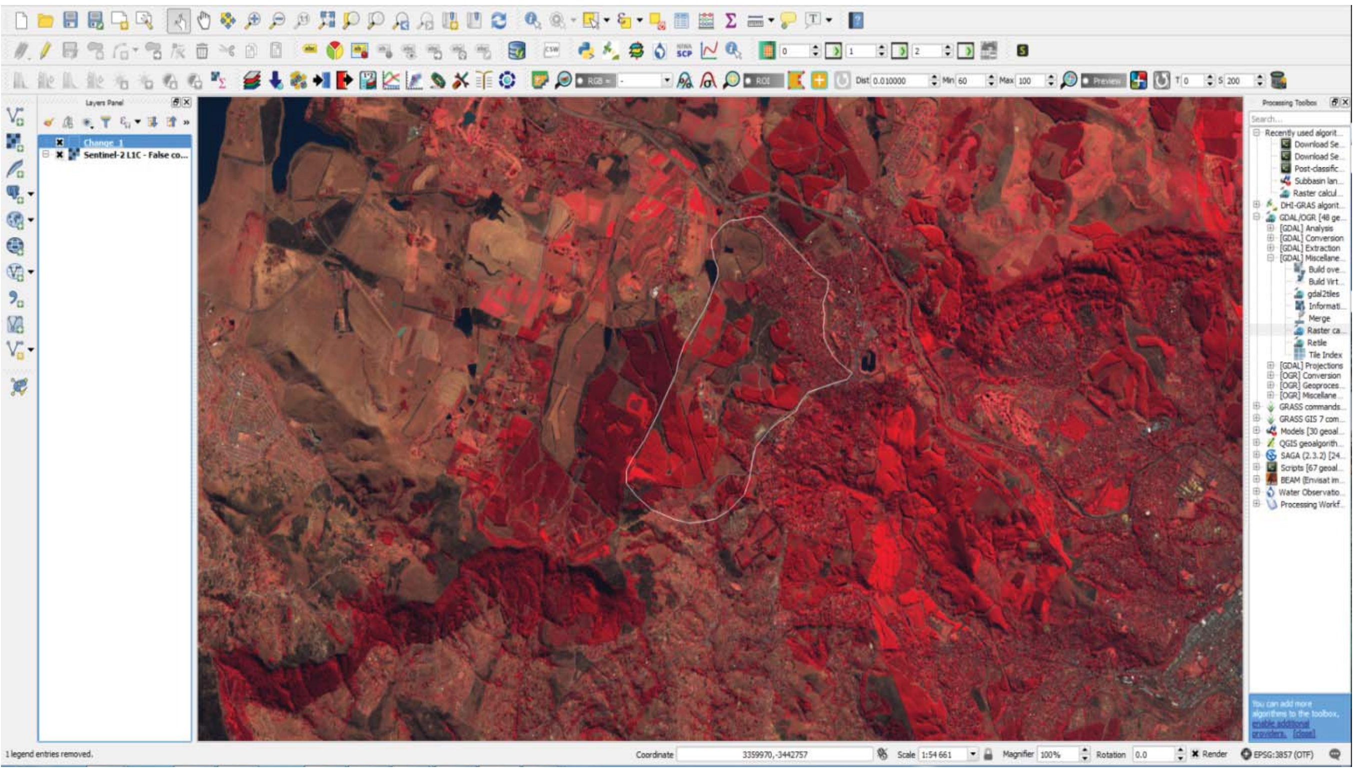


Figure 47: An example of a false colour vegetation layer for an area of interest

14.1.3. Step 2: Sentinel-2 layer parameters and download

Follow the steps below:

- Select "Download" tab from the Sentinel Hub window

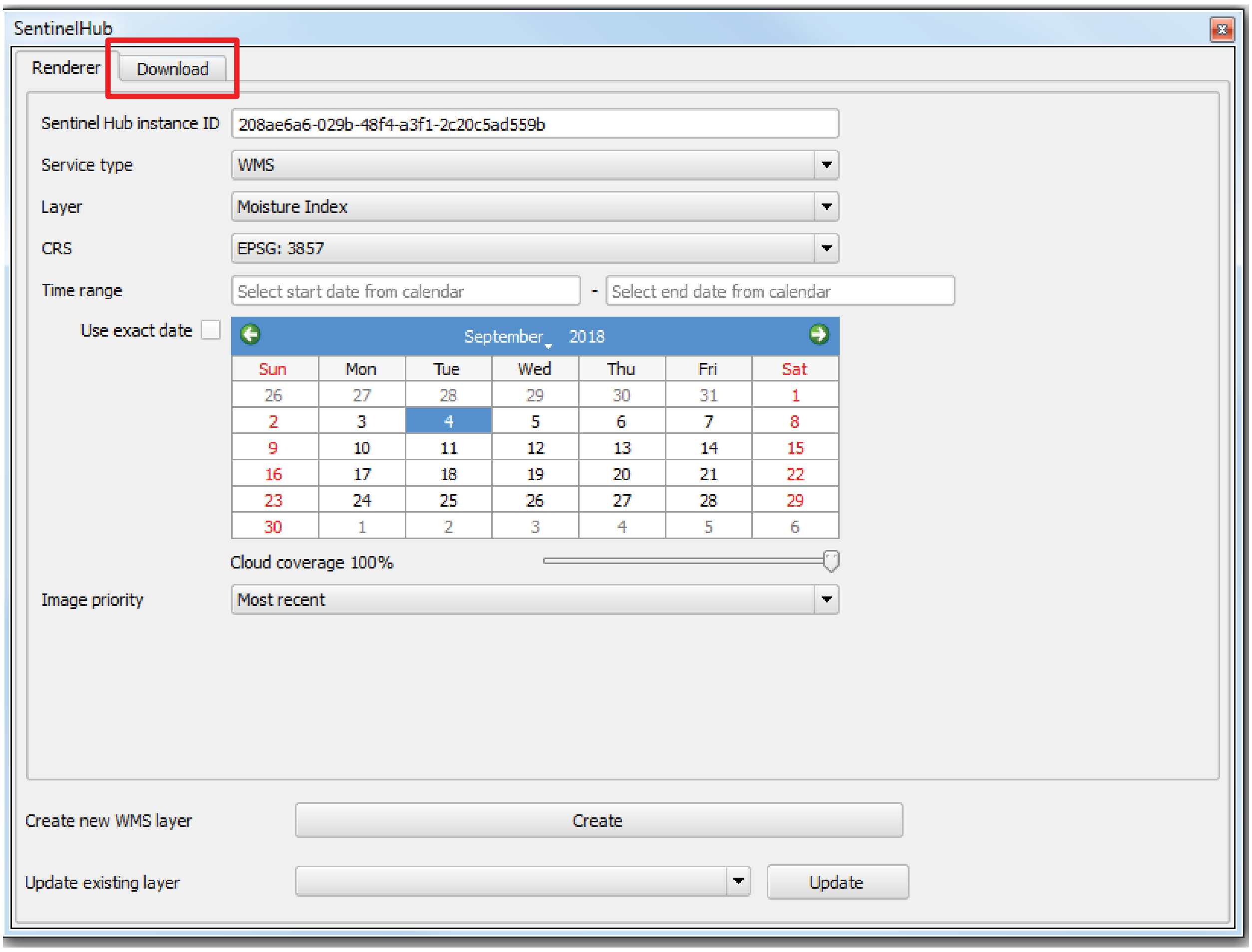


Figure 48: Locating the Sentinel Hub Download page

- Select image format – Preferably "32-bit float TIFF".
- Default resolution.
- Default Service type and CRS.
- Bounding box should be set to "Current window". Ensure the entire study area is visible in the display box as this setting downloads the portion of the image that is in the current display window.
- Select folder to save Sentinel-2 imagery.
- Click download and the imagery will download and open in QGIS.

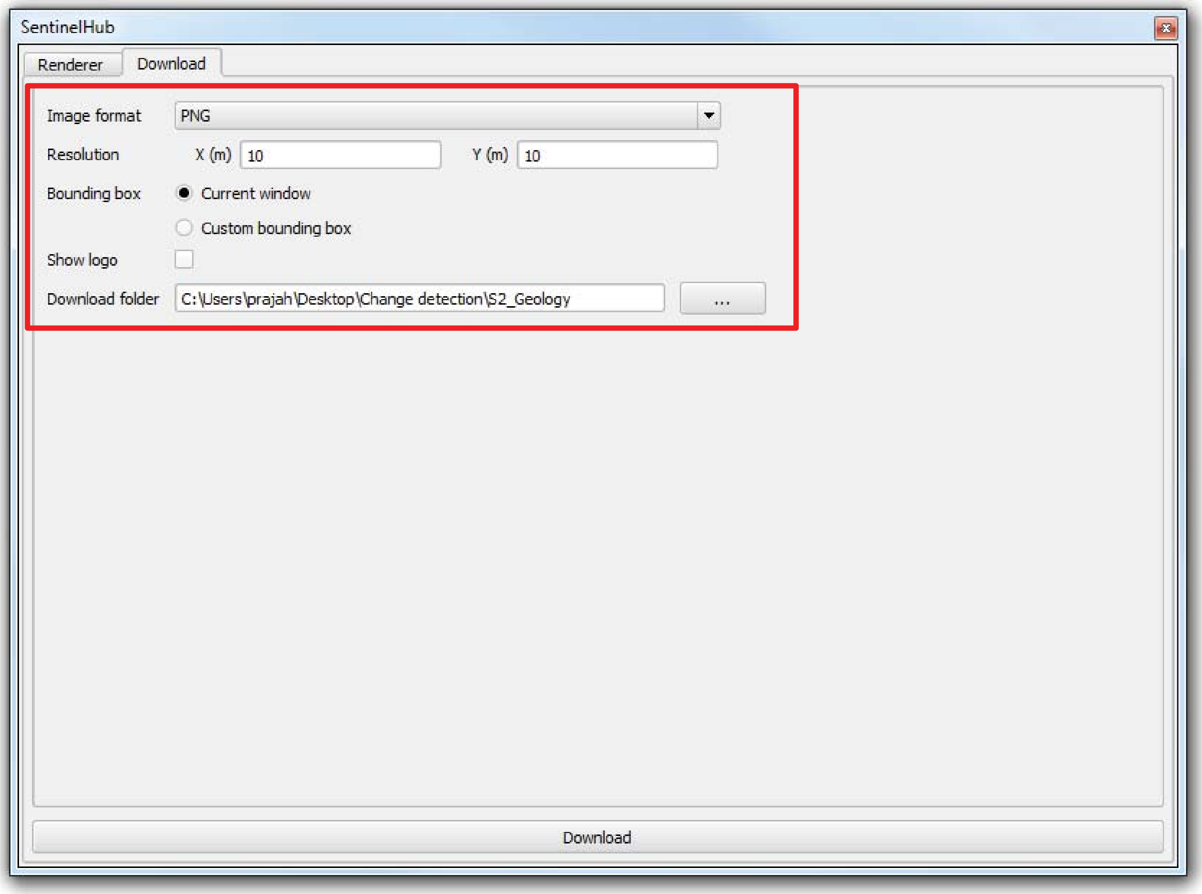


Figure 49: Sentinel Hub Download selection criteria

If the downloaded image appears with a warning message, then the study area or the visible extent of the display window is larger than 5000 x 5000 pixels and needs to be zoomed in to be within these parameters. If the study area is greater than these parameters, the study area can be broken up into two or more images that can then be mosaicked before proceeding to Step 3.

14.1.4. Step 3: Raster calculator and the change detection analysis

Follow the steps below:

- Search for the "GDAL Raster calculator" tool in QGIS processing toolbox window.

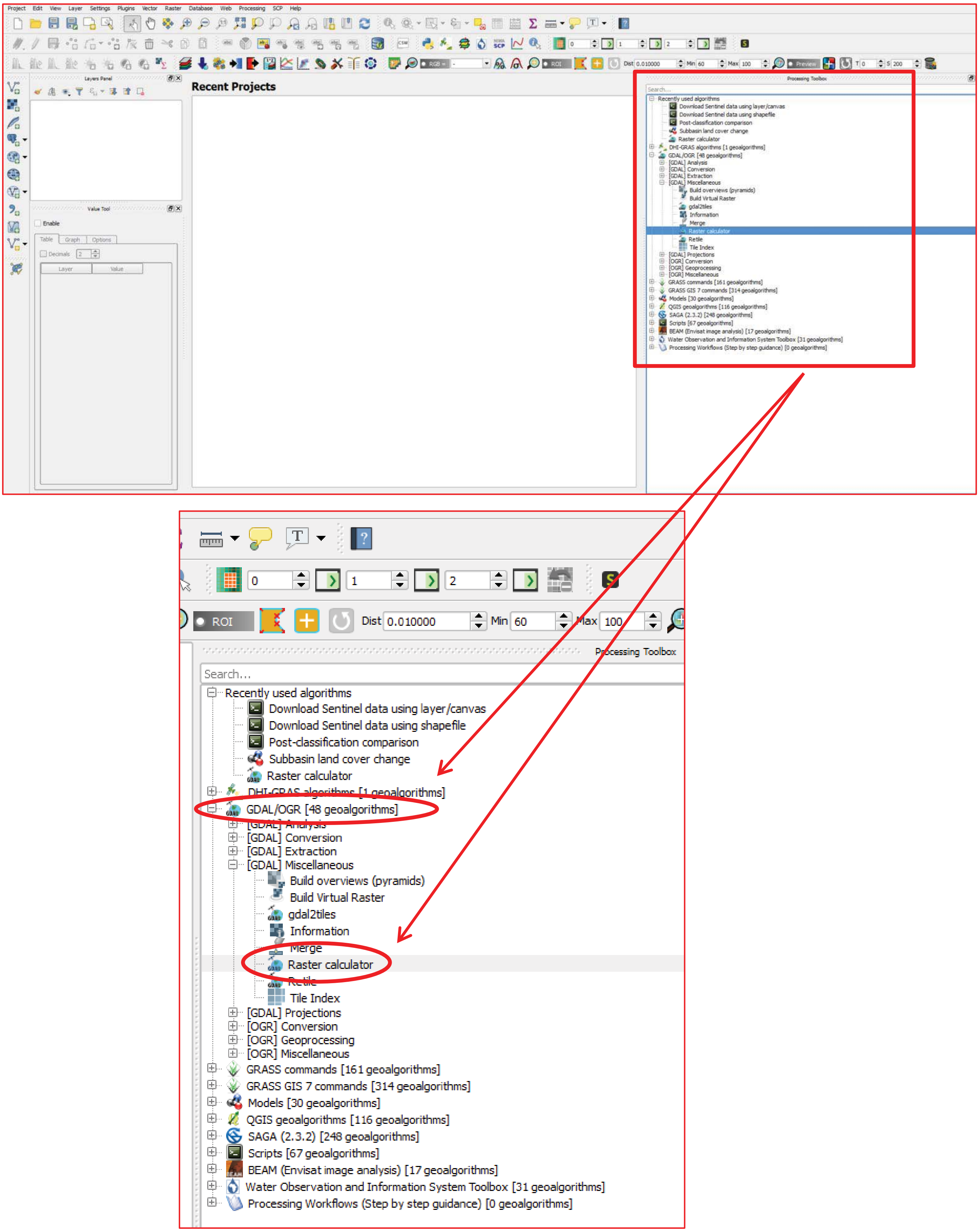


Figure 50: GDAL Raster calculator" tool in QGIS

- Open the raster calculator and select the parameters tab

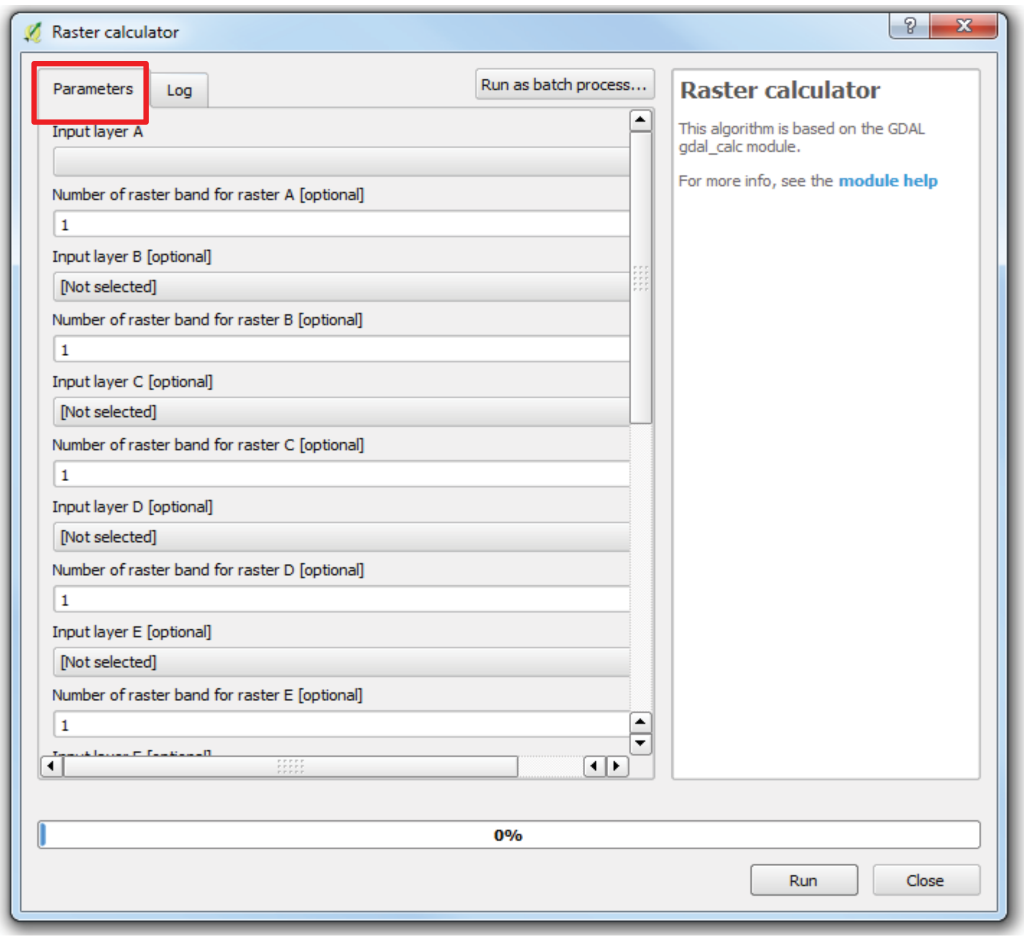


Figure 51: Screen shot of the raster calculator

- Select Sentinel-2 image that you wish to use as reference image for change (Input layer A).
  The initial reference image will be the Sentinel-2 image from the year and month the initial baseline land cover assessment was undertaken. The subsequent reference image will be the following year's image (from the same month).
- Input "Number of raster band for raster A" based on the Sentinel-2 image
  The recommended default raster band combination is Band 1.
- Select Sentinel-2 image that you wish to use as most recent image to detect change (Input layer B).
- Input "Number of raster band for raster B" based on the Sentinel-2 image.

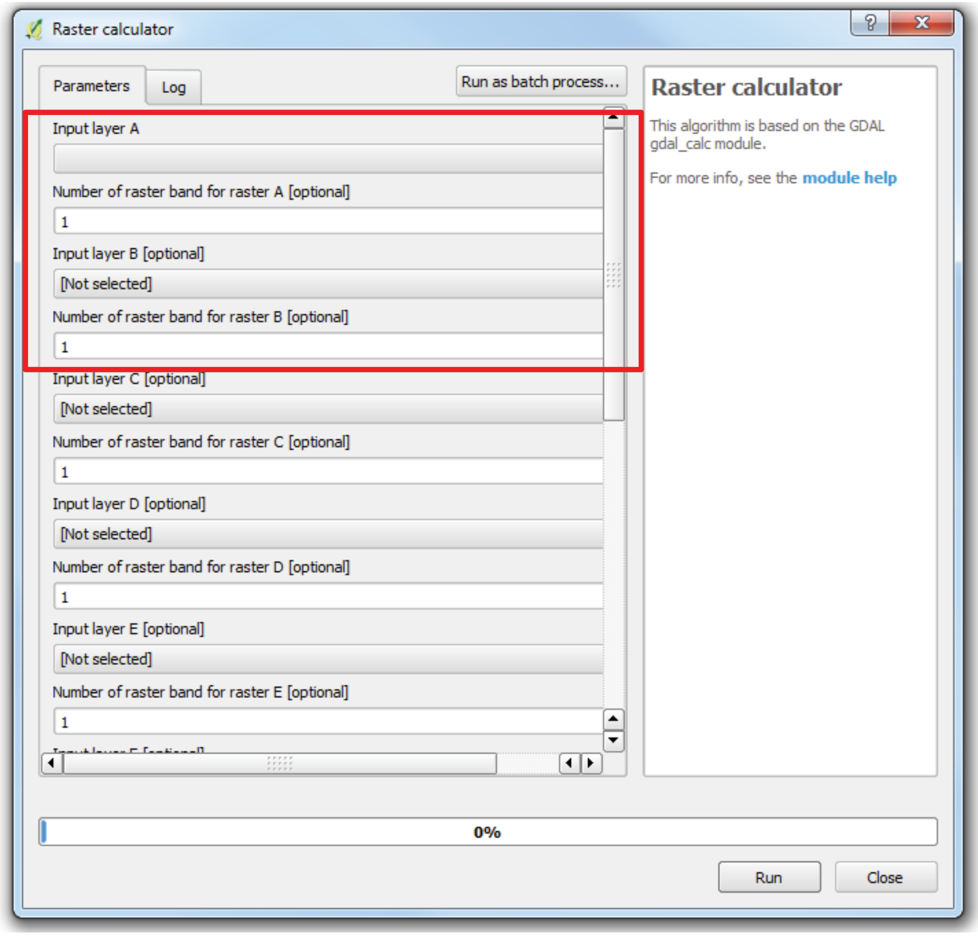


Figure 52: Screen shot of the key inputs into the raster calculator

- Under the “Calculation in GDAL syntax” insert “A-B” (this is the step that actually finds the difference between the two images).
- Run the process.

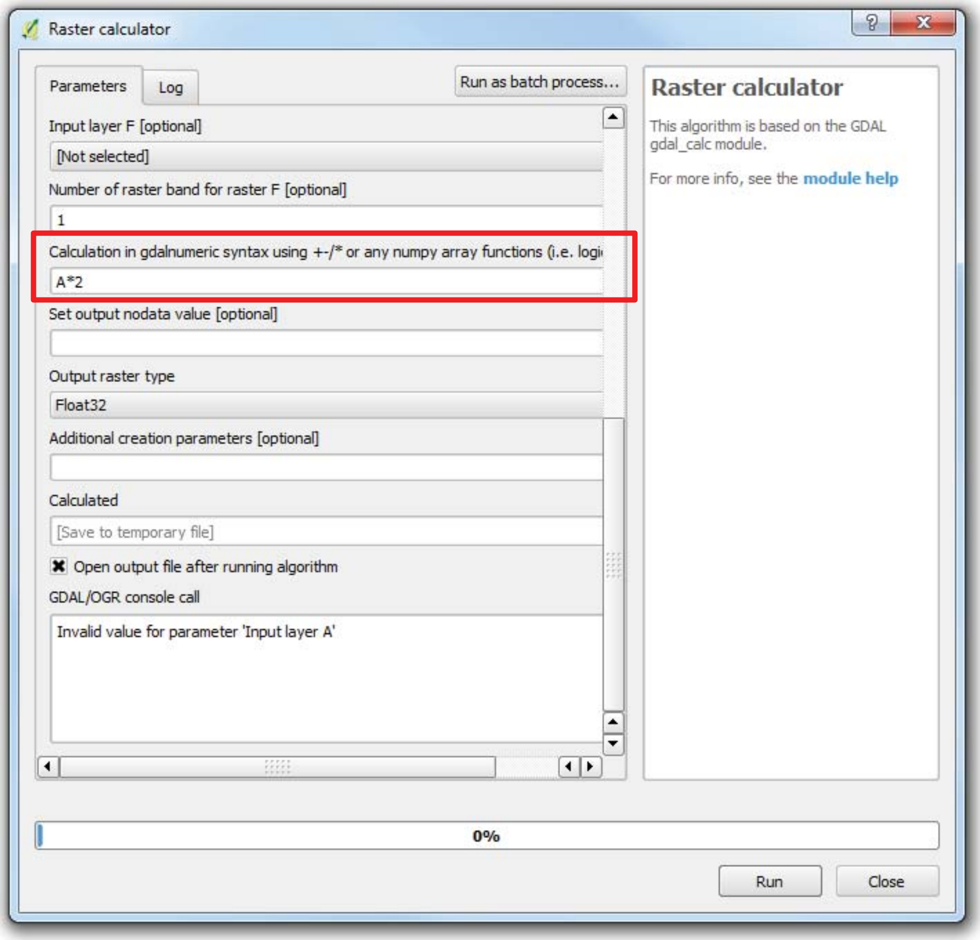


Figure 53: Screen shot of the raster calculator with calculation in GDAL syntax inserted

14.1.5. Step 4: Determining class thresholds for significant change detection

Follow the steps below:

- Classify the raster into 3 classes (three threshold values are required to classifying the 'value range').
- Select layer properties of the raster. The recommended render type is 'Singleband pseudocolor'. Interpolation should be set to 'Discrete'.
- Threshold values can be adjusted to increase or decrease the level of change detected. A normal distribution of values is assumed. The objective is to identify 5-10% (this is an approximate guideline, which may vary) on either end of the normal distribution of values. A conservative approach may lead to too much change, which will result in 'noise', making it difficult to detect the areas of concern. The user is encouraged to adjust the threshold values to reduce 'noise' as much as possible and without losing large areas of potential change.

  It is important to note that both positive and negative change needs to be taken into consideration (i.e. change in either direction needs to be assessed to determine if it warrants changing the respective land cover category used to assess the wetland resources condition during the baselines assessment.
- An example of the expected end product (change detection results) is given in **Figure 13**.

Any changes of significance need to be saved for comparison with future results. Comparisons across years will allow for a more accurate assessment of change and improve the land cover based condition assessment.

- The raster depicting the changes of significance should be converted to vector format. In the Processing toolbox, search for ‘Polygonize’. This ‘QGIS tool’ will allow for the conversion of the raster to vector format. In the event of reverting to ArcGIS to undertake the land cover analysis (as per Section 5.1.2 of the Procedure), the vector format will be required to overlay on the land cover layer to allow for the updating of the layer according to the change that has taking place.

Changes of significance are defined as an change in land use that will result in a shift of the wetland condition score for the priority wetland resource, through applying the Wet-Health Level 1B assessment (Macfarlane et al., 2018) using the revised land cover that factors in the change. Even a shift in the condition score that does not result in an overall change in the categorisation of the condition should be considered significant, as future changes may well result in a change in condition category.

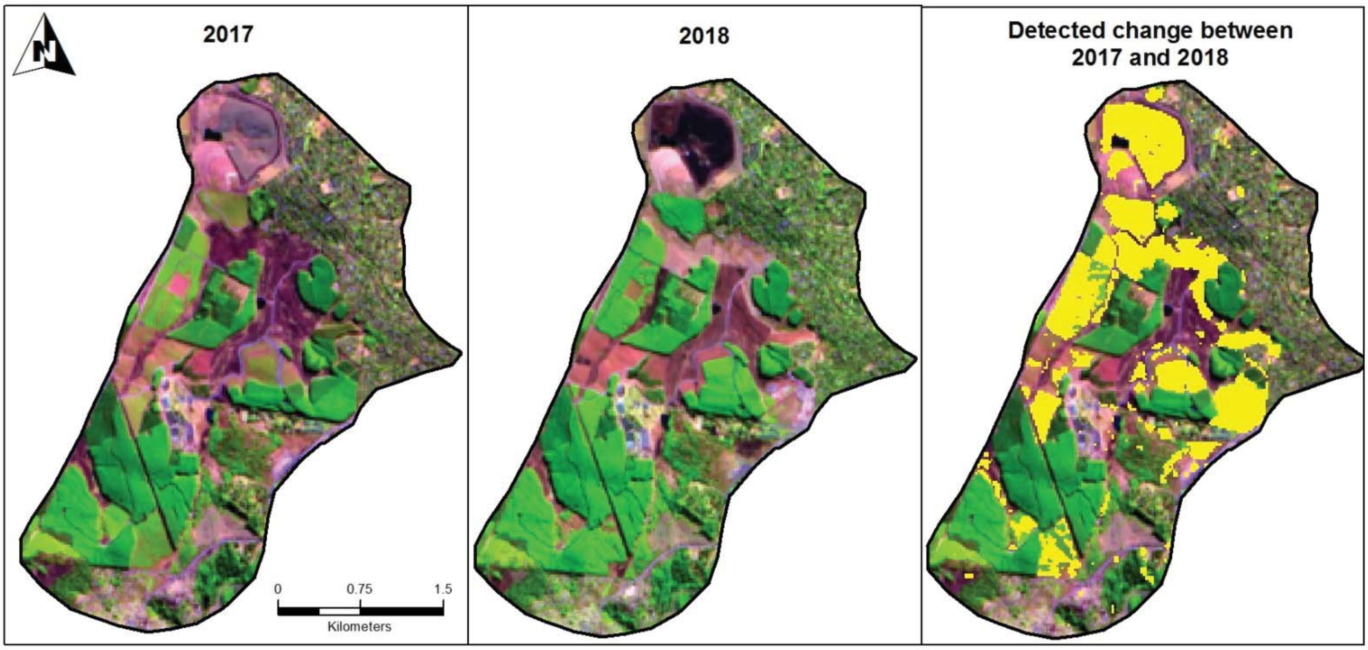


Figure 54: An example of change detection using Sentinel 2 imagery and freely available GIS software (areas of change are highlighted in yellow)

14.2. Visual assessment of change and correcting land cover

The comparison of Sentinel 2 aerial imagery for a study site from one year to the next, during the same month, provides a useful guide for detecting change in land use. This semi-automated process helps reduce the manual / visual assessment of the zone of influence and the wetland resources. However, manually assessing why change has been detected still needs to be undertaken. The user should be guided by the change detection to determine the cause of the change (examples provided in Figure 14). Best available imagery of the area of concern should be used to assist in identifying the cause of the change.

Once a potential change in land use is detected the magnitude and/or type of change triggers need to be identified. Sufficient understanding of the change may be possible through a visual assessment but typically one would need to consult stakeholders with knowledge of the area, or contact the DWS licencing department to establish if a licenced activity is taking place, or contact the landowner (if known), and if required undertake a site inspection to clarify the change in land use so that the reassessment of the wetland condition can be as accurate as possible.

Once there is an understanding of the change and evidence of what is taking place, the baseline land cover layer for the wetland resource and zone of influence will need to be adjusted to reflect this change. The revised Wet-Health Level 1B assessment (Macfarlane et al., 2018) is required to be re-run / undertaken for the priority wetland resource, taking into consideration the changes that have taken place (as per the approach detailed in Bredin et al., 2019). The revised land cover layer therefore allows for the reassessment of the condition (PES) of the priority wetland resource to determine if the habitat RQO is still being achieved.

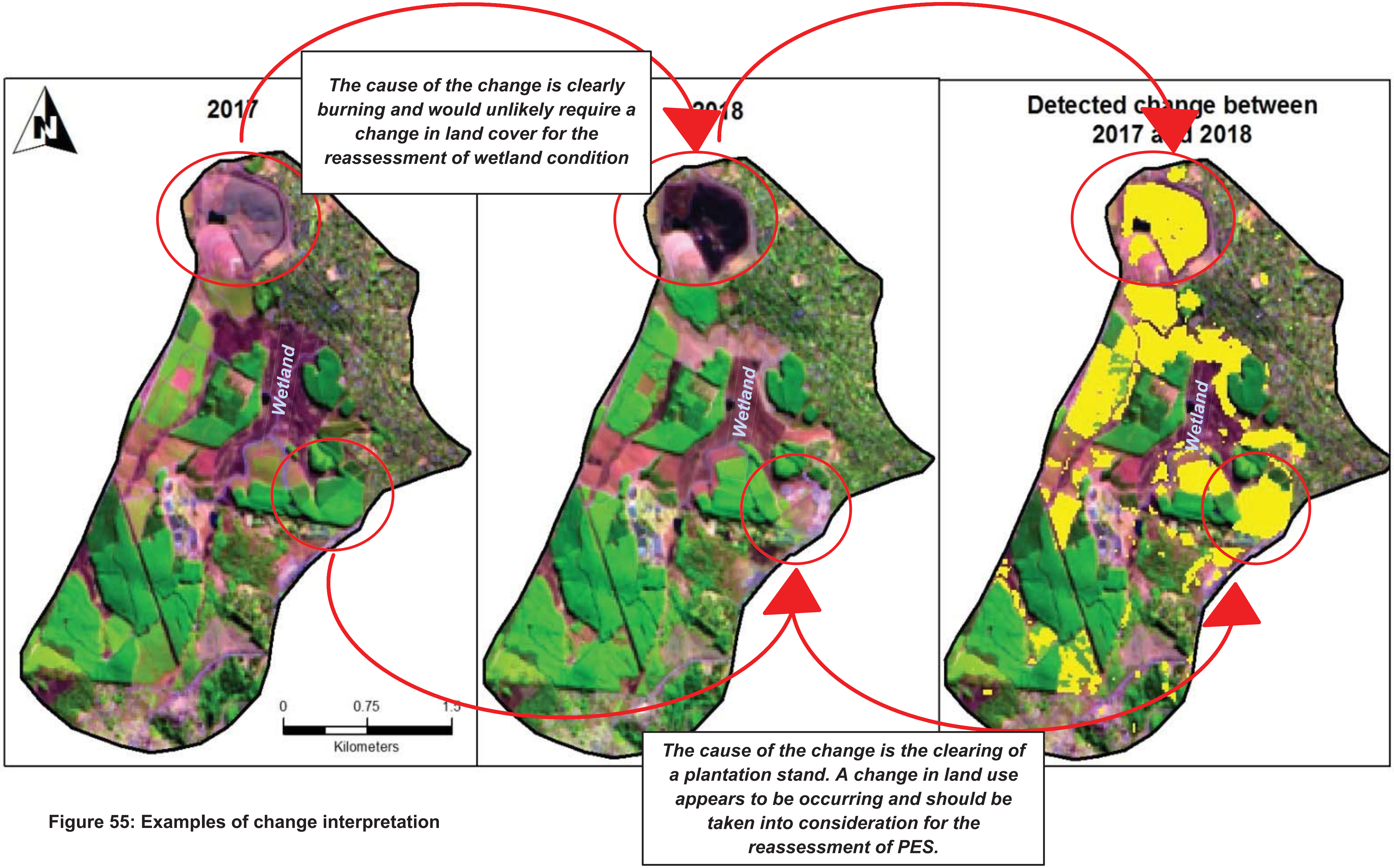


Figure 55: Examples of change interpretation

14.3. Addressing the outcomes of the monitoring

The proposed monitoring of priority wetland resources is a 'flagging' mechanism to detect if change is taking place within the wetland/s and the zone of influence and whether the change will result in a deterioration of the condition of the wetland based on the assessment of land cover. The severity of the deterioration will guide the action required to mitigate the impact. The worst case scenario is if the change is likely to result in the habitat RQO not being achieved. If this is the case a more detailed assessment will be required. The monitoring will be guided by the requirements for monitoring of the selected indicators, in accordance with the set RQOs (refer to Action 17 of the Procedure). Thus the desktop monitoring acts a trigger for the monitoring of the select indicators, which allows for a more flexible cost-effective and efficient approach to monitoring priority wetland resources.

Other factors which may trigger the more detailed monitoring could include the level of confidence in the change analysis using remote sensing. For example, where the change is obvious, and verified by stakeholders / technical reports / etc., then further detailed monitoring may not be required. However, where there is uncertainty around the potential impact to a priority wetland resource based on the findings from the desktop monitoring, then it would be prudent to undertaken further monitoring of select indicators.

It is important to note that this method focuses on the desktop monitoring of the likely change in wetland condition (i.e. habitat RQO) and not all of the possible RQOs that can be set for wetlands (i.e. quantity, quality, and biota RQOs). In some cases the monitoring of condition is an appropriate surrogate for monitoring of other RQOs. However, the primary objective of this proposed desktop monitoring is to detect change that has resulted in a deterioration of wetland condition. This should be seen as a 'trigger' for undertaking the monitoring of the select indicators for the respective sub-components and not wait to undertake the monitoring according to the general recommended timeframe (i.e. every 3-5 years).

15. CONCLUSION AND RECOMMENDATIONS

In order for this desktop monitoring method to be implemented the procedure for determining wetland RQOs (Bredin et al., 2019) will need to be applied, or at the very least components of the procedure. Given that a large majority of RQOs studies have already been undertaken for WMAs this presents a challenge for these catchments where the revised procedure has not been applied. However, this could be overcome through undertaking a baseline assessment of land cover, 'cleaning' of land cover, and an assessment of condition of all priority wetland resources (regardless of whether RQOs have been gazetted for the wetland resources or not). This will then create an opportunity for regular monitoring of all identified priority wetland resources across the country.

This report is an initial approach to designing an efficient way of monitoring priority wetland resources. The scope of the project has allowed for the development of this initial desktop monitoring method. However, through developing the method it was identified that there is an opportunity to improve on the desktop method, which would likely allow for a more efficient and effective (including cost-effective) way of monitoring priority wetland resources across South Africa. Recommendations for improving on this initial desktop monitoring method include:

- Designing an automated process to delineate the catchment of the wetland or wetland complex, which would allow for a more accurate way of monitoring condition (i.e. including the catchment and not just a zone of influence would likely result in a significant improvement).
- Further testing of the combination of ‘bands’ and ‘thresholds’ to refine the detection of relevant change.
- Further investigation into the proximity of impacts within the catchment of priority wetland resources and extent to which these will affect condition.

A key criterion for water resource managers to consider when undertaking the monitoring of priority wetland resources is the need for identifying ownership of the land within the zone of influence or alternatively the regulated area, and the wetland resource. This is likely to be difficult and is likely to change over time. However, understanding who the land owners are will provide an important and useful platform for not only monitoring but overall implementation as well.

16. REFERENCES

Bredin, I.P., Awuah, A., Pringle, C., Quayle, L., Kotze, D.C. and Marneweck, G.C. (2019). A procedure for determining wetland resource quality objectives. WRC Report No (tbc), Water Research Commission, Pretoria.

DWA (2011). Procedures to develop and implement resource quality objectives. Department of Water Affairs, Pretoria, South Africa

DWA (2013). Classification of significant water resources in the crocodile (West), Marico, Mokolo and Matlabas catchments: Ecologically Sustainable Base Configuration (ESBC) Report. Directorate Water Resource Classification. Department of Water Affairs, South Africa. Report No: RDM/WMA1, 3/00/CON/CLA/0412

DWA (2014). Draft position paper for the protection, use, development, management and control of wetlands. Department of Water Affairs, Pretoria. South Africa

DWS (2016). Development of Procedures to Operationalise Resource Directed Measures. Wetland tool analysis and standardisation Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/0616.

Kaplan, G. and Avdan, U. (2017). Mapping and monitoring wetlands using Sentinel-2 satellite imagery. ISPRS Annals of the Photogrammetry, Remote sensing and Spatial Information Sciences, Volume IV-4/W4, 4th International GeoAdvances Workshop, 14-15 October 2017, Safranbolu, Karabuk, Turkey.

Kaplan, G. and Avdan, U. (2018). Sentinel-1 and Sentinel-2 Data Fusion for Mapping and Monitoring Wetlands. Preprints. Doi: 10.20944/preprints201807.0244.v1.

Kotze, D.C. (2016a). A method to assess wetland ecological condition based on land-cover type. Part 1: User manual. A simple Citizen Science tool to assess the ecological condition of a wetland, Version 1.3 (May 2016). WRC Project number K5/2350. Water Research Commission, Pretoria.

Kotze, D.C. (2016b). A method to assess wetland ecological condition based on land-cover type. Part 2: technical background. A simple Citizen Science tool to assess the ecological condition of a wetland, Version 1.3 (May 2016). WRC Project number K5/2350. Water Research Commission, Pretoria.

Macfarlane, D.M., Ollis, D.J. and Kotze, D.C. (2018). WRC Project K5/2549: Wet-health (Version 2.0) tools for assessing the present ecological state of wetland ecosystems. Draft report submitted to the Water Research Commission.

RAMSAR (2018). Wetlands and the SDGs: Scaling up wetland conservation, wise use and restoration to achieve the Sustainable Development Goals. RAMSAR CONVENTION ON WETLANDS, July 2018.

Wilkinson, M., Mulders, J., Mitchell, S., Malia, D. and Danga, L. (2016). The design of a National Wetland Monitoring Programme, Implementation Manual, Volume 2. WRC Report No. 2269/2/16.