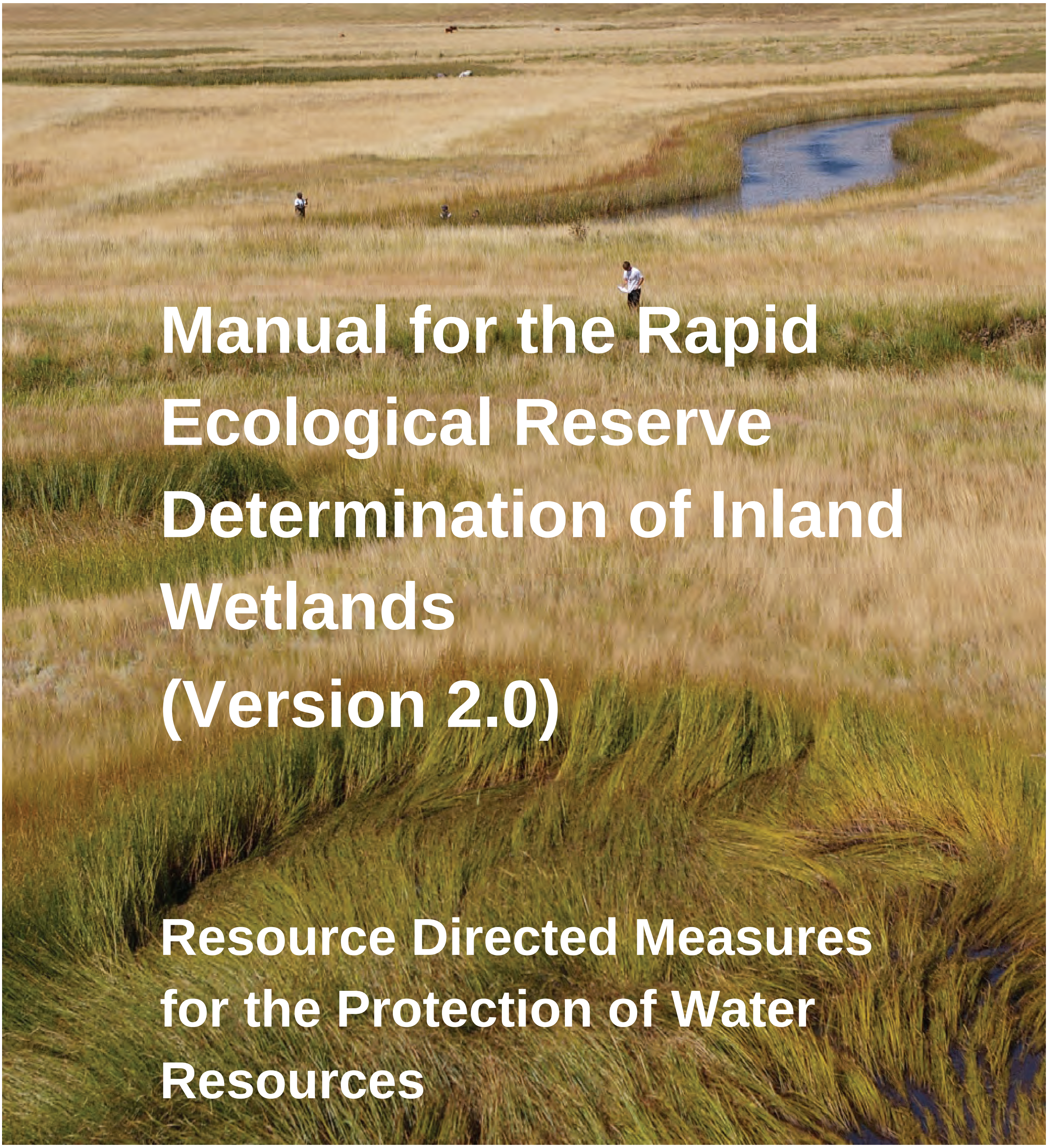

Manual for the Rapid Ecological Reserve Determination of Inland Wetlands (Version 2.0)

Resource Directed Measures for the Protection of Water Resources

WATER RESEARCH COMMISSION

water affairs
Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

Manual for the Rapid Ecological Reserve Determination of Inland Wetlands (Version 2.0)

Report to the
WATER RESEARCH COMMISSION
and
DEPARTMENT OF WATER AFFAIRS
Chief Directorate: Resource Directed Measures

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It should also be noted that the development of these methods has relied upon previous research undertaken by the Water Research Commission into hydraulics in vegetated channels (notably the research on flow in vegetated channels undertaken by Drs. Chris James, Angelina Jordanova and Andrew Birkhead). Without this initial research it would not have been possible to derive flow estimates in or for wetlands, and the contributions of these researchers, and the strategic investment by the WRC into this research, are gratefully acknowledged.

The team of experts tasked with developing and testing the technical approaches required for Environmental Water Requirement determination are thanked for their valuable contributions. That these are cost-effective and also provide results with an acceptable level of confidence bear testimony to their skill and resourcefulness. Authorship of specialist appendices denotes the significant contributions made by the team.

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Lastly, the many hours of behind the scenes input, guidance, clarification and comment, provided by Barbara Weston and Jackie Jay, and their patience in the development of this manual, are very gratefully acknowledged.

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ABBREVIATIONS AND GLOSSARY

Aerobic: having molecular oxygen (O_2) present.

Anaerobic: not having molecular oxygen (O_2) present.

Anthropogenic: of human creation

Biota: living things; plants, animals, bacteria

Channel competency: The ability of a channel to transport water. Related to its size, slope and roughness.

Delineation (of a wetland): to determine the boundary of a wetland based on soil, vegetation, and/or hydrological indicators (see definition of a wetland).

DO: dissolved oxygen

DWA: Department of Water Affairs (2010 onwards)

DWAF: Department of Water Affairs and Forestry (from 1996-2009)

EC: Ecological Category

EcoClassification: This is a procedure to determine and categorise the ecological state of various biological and physical attributes compared to the reference state. The procedure of EcoClassification describes the health of a water resource and derives and formulates management targets / objectives / specifications for the resource. This provides the context for monitoring the water resource within an adaptive environmental management framework. The classification ranges from A (natural) to F (highly impacted).

EcoRegions: "*Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources*", and are designed to serve as a spatial framework for the research, assessment, management and monitoring of ecosystems and ecosystem components (US EPA). Several levels or scales of EcoRegions can be delineated (e.g. Level I low resolution/detail; Level III high resolution and detail). In South Africa, EcoRegions form the basis of the River Health monitoring assessments.

EcoStatus: The overall PES or current state of the resource. It represents the totality of the features and characteristics of a river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services. The EcoStatus value is an integrated ecological state made up of a combination of various PES findings from component Ecostatus assessments (such as for invertebrates, fish, riparian vegetation, geomorphology, hydrology and water quality).

EIS: Ecological Importance and Sensitivity

Endorheic: closed drainage, e.g. a pan.

Floodplain: Wetland inundated when a generally meandering river overtops its banks during flood events resulting in the wetland soils of the floodplain being saturated for extended periods of time. Meandering usually develops upstream of a local (e.g. resistant dyke) base level, or close to the mouth of the river (upstream of the ultimate base level, the sea). Ox-bows or cut-off meanders – evidence of meandering – are often present on the floodplain.

GIS: Geographical Information Systems

Groundwater table: the upper limit of the groundwater.

Groundwater: subsurface water in the zone in which permeable rocks, and often the overlying soil, are saturated under pressure equal to or greater than atmospheric.

HGM: hydrogeomorphic, referring to particular wetland typing ("classification") methods based on the landscape setting and hydrological characteristics of different wetland types.

HGM unit: A HydroGeomorphic Unit – a single "reach", segment or unit of a particular type of HGM wetland type. Refer to page 21 for an example of how HGM units can be delineated.

Hydric soil: soil that in its undrained condition is saturated or flooded long enough during the growing season to develop anaerobic conditions favouring the growth and regeneration of hydrophytic vegetation (vegetation adapted to living in anaerobic soils).

Hydrology: the study of water, particularly the factors affecting its movement on land.

Hydrophyte: any plant that grows in water or on a substratum that is at least periodically deficient in oxygen as a result of soil saturation or flooding; plants typically found in wet habitats.

Infilling: dumping of soil or solid waste onto the wetland surface. To fill in a wetland (or riparian area) in order to raise the ground level above the flooding or saturated zone; usually for the purposes of construction.Infilling generally has a very high and permanent impact on wetland functioning and is similar to drainage in that the upper soil layers are rendered less wet, usually so much so that the area no longer functions as a wetland.

Macro-channel: Over much of southern Africa, uplift in the recent geological past and subsequent incision has caused many rivers to flow within an incised 'floodplain', outside of which flood flows have no recorded influence. This incised feature has been termed the macro-channel.

MAP:PET : ratio of mean annual precipitation to potential evapotranspiration

Palustrine (wetland): All non-tidal wetlands dominated by persistent emergent plants (e.g. reeds) emergent mosses or lichens, or shrubs or trees (see Cowardin *et al.*, 1979).

Peat: a brownish-black organic soil that is formed in acidic, anaerobic wetland conditions. It is composed mainly of partially-decomposed, loosely compacted organic matter with more than 50% carbon. The 50 % carbon content is mostly applicable for the sphagnum peat moss peat deposits in the Northern Hemisphere. The South African soil classification uses a > 10 % carbon content as a guideline. Inorganic soil particles are blown or washed into peatlands and also form part of the peat.

Perched water table: the upper limit of a zone of saturation in soil, separated by a relatively impermeable unsaturated zone from the main body of groundwater.

Permanently wet soil: soil which is flooded or waterlogged to the soil surface throughout the year, in most years.

PES: Present Ecological State: the current ecological condition of the resource. This is assessed relative to the deviation from the Reference State.

Platform: The elevated surface of an ***infilled*** area of wetland or riparian zone. Platforms are often constructed using *ex-situ* material which is used to increase the ground level height in order to reduce flooding or saturation of the soils. Platforms can then be used for construction of residential or commercial properties, or for cultivation of crops.

Reference State: (*also Reference Condition*). The natural or pre-impacted condition of the system. The reference state is not a static condition, but refers to the natural dynamics (range and rates of change or flux) prior to development.

RDM: Resource Directed Measures (Chief Directorate within the Department of Water Affairs)

REC: Recommended Ecological Category

Roughness coefficient: an index of the roughness of a surface; a reflection of the frictional resistance offered by the surface to water flow.

RQO: Resource Quality Objectives

Runoff: total water yield from a catchment including surface and subsurface flow.

SANBI: South African National Biodiversity Institute

Seasonally wet soil: soil which is flooded or waterlogged to the soil surface for extended periods (>1 month) during the wet season, but is predominantly dry during the dry season.

Sedges: Grass-like plants belonging to the family Cyperaceae, sometimes referred to as nutgrasses. Papyrus is a member of this family.

SPI: Specific Pollution sensitivity Index

Temporarily wet soil: The soil close to the soil surface (i.e. within 50 cm) is wet for periods > 2 weeks during the wet season in most years. However, it is seldom flooded or saturated at the surface for longer than a month.

Vlei: a colloquial South African term for wetland.

Water regime: When and for how long the soil is flooded or saturated.

Waterlogged: soil or land saturated with water long enough for anaerobic conditions to develop.

Wetland catchment: the area up-slope of the wetland from which water flows into the wetland and including the wetland itself.

Wetland delineation: the determination and marking of the boundary of a wetland on a map. The DWAF (2005) guidelines should be employed to undertake this for field application.

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 under normal circumstances supports or would support vegetation typically adapted to life in saturated soil (Water Act 36 of 1998).

1. INTRODUCTION

1.1. Policy Context

The purpose of the National Water Act (No. 36 of 1998) (NWA) is to achieve equity, sustainability and efficiency in the use and protection of South Africa's water resources: – to fulfil the vision of "some, for all, forever".

With the passing of the NWA the approach to water resource management in South Africa has undergone a fundamental shift:

- From a focus on increasing supply to a focus on managing demand.
- From reactive to proactive (goal-seeking) resource protection.
- From viewing the aquatic ecosystem as a competing water user to the recognition that the ecosystem is 'the resource'. A 'water resource' is now understood to refer to the entire aquatic ecosystem and not merely the water it provides. This has also redefined the concept of 'water resource use', to include not only water but the full range of goods and services that aquatic ecosystems provide.

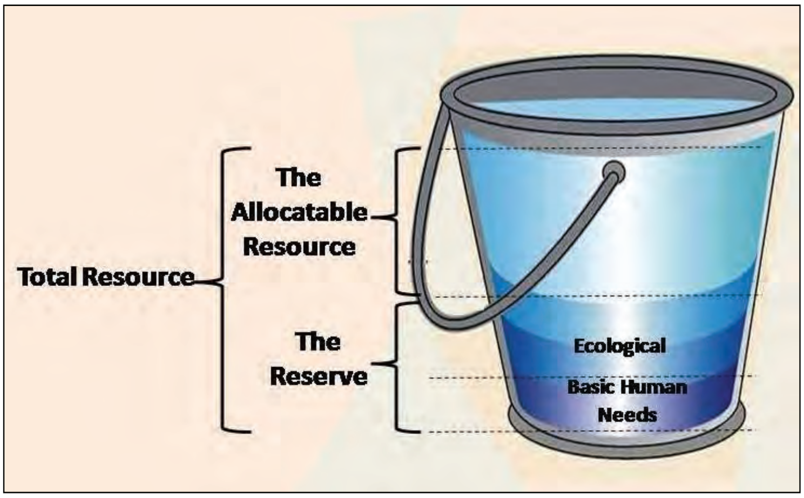


Figure 1.1: The total Water resource, comprised of the Reserve and Allocatable Resource.

Under the NWA all water resources are an indivisible natural asset under the custodianship of national government. Thus there is no riparian ownership of water any more. The only right to priority of use is that of the 'Reserve', consisting of a 'Basic Human Needs Reserve' and an 'Ecological Reserve' (Figure 1.1). The Basic Human Needs Reserve ensures the water that is required by domestic users for drinking, food preparation and personal hygiene. The Ecological Reserve refers to "t*he quantity and quality of water required … to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource*" (NWA, Ch 1, para. 1.(xviii)).

The quantity and quality of water which remains in excess of the Reserve is considered to be the 'total allocatable resource' (Figure 1.1), which may be distributed amongst competing users guided by the objectives of social equity and economic efficiency (DWAF, 1997). The water requirements of the ecosystem must thus be met before any allocation of resource quality or quantity for productive use may be made. This does not mean that the needs of conservation are placed above those of people – the intention of the Ecological Reserve is to “maintain the ecological functions on which humans depend” (DWAF, 1997 p. 35).

The Water Resource Management cycle (Figure 1.2) has been designed as an adaptive resource management approach that is strategic (goal-seeking). The first step in the management cycle is the determination of a vision for the desired future state of the resource. This vision sets both the aspirations and constraints for the future use of the water resource. The basis of a proactive approach to the protection of water resources is a protection-based classification system – the vision for the future of the resource is ultimately expressed as a choice between four Ecological Management Categories (EMCs) that can be set for a water resource and its component units. These range from A to D, in order of decreasing levels of protection for, or increasing levels of risk to, aquatic species and habitats.

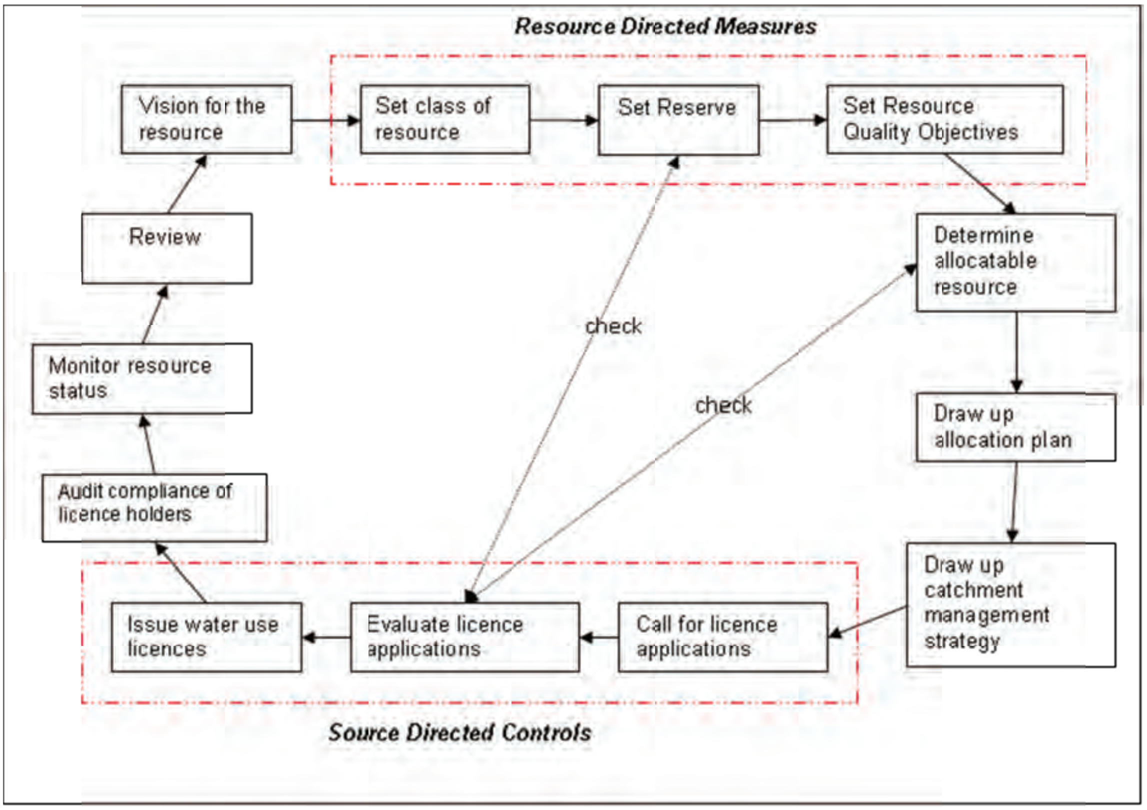


Figure 1.2: The Water Resource Management cycle

The chosen EMC and ultimately Class of a resource will determine the Reserve and associated Resource Quality Objectives that are set to achieve it. The Resource Directed Measures (RDM) thus collectively comprises of:

- the classification system,
- the Reserve and
- Resource Quality Objectives

In addition to these measures, Source Directed Controls help to give effect to the RDM by incorporating conditions into water use authorisations through the licensing process. The NWA states that the Minister must use the classification system to determine the Class, RQOs (Ch. 3 part 2) and Reserve (Ch. 3 part 3) – i.e. the RDM – for all or part of every significant water resource in South Africa.

All the procedures were based on the following design specifications (DWAF 1999):

- that they be **legally defensible**, since they had to serve as a basis for issuing legally valid water use licenses;
- that they be **scientifically defensible**, and in line with IWRM;
- that they **match administrative requirements**, i.e. that the information be provided to the licensing agencies in a format that could be used as a basis for drawing up water use allocation plans and catchment management strategies, and for setting individual water-use license conditions;
- that they provide **conservative estimates** of the water quantity and quality required to meet the ecological Reserve, since it was intended to serve until the Water Resources Classification system is implemented and prevent irreversible degradation of water resources in that time;
- that there be options for **rapid determinations** in order to meet projected demands for NWA implementation in the transitional period.

The need for rapid determinations resulted in several levels of determination that differed in terms of the time and cost to implement them (Table 1.1).

Table 1.1 Recommended levels of assessment of the Ecological Reserve, with indications of the resources required and type of results generated (DWAF, 1999; King *et al.,* 2008)

Method	Resources required	Time required	Resolution of results
Desktop	Low	2 days	Low
Rapid	Low	2 weeks	Low
Intermediate	Medium	8 weeks	Medium
Comprehensive	High	32 weeks	Medium/High

1.2. Overview of the Reserve Determination Process

1.2.1 Levels of Reserve Determination

Four levels of Reserve determination have been designed to accommodate the need for assessments involving varying levels of detail and confidence. These four levels of Reserve determination require different lengths of time and levels of specialist and stakeholder input to complete. The characteristics of the levels are summarized in Table 1.2.

This document focuses only on the low confidence, Rapid level of Reserve determinations. However, occasional references to other higher and lower confidence levels of determination studies are made throughout the document. The higher level confidence method refinement (of the 1999 intermediate methods) and development (of comprehensive methods) will be published in a separate document.

A separate document to provide guidelines as to the relevant level of confidence (and therefore required level of Reserve Determination) required for Wetland Reserve Determinations under various circumstances, and within different types of wetlands, has been developed by the DWA (DWA, 2012).

Table 1.2: Levels of RDM procedures for various levels of Reserve determinations

Level of Reserve	Characteristics	Use
Desktop estimate	*Very low confidence:* desktop assessment with about 2 hours allocated per water resource	Individual licensing for very small, low risk impacts in unstressed catchments of low EIS. *Currently not undertaken for wetlands unless supporting (EIA) documents are sufficiently detailed to confirm low EIS and small size.*
Rapid determination	*Low confidence:* desktop assessment combined with rapid field assessment of present status. Entire study concluded within about 2 days	Individual licensing for small impacts in relatively unstressed catchments of low importance & sensitivity; compulsory licensing “holding action”
Intermediate determination	*Medium confidence:* specialist field studies. Study concluded within about 2-6 months.	Individual licensing of moderate to large impacts at the sub-catchment level. This may be motivated based on the envisaged magnitude and significance of the impact, and/or availability of methods.
Comprehensive determination	*Relatively high confidence*: extensive field data collection by specialists over 8-12 months	All compulsory licensing. In individual licensing, for large impacts in any catchment where it is envisaged that intermediate determination would not provide high enough confidence. Small or large impacts in very important/water stressed and/or sensitive catchments.

1.2.2 The 8-Step Approach for Preliminary Reserve Determinations

To facilitate easier linkages between RDM studies of different water resource types (rivers, estuaries, groundwater and wetlands), a generic 8 step procedure (Figure 1.3) has been developed for all Reserve determination studies. The procedural steps within DWA are thus similar for each study to facilitate integration of the results, although the technical tools and methods are specific to each water resource type. This manual provides the detailed technical information for the Rapid level of Reserve determination for wetlands for each of these steps, and that detail is provided step by step in later sections of this document.

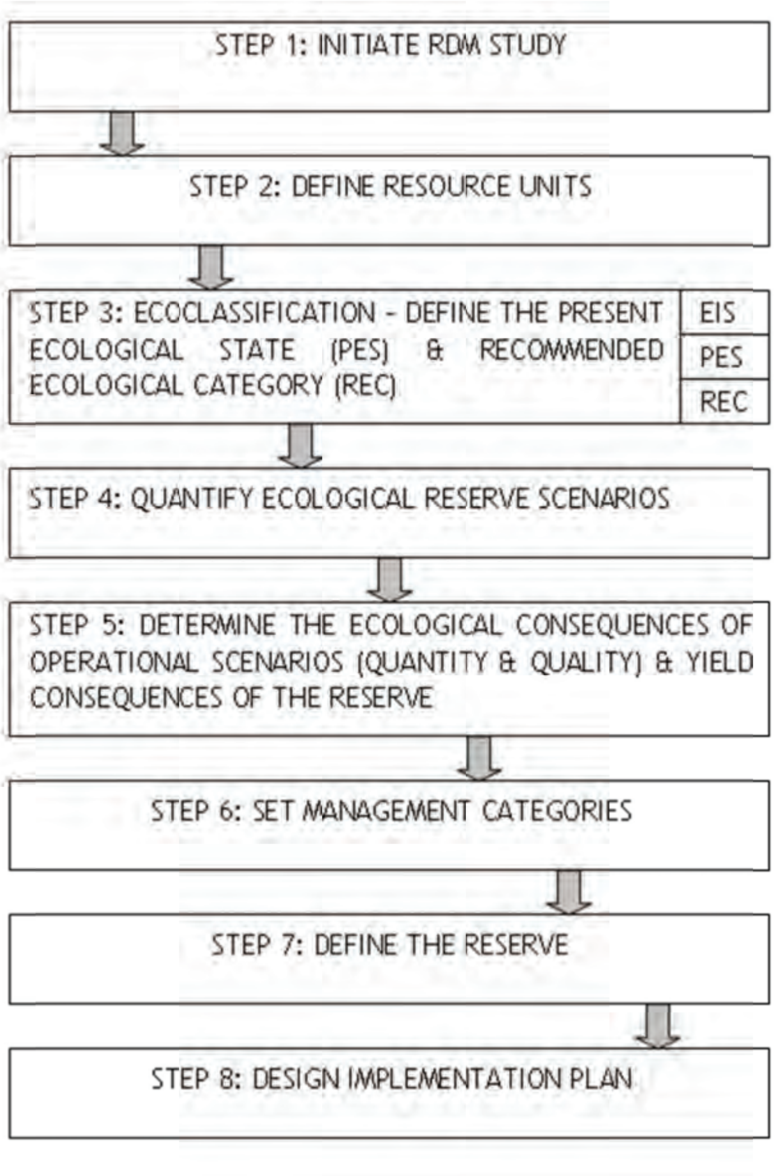


Figure 1.3: The generic 8 step procedure for Preliminary Reserve Determination studies. The methodology for each step is described in the relevant chapter following in this report.

1.3. Introduction to EWR methods for wetlands

Whilst an earlier version of methods for Reserve Determination in wetlands (DWAF, 1999) was published, this was only for the Intermediate level of determination and for a limited range of wetland types. The DWA is required to evaluate many applications for proposed Water Use of a variety of wetland types, and is required to consider the impact of the proposed use upon the Reserve. It is not feasible to determine the Reserve at an Intermediate Level for numerous wetlands due to the cost and time implications associated with these high confidence Reserve methods. In addition, many water use applications are low risk and do not necessitate expensive, high confidence Reserve studies. The need for lower confidence, faster Rapid Reserve methods thus became a priority.

The Rapid Reserve Determination process places constraints on the methods which can be used, requiring them to be

- Fast and efficient (enabling a report to be produced within a few days following 1 day in the field);
- Relatively cheap, and
- Relatively simple, since the Rapid methods are designed for low confidence, cost-effective applications.

Capacity to carry out very detailed Reserve determinations is limited, both in terms of expertise within DWA, and of budget constraints to employ numerous specialists for every assessment required. Any methods developed therefore need to be pragmatic, but at the same time scientifically defensible.

EWR methods for wetlands were poorly developed in 1999 when the DWA published their first manual of Reserve Determination methods, and this partially constrained the development of wetland EWR assessments to Intermediate assessments, since more data over longer time periods were required to develop an adequate understanding of the wetlands. Although there has been only limited development of EWR methods for wetlands since this time (for a review see Rountree *et al.*, 2005), research undertaken by the WRC and others in to related aspects of wetland functioning and the hydraulics of vegetated channels has enabled some refinement and streamlining of the earlier methods. Building upon this research has thus enabled Rapid EWR Methods for wetlands to be developed.

1.4. Purpose of this manual

This manual provides the technical information (or references to the appropriate methods, where published) for the Rapid level of Reserve determination for wetlands of all types (excluding lakes, since the size, complexity and rarity of these wetland types in South Africa precludes them from rapid, low confidence assessments).

The Rapid level of Reserve determination requires a small team of variously qualified specialists to undertake fast assessments of the wetland resource in question. The methods described below are thus cognisant of these limitations and constraints. The composition of the team of specialists required to undertake a Rapid Reserve study is dependent on the type of wetland being investigated, and may also require additional specialist expertise in certain circumstances where the risks posed by proposed developments/licensable activities warrant special attention. The Guideline for identifying appropriate levels of Resource Protection Measures for Wetlands (DWA, 2012) will guide the composition of the specialist team required.

2. STEP 1: INITIATE RDM STUDY

The initiation of an RDM study would normally be carried out by DWA and would include defining the extent of the study area and selecting the required level for the Reserve Determination. At the Rapid level of Reserve determination, single wetland units (e.g. a single floodplain) or small wetland clusters (e.g. a series of pans) will be evaluated.

Where very large areas need to be evaluated (such as very large catchments and entire Water Management Areas), an initial desktop assessment of the wetlands is recommended. Such studies, for example the wetland assessments linked to the Upper Vaal, Inkomati and Outeniqua Reserve Determinations (DWA 2010a; DWA2010b; DWAF 2009) provide an indication of the Present Ecological State (PES) and Ecological Importance and Sensitivity (EIS) of wetlands at a catchment scale, and enable priority areas where the higher confidence Reserve studies should be focussed to be identified. Although the scope of such a desktop overview of wetlands across a large area is outside of the scope of work for a Rapid reserve study *per se*, these studies do allow the areas where Rapid Reserve studies should be undertaken to be identified.

2.1. Define the study area

The first step in initiating a Reserve Determination study is to define the study area. This will dictate the spatial extent and scope of the study. As mentioned above, it would not be practicable to undertake Rapid Reserve studies on numerous wetlands across very large areas (such as within large catchments or entire water management areas). As with the River Reserve determination methods, the spatial extent of the wetland Rapid Reserve level is likely to be limited to a particular site (i.e. a specific wetland system for which a Reserve is required) or small areas where there is a high density of wetlands (such as a series of pans in close proximity).

Once the study area boundaries have been defined, it will be necessary to identify the type of wetland/s to be assessed in order to select the required (confidence) level of the Reserve determination study and appoint the correct specialists to the study team.

2.2. Identify the main wetland type/s

Due to the complexity of wetland systems – specifically the hydrological drivers (rainfall, surface flow, interflow and/or geological groundwater) and the different expertise which are required to assess different wetland types associated with each of these drivers – it is first necessary to define the wetland type (i.e. the resource unit which is to be assessed) before the full specialist team can be assembled.

The wetland type/s being assessed may be one or more of the main hydrogeomorphic (HGM) wetland types – viz. Lakes; Unchannelled Valley Bottom; Channelled Valley Bottom; Meandering Floodplain; Seepage wetland; Pan; or Wetland flat. Table 2.1

describes the landscape positions and hydrological characteristics of these types of wetlands. Refer to Appendix 1 for further guidelines on the identification and characteristics of wetland types.

2.3. Select the required Reserve Determination level

Using the Guideline for identifying appropriate levels of Resource Protection Measures for Wetlands (DWA, 2012), factors such as:

- Desktop estimates of the stress of the resource;
- The size, type and hydrological complexity of the wetland being assessed;
- The likely ecological, functional and social importance of the wetland/s; and
- The types of licence applications (i.e. the risk of resource degradation) for which the Reserve is expected to be used to evaluate

would be used to select the necessary level of Reserve Determination study. As mentioned above, at present this manual only focuses on the Rapid level of Reserve Determination for wetlands.

The RDM Reserve database should be consulted to determine if any previous approved wetland reserve studies have been undertaken within the study area. A DSS to advise on extrapolation potential for wetland Reserve studies is under development. If there are existing approved wetland Reserve studies within the study area, the DWA:RDM should be consulted to advise on the potential for extrapolation.

It is important to note that ***Rapid Reserve determinations should not be carried out on wetlands where groundwater is the dominant input***. In these cases, the wetlands are merely a reflection of the condition of the groundwater resource, and the groundwater resource should be the focus of any assessments in such cases. ***A Groundwater Reserve study should be undertaken, with the wetlands used to set EcoSpecs and for monitoring purposes to indicate the condition of the groundwater resource upon which it is dependent***.

2.4. Assemble the relevant expert study team

Upon the identification of the type/s of wetland which are to be assessed, and the suitable level of Reserve study, the appropriate experts required for the study should be appointed (Table 2.1).

Table 2.1: HGM wetland types and the specialists required to undertake Rapid Reserve studies on each wetland type.

Landscape Position:	**Valley Bottom**				**Slope**		**Crest**		**Flat**
Flow/inundation pattern:	standing water	Diffuse	channelled (parallel to the valley)	channelled (meandering across valley)	diffuse to diffuse	diffuse flow to surface/ channel	diffuse flow to standing water	standing water	standing water
HGM wetland type:	***Lake*** [1]	***Un-channelled Valley Bottom***	***Channelled Valley Bottom***	***Meandering Floodplain***	***Seepage wetlands***			***Pan***	***Wetland Flat*** [2]
Essential Experts for Rapid Reserve study	n/a	Hydrologist Hydraulician Botanist Geomorphologist [4] Diatomologist	Hydrologist Hydraulician Botanist Geomorphologist Diatomologist	Hydrologist Hydraulician Botanist Geomorphologist Diatomologist Fish	Single wetland expert to undertake PES assessments and provide EcoSpecs			Hydrologist Botanist Diatomologist	Geohydrologist Botanist Diatomologist
PES outputs	n/a	Hydrology Vegetation Geomorphology Diatom	Hydrology Vegetation Geomorphology Diatom	Hydrology Vegetation Geomorphology Diatom Fish	Hydrology Vegetation			Hydrology Vegetation Diatom	Hydrology Vegetation Diatom
Additional expertise that could be considered [3]	n/a	*Water Quality* *Fish Geohydrologist*	*Water Quality* *Fish* *Geohydrologist*	*Water Quality* *Geohydrologist*	*Water Quality* *Geohydrologist*			*Water Quality* *Geohydrologist*	*Water Quality*

1: Only assessed at Intermediate Reserve Level – refer to DWAF (1999) methods

2: The reliance of these wetlands on complex groundwater inflows , which cannot be assessed at a Rapid Level, precludes EWR assessments from being undertaken. PES and RQO's will be set for these wetlands. Wetland flats can be used as indicators of the condition of the groundwater resource upon which they are dependent.

3: Additional experts may be added to the core team according to the wetland and scope of WULA's being considered by Reserve study.

4: Geomorphologist or soil scientist will be required to identify wetting zones.

Additional expertise (such as groundwater/interflow (shallow groundwater) and water quality expertise) may be required for the study. The requirement for additional expertise will be guided by the site specific conditions of the wetland/s within the study area, as well as the condition of the catchments and intensity and type of impacts upon the wetland/s.

Groundwater expertise would be required where the wetlands are known to have a significant input from groundwater which maintains them. This would typically be the situation in the Dolomitic geological formations, as well as in coastal flat areas where the aquifer permanently or seasonally is raised to the surface. The groundwater expertise may be provided through linking with a Groundwater Reserve study, and/or through seconding groundwater experts to assist with the wetland Reserve study (specifically in the hydrological components of the study).

As with the rapid Reserve studies in river systems, water quality would not be a standard component of a rapid assessment. Diatoms can be used to provide an indication of water quality where low confidence situations allow (similar to the role that macro-invertebrates play in river assessments). However, water quality expertise would be required in studies where water quality problems are encountered or are likely to feature in the future scenarios of a wetland system. In this case, additional wetland water quality experts must be seconded to the wetland Reserve team.

3. STEP 2: DEFINE RESOURCE UNITS

3.1. Scoping meeting with national and regional officials

An initial scoping meeting with the relevant national and regional DWA officials should be convened. Additional local and regional insight from DEA, DoA, DME, SANBI, municipalities, WfWetlands and major local industries (ESKOM, mining houses, etc.) would also be valuable. This meeting should discuss and evaluate the present and likely future water resource plans for the study area. This meeting should identify:

- WULA and Reserve applications received;
- A general description and status of the study area, including the common impacts and issues;
- The current and possible future water resource use scenarios or expected WULAs (as discussed by national and regional DWA and other officials);
- Any local objectives or management plans which may exist within local municipalities, etc.

This information will aid in the development of management resource units and the number and location of EWR sites for the Reserve study, as well as identify any future scenarios for the catchment that may need to be evaluated in the Reserve study.

3.2. Identify Resource Units

Within the defined study area (Step 1a), Resource Units should be identified within which specific study sites will be selected. Resource Units should be delineated based on biophysical attributes such as geological, geomorphological and vegetation characteristics, as well as the type and intensity of catchment landuse which the system is exposed to. The following information sources should be used to aid in the delineation of the Resource Units:

- The hydrogeomorphic wetland types across the study area;
- 1:50 000 topographical maps and other sources of landuse across the study area
- Google Earth or other high resolution imagery of the study area;
- Groundwater and/or Geological maps;
- Water quality data;
- The SANBI National Wetlands Inventory;
- The NFEPA database; and
- EcoRegion (DWA), underlying geological formations and vegetation community information can be used to aid with the delineation of Resource Units.

In the case of Rapid Reserve studies, the study areas would generally be small and thus the number of Resource Units is not likely to be high.

DEFINING WETLAND WATER QUALITY RESOURCE UNITS

Experience in the River Reserve studies shows that water quality resource units may not always correlate with the surface water (quantity) Resource Units. In addition to the above information sources listed above, the following should be considered for studies where water quality assessments are to be included:

- Collate relevant literature and check for any historic water quality data for the wetland itself (DWA monitoring, municipalities, Parks Board, Nature Conservation, etc.).
- Check relevant databases (e.g. SANBI National Wetland Inventory Attributes database once completed). If a river flows in/out of the system check for DWA WQ monitoring data taken from a station close to wetland. Check also for River Health Programme (RHP) data as this may be useful for inferring water quality in the wetland.
- Water quality data from the dry season in unimpacted rivers (i.e. sampled under dry season baseflow conditions) is useful for inferring groundwater chemistry (Batchelor, A. *pers. comm*. 2008).
- Check for available geohydrochemical (groundwater water quality) data if there are significant groundwater linkages (see below). Note: If water is bottled in the area from springs, water chemistry data is also usually available for that water source. This can be useful in inferring water quality for wetlands that are largely groundwater-fed.

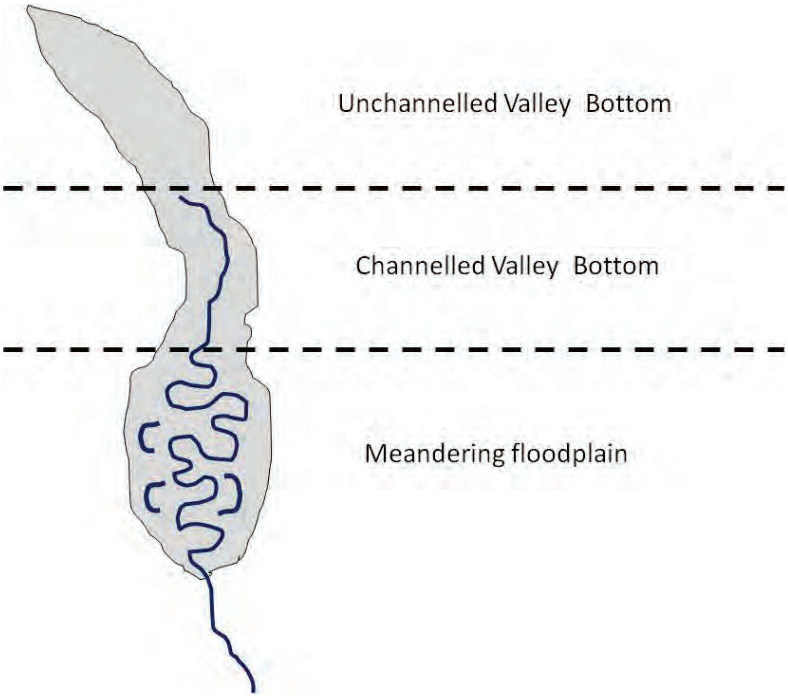
3.3. Identify focal (study site) wetland unit/s

- In the Resource Unit/s where the Reserve study is to be focussed, the main HydroGeomorphic (HGM) wetland type/s to be assessed in the Reserve study must be verified by the study team specialists (i.e. confirm the output of step 1 b). Refer to Appendix A1 for information on wetland types.

Site selection is a trade-off between representivity (of the site for the resource unit), access to the site, reliability of hydrology and hydraulics that can be generated at the site and the diversity and reliability of ecological cues that are present for EWR determination.

Sometimes, in valley bottom wetlands for example, sites that are not representative of the resource are selected because flow cues and/or hydraulics are more reliable, or the habitat is more critically important, at the site relative to the general characteristics of the wider reach. For example, in wetlands rare unchannelled sections may be selected because of their stronger habitat-flow cues. Similarly in river systems, often atypical riffle sections will be selected for focal study sites because of the critical instream habitat conditions that are represented in the riffle.

- This is to ensure that the type of wetland which needs to be assessed has been correctly identified and thus that the appropriate team of specialists to conduct the study has been assembled.
- These HGM units should be roughly mapped[1] within the Resource Units to indicate the extent and types of HGM units which characterise the Resource Unit.



- A suitable HGM unit, or section of HGM unit, should then be selected by the Reserve study team for the field assessment. In the case of valley bottom wetlands, this will be the focal area for field assessments including the survey of cross-section/s for hydraulic profiles through the wetland.

[1] SANBI is developing guidelines for wetlands mapping, but these are not available at present. Guidance on wetland mapping procedures could be obtained from this organisation in future if required.

4. STEP 3: DEFINE PRESENT ECOLOGICAL STATE AND RECOMMENDED ECOLOGICAL CATEGORIES

Once the study team has selected the focal wetland/s for the study, field assessments to determine the Present Ecological state (PES) and Ecological Importance and Sensitivity (EIS) of the wetland, as well as to collect critical data to quantify ecological water requirements for the wetland, must be undertaken. ***Field assessments should ideally take place during the wet season because***:

- Vegetation, which is the primary cue for identifying water requirements, is most easy to identify at this time;
- There is likely to be flow in the wetland, and where hydraulic calibrations are necessary, this is important to improve the confidence in the hydraulics; and
- Vegetation is also in the condition that it would be in when flows are coming through the wetland, so the roughness estimations for the hydraulics necessary for the valley bottom wetland types can be more accurately estimated.

Prior to the field surveys, the ***specialists must be made aware of the type and resolution of information they can expect from, and similarly the type and resolution of information they may be required to provide to, other specialists in the study team in order for everyone to be able to undertake their required assessments***. This is particularly important for the determination of the water quantity and quality requirements (Step 4).

- Establish (qualitatively) the major source of water inputs to the wetland (river channel, surface flow, rainwater, interflow (shallow groundwater or sub-surface flow) and groundwater) and the major outputs (river channel, groundwater, evapotranspiration, sea). Discuss and construct a conceptual model of the likely hydrological functioning of the wetland.

- If necessary, consult with groundwater and/or interflow specialists or evaluate local geological information to qualitatively establish the likely extent of linkage with groundwater.

- The approximate extent of the permanent, seasonal and temporary wetland zones, and types of vegetation in each, will need to be determined by the wetland specialists, and this information then provided to the hydrologist for modelling purposes.

4.1. Present Ecological State (PES) Assessment

Each specialist component of the study (excluding hydraulics, if undertaken) must determine the Present Ecological State (Table 4.1) of the wetland resource being evaluated, as dictated by the HGM type of wetland being assessed (Table 4.2). The detailed methods for PES assessments of each of the component specialist studies are provided in the Appendices.

A weighted average score then needs to be derived from the individual PES scores in order to determine the overall PES of the wetland system being assessed.

Table 4.1: Descriptions of the A-F Present Ecological State (PES) categories (after Kleynhans, 1996, 1999).

Ecological Category	PES % Score	Description
A	90-100%	Unmodified, natural.
B	80-90%	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	60-80%	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	40-60%	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	20-40%	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	0-20%	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

Table 4.2: HGM wetland types and the ecosystem components for which PES must be assessed during a Rapid Reserve study.

	HGM Wetland Type						
Ecosystem component:	***Lake***	***Un-channelled Valley Bottom***	***Channelled Valley Bottom***	***Meandering Floodplain***	***Seepage***	***Pan***	***Wetland flat***
PES Assessments:							
Hydrology	n/a	X	X	X	X	X	X
Vegetation	n/a	X	X	X	X	X	X
Geomorphology	n/a	X	X	X	**		
Diatoms	n/a	X	X	X		X	X
Fish	n/a	*	*	X			
Groundwater	n/a	*	*	*		*	X
Water Quality	n/a	*	*	*		*	*

X – PES assessment required for EcoStatus determination

***** – Expert could be called in to assist in the study, depending on the site and the purpose of the Rapid Reserve Study (e.g. if the scope of WULA being considered includes significant water quality impacts, then water quality should be included in the study)

** – Geomorphologist or soil scientist required.

n/a – Lakes only investigated at the Intermediate Reserve level, as described in DWAF (1999).

The weighted average score can be derived by weighting scores according to the importance of the ecosystem component :

- Drivers such as hydrology, water quality and geormorphology generally would be weighted the highest, since these components define habitat conditions;
- Vegetation, which is both a driver and responder, would be weighted the next highest; and
- Other ecosystem responders (such as birds or fish) would generally be weighted lower.

The rationale is that the drivers of a wetland are primarily responsible for the presence and maintenance of the system. Whilst responders may react to short term fluctuations, the drivers, which operate over longer time scales, are more robust indicators of overall change and condition. Generally speaking, a responder component of an ecosystem would be easier to rehabilitate than the underlying driver conditions (hence their higher weighting). However, it is important to consider the CONFIDENCE in the results from the PES assessments of each component. Results with low confidence should be downweighted due to the inherent uncertainty. Diatoms, although a responder to water quality, are a very reliable indicator of water quality (whereas the current approaches for assessing water quality PES are not well tested). The PES of Diatoms is thus recommended to be weighted higher than water quality PES. It is additionally recommended that diatoms be included in every Reserve study as a cheap, reliable surrogate for water quality (in much the same way as aquatic invertebrates are used to indicate water quality in rivers). A dedicated water quality component of Rapid Reserve studies should only be included in cases where water quality concerns are high, such as when the Reserve study is evaluating WULA's that may have water quality impacts.

The recommended weightings for generating an integrated PES of the wetland being considered are provided below (Table 4.3). As mentioned above, these weightings could be adjusted up or down if the confidence in the assessment of individual components is very high or low respectively, but should remain broadly within the ranges of the figures provided below.

Table 4.3: Recommended weightings for deriving overall PES scores for a wetland.

EcoStatus Component	Floodplains and Channelled Valley Bottoms	Unchannelled Valley Bottoms	Pans	Flats	Seeps
Hydrology	100	100	100	100	100
Geomorphology	100	100	n/a		100
Water Quality	60*	70*	80*	80*	80*
Vegetation	90	90	90	90	100
Diatoms	80	80	100	100	80*
Fish	50*	30*	n/a	n/a	n/a

*if component is included

Weighting the Water Quality PES Score

In general, many wetland biota are well-adapted to widely varying water quality conditions because of the stagnant, low-oxygen conditions that can naturally develop in wetland environments. Thus in many cases it could be expected that the water quality is assigned a lower weighting in the overall PES score, in part due to these factors and also to account for situations where the confidence in the water quality assessment is low (unlike river studies, the presence of water quality monitoring data is likely to be very sparse). The use of Diatoms in some ways offsets this limitation.

In cases of nutrient-poor wetland systems (such as in the Western Cape) which are highly sensitive to increased nutrient loads and other water quality impacts, or situations where the wetlands are exposed to very high nutrient or other related inputs, the weighting of the water quality in these situations should be increased to reflect this sensitivity.

4.2. Wetland Importance and Sensitivity

The National Water Act's purpose is to ensure that the nation's water resources are protected, used, developed, managed and controlled in a way that takes into account:

- meeting basic human needs both present and future;
- promoting equitable access and beneficial use;
- facilitating social and economic development;
- protecting ecosystems and biodiversity; and
- reducing and preventing pollution and degradation.

Whilst protection of ecosystems and biodiversity are part of the purpose of the NWA, so too is meeting basic human needs and ensuring that the ecological functions upon which people depend are sustained. The ecological importance of a water resource is an expression of its importance to the maintenance of biological diversity and ecological functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience) (Resh *et al*., 1988; Milner, 1994). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity. (Kleynhans *et al.,* 2005).

When evaluating a water resource and providing recommendations for the future preliminary management class (or Recommended Ecological Category), the NWA requires consideration of the:

- 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).

Water 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).

A rapid scoring system to evaluate

- Ecological Importance and Sensitivity;
- Hydrological Functions; and
- Direct Human Benefits

has been developed to provide a scoring approach for assessing these aspects of importance and sensitivity of wetlands.

These scoring assessments for these three aspects of wetland importance and sensitivity have been based on the requirements of the NWA, the original Ecological Importance and Sensitivity assessments developed for riverine assessments (DWAF, 1999), and the work conducted by Kotze *et al*. (2009) on the assessment of wetland ecological goods and services (the WET-EcoServices tool).

The three rapid level importance assessments are to be completed at the start of the workshop by the specialist team, and motivations are to be provided for the scores (ranging from 0 to 4 for each of the criteria) and confidences are also required. The tables are provided in Appendix A3. The highest score of the three modules assessed must dictate the overall importance category of the wetland.

4.3. Determining the Recommended Ecological Category

Upon completion of the PES and EIS assessments for the wetland, a Recommended Ecological Category for the Recommended Ecological Category (REC) of the water resource must be determined.

The REC is determined by the Present Ecological State of the water resource and the importance and/or sensitivity of the water resource. Water resources which have Present Ecological State categories in an E or F ecological category are deemed unsustainable by the DWA. In such cases the REC must automatically be increased to a D.

Where the PES is in the A, B, C or D EC, the EIS components must be checked to determine if any of the aspects of importance and sensitivity (Ecological Importance; Hydrological Functions and Direct Human Benefits) are high or very high. If this is the case, the feasibility of increasing the PES (particularly if the PES is in a low C or D category) should be evaluated. This is recommended to enable important and/or sensitive wetland water resources to maintain their functionality and continue to provide the goods and services for the environment and society.

If:

- <u>PES is in an E or F category</u>:
    - The REC should be set at at least a D, since E and F EC's are considered unsustainable.

- <u>The PES category is in a A, B, C or D category</u>, ***AND*** the EIS criteria are low or moderate ***OR*** the EIS criteria are high or even very high, but it is not feasible or practicable for the PES to be improved:
    - The REC is set at the current PES.

- <u>The PES category is in a B, C or D category</u>, ***AND*** the EIS criteria are high or very high ***AND*** it is feasible or practicable for the PES to be improved:
    - The REC is set at least one Ecological Category higher than the current PES.

5. STEP 4: QUANTIFY ECOLOGICAL RESERVE SCENARIOS

5.1. Determining Ecological Water Requirements

The objective of any Reserve determination, whether this is for a river, estuary or wetland, is to estimate how much water, and of what quality, should remain in the system. This is usually estimated using the naturally occurring flow as a reference. However, very few systems are in a natural state since there is water use upstream of the estuary, wetland, or river reach under consideration.

During a Reserve determination study, ecologists and aquatic scientists will visit the site to determine its current state and will need to understand to what extent the flow has changed over time and how the current situation deviates from the natural condition. Additional consideration must be given to likely changes under various possible future water use scenarios. Hydrological information is therefore required in order to quantify how much water would naturally have flowed through the system; and how the current day and/or future flow deviates from the natural condition.

Specialist ecological insight is then required to translate this hydrological understanding into the various biophysical/ecological impacts which are occurring (under the Present Ecological State) or which may result (as in the evaluation of future scenarios) within the wetland system being evaluated.

For some wetland types like the valley bottom systems, hydraulic studies at the site play a critical link in enabling the larger scale hydrological information to be translated into local hydraulic conditions (depth and extent of flooding, velocity of the water, etc.) which can be more easily interpreted in terms of the ecological responses which would result.

For other wetland systems, such as pans, at the Rapid level of Reserve Determination, a simple hydrological understanding of the wetting and drying intra- (seasonal) and inter-annual (longer term) patterns of the pan may be sufficient for low confidence assessments. Under such conditions, hydraulic expertise would not be required to determine the Reserve. Thus for each wetland type, slightly different approaches in terms of hydrological modeling may be employed, and hydraulic expertise may not always be required to translate the hydrological information into an ecologically meaningful form. The complexity of the wetland, and specifically the form of the hydrological drivers or source of the water maintaining the wetland, would to a large extent dictate the complexity of the study which would need to be undertaken.

5.1.1 Integrating specialist input to derive the overall Ecological water Requirements

A suite of approaches have been previously developed for rivers to enable the water requirements from the various component ecological studies (geomorphology, vegetation, etc.), linked to a specific Ecological Category, to be integrated to derive the overall Ecological Water Requirement (Table 5.1).

Table 5.1: Methods for deriving integrated EWRs in rivers.

Method for integration	Pros	Cons	Suitability for wetland Rapid Reserves
BBM – Building Block Methodology (King and Louw, 1998; King et al., 2000)	Relatively cheap, fast and easy.	Poor ability to evaluate scenarios; low flow variability/uncertainty not easy to incorporate.	For Rapid Reserves, which do not generally consider scenarios and time/budget is very limited, this is the most suitable integration approach.
DRIFT – Downstream Response to Imposed Flow Transformation (Brown et al., 2005; Brown et al., 2008)	Relatively easy evaluation of hydrological scenarios; uses data and/or expert knowledge to describe ecosystem responses.	Technically complex and time consuming to set up models.	This is likely to be the most appropriate method for the Intermediate and Comprehensive methods, since ecological responses can be linked to water availability patterns and assumptions tested with stylized flow sequences.
Habitat-Flow Stressor Response (O'Keefe et al., 2002; IWR, 2004)	Detailed evaluation and consideration of low flows; the critical periods for instream biota.	Technically complex; and (intra- and inter-annual) floods are not incorporated directly in this approach.	This method may not be appropriate for most wetlands since intra- and inter-annual floods are not well incorporated, and the focus on low flows is less important for many wetland types.

5.2. Linking Ecological cues to Water Quantity

The Reserve has both a quantity and quality component linked to the water resource – i.e. both an amount, and the quality, of the water required to meet the Ecological Reserve must be considered. The determination of the quantity component of the Reserve is dependent on ecological cues and responses being linked to specific water quantities.

The simplest way to assess the quantities of water flowing into, through and out of a wetland is to use a Water Balance model – a modeling exercise which balances inflows, outflows and losses from the system. Water balances *per se* have not been carried out on previous estuary and river reserves, but typically a yield analysis or water resources model is set up for detailed Reserve estimates. These models carry out a 'water balance' although this is typically carried out at a monthly time step and the mean or average condition is not necessarily reported on. It is noted that rapid and desktop **river** Reserve methodology do not require that a water balance be undertaken, but it has been decided that water balances must be carried out for Wetland Reserves on selected wetland types (where there is a need to understand the effects of altered flow provisions). Water balance models would thus be required even at a Rapid level; albeit with low confidence results.

Several different types of wetlands have been identified, but many aspects of the water balance approach will be the same regardless of the wetland type. The water balance methodology has therefore been described firstly in generic terms which apply to all wetland types (as well as rivers and estuaries) and then the methodology is refined for each identified wetland type. The detail of this refinement for each wetland type is discussed in the relevant Appendix on hydrological methods.

Where possible the water balance methodology has been adapted to use simple spreadsheets since these are generally easier to use than complex models. However, in some cases water resources models will be required and the Reserve team undertaking these more complex Reserve determinations will need to have the necessary hydrological (surface flow and interflow where necessary) modelling skills in their team.

The following information is proposed to be developed for the Rapid level of Reserve studies for wetlands:

- An indication of natural inflows (surface flow and interflow where necessary)
- Current day inflows
- Water use within the wetland:
  - Storage-volume relationships
  - Vegetated versus open water areas
  - Permanent versus seasonal wetland areas
  - Evapotranspiration losses and rainfall gains
- Evaluation of scenarios and how these may impact upon factors such as extent of permanent wetted areas, and reduction in the frequency of flooding.

The time steps of the model (i.e. seasonal, monthly or daily) and choice of model at this stage is not yet clear. Further information on this will be provided following testing of the proposed methods. For detail of the approaches which are proposed to be used to generate this information, please refer to Appendix A8 (Hydrology).

For each HGM wetland type, a conceptual hydrological model and water balance model will be generated to describe the reference state, current (present day) and scenario hydrology. In some cases hydraulic studies will be undertaken to provide mode detail to the ecologists. ***The responsibility of the ecological specialists will be to translate the hydraulic and hydrological information into ecological responses and feedback the ecological requirements of the different ecosystem components in order to identify the ecological water requirements linked to a specific EcoStatus***.

The hydrological approach adopted for wetland Reserve studies would depend on the underlying drivers of the wetland, and would therefore be specific to each wetland HGM type (see Appendix A1). These are described briefly below, with further detail of the technical approaches in Appendices A8 (Hydrology) and A9 (Hydraulics) for the different wetland types.

5.2.1 Seepage wetlands

A seep is generally associated with a perched water table and hence located on a hill slope with little or no upstream influence. The only likely upstream impact would be the presence of boreholes, hard (impervious surfaces) and/or cut off drains located upslope of the seep.

Due to the generally small size of seepage wetlands, cryptic (i.e. subsurface) inflows, throughflows and often subsurface outflows and difficulties in modelling these, it is not recommended that EWR requirements or the associated hydrological studies be undertaken for seepage wetlands at the rapid level. The recommended approach for the assessment and protection of seepage wetlands would be through PES assessments and the setting of Resource Quality Objectives (RQO's).

5.2.2 Unchannelled valley bottoms

An unchannelled wetland can be modeled in the same manner as a reservoir, the only difference being that it is necessary to distinguish between the areas of open water and the areas of vegetation, since the evaporation rates from these two areas will be different. It will be necessary to determine the area-capacity relationship of the valley bottom. This will need to be done with the aid of 1:10 000 maps.

Approach to estimating flows

It is highly likely that change in stage in most South Africa's wetlands will be relatively rapid and it will not be possible to model this using monthly time series models. Daily modeling on the other hand will be difficult due to a lack of daily data. A simpler approach based on the use of a duration curve derived from daily flow data is therefore proposed. These daily flow duration curves can be derived from observed data if there is a gauge in close proximity to the wetland, or alternatively, duration curves can be derived from ACRU daily time series, adjusted to match the monthly hydrology which has been accepted by DWA for water allocation purpose (refer to Appendix A8 (Hydrology) for further detail).

The relationship between discharge and inundation depth/extent within the wetland will be determined by a stage-discharge relationship which needs to be provided by the hydraulician.

The stage-discharge relationship can be developed through resistance equations (James *et al.*, 2001). The ability to quantify vegetation resistance in unchannelled valley bottom wetlands is essential due to the high vegetation resistance. The influence of aquatic vegetation on flow resistance is determined by the morphology of the individual vegetation stems and characteristics of the whole wetland bed. Plant characteristics such as stem diameter, stem height, the distribution of leaves and branches influence the drag imposed on the flow. These influences also vary seasonally according to the plant growth (James *et al.,* 2004).

It is likely that in these wetland types, an iterative procedure developed for routine conveyance estimation for practical stage-discharge determination for waterways with emergent vegetation will be required to develop stage-discharge relationships (Jordanova *et al.*, 2006; Jordanova and James, 2007).

During the field trip the following data needs to be obtained:

- Average stem diameter (D) of aquatic vegetation
- Average stem spacing (s)
- Bed slope (S)
- Average height of stems from the bed to the first leaf.

Refer to Appendix A9 (Hydraulics) for further technical detail of this method.

5.2.3 Channelled valley bottoms

Channelled Valley bottoms would (hydraulically) function similarly to rivers with terraces or flood benches. The more traditional river-based hydrology and hydraulic approaches would apply to this wetland type in many cases.

Approach to estimating flows

The procedure for channeled valley bottoms will be the same as for unchannelled valley bottoms, the only difference is that the stage-discharge relationship will indicate that below a certain flow rate the wetland is not inundated (i.e. all flow will be within the narrow active channel).

Channelled valley bottoms wetlands are characterise by greater local resistance by vegetation and by retarding flow in adjacent clear water zones. Under these conditions discharges can be calculated separately for the vegetated and clear zones of a cross section, and added together to obtain the total discharge (James and Makoa, 2006).

5.2.4 Meandering floodplains

Floodplains would (hydraulically) function similarly to rivers, although the overbank features are unique and this makes these wetland types more complex than river studies. However, with some adaption, traditional river-based hydrology and hydraulic approaches would apply to this wetland type.

Approach to estimating flows

The water balance procedures for floodplains are the same as for a channeled valley bottom, and hydraulic approaches similar as for the traditional river-based approaches. However special attention would need to be paid to floodplain features such as cut-off meanders and backwater swamps. Please refer to Appendix A8 (Hydrology) for further detail.

5.2.5 Pans

Pans are depressions in the landscape that tend to have relatively small catchments. Groundwater (including shallow groundwater or interflow) is usually an important hydrological variable. This is however difficult to account for using traditional river-based approaches for EWR's.

Approach to estimating flows

An accurate area-capacity relationship is required for a depression and this will need to be determined from the following:

- Hydrographic Survey (possibly only applicable for the Intermediate Reserve level), or
- 1:10 000 maps (Rapid Reserve level)

Also of prime importance is the catchment area of the depression. The natural inflow into the depression can be assumed to be scaled from WR2005 natural flow time series.

- Soil and vegetation to be used to infer the levels/extents of wetting/inundation
- Hydrological modeling of the pan can be undertaken, with wetted period evidenced from historical satellite imagery to derive Reference Condition and/or Present Day inundation patterns (Appendix A8b) that can be used for model calibration.

The important aspect to consider is that a request could be made for a license to abstract water from a depression and this will require a water balance calculation. An abstraction will reduce the surface area of the depression and the decision on whether or not to issue the license will be based on reduction in area (if any) that could be allowed.

5.2.6 Lakes

Due to complexities of groundwater contributions, and important aspects of water quality, lakes cannot be assessed at the Rapid Level. Methods for Intermediate Reserve Determination for freshwater lakes were developed as part of the 1999 RDM Reserve methods, and these methods have been successfully applied in previous Reserve studies. Given the paucity of freshwater lakes in South Africa, it was not felt that investment in further method development was warranted at this stage.

It should be noted that most lakes in South Africa are coastal lakes. If the lake is connected to an estuary, and salinity is the driving process in the system, then the lake should be considered as an extension of the estuary and the estuarine RDM methods need to be applied.

5.2.7 Flats

Due to the critical role of groundwater in wetland flats, and difficulty in assessing groundwater and interflow, studies of these wetland types should not be undertaken at a rapid level.

In such cases wetlands merely reflect the condition of the groundwater resource.

Whilst such wetlands could be monitored as an indicator of the groundwater resource, the Reserve quality and quantity components would need to be assessed by a dedicated Groundwater Reserve study and not as part of an EWR assessment of the wetlands per se.

5.3. Assessing Water Quality Condition and Requirements

Generally water quality is not undertaken at a Rapid level of Reserve Determination for rivers. In the case of wetlands, little water quality data are likely to exist, meaning that many water quality studies in wetlands will be low confidence unless the studies are undertaken over many years and with intensive data collection. These time and cost constraints, especially when considered against the generally small size of the wetlands and associated catchments, and demands on DWA for available funding and resources, means that such studies are unlikely to be undertaken.

However, because of the often small catchment sizes, the likely impacts on water quality can often be indicated from landuse activities. When linked to a suitable indicator, such as the assessment of Diatoms, this information can be used to undertake a rapid, low confidence assessment of the water quality. A rapid method for assessing the PES of water quality, linked to diatom assessments, in the same way that macro-invertebrate studies have been widely used in river Reserves, has been developed in this study to improve confidence and verify results.

The approach for water quality assessments linked to catchment landuse is described in Appendix A7. It is critical that such an assessment is conducted in conjunction with the Diatom assessment (Appendix A6), since this biological indicator (Diatoms) is used to verify the water quality assessment.

6. STEP 5: ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

In Ecological Reserve studies undertaken for rivers, ecological scenarios are not generally considered in Rapid Reserve studies. In the case of wetland Rapid Reserve studies however, it is feasible that scenarios associated with proposed catchment developments will need to be considered; specifically where the Reserve study has been initiated by specific Water User Licence applications.

In such cases the hydrologist will provide future scenarios where appropriate. Current Water Use Licence applications (WULAs) or future development scenarios, where known, will also be taken in to account. When determining the likely consequences of operational scenarios, it is important to consider any changes to water inputs and outputs as well as any changes in the pollution loading to the system that may result.

The ecological specialists will then need to provide the ecological consequences of the proposed scenarios. This was the approach adopted in the Bedford Wetland Rapid Reserve Determination study (conducted on behalf of DWA in 2010).

7. STEP 6: DWA MANAGEMENT CLASS DECISION MAKING PROCESS

If the Resource being assessed has not been classified (using the National Water Resource Classification system) as per section 13 of the National Water Act, the Recommended Ecological Category (REC) will act as the surrogate Management Class.

8. STEP 7: ECOSPECS AND MONITORING

Ecological Specifications and monitoring procedures to assess these will be provided by each of the ecological specialists.

In this step the major output is the design of a monitoring programme to ensure that the ecological condition of the wetland can be assessed easily and cost-effectively. This is especially important for wetlands as so little is known about them and there is an urgent need to build the knowledge base. It is recommended that the monitoring data collected can be added to the attributes database for SANBI’s National Wetlands Inventory.

Recommendations for the wetlands may include suggestions for the involvement of the Working for Wetlands programme; particularly in situations where negative trajectories of change need to be addressed and/or the Recommended Ecological Category (REC) is higher than the Present Ecological State (PES) and rehabilitation actions are required to enable the REC to be achieved.

Ecospecs will be required to be included as part of Water User Licence conditions to allow for monitoring and auditing of the condition of the resource. EcoSpecs should be clear, specific and unambiguous statements relating to sensitive components that are indicative of the condition of the resource.

9. STEP 8: IMPLEMENTATION PLAN

The implementation plan is the responsibility of DWA, but note should be taken of possible recommendations for involving Working for Wetlands where such rehabilitation actions would enable the Management class or Recommended Ecological Category (REC) to be maintained or met.

The implementation plan is essential to give effect to the management and protection of wetland water resources. The implementation plan should describe the role out (scope and frequency) of the monitoring programme, role and responsibility of role players and potential intervention actions.

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SPECIALIST APPENDICES

APPENDIX A1

IDENTIFYING HYDROGEOMORPHIC WETLAND TYPES AND WETLAND RESOURCE UNITS

AUTHORS: MW Rountree and AL Batchelor

A1.1 HydroGeoMorphic (HGM) Wetland Types

Landform and ***hydrology*** are generally acknowledged as the two fundamental features that determine the existence of all wetlands (Brinson 1993; Semeniuk & Semeniuk 1995; Finlayson *et al.,* 2002; Jones 2002; Kotze *et al.,* 2005, Ellery *et al.,* 2005), and this is the basic foundation for the hydrogeomorphic (HGM) classification system for wetlands (Brinson, 1993; Semeniuk & Semeniuk, 1995). Essentially geomorphological and hydrological features are used as key criteria in the description and classification of wetland types; classifying wetlands by (1) their hydrological characteristics; by the way water flows into, through and out of the wetland system, and (2) by their geomorphological or landscape settings.

> **What is meant by "classification"?**
>
> Wetland classification refers to the process of grouping wetlands into similar types according to their biophysical characteristics and the way in which they function.
>
> This system should not be confused with the National Water Resource Classification System (NWRCS) of the Department of Water Affairs (DWA), which is the process of classifying every priority water resource in South Africa in a complex set of technical and social interactions, to be used to guide resource development.
>
> (after Ewart-Smith *et al*., 2006)

Wetland classification systems based on geomorphic and hydrologic aspects are regarded as far more robust and consistent than classification systems based on other criteria (Finlayson *et al.,* 2002). Some adaptation of the Hydrogeomorphic (HGM) classification system has been undertaken for South African Palustrine wetlands (Marneweck and Batchelor, 2002; Jones and Day, 2003; Kotze *et al*., 2005), and a HGM approach has recently been proposed as the basis for all inland wetland classifications in South Africa (Ewart-Smith *et al*., 2006).

A HydroGeomorphic-based classification system that can be applied at a single spatial scale – that of a wetland "reach" – was developed for a wetland PES assessment tool (DWAF, 2007). Wetland systems can, using this HGM approach, be distinguished on the basis of their landscape (geomorphic) setting or position, and secondly by their flow (hydrological) characteristics (Table A1.1). Such an approach has been adapted from Marneweck and Batchelor (2002) and Kotze *et al*. (2005), modified according to the HGM principles of Brinson (1993) and Semeniuk and Semeniuk (1995). We believe that this revised, HGM-based classification system accounts, at a broad national scale, for the major differences in wetland types and would additionally allow for the automation of classification of the country's wetland systems. Nine major wetland types are recognized at Level III of the classification. These are:

In valley bottoms positions:

- o Rivers;
- o Lakes;
- o Wetland flats;
- o Unchannelled Valley Bottoms;
- o Channelled Valley Bottoms; and
- o Meandering Floodplain systems

In slope positions in the landscape:

- o Seepage (isolated), and
- o Seepage (connected)

In crest positions in the landscape:

- o Seepage (connected), and
- o Pans/Depressions.

The landscape settings and hydrological/flow characteristics of these main wetland types are described in Table A1.1, and individually in more detail below.

Table A1.1: Landscape settings and flow characteristics of the HGM wetland types (after DWAF, 2007*).*

Landscape setting		Flow pattern	HGM Wetland Type
Valley Bottoms	*confined*	channelled	**River**
		standing water	**Lake**
	unconfined	standing water	**Wetland flat**
		diffuse (parallel to valley)	**Unchannelled Valley Bottom**
		channelled (parallel to valley)	**Channelled Valley Bottom**
		channelled (meandering across valley)	**Meandering Floodplain**
Slopes		diffuse	**Seepage (isolated)**
		diffuse(into channel)	**Seepage (connected)**
Crests		diffuse flow	**Seepage (connected)**
		standing water	**Pans and Depressions**

A1.1.1 Rivers

Linear fluvial, eroded landforms which carry channelized flow on a permanent, seasonal or ephemeral/episodic basis. The river channel flows within a confined valley (gorges) or within an incised macro-channel. The “river” includes both the active channel (the portion which carries the water) as well as the riparian zone.

A1.1.2 Meandering Floodplain

Linear fluvial, net depositional valley bottom surfaces which have a meandering channel which develop upstream of a local (e.g. resistant dyke) base level, or close to the mouth of the river (upstream of the ultimate base level, the sea) . The meandering channel flows within an unconfined depositional valley, and ox-bows or cut-off meanders – evidence of meandering – are usually visible at the 1:10 000 scale (i.e. observable from 1:10 000 orthomaps).

The floodplain surface usually slopes away from the channel margins due to preferential sediment deposition along the channel edges and areas closest to the channel. This can result in the formation of backwater swamps at the edges of the floodplain margins.

- ***Channelled Valley Bottoms***

Linear fluvial, net depositional valley bottom surfaces which have a straight channel with flow on a permanent, seasonal or ephemeral/episodic basis. The straight channel tends to flow parallel with the direction of the valley (i.e. there is no meandering), and no ox-bows or cut-off meanders are present in these wetland systems. The valley floor is, however, a depositional environment such that the channel flows through fluvially-deposited sediment. These systems tend to be found in the upper catchment areas.

Distinguishing between naturally channelled versus artificially channelled (historically unchannelled) Valley Bottom Systems

Care should be taken to ensure that the channels in the valley bottom are natural – i.e. that the channelled state of the system is representative of the reference state of the wetland. At times unchannelled valley bottom systems which have become artificially channelised through direct dredging/channel construction, or as a result of increased flood flows due to catchment hardening, can be mistaken for channelled valley bottoms. Therefore evaluate the reference state carefully where the apparent channelised wetland is in an urbanizing catchment area, or where the channel in the valley bottom is very straight or otherwise shows signs of being constructed. Historical aerial photographs can also be used to assess the historical condition.

- ***Unchannelled Valley Bottoms***

Linear fluvial, net depositional valley bottom surfaces which do not have a channel. The valley floor is a depositional environment composed of fluvial or colluvial deposited sediment. These systems tend to be found in the upper catchment areas.

- ***Lakes***

These are depressions in the valley bottoms which may be temporarily, seasonally or permanently inundated. Unlike pans, they are not deflationary erosional features, but instead they have, or would have had, an outlet at the downstream end of the valley (a low point); which has been variously blocked or otherwise restricted by dune deposits (Eastern Cape coastal lakes); terminal moraines (e.g. Lake District; U.K.), landslides or other depositional features across the valley bottom.

Their shape is therefore determined by the surrounding slopes/higher ground rather than deflational processes creating the typical circular or oval pan shape.

- ***Wetland flat***

These wetland types are found in regions of the country where high local water tables intersect with lowlying topography. Many wetlands in the Cape Flats (Western Cape) and interdune depression wetlands of the northern KwaZulu-Natal coastal belt are examples of these very low energy wetlands. Diffuse groundwater and interflow in to these low points of the landscape cause permanent or seasonal saturation of the soils. These wetlands can be distinguished from pans in that their source of inflows does not arise from the topographical catchment area (but is instead dependent on the wider groundwater resource) and the topographical position, unlike pans, is not on the crest position in the landscape.

- ***Seepage wetlands (connected to river)***

Hillslope seepage wetlands are the most common type of wetland (in extent and number), but also probably the most overlooked.

Hillslope seepage wetlands are located on the mid- and footslopes of hillsides, and are connected to valley bottom wetlands or riparian zones. Hillslope seepage wetlands occur where springs are decanting into the soil profile near the surface, causing hydric conditions to develop; or where interflow in the soil profile is forced up to/near the surface due to impervious layers (such as plinthite or clay layers, or where large outcrops of impervious rock force subsurface water to the surface).

- ***Seepage wetlands (connected to pan)***

As above, but the seepage wetlands fringe the slopes surrounding pan wetlands.

- ***Seepage wetlands (isolated)***

Isolated hillslope seepage wetlands can occur in the hillslope or crest positions of the landscape. As with the other hillslope seepage wetlands, these occur where springs are decanting into the soil profile near the surface, or where interflow in the soil profile is forced up to/near the surface due to impervious layers

- ***Pans***

Small (deflationary) depressions which are circular or oval in shape; usually found on the crest positions in the landscape. The topographic catchment area can usually be well-defined (i.e. a small catchment area following the surrounding watershed). Although often apparently endorheic (inward draining), many pans are "leaky" in the sense that they are hydrologically connected to adjacent downslope valley bottoms through subsurface diffuse flow paths.

A1.2 Using Wetland Resource Units for extrapolation between sites

The HGM units described above can be used to distinguish individual wetland systems. These wetland systems can then be nested within larger spatial units of a hierarchical classification system (Table A1.2). Wetland Resource Units have been delineated in several DWA catchment studies and represent broad groupings of wetlands based on, inter alia, underlying dominant geology and/or EcoRegions.

Table A1.2: Hierarchical wetland classification system (DWAF, 2007, modified from Ewart-Smith et al., 2006)

Level I	***Level II: Resource Units***		***Level III: Functional Units***
System	**Wetland Resource Units**		**HGM Wetland types**
INLAND	South African EcoRegions (data available from DWA)	Dominant Geology derived from 1:250 000 maps	**River**
			Lake
			Unchannelled Valley Bottom
			Channelled Valley Bottom
			Meandering Floodplain
			Seepage (isolated)
			Seepage (connected)
			Seepage (connected)
			Pan and Depressions

This nested approach to classification provides a major advantage in that it allows for the extrapolation potential of well-studied sites across to other, un- or understudied wetland systems, to be evaluated.

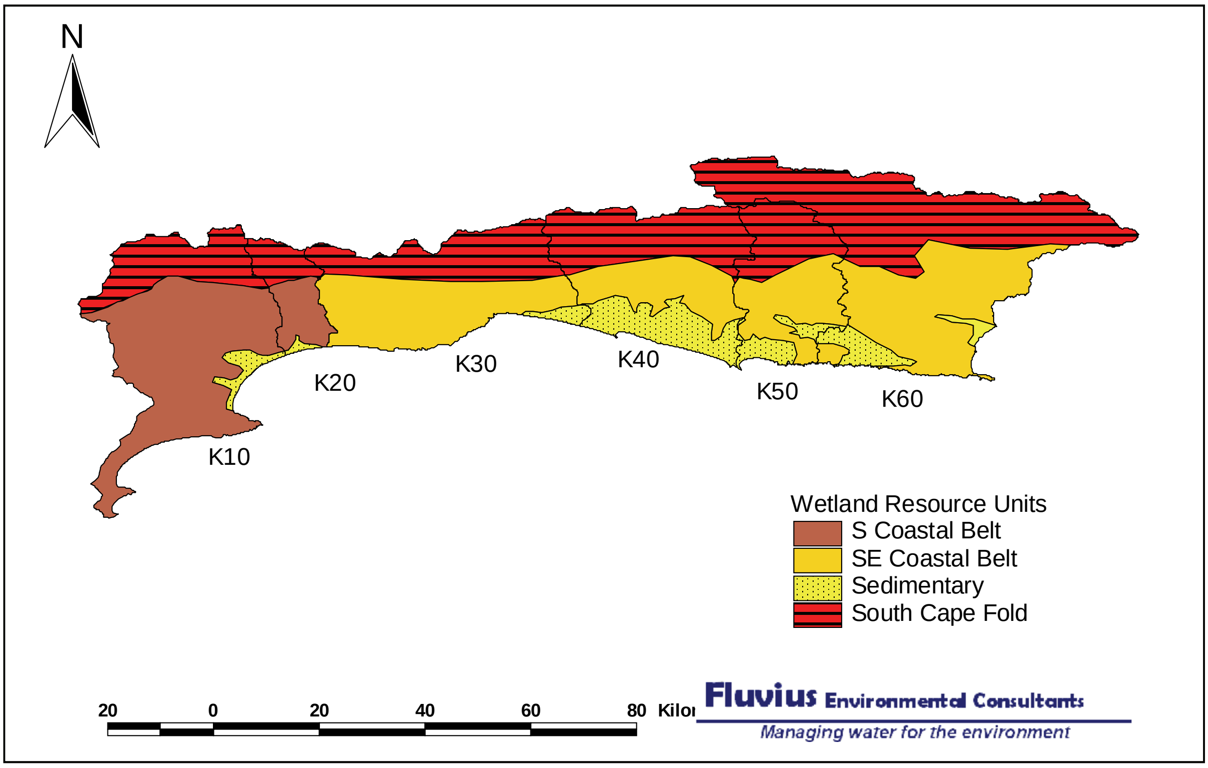

Figure A1.1: Wetland Resource Units identified in the Southern Cape (source: DWA, 2009).

Some types of HGM wetland types lend themselves to extrapolation across different layers/levels of classification better than others. In the case of seepage wetlands particularly, there is likely to be a very strong influence of the underlying geology, such that a seepage wetland on granites may have greater similarity with a seepage wetland on another granite system in a different EcoRegion than with a seepage wetland which is within the same EcoRegion but on a different geology. Geology plays an increasingly important role in extrapolation potential across wetlands where interflow and groundwater are important inflows to the wetland (e.g. seeps, pans, wetland flats and dolomitic unchannelled valley bottom wetlands). Where wetlands are more dependent on upstream inflows; and especially from rivers (such as channeled valley bottoms and floodplains); EcoRegions are likely to be a more important factor for extrapolation potential.

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APPENDIX A2

PRESENT ECOLOGICAL STATE HYDROLOGY ASSESSMENT

AUTHOR: MW Rountree

Hydrology is the key driver of wetlands. An assessment of the Present Ecological state (PES) of this driver must be conducted as part of the EcoStatus assessment within the Reserve Determination study.

A2.1 PES Assessment

A PES Assessment tool has been previously developed by DWA for floodplain and channelled valley bottom wetlands (DWAF, 2007). It is recommended that for these wetland types, the Hydrology module from this tool be used to derive a rapid, low confidence PES Ecological Category for hydrology.

At present there are no DWA-developed or formally approved EcoStatus tools for seepage wetlands, pans and unchannelled valley bottom wetlands. However, Wet-Health, a PES assessment tool developed for wetland rehabilitation purposes (MacFarlane et al., 2008), could be applied. A Level 1 assessment of the hydrology module can provide a rapid, low confidence score to derive an EC for hydrology.

A2.2 Published methods

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.

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APPENDIX A3

ECOLOGICAL IMPORTANCE AND SENSITIVITY ASSESSMENT

AUTHOR: MW Rountree and DC Kotze

The purpose of assessing importance and sensitivity of water resources is to be able to identify those systems that provide higher than average ecosystem services, biodiversity support functions or are especially sensitive to impacts. Water resources with higher ecological importance may require managing such water resources in a better condition than the present to ensure the continued provision of ecosystem benefits in the long term.

A tool for identifying the types and qualitatively assessing the degree of performance of ecosystem services in individual wetlands was developed for a national wetland rehabilitation programme (Kotze *et al.,* 2005). Test cases of Rapid Reserves Assessments undertaken through this and other studies indicated that, whilst this tool (WET-EcoServices) is extremely valuable, the outputs did not align well with the Ecological Importance and Sensitivity assessments undertaken for other water resource types by DWA, and that other criteria such as importance for human use and hydrological functions were included although not necessarily liked to Ecological Importance.

To align these outputs more closely with the EIS approaches for other water resources, but also to not lose the valuable insight of human use and hydrological functional importance issues, a tool for assessing importance and sensitivity was developed using criteria from the WET-Ecoservices (Kotze et al., 2005) tool and the earlier DWA EIS assessment tools. The Importance and Sensitivity tool for wetlands thus proposed three suites of importance criteria, namely:

1) Ecological Importance and Sensitivity, incorporating the traditionally examined criteria used in EIS assessments of other water resources by DWA and thus enabling consistent assessment approaches across water resource types;
2) Hydro-functional importance, which considers water quality, flood attenuation and sediment trapping ecosystem services that the wetland may provide; and
3) Importance in terms of basic human benefits – this suite of criteria consider the subsistence uses and cultural benefits of the wetland system.

It is recommended that the highest of these three suites of scores be used to determine the overall Importance and Sensitivity category (Table A3.1) of the wetland system.

Table A3.1: Ecological Importance and Sensitivity categories and the interpretation of median scores for biota and habitat determinants (adapted from Kleynhans, 1999).

Ecological Importance and Sensitivity categories	Range of EIS score
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 that 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

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Ecological Importance and Sensitivity	Score (0-4)	*Confidence (1-5)*	Motivation	Guideline
Biodiversity support	*A (average)*	*(average)*		
Presence of Red Data species	a			*Endangered or rare Red Data species presence*
Populations of unique species	a			*Uncommonly large populations of wetland species*
Migration/breeding/feeding sites	a			*Importance of the unit for migration, breeding site and/or a feeding.*
Landscape scale	*B (average)*	*(average)*		
Protection status of the wetland	b			*National (4), Provincial, private (3), municipal (1 or 2), public area (0-1)*
Protection status of the vegetation type	b			*SANBI guidance on the protection status of the surrounding vegetation*
Regional context of the ecological integrity	b			*Assessment of the PES (habitat integrity), especially in light of regional utilisation*
Size and rarity of the wetland type/s present	b			*Identification and rarity assessment of the wetland types*
Diversity of habitat types	b			*Assessment of the variety of wetland types present within a site.*
Sensitivity of the wetland	*C (average)*	*(average)*		
Sensitivity to changes in floods	c			*floodplains at 4; valley bottoms 2 or 3; pans and seeps 0 or 1.*
Sensitivity to changes in low flows/dry season	c			*Unchannelled VB's probably most sensitive*
Sensitivity to changes in water quality	c			*Esp naturally low nutrient waters – lower nutrients likely to be more sensitive*
ECOLOGICAL IMPORTANCE & SENSITIVITY	**(max of A, B or C)**	*(average of A. B or C)*		

Hydro-Functional Importance			Score (0-4)	*Confidence (1-5)*	Motivation	Guideline
Regulating & supporting benefits	Flood attenuation					*The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream*
	Streamflow regulation					*Sustaining streamflow during low flow periods*
	Water Quality Enhancement	***Sediment trapping***				*The trapping and retention in the wetland of sediment carried by runoff waters*
		Phosphate assimilation				*Removal by the wetland of phosphates carried by runoff waters, thereby enhancing water quality*
		Nitrate assimilation				*Removal by the wetland of nitrates carried by runoff waters, thereby enhancing water quality*
		Toxicant assimilation				*Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters, thereby enhancing water quality*
		Erosion control				*Controlling of erosion at the wetland site, principally through the protection provided by vegetation.*
	Carbon storage					*The trapping of carbon by the wetland, principally as soil organic matter*
HYDRO-FUNCTIONAL IMPORTANCE			**(average score)**	(average confidence)		

Direct Human Benefits		Score (0-4)	*Confidence (1-5)*	**Motivation**	**Guideline**
Subsistence benefits	***Water for human use***				*limited abstraction by a very few houses and lodges dotted around the lake*
	Harvestable resources				*very limited, if any, subsistence offtake*
	Cultivated foods				*no cultivation/agriculture in the wetland*
Cultural benefits	***Cultural heritage***				*very limited, if any*
	Tourism and recreation				*very important recreational area*
	Education and research				*important study area – protected area with unique wetland types*
DIRECT HUMAN BENEFITS		**(average score)**	(average confidence)		

APPENDIX A4

GEOMORPHOLOGY PES & EWR ASSESSMENT

AUTHOR: M Rountree

Geomorphology is a key driver of wetlands, since the morphology of wetlands influences the way in which water is moved into and remains within the wetland. An assessment of the PES of this driver must be conducted as part of the Reserve Determination for the EcoStatus assessment. In order to maintain the morphology of some wetland types, EWR's for geomorphology are also necessary.

A4.1 PES Assessment

A PES Assessment tool has been previously developed by DWA for floodplain and channelled valley bottom wetlands (DWAF, 2007). It is recommended that for these wetland types, the Geomorphology module from this tool be used to derive a rapid, low confidence PES Ecological Category for hydrology.

At present there are no DWA-developed EcoStatus tools for seepage wetlands, pans and unchannelled valley bottom wetlands. However, Wet-Health, a PES assessment tool developed for wetland rehabilitation (MacFarlane et al., 2008), could be applied. A Level 1 assessment of the Geomorphology module can be applied to provide a rapid, low confidence score to derive an EC for the Geomorphology driver.

The PES must be determined to assess the current condition of the wetland relative to the natural condition. It is strongly recommended that historical aerial photographs be used to confirm the expected Reference Conditions of the wetland being examined. Historical aerial photographs can be sourced from the Department of Land Affairs' (formerly Land survey General) office in Mowbray. Google Earth imagery, 1:50 000 topographical maps and (where available) 1:10 000 orthomaps should be used to aid field work and the assessment of the current condition of the wetland (PES) and description of impacts.

A4.2 Approach for EWR determination

Geomorphological assessments should be undertaken for Rapid Reserve studies on floodplains, channelled and unchannelled valley bottom. Assessment of seepages would also be undertaken, but these would only be for Ecostatus purposes since no EWR determinations are recommended for seepages.

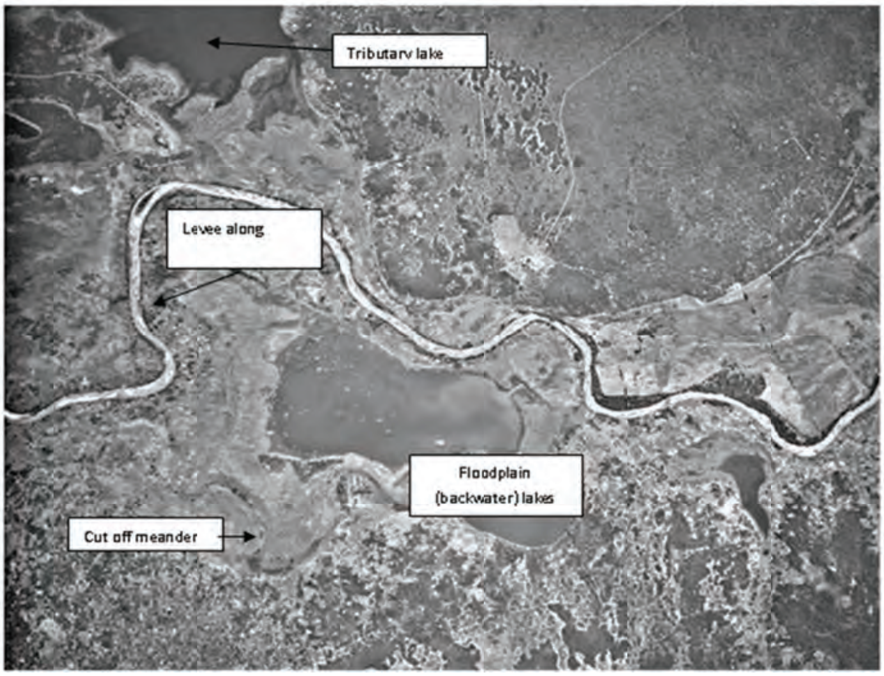
Along the cross-sections the soils should be examined for indicators of wetness, and these locations recorded in order to delineate the zones of permanent and seasonal wetness (using the methods of DWAF, 2005). These indicators denote the zones of permanent and seasonal saturation, and can be used to verify the areas of permanent and seasonal wetland for hydrological modelling of baseflow (evapotranspirative) requirements, and in low confidence assessments of the extent of wet season flooding (approximating the seasonal zones on valley bottoms).

Additionally, the morphodynamics of the system would need to be determined. Current and historical aerial photography, satellite imagery, maps and field observations should be used to identify important morphological features that, with the aid of the hydraulician, can be translated in to flow cues for habitat maintenance. The example provide below demonstrates how morphological features can be used as flow requirement cues, and, when linked to appropriate hydraulics or suitable historical imagery and hydrological records, can be used to determine the flow volumes required for maintenance of geomorphological features. Whilst this approach follows the traditional morphological cue approach of the early river reserve studies, the approach is valid for floodplain wetlands; channelled and unchannelled wetlands; albeit that the identification of morphological cues often becomes more difficult as the flows become progressively less channelled, and vegetation more dense across the valley bottom.

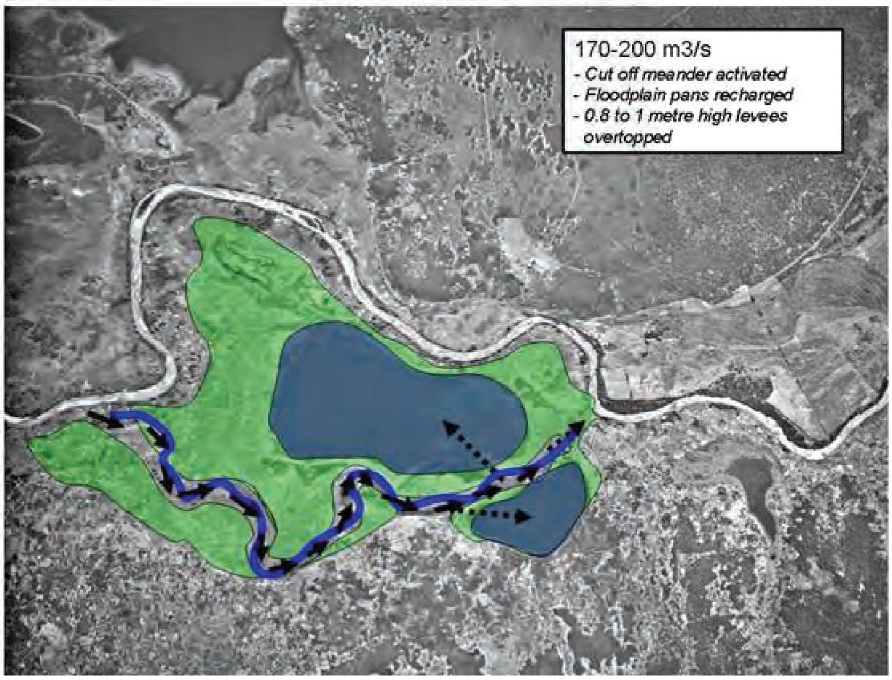
Geomorphological input in to EWR determinations for pans or wetland flats is not required, and EWRs for seeps will not be undertaken. The geomorphologist would thus only assist with the EWR determination of valley bottom (floodplain, unchannelled and channelled valley bottom) wetland types.

A4.2.1 Example of floods required for floodplain maintenance

The following example of the floods identified for floodplain maintenance is extracted from a study (IWR, 2008) conducted in 2007 on the Usutu floodplain below the confluence with the Pongola River.

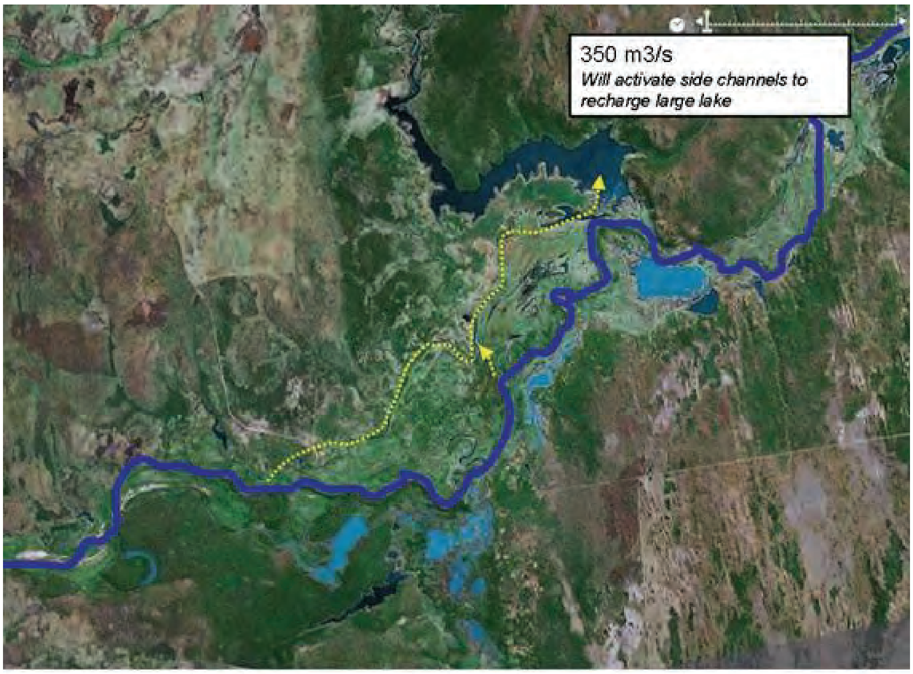


The activation of floodplain features present on the lower Usutu floodplain were linked to discharge by identifying the morphological cues associated with each. Cross-section surveys provided approximate flow classes for the elevations at which levees are breached and the cut-off meander and floodplain lakes are recharged. Current and historical aerial photographic records and Google Earth imagery were correlated with historical flow records to indicate likely activation events of the higher elevation floodplain areas and recharge of tributary lakes.



Floods in the 170-200 m^3/s range will result in the activation of the cut off meander, and recharging of the floodplain lakes and associated swamps in the backwater areas on the southern banks of this site. 200m^3/s floods would be sufficient to activate and recharge the floodplain aquifer and lakes. These discharges were determined from cross-sectional analyses linked to the height of the levee breach.

Floods of approximately 250 m^3/s will result in the activation of the backwater pans and channel on the northern section of the floodplain at this site, as well as activation of sections of the higher lying levees. Below: Example of levee breach to upper levels of the floodplain, first along back channels and depressions associated and then to higher level areas of floodplain associated levees. The backwater breach is expected to be activated by an approximately 200 m^3/s flood. These discharges were determined from cross-sectional analyses.



Floods of approximately 350 m^3/s are expected to be sufficient to recharge the large tributary lake seen in the top centre of the above image. The flow of water from the main channel in to the lake system is thought to be a complex process, caused by the activation of old meander channels and/or activation of backwater areas on the edge floodplain from a breach in the levees very far upstream (along the section of the Usutu flowing past the Ndumo Game Reserve in South Africa). The arrows above indicate the likely flow path from the Usutu into the lake, as evidenced from historical imagery.

A4.3 Published methods

DWAF (2005). A practical field procedure for identification and delineation of wetland and riparian areas. Department of Water Affairs and Forestry, Pretoria.

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.

Macfarlane, D.M., Kotze, D.C., Ellery, W.N., Walters, D., Koopman, V., Goodman, P and Goge, C. (2008) WET-Health: a technique for rapidly assessing wetland health. Version 1.0. Water Research Commission, Pretoria.

A4.4 References

IWR (2008). Usutu floodplain EWR assessment. Report prepared by MD Louw for JMBRS.

APPENDIX A5

VEGETATION ASSESSMENT

Authors: DC Kotze and DJ Walters

A5.1 Introduction

Wetland vegetation is strongly influenced (Mitsch and Gosselink, 2000; and Wassen et al., 2002) and affected both directly and indirectly (Figure A5.1) by hydrology. An example of a direct effect is where the permanent presence of water throughout the soil profile sustains a particular plant species that is not adapted to drying out of the soil. Water also affects plants indirectly through its profound influence on the biogeochemistry of the soil, most importantly the soil oxygen levels. Here, for example, the soil chemical conditions that develop under permanent saturation (very low free oxygen in the soil) may act to exclude many plant species not adapted to these conditions and allow only those few species that are adapted. Hydrology also affects plants indirectly through the influence that it has over the geomorphological processes of sediment deposition and erosion.

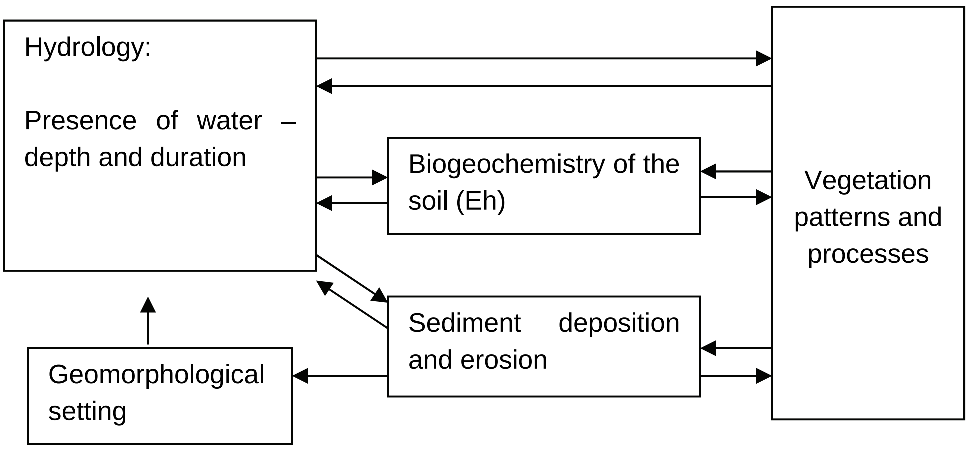


Figure A5.1: The direct and indirect effects of hydrology on wetland vegetation

Wetlands range from areas which remain permanently flooded or saturated throughout the year to areas which are flooded or saturated at, or close to, the soil surface for only a few weeks in the year, but still long enough to develop anaerobic conditions, and therefore influence the vegetation. Some wetland areas, particularly those that are temporarily saturated, are subject to prolonged drought. Wetland plant species vary according to the level to which they are adapted to drought periods (Pagter et al., 2005; Touchet et al., 2008). Many wetland plants are vulnerable to drought as they have high amounts of aerenchyma that improve oxygen availability in flooded soils but also enhance transpiration in dry conditions (Lenssen and De Kroon, 2005). However, even some plants typically adapted to the most prolonged saturation conditions may also have mechanisms

for dealing with droughts, e.g. Phragmites australis is able to shed some of its leaves under drought conditions in order to reduce water loss by the plant (Pagter et al., 2005).
The water depth in a wetland can constrain plant growth by limiting the availability of resources, particularly atmospheric carbon and oxygen. Although submerged macrophytes are specifically adapted to photosynthesizing below the water level, emergent macrophytes require an emergent photosynthetic canopy to support growth (Deegan et al., 2006). Thus, shorter-growing emergent macrophytes will be limited to water depths of less than 0.5 m, whereas tall growing wetland plants such as *P. australis* can occur in water of about 1.5 m in depth (sometimes up to 3 m) depending on the particular local circumstances. Most South African wetland areas are characterized by open drainage and are generally shallowly flooded (<0.5 m deep water) but South African wetland areas vary considerably in terms of the duration of inundation/saturation.

If a soil remains saturated, over time the free oxygen in the soil will become progressively depleted[2] (measured by soil redox potential [Eh]), which, in turn, places stress on the plant roots (Pezeshki, 2001). Wetland plants characteristically have adaptations to deal with low soil Eh conditions, e.g. aerenchyma tissue, which allows for the transport of needed oxygen to the roots (Pezeshki, 2001). Nevertheless, wetland plant species vary according to the level to which they are adapted to low soil Eh, with some such as *Phragmites australis* being well adapted to prolonged and very low Eh while others are much less well adapted.

A further indirect effect of the hydrological regime is the effect that it has as an important solvent that carries a range of solutes (nutrients and detrimental solutes) into, through and out of the system. An increase in pollutants or a reduction in water input (reduced dilution or "flushing" effect) can alter the soil and water chemistry that can lead to changes in the biotic response (Barnes *et al.*, 2002; Wassen et al., 1996; Bootsma and Wassen, 1996).

When assessing the water requirements of a wetland plant species, it is important to remember that the water requirements of adult plants may be different to those required by seedling or vegetative propogules (Lenssen *et al.*, 2000 and Shipley *et al.*, 1989). The majority of wetland plants reproduce through vegetative or clonal reproduction (van der Valk, 1998), however in arid areas wetland plants may depend on long lived dormant seed banks to survive (Casanova and Brock, 2000). These species survive by various life cycles patterns (phenology) and by spreading themselves over time, space and flooding regimes (Brock and Rogers, 1998) and may require specific flooding regimes to ensure their persistence (Warrick and Brock, 2003).

To summarize, hydrology is multi-dimensional (it encompasses water depth, duration of saturation, timing of saturation, etc.) and it affects wetland plants directly, through the supply of water to plants, and indirectly, through its influence on the biogeochemistry of the soil and the geomorphology of the wetland site, which, in turn, influence the plants. The multidimensional aspect of hydrology in relation to river systems is well represented by Brierley and Fryirs (2005) (Table A5.1), and this framework is likely to be applicable to

[2] The water in a saturated soil profile acts to exclude O_2 from the profile because O_2 has a diffusion rate 10 000 times slower in water than in air.

wetland systems associated with a river channel, particularly channelled valley bottoms and floodplains, but also un-channeled valley bottoms.

Table A5.1: Possible environmental flow types and associated roles and relevance to vegetation (adapted from Brierley and Fryirs, 2005)

The role of environmental flows in wetlands		
Type of flow	**Role**	**Relevance to vegetation**
Biotic maintenance flows	Minimum flows required to maintain biotic populations in the short term	Supplies the basic water requirement for populations of plants to persist. Provides the basis to the environmental stress that favours hydrophytes. Provides pulses of particulate organic matter and nutrients and propogules into off channel or thalweg areas
Riparian maintenance flows	Over topping flows – maintain off channel vegetation & habitat	
Low flows & base flows	Long duration flows – provides seasonal habitat and refugia during dry periods	
Channel maintenance flows	Minimum flows required to maintain the erosional & depositional process in channels, preferential flow paths and adjacent areas.	Maintains a diversity of habitat by providing hydraulic variability at different scales which provides environmental gradients that shape community
Valley forming flows	Large infrequent flows that configure channel & preferential flow path patterns, riparian areas & buffer hillslope infringement process	
Sediment maintenance flows	Maintains sediment transport, distribution & storage	
Freshes	Small short term flow increase – initiates scour, cleanses river bed, dilutes poor quality water and triggers fish spawning	Introduces disturbance at varying spatial scales and intensities. This reduces competition, creates gaps and allows the expression of a wide range of species.
Floods	Substantial flow increase – Significant bed scour, bank erosion & sediment transport. Provides hydraulic link between channel & floodplain	

Although hydrologic conditions are among the key factors that structure wetland plant communities, there are other environmental drivers (including the nutrient regime and physical disturbances) that may be occurring at multiple scales, which often affect the relationships of individual species or assemblages to hydrologic conditions. In addition, biotic interactions (competition) may influence the response of a given species to the environment in which it is growing (Magee and Kantula, 2005). When considering the impact of altering a wetland's hydrological regime, one needs to consider the effect of the other factors acting on the system. These factors include the nutrient regime of the system (oligotrophic, mesotrophic or eutrophic) and the system's disturbance regime (common natural disturbances include, grazing and fire, and the deposition and erosion of sediment).

The natural level of nutrients and the intensity and pattern of disturbances varies greatly from one wetland to the next.

One may find, for example, a seepage slope wetland in the moist, highland fynbos under natural conditions that is oligotrophic and is subject to occasional burning, but leniently grazed. In contrast, a floodplain wetland in the semi-arid savanna under natural conditions may be mesotrophic to eutrophic, and very heavily grazed by indigenous ungulates, as well being subject to widespread natural erosion and deposition associated with re-working of the floodplain sediments by the floodplain channel. The extent to which the nutrient and disturbance regimes have been altered by human influence may vary greatly from one wetland to the next. For example, in the fynbos wetland, it may be a shift from an oligotrophic regime to a eutrophic regime as a result of effluent discharge. There have been large changes in wetland ecosystem structure and function as the result of increased anthropogenic nutrient loading and hydrologic changes (Noe and Childers, 2007). The degree to which the species composition changes in wetlands depends on the natural nutrient richness of the system (Wassen *et al.*, 1996 and Bootsma and Wassen, 1996). Naturally nutrient-poor (i.e. oligotrophic and mesotrophic) systems react more severely than do naturally nutrient-rich (eutrophic) systems. Nutrient-poor systems (such as the fynbos example) may show a complete shift in plant species composition as well as a drastic change in nutrient dynamics, whereas nutrient-rich systems might show only further increased productivity (Verhoeven *et al.*, 2006).

In the floodplain wetland, an example of a human alteration to the system may be a disruption of the natural deposition of sediment as a result of sediment retention in a dam upstream of the floodplain. Another human alteration to the floodplain may be a reduction in the grazing intensity, altering the competitive interaction between species and allowing competitive species such as *Phragmites australis*, which are otherwise potentially suppressed by grazing, to become much more dominant.

Individual wetland species vary in their capacity to respond to nutrients. *Typha* spp., for example, are generally well known in terms of their high capacity to respond to increased nutrients, which is generally at the expense of the native species). Plants also vary in their capacity to rapidly colonize newly disturbed or deposited sediment and their capacity to tolerate grazing and fire.

A5.1.1 The effects of altered flow regimes on wetland vegetation

To understand the effects of altered flows to a wetland requires an understanding of the effect of hydrology on the wetlands because, as discussed in Section 1, the hydrologic conditions in a wetland affect many abiotic factors, including soil anaerobiosis, depth of water, availability of nutrients and other solutes, and sediment fluxes. These factors strongly affect the fauna and flora that develop in a wetland, which in turn have a feedback effect on hydrologic conditions (e.g. through transpiration) (Mitsch and Gosselink, 2000). Clearly therefore, the consequences of altering the hydrologic conditions in a wetland may be enormous in terms of the overall structure and functioning of a wetland. However, complex and cause and effect linkages amongst the different interacting factors confound attempts to predict the effects of altered hydrologic conditions of wetlands. Nevertheless, some general effects of diminished flows to wetlands have been documented, which are useful to highlight at the outset. These effects include the following:

- Loss of specific saturation (and associated redox) conditions, for which native biota are specifically adapted. Many plant species show a strong preference for particular hydrological conditions (Davis et al., 1996; Runhaar et al., 1997; Kotze and O' Connor, 2000) and if altered these species may potentially be lost to other species better adapted to the new conditions.
- Similarly, different species are adapted to water depths, and a change in water depth has the potential the alter the abundance of different species (Fraser and Miletti, 2008).
- Diminished "flushing" of solutes from wetlands as a result of reduced throughflows. This applies particularly to wetlands overlying strata (e.g. marine Cretaceous deposits) that supply high concentrations of solutes to the wetland. Under natural conditions, in the intervening periods between throughflows the concentration of solutes naturally increase within the wetland through evapotranspiration, which would have a profound effects on aquatic life. However, with throughflows artificially reduced, the frequency and intensity of high salinity periods would be increased considerably, with the potential, therefor to have a profound negative impact on the biota of these systems (Heeg et al., 1989; Heeg and Breen., 1994).
- The loss of flood events can eliminate seasonal signals to migratory and seasonally-breeding biota, especially fish (Bruwer and Ashton, 1989). This applies particularly to riverine wetlands but is likely to also apply to some non-riverine wetlands as well.
- Invasion by alien species better adapted to capitalize on the altered conditions. Cleverly et al. (1997), for example, document. Tamarix sp. invasion with the drying of the riparian wetlands of the western USA. A change in the hydrological regime (in terms of quantity, timing and/or quality) is a disturbance that can potentially facilitate the recruitment of alien species or invasive indigenous species into the wetland (Magee and Kantula, 2005).
- Altered accumulation of organic material. The water regime is a key factor affecting the level of accumulation of organic material in a wetland's sediments: the longer the period of saturation, the higher the accumulation (Tiner and Veneman, 1988). Thus, if a wetland is desiccated, the more oxic soil conditions are likely to lead to diminished organic matter accumulation, which may have further secondary impacts (e.g. increased susceptibility to erosion, diminished capacity for the assimilation of certain elements such as certain heavy metals) (Lavesque et al., 1982; Ingram, 1991).
- Altered clastic sediment regime, both in terms of reduced sediments being delivered to the wetland, particularly in the case where upstream dams are present) and diminished flows in the wetland altering the pattern of transport and deposition of sediment within the wetland.
- Reduced connectivity, especially of "off-channel" wetlands. This applies particularly to aquatic fauna (Ward et al., 1999) but plants may also potentially be affected.

While the focus above is on reduced flows, an increase in flows and reduced seasonality of flows, as characteristically occurs in many urban wetlands, may have as profound an impact on wetland vegetation as diminished inflows to a wetland. For example, Magee and Kantula (2005) describe a wetland where the species assemblages richest in native plant species occurred in slightly drier conditions than assemblages dominated by the alien species *Phalaris arundinacea*, and they suggest that a slight increase in wetness could result in these assemblages being lost to *P. arundinacea* dominance.

A5.1.2 The water requirements of individual wetland plants

A key practical difficulty with conducting Reserve Determinations for wetland vegetation is that the specific water requirements of almost all of the individual species occurring in South Africa have not been quantified. Although the water requirements of wild rice (*Oryza longistaminata*) are fairly well understood (Box 1), for most other plant species, the water requirements are understood in much less detail. However, at a very course level, the water requirements of individual species can be inferred from where they occur in the field in relation to coarsely-defined hydrological zones (Table 3.1). Table 3.1 was derived from existing research (e.g. Kotze and O' Connor, 2000) observations by the authors and consultation with experienced fieldworkers. Given that the availability of long-term hydrological data is very limited in South Africa, the hydroperiod was inferred mainly from soil morphology (e.g. depth and intensity of mottling and chroma of the soil matrix) (Kotze et al., 1996).

Box 1: The water requirements of wild rice (*Oryza longistaminata*) on the Nylsvley floodplain

Wild rice (*Oryza longistaminata*), which is the most extensive plant on the frequently-inundated portion of the Nylsvley floodplain, was used as an indicator of the ecological response of the floodplain biota to potential changes to the floodplain hydrology (Kleynhans et al., 2007).

According to Marneweck (2003, as cited by Kleynhans et al., 2007) *O. longistaminata* needs at least 25 days of continuous inundation of flow depths between 0.1 and 0.5 m to flower and set seed if the flood occurs in January or February, but longer if inundation occurs earlier or later in the rainy season. Wild rice is adapted to the seasonal and periodic nature of flooding and if there is no inundation in a particular year, the plant relies on stored reserves and water in the rhizome to persist. However, it becomes severely stressed after about three years of continuous drought, when the population becomes fragmented, old rhizomes become moribund, and species dominance on the floodplain declines (Marneweck, 2003, as cited by Kleynhans et al., 2007).

The area of floodplain that is suitable for Wild Rice could therefore be determined as that which is inundated to the appropriate depth, for the appropriate duration, at the appropriate time of season, and with sufficient frequency. Changes in these descriptors (depth, duration, timing and frequency) can be estimated from hydrological (Havenga et al., 2007) and hydraulic models (Birkhead et al.,2007).

When applying the understanding of the Nylsvley site elsewhere, it is important to note that although the water requirements of the wild rice are likely to be similar to that at Nylsvley, local differences (e.g. in terms of grazing regime, climate and soils) may result in the water requirements differing somewhat. It is also important to take account of the extent to which other factors affecting may confound the effect of altered hydrology. For example, if utilization of wild rice by herbivores was particularly high, leading to diminished stored reserves then the potential of the plants to survive drought conditions is potentially reduced.

Table A5.2: Occurrence, in relation to hydrological zones, of some dominant/ co-dominant plant species found in South African wetlands

Some dominant/ co-dominant species occurring in wetlands	Biome	Hydroperiod			
		Permanent	**Seasonal**	**Temporary**	**Non-wetland**
Grasses: *Arundinella nepalensis*	G,S		*	***	*
Hemathria altissima	G,S		***	***	
Hyparrhenia dregeana	G,S			***	***
Leersia hexandra	G,S	***	***		
Imperata cylindrica	F,G,S		*	***	*
Merxmuellera macowanii	G		*	***	***
Merxmuellera stricta	F,K,G		*	***	*
Miscanthus capensis	G,S		*	***	***
Oryza longistaminata	S		***		
Phragmites australis	F,K,G,S	***	*		
Phragmites mauritianus	S	***	***	***	*
Stenotraphrum sescundatum	F,S		*	***	*
Sedges: *Carex acutiformis*	G	***	*	*	
Carex cognata	G,S	***			
Carpha filifolia	G		***	*	
Cladium mariscus	S	***			
Cyperus marginatus	F,K,G,S		***	***	
Cyperus fastigiatus	F,G,S	***	*		
Cyperus textilis	F,S	***	*		
Eleocharis dregeana	F,KG,S	*	***	*	
Eleocharis limosa	F,K,G,S	***	*		
Ficinia nodosa	F,K		***	***	
Fuirena pubescens	G,S		***	***	
Isolepis fluitans	G,S	***	*		
Kyllinga erecta	G,S		***	*	
Mariscus thunbergeii	F, K		***	***	
Schoenoplectus brachyceras	G,S	***	*		
Schoenoplectus decipiens	G,S		***	*	
Scleria welwitscheii	G		***	***	
Rushes: *Juncus kraussii*	F,S	***	***	*	
Juncus effusus	G,S	*	***		
Prionium seratum	F	***	*		
Restios: *Condropetalum tectorum*	F	*	***	*	*
More restios to be inserted					
Bulrushes: *Typha capensis*	F,K,G,S	***	*		
Pokers: *Kniphofia linearifolia*	G	***	***		
Kniphofia uvaria	F	***	***		
Other taxa: *Persicaria* spp.	F,K,G,S	***	***		
Gunnera perpensa	G,S	*	***	*	

* = Occurs to a limited extent; *** = Occurs extensively

Biome (as per Mucina and Rutherford, 2006):

F= Fynbos | K= Succulent Karoo, Nama-Karoo and Desert

G=Grassland | S=Savanna, Albany Thicket and Indian Ocean Coastal Belt.

A species confined to a narrow portion of the hydrological gradient is potentially more sensitive to a change in hydrology than a species that occupies a wider portion of the gradient. For example, *Cladium mariscus* is confined to permanently wet areas, whereas *Phragmites mauritianus* occurs from permanently through to temporarily wet areas. One could therefore conclude that if an area which was naturally permanently wet was to be dried out to the point of being seasonally wet, the vegetation of this area would be more sensitive to change if it was dominated by *C. mariscus* than if it was dominated by *P. mauritianus.* Given such a change, *P. mauritianus* is much more likely to maintain its dominance than *C. mariscus*.

It is recognized that the less abundant species that are growing in association with the dominant/ co-dominant species are unlikely to respond in exactly the same way to a change to the hydrology as the dominant/ co-dominant species. However, at the level of a rapid assessment (and in most cases, also an intermediate assessment) it is not possible to describe all of the less abundant species. Therefore, these less abundant species will not be accounted for directly unless they have been identified as being particularly important (e.g. because they are Red Data species).

A5.2 PES Assessment

PES (present ecological state) of the vegetation should be assessed based on the vegetation component of WET-Health assessment (Macfarlane et al., 2008). Level 2 WET-Health is recommended, but the faster Level 1 assessment may have to be used for Rapid Reserve Studies where time and budget are usually limited.

The vegetation present must be compared with what one would expect in a reference site based on the assessor's field experience, and Table A5.1 is then used to subjectively allocate an intensity of impact score that reflects the degree to which each disturbance class deviates from the reference conditions. The confidence of the assessment is rated a scale of 0 [no confidence] to 5 [high confidence].

Once the intensity of impact scores for all of the sample sites/vegetation units have been described, an area-weighted average is calculated for the overall wetland or site and the PES determined from the overall impact score (Table A5.2). For example:

> Where the extents and intensity of impact scores for three disturbance units in a wetland are:
>
> - Currently cultivated land: 30% and 9
> - Old abandoned lands: 50% and 5
> - Natural vegetation: 20% and 1,
>
> then the weighted average would be (30/100 x 9) + (50/100 x 5) + (20/100 x 1) =5.4. The PES category for an impact score of 5.4 is a "D" (Table A5.2).

Table A5.3: Impact categories for assessing the intensity of impacts on vegetation integrity within disturbance classes (from Macfarlane et al., 2008)

IMPACT CATEGORY	DESCRIPTION	INTENSITY OF IMPACT SCORE
None	Vegetation composition appears entirely natural.	0.5
Small	A very minor change to vegetation composition is evident at the site (e.g. abundance of ruderal, indigenous invasive slightly higher than would be the case naturally)	1.5
Moderate	Vegetation composition has been moderately altered but introduced; alien and/or increased ruderal species are still clearly less abundant than characteristic indigenous wetland species.	3
Large	Vegetation composition has been largely altered and introduced; alien and/or increased ruderal species occur in approximately equal abundance to the characteristic indigenous wetland species.	5
Serious	Vegetation composition has been substantially altered but some characteristic species remain, although the vegetation consists mainly of introduced, alien and/or ruderal species.	7
Critical	Vegetation composition has been almost totally altered, and in the worst case all indigenous vegetation has been lost (e.g. as a result of a parking lot)	9

Table A5.4: Impact scores and categories of Present State (from Macfarlane et al., 2008)

IMPACT CATEGORY	DESCRIPTION	IMPACT SCORE	PRESENT STATE CATEGORY
None	Unmodified, natural.	0-0.9	A
Small	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	1-1.9	B
Moderate	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact	2-3.9	C
Large	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota and has occurred.	4-5.9	D
Serious	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable.	6-7.9	E
Critical	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8-10	F

A5.3 Approach for Seepage wetlands (RDM studies with no EWR component).

This approach (Figure A5.2) describes the assessment for seepage wetlands and other studies of wetlands where hydraulic cross-sections are not employed as part of the RDM study (i.e. where there is no EWR component in the study). The approach relies on the

PES (Present Ecological Sate) and the Ecological Importance of the vegetation for setting of EcoSpecs (i.e. there is generally little data available for the elucidation of the relationship between vegetation and hydroperiod for the specific site). These steps follow the same initial approach described for EWR assessments below, but would not be linked to specific cross section surveys and hydraulic analyses.

STEP 1: Identify the main vegetation/disturbance units in the wetland, with units identified as having fairly uniform vegetation and human disturbance conditions

STEP 2: For each disturbance unit, estimate the approximate aerial extent, and score the intensity of impact on vegetation composition.

STEP 3: Based on an area-weighted average of the intensity scores for all disturbance units, determine the Present Ecological State of the wetland vegetation.

STEP 4: Conduct a rapid assessment of the conservation importance of each of the vegetation types, based on existing information and referring to the EIS assessment

STEP 5; Conduct a rapid assessment of the suspected effect of a drying out of the wetland on the compositional integrity of each of the vegetation types

STEP 6: Define the Recommended Ecological Category of the vegetation (A to F) $$

STEP 7: Determine the Ecological Specifications (EcoSpecs) (e.g. maintenance of permanent saturation) and describe the conditions required to meet the specifications

Figure A5.2: Vegetation assessment in the RDM studies where no EWR assessment is being undertaken (i.e. PES, EIS and Ecospecs only).

A5.4 Approach for EWR determination

The approach below (Figure A5.3) describes how vegetation assessment in conjunction with a hydrological (and hydraulic, where appropriate) study of a wetland can be used to determine the EWR's for wetland vegetation.

Identify the main vegetation/disturbance units in the wetland, with units identified as having fairly uniform vegetation and human disturbance conditions

For each vegetation/disturbance unit, estimate the approximate aerial extent, and score the intensity of impact on vegetation composition.

Based on an area-weighted average of the intensity scores for all disturbance units, determine the Present Ecological State of the wetland vegetation.

Assess how representative the transect is considered to be of the overall wetland, with reference to the disturbance unit descriptions and a conceptual diagramme of "how the wetland works", developed jointly with all of the specialists
.

Select, in conjunction with the hydraulics specialist, a site for the cross section which is reasonably representative of the different vegetation units in the wetland and has been subject to minimal non-flow related impacts as possible.

Describe the vegetation and soil morphology at sample points representing the main hydroperiod-vegetation differences along the transect (usually 3 to 10 sample points per transect)

For each sample point, score the extent to which the vegetation composition has deviated from the natural reference condition. (Although generally expected to be low, this is likely to vary across the transect).

For the vegetation in the transect, define the Recommended Ecological Category of the vegetation (A to F) taking into account the EIS of the vegetation.

For the vegetation in the transect, determine the Ecological Specifications (EcoSpecs) (e.g. maintenance of permanent saturation) and, drawing on the results of the hydraulic assessment, determine what are the Water Requirements required to meet the specifications

Evaluate how applicable the Flow Requirements assessment conducted for the cross section is for the overall wetland, based on how representative the transect is considered to be of the overall wetland, and adjust EcoSpecs and Water Requirements where required, taking into account all of the vegetation units and the ecological importance and sensitivity of the wetland

Figure A5.3: Vegetation assessment in the Reserve Determination process where the vegetation assessment is being conducted in conjunction with a hydrological/hydraulic assessment.

At the rapid level, there is unlikely to be time for distinguishing more than about five units per wetland, and these are assessed based primarily on remotely sensed data (e.g. from Google Earth) and/or observations of the wetland from a few vantage points. Field verification time is usually very limited.

In a highly transformed wetland, the type of disturbance is usually the primary criterion used to distinguish the different spatial units in the wetland, and this applies to both approaches and all levels of assessment. The following are some disturbance units commonly encountered in highly transformed wetlands: currently cultivated land, old abandoned lands, dams and natural vegetation. In wetlands with little transformation, the units would generally be defined based upon the natural vegetation units.

The transect survey of the vegetation and its relationship with hydrology (though hydraulic calibration) should allow for some specific flow/vegetation understanding of the particular site to be developed, rather than relying on general vegetation-hydrology relationships that have been observed at other sites.

A key element is describing vegetation soil morphology and water table depth along a transect running approximately perpendicular to the wetland. The points are selected to represent the range of vegetation-hydrology differences occurring along the transect. For example, if temporarily, seasonally and permanently saturated conditions are represented across the transect then sample points representing each of these hydroperiods would be required. Further, if in the permanently saturated zone supported an area of tall *Phragmites* reeds and an area of shorter mixed sedge then both of these would need to be sampled[3].

The water requirements of these wetland communities can be linked to volumes through hydraulic calibration of their position on cross section (for valley bottom wetlands) where the relationship between different vegetation types and elevation is determined along the transect. Refer to Table 3.l to determine what is assumed to be the general hydroperiod required by the particular species present. The hydraulic assessment provides an indication of the discharges that will be required to maintain the identified hydroperiod. Baseflows can also be evaluated, in an albeit very low confidence manner, through the assessment of evapotranspirative requirements of plants and how these compare to present day flows. An example of this approach is given in the Reserve Determination carried out for Franklin vlei (Rountree et al., 2006). In the case of pans, wetting patterns and extents can be correlated with vegetation requirements (Fluvius, 2007).

As indicated in Section 3, the water requirements of most wetland plants are generally poorly understood, and Table 3.1 provides a very coarse-level assessment of the sensitivity of the vegetation to hydrological change can be undertaken based on the anticipated response of the dominant plant species, based on the hydrological range typically associated with that species. For example, if a zone within a transect is

[3] In order for the hydraulic assessment to be conducted, the elevation along the transect is surveyed, and based on this, the relationship between different vegetation/hydroperiod units and elevation is determined. The hydraulic assessment establishes the relationship between specific discharges and elevation of flooding.

dominated by *Cladium mariscus*, which has a requirement for permanent saturation, then a discharge would be required to maintain such permanent conditions.

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APPENDIX A6

DIATOM ASSESSMENT

Rapid methodology for inferring wetland water quality based on diatom analysis

Authors: S Koekemoer and JC Taylor

The diatoms are a unique group of algae which have cell walls composed of hydrated amorphous silica. They are also distinguished by having a golden brown rather than a green colour of chloroplast. Most diatom species are, to a lesser or greater extent, locally motile. Diatoms may occur as fee living organisms in the phytoplankton or may be attached to various substrata and form part of the phytobenthos. Most diatoms occurring in fresh waters have cell sizes ranging from ~3-140 µm. The small size of the diatoms makes them difficult to identify with certainty using magnifications of less than 1000x. Although diatoms are routinely identified to genus level from living material in the phytoplankton at a magnification of 400x in many laboratories, benthic samples contain a lot of detritus and other extraneous material making some sort of cleaning technique necessary, especially when attempting to identify these organisms to species level.

Diatoms are good indicators of wetland water quality and test cases indicated that they can be used for rapid reserve determination. Although they are rather small organisms, they also reproduce rapidly and may form dense biofilms several millimetres thick. These biofilms are usually easily visible, especially in winter time. The biofilms are golden brown and jelly like and contain many millions of cells. The diatoms and other algae may be equated with the grasses found in terrestrial biotopes. They form the base of the food chain for aquatic grazers and even non aquatic organisms such as flies may feed on them. Individual cells are ingested by a variety of organisms and the integrity of the bioflims are also disturbed by fish, aquatic insects, wading birds, etc. Cells dislodged from the biofilm may be easily transported to other parts of the wetland by a variety of means (water flow, on bird or insect body parts, etc.) In addition, because the diatoms are so small, living cells or spores may be transported in dust or aerosols. Thus in a spatially fragmented wetland were the water quality is similar throughout the wetland, the diatom communities will also be similar.

Diatoms also persist in environments where water is very shallow (a few millimetres) and the desiccated frustules of dead diatoms may be found on dry substrata allowing for conclusions to be drawn on the state of the water quality shortly before drying. Immigration of cells into newly wetted habitats is also very rapid and a climax community will be established within four to six weeks.

Diatoms are found on a variety of substratum. The phytobenthos may be divided into 4 main groups:
Epilithon – those algae inhabiting rocky substrata.

Epiphyton – algae attached to other plants (including other algae).
Epipelon – algae inhabiting sediments.
Epipsammon – those algae found inhabiting sandy substrata.
The first group (epilithon) is usually chosen for river water monitoring (Taylor et al., 2005), however, the last two groups of algae may be readily most found in wetland environments and will yield enough cells for analysis. Thus the epiphyton and epipelon are the groups recommended for collection in this protocol.

Relationship of diatoms to water quality

The relationship between diatom species and water quality variables has been discussed at length in numerous papers both from South Africa and other parts of the world. It will suffice to mention that diatom species have well characterised relationships with water quality variables such as pH, nutrients (N and P), organic materials and the electrolyte content of water. These relationships have been ascribed numerical values and resolved into indices. Diatoms are also well suited for indicating water quality as the communities are typically species rich, i.e. many species will similar tolerances or slightly different tolerances allow conclusions to be usually on a number of species rather than a single dominant. The Specific Pollution sensitivity Index includes the most number of species (over 2000) and has been tested and refined over a period of 25 years. This index has proved very successful in indicating stream/river water quality in South Africa (de la Rey et al., 2004; Taylor et al., 2007a; Taylor et al., 2007b) and has been informally tested in several wetlands. This index will be used to provide a score for general water quality in wetlands.

A6.1 PES Assessment

Field methods
Substratum selection
Substratum selection will depend on the type of wetland and the vegetation found there. Substrata from which diatom samples can be obtained are, in order of preference:

- Submerged macrophyte vegetation
- Emergent macrophyte vegetation
- Sediments

Sampling
Note:
Inspect the substrata first for the presence of biofilms. One of the most common errors reported during diatom assessments is the sampling of naked substrata Prygiel et al. (2002). Biofilms may appear as a golden brown layer or haze on the substrata (see Figure A6.1 and A6.2) or may be felt as a slimly layer due to the mucous secreted by diatoms for movement and attachment.

Submerged macrophyte vegetation

Submerged aquatic plants provide and excellent substratum from diatom attachment and may be sampled as follows:

- Select 5-10 stems in a radius of about 10 m. A stem is defined as an un-branched section of the plant from node to tip.
- Place the selected stems in a clear sealable polythene bag (e.g. a Ziplock bag) with a little water and shake the bag vigorously; the vegetation may also be agitated in the bag by hand to ensure the removal of as many diatom cells as possible.
- Pour the suspended material into a plastic sample bottle without including any of the gross plant material.

Emergent macrophyte vegetation

Reeds and rushes are often colonised below the waterline by diatoms and other algae. However, these plants have protective mechanisms to prevent the attachment of epiphytes and thus the biofilms (Figure A6.1) are very easily detached from these plants. Extra care should be taken when sampling from reeds.

- Select 5-10 reed stems in a radius of about 10 m.
- Cut each stem off above the water-line with a sharp knife.
- Carefully lower a wide-mouthed bottle over the remaining section of the stem and cut it off where the stem emerges from the sediment.
- Invert the bottle and remove the stem.
- The stem should be placed in a clean tray with a little water.
- Remove the bioflilm from the stem with a small brush or hard object such as a spoon or blunt knife.
- Mix the diatom suspension well and place into a plastic sampling bottle.

Figure A6.1: Biofilms on the stems of *Phragmites* sp.

Sediments

The diatoms are motile moving by a mechanism which combines the secretion of mucous and the movement of actin filaments. The diatoms live and move in the surface of the sediment and the mucous secretions bind the sediment particles together forming a delicate biofilm at the sediment/water interface. This biofilm may be distinguished as a golden-brown sheen on the surface of the sediment (Figure A6.2), when it is disturbed it gently peels away leaving sediment of a different colour underneath.

- Select a submerged area of 1-2 m^2 where diatom biofilms are visible.

- Gently remove the very top layer of the sediment using either a spoon or a suction device such as a pipette or large syringe.
- Sample 5-10 areas of sediment and transfer each sub-sample to the same sample bottle.

Figure A6.2: Diatom biofilm on sediment

Field processing

Sample preparation (see Figure A6.3)

- Mix the sample well.
- Take a sub-sample of 1-2 ml and transfer to a plastic tube.
- Add 4 drops of 10% ammonium chloride (NH_4Cl) solution to the sub sample and mix well.
- Dilute the sample to a cloudy consistency using distilled water (~1-2 ml).
- Clean a glass coverslip well and place it on an asbestos plate over a gas burner.
- Place 1-2 ml of the diatom solution on the coverslip and heat SLOWLY until the water has all evaporated
- Increase the heat and allow the organic material to burn off the coverslip. The progress of this process may be seen in the changing colour of the sample. The sample will first turn brown, then black and should eventually turn grey/white when all the organic material is burnt away. Care should be taken not to overheat the coverslip and distort it.
- Once the organic material has been incinerated allow the coverslip to cool.
- Once the coverslip is cool place a drop of Pleurax on the coverslip. Heat the coverslip gently for 20-30 seconds then invert a well-cleaned slide onto the coverslip.
- The slide should then be turned over, coverslip facing upwards and again gently heated until the Pleurax is cured. This can be tested by allowing the slide to cool and chipping the Pleurax with a scalpel blade, if cured the Pleurax will be brittle.
- The slide should then be labelled and is now ready for examination under the microscope.

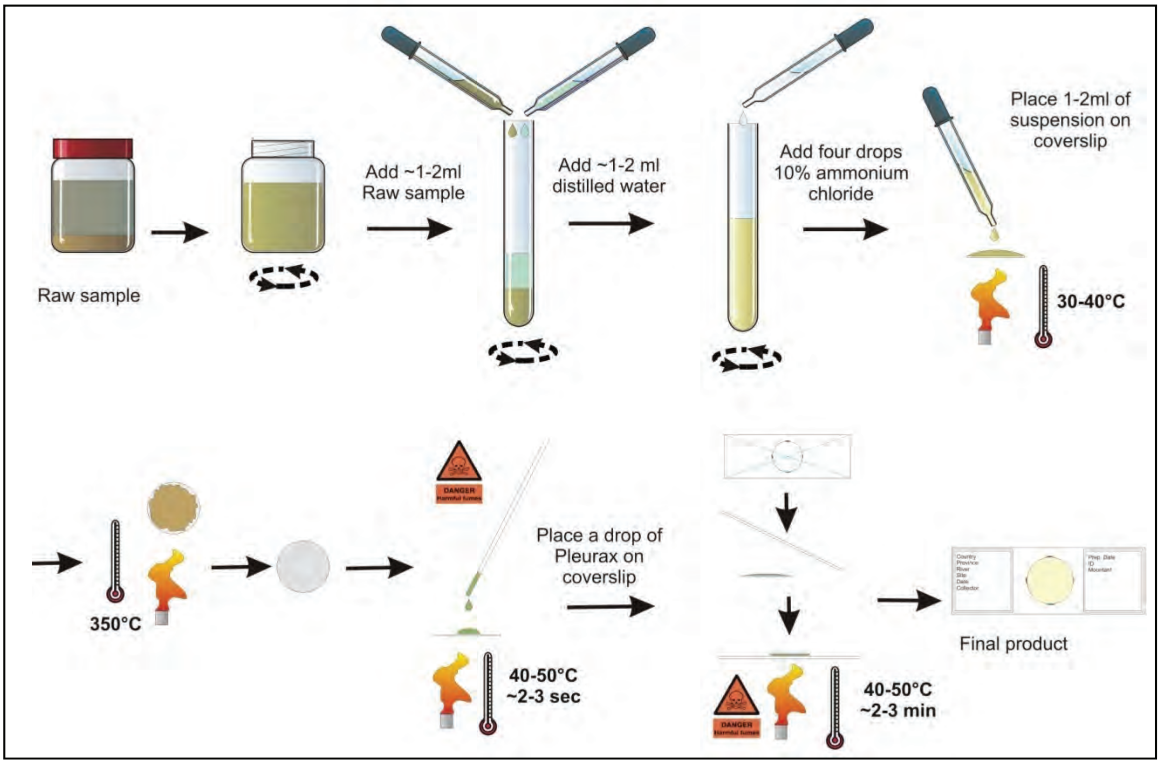

Figure A6.3: Schematic representation of diatom sample preparation

Sample analysis and interpretation

Diatom counts, when analysed may be used to infer the average water quality at a particular sampling site. Once the sample has been counted in the correct manner the data can be entered into a computer data-base (Omnidia) from which several calculations can be made using a specific equation or using the sum of the water quality optima of all the species in the sample.

The aim of counting diatom units is to produce semi-quantitative data from which ecological conclusions can be drawn. With this in mind it is important to know how many valves to count to get a reliable estimation of the relative species composition at a specific sampling site. The total number of valves to be counted for each sample varies according to the purpose of the analysis and according to the need to produce statistically good results; for the purpose of wetland water quality assessment a standard count of 400 diatom valves is recommended.

Enumeration summary

- A magnification of 1000x times should be used, preferably in conjunction with phase contrast optics.
- 400 cells should be enumerated and recorded, detailed rules for enumeration (Taylor et al., 2007d) may be found below. Electronic counting programs such as Opticount are available to facilitate this procedure.
- Identifications should be to species level when possible and follow Taylor et al., 2007c (available from order@wrc.org.za) and Krammer and Lange-Bertalot 1986-91 (available from www.koeltz.com).
- Enumeration of the sample is the most labour intensive step in the process of diatom analysis and may take up to four hours to complete.

Different conventions have been evolved for the enumeration of diatoms, using either valves or frustules as the basic unit, or not distinguishing between valves and frustules. The effect that such conventions have on the final results has not been evaluated, but is likely to be small. However, it is important that the convention used be specified in advance and kept consistent. In the case of small diatoms, such as some *Achnanthidium* and Naviculoid species common in wetlands, it may not be possible to distinguish with certainty between intact frustules and isolated valves on all occasions. In addition, the preparation technique used in the present protocol (incineration) will most likely not result in the separation of the valves into component frustules.

Suggested rules for counting diatoms can be summarised as follows:

- Counts of diatom valves on slides should be made using a microscope equipped with incident light (bright field illumination), phase contrast optics or differential interference (Normarski) optics (DIC) at a magnification of 1000 x and higher (i.e. 100 x oil immersion objective in combination with a 10 x eyepiece).
- The eyepiece graticule or other measuring equipment must be calibrated against a stage micrometer prior to the analysis to allow for measurement of dimensions and taxonomic features.
- Either the field of view or the grid of a graticule is used as the area defining the limits of the count. All diatoms visible in the field of view (or within the grid of a graticule) are identified and counted before moving along either a horizontal or vertical traverse to the next field, or selecting a new field of view at random.
- The edge of the dried sample suspension is recommended as the position to begin counting, but if this rule is to be adopted, ensure that there are no significant "edge effects".
- A rule is needed to cover situations where a diatom lies only partially inside a defined counting area. For example, such a rule might include taxa that are only partially visible at the upper but not the lower margin (in the case of vertical traverses) or the left but not the right margin (in the case of horizontal traverses). The precise form of the rule is less important than the consistency of its use when analysing samples.
- Whether a horizontal or vertical traverse is used, it is important that each subsequent traverse does not overlap with the previous one. No diatom valve should ever be counted twice. The distance that the stage is moved on each occasion must also account for any diatoms only partially visible in the field of view.
- Each individual specimen encountered is counted as a single unit, with no differentiation between a valve and a frustule.
- Girdle bands (copulae) should NOT be enumerated as being representative of diatom taxa.
- Occasional filaments should be recorded as the corresponding number of diatom units.
- In order to eliminate the risk of including separate fragments of broken valves or frustules, a consistent approach must be decided on before starting a project. Valves should be counted only if approximately three quarters is present, or alternatively broken valves may be excluded from the count altogether. Since the scale of physical damage during the sampling and preparation stages is unlikely to be significant, the presence of many small fragments of diatoms may indicate that dead diatoms are being washed in from upstream sites.

- A diatom may not be identifiable for a number of reasons, including the presentation of a girdle view, the presence of overlying material obscuring the view, or the taxon not being recognised by the analyst. If many valves are obscured, then new slides should be prepared using more dilute suspensions.
- Some taxa are identifiable from girdle (side) views, either because the girdle view is particularly characteristic (e.g. *Rhoicosphenia curvata*) or because the girdle view can be assigned with confidence to a particular taxon by matching it with corresponding valve views of taxa found in the sample. However, this is not always possible and, in cases of doubt, the analyst should record the girdle views at the lowest level to which they can be assigned with confidence (e.g. "unidentified *Gomphonema* sp.", "unidentified pennate girdle view").
- This convention should also be applied to other individuals found on the slide but not identifiable by the analyst. A large number of such individuals may indicate a problem either with the slide preparation or the identification skills of the analyst.
- As most diatom indices presume that all taxa in a sample are identified, it is recommended that *not more than five per cent of the total count should comprise unidentifiable individuals*. If a diatom unit cannot be identified for any reason, detailed drawings should be made. Notes should also be taken of the shape and dimensions of the diatom unit, striae density and arrangement (at the centre and poles), shape and size of the central area, number and position of punctae and arrangement of raphe endings.

Data analysis

- The Omnidia data base is used for the storage of count data as well as the calculation of index (SPI) scores.
- Species encountered in the analysis are entered using a four letter acronym (found in the database) accompanied by the absolute abundance of that particular species. Data may also be directly uploaded in the form of tab delimited text, details of this procedure may be found in the Omnidia help file.
- Once an index score has been generated it should be interpreted with the aid of the following table:

Interpretation of SPI scores	
Index score	**Class**
>17	high quality
13 to 17	good quality
9 to 13	moderate quality
5 to 9	poor quality
<5	bad quality

Recommended software packages

Package	Applications/comments	Available from:
Opticount	A counting program especially designed for the enumeration of algae species and calculation of biomass based on species counts.	DoMix Software Dr. Dominik Hepperle Dorstrasse 20 D-18249 Klein Raden Germany info@do-mix.de http://science.do-mix.de/software.php
Omnidia	Diatom-based index calculation and archiving both diatom sample information and species counts. This is a very valuable tool containing about 11 000 diatoms species with synonyms and references.	CLCI Mrs. Catherine Lecointe : Fax: +33 5 53 61 26 73 Give your computer type (Mac or PC and Windows version) Payment can be made by cheques or international postal order PRICE: Euros 701,27 (07/2005) clci@club-internet.fr http://membres.lycos.fr/rimetfrederic/links.html

Storage and archiving of sample

- Add ethanol to the original sample to reach final concentration of 20%.
- Label the sample with the following information:
    - Province
    - Locality
    - Water source
    - Date of collection
    - Substratum
    - Co-ordinates
    - Elevation
    - Collector

- Sub-samples should be submitted by post along with any available water quality information to :

  The North-West University Diatom Collection
  c/o Dr. Jonathan C Taylor
  School of Environmental Sciences and Development (178)
  North-West University, Potchefstroom Campus
  Private Bag X6001
  Potchefstroom
  2520

A6.2 Published Methods:

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TAYLOR J.C., JANSE VAN VUUREN, M.S. and PIETERSE A.J.H. (2007a) The application and testing of diatom-based indices in the Vaal and Wilge rivers, South Africa. *Water SA* **33** (1): 51-60.

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TAYLOR J.C., HARDING, W.R. and ARCHIBALD, C.G.M. (2007c) *An illustrated guide to some common diatom species from South Africa.* WRC Report No TT 282/07. Water Research Commission, Pretoria.

APPENDIX A7

WATER QUALITY ASSESSMENT

Authors: Heather Malan; Allan Batchelor; Patsy Scherman; Jonathan Taylor; Shael Koekemoer; Mark Rountree

Water quality assessments are not mandatory for Rapid Reserves, since diatom assessments provide an indicator as to the condition of the water quality (in a similar way to aquatic invertebrates in river systems). However, in wetlands where water quality issues are of concern, and/or the WULA for which the Rapid reserve has been initiated proposes significant risks to wetland water quality, then a dedicated water quality component should be included in the Rapid Study and the approaches described in this section should be followed.

ABBREVIATIONS:

D: RQS – Directorate of Resource Quality Services
DO – dissolved oxygen
DWA – Department of Water Affairs
DWAF – Department of Water Affairs and Forestry
EC – Ecological Category
EIS – Ecological Importance and Sensitivity
GIS – Geographical Information Systems
HGM – hydrogeomorphic
MAP:PET – ratio of mean annual precipitation to potential evapotranspiration
PES – Present Ecological State
RC – Reference Condition
RDM – Resource Directed Measures
REC – Recommended Ecological Category
RHP – River Health Programme
RQO – Resource Quality Objectives
SANBI – South African National Biodiversity Institute
SPI – Specific Pollution Sensitivity Index
TOR – Terms of Reference
WQ – water quality

ACKNOWLEDGEMENTS:

In formulating this approach the water quality (WQ) team have made extensive use of existing tools for assessing wetland ecological condition, especially the Wetland Index of Habitat Integrity (WIHI) (DWAF 2007) and various versions of WET-Health (Macfarlane *et al*., 2008). Furthermore, many people have given their input at various workshops. The approach presented here is a synthesis of all the sources, and the WQ team would like to thank the many contributors for their input. Thanks are especially due to Dr Donovan Kotze who was responsible for some of the original thinking on linking landuse to water quality impacts and gave valuable advice during the course of the project.

A7.1 Purpose

The aim of this project was to develop a relatively simple, rapid method for determining the WQ component of the Ecological Reserve for different wetland types, i.e.

- to establish present WQ condition (in terms of categories from A-E/F)
- to establish wetland sensitivity to potential changes in WQ, and
- to identify likely changes in WQ under different future development scenarios.

A putative method was developed (Malan *et al.,* 2008) and tested in two Rapid Reserve studies (the Klip River wetland and the Bedford-Braamhoek pumped storage scheme) during 2009/2010. Using the results from the two test cases the method was revised and is presented here. This method is for Rapid Reserve Determinations only.

A7.2 Introduction

Wetlands are an important, but neglected component of the limited water resources in South Africa and the National Water Act (1998) recognizes that both water quantity and quality need to be determined for this type of aquatic ecosystem. Wetlands, however, are naturally variable with regard to water quality both spatially and temporally. This is a consequence of the many different types of wetland differing in (amongst other attributes) water chemistry, geology and also because levels of inundation (and hence dilution capacity) vary with time. There is considerable pressure on these systems with regard to development in the surrounding catchments as well as the discharge of effluents directly into them. Furthermore, water quality data for wetlands in this country are limited and thus we have a poor understanding of the natural range of values of water quality parameters and what constitutes "good", or "poor" water quality in wetlands (Malan and Day 2005).

Determining the water quality component of the Ecological Reserve for a wetland entails *inter alia*, establishing the present WQ condition (the "Present Ecological State (PES)), comparing this to the condition in the unimpacted (reference) state, and setting a "water quality condition" (Recommended Ecological Category) for which the resource should be managed. Due to the natural variability of WQ in wetlands and lack of data noted above, determining the WQ component of the Ecological Reserve for wetlands whilst vitally important, presents distinct challenges. A further problem is that currently, there is a poor understanding of the links between WQ components (e.g. phosphorus levels) and ecosystem response for most biotic elements. Whilst many of these links may be understood at a qualitative level (e.g. excessive nutrient loads are likely to result in eutrophication), quantitative values which are needed especially in setting Ecological Specifications (WQ objectives) for high confidence levels of Ecological Reserves, are lacking.

In terms of the TOR for this project, the protocol to be developed is for Rapid Reserve determinations. This lends certain constraints to any method developed, namely; it must be quick (2 days to produce the final report, with only 1 day in the field), relatively cheap, and relatively simple. There is a lack of capacity in the country for carrying out Reserve determinations and thus any methods developed need to be pragmatic, but at the same time scientifically defensible.

As a consequence of the challenges noted above, three basic complementary approaches are recommended for determining the WQ component of the Rapid Ecological Reserve for wetlands. These are:

1. Measurements of **WQ parameters** (either historical or new data).
2. The use of **diatoms** for inferring WQ.
3. An impacts-based approach based on **landuse** in the catchment surrounding the wetland.

Why use three different approaches?
The reason for proposing three different approaches for the WQ component, even at a Rapid level, is because no single approach is at this stage of our understanding of wetlands likely to give enough information.

As mentioned previously, WQ data for wetlands in South Africa is scanty, highly variable, but most importantly, difficult to interpret as we still have a poor understanding of what measured values mean in terms of ecological condition (e.g. does a phosphate concentration of 0.4 mg/L in the wetland water column mean the system is likely to be eutrophic, as would in a river?). The reality is that for many wetlands no WQ data will be available, other than a once-off sample taken during the field visit, and even if there is, what does this value mean?

Initial field trials using diatoms for assessing WQ in South African wetlands have been promising. These organisms are potentially useful in establishing present WQ for wetlands, because they integrate WQ over a period of several months, rather than giving the "snap-shot" picture of WQ from once-off sampling of physico-chemical variables. They are also useful because they allow meaningful interpretation of WQ data, which as noted above, is currently problematic in this country. However, final development and rigorous testing of a diatom index for wetlands still needs to be undertaken and there are constraints to using diatoms as biomonitoring tools for wetlands, especially at the Rapid Reserve level. The most important constraint is that the samples can only be analysed by a trained diatom specialist (and there are currently few in the country). Further discussion of the use of diatoms in the biomonitoring of wetlands can be found in Matlala *et al.* (2007). Appendix 1 outlines a method for sampling and assessing wetland water quality using diatoms.

The third approach that is proposed is based on landuse. It is well established in the literature that activities in the catchment generate contaminants which subsequently impact on the WQ of aquatic systems in fairly a predictable manner (Showalter *et al.,* 2000). Thus we know that wetlands in catchments that are highly developed in terms of urban infrastructure or agriculture are much more likely to have impaired WQ than wetlands in a catchment that is largely comprised of natural vegetation. However *quantifying* relationships between landuse and resultant WQ impacts is difficult and requires testing. Nevertheless, this is a very useful approach to use since landuse data (in various forms, e.g. from maps, from GIS covers) even for wetlands in remote areas is becoming easily available. A Landuse/WQ model was developed in this project based on previous draft methods (DWAF 2007; Macfarlane *et al*., 2008) and is presented in Appendix 2. Only limited testing has been undertaken on different types of wetlands during 2009 and 2010 and the model still requires extensive testing and validation.

General points
From the results of the field testing of the Wetland Reserve methodology it is recommended that ***diatom samples must be taken for wetland Rapid Reserve determinations.*** The samples could be taken by the WQ specialist following the prescribed method (see Appendix 1), but should be sent to an accredited diatomologist for identification of species and evaluation of WQ indicators.

It is important to note that assessing the PES of a wetland is a multi-disciplinary exercise and it is important that the WQ specialist is involved in discussions around the wetland. For example, there are important links between hydrology and WQ, and of course WQ and the biotic response variables. It is also important for the WQ specialist to undertake a site visit in order to examine landuse in and around the wetland. During this time the specialist can take measurements of WQ parameters (pH, electrical conductivity, temperature) and samples for diatoms. If budget allows, samples can also be taken for further WQ analysis (nutrients, metals, salts according to the prescribed methods used by DWA for rivers).

Note: The proposed method outlined in this document is for application to INLAND wetlands. It should not be applied to estuarine systems.

A7.3 PES Assessment

The aim of this step is for the WQ specialist to build up a picture of the Present Ecological State (PES) with regard to WQ and to compare this, if possible with the Reference Condition WQ.

As part of this process the Ecological Importance and Sensitivity (EIS) is assessed for the wetland based on several different components, e.g. vegetation, hydrology and WQ. Given below are issues to be considered by the WQ specialist in this regard.

Step 3 a: Give input to the EIS (Ecological Importance and Sensitivity)
Based on the results of Step 2, the WQ specialist must now consider water quality inputs to the EIS by answering the following questions:

- Is the wetland particularly unique in terms of its WQ in the region, and thus important for biodiversity? (For example an acidic, humic-acid dominated wetland in an area of neutral/alkaline wetlands).
- Are there any particular factors that may make the wetland sensitive to changes in WQ? (See the characteristics that affect sensitivity to pollution listed below).
- Is the wetland important for maintaining good water quality for downstream aquatic resources? Are those systems of high ecological/sociological importance? (See listed “Characteristics that make a system important for WQ amelioration” below).

- Does the wetland support any biota which are especially dependent on very good water quality (ask the vegetation, invertebrate, bird or diatom specialists)?

Wetland characteristics that affect sensitivity to pollution:

- Drainage (i.e. endorheic/exorheic): Endorheic systems are particularly vulnerable to pollution.
- If the wetland is in an arid area, it is likely to have a low dilution capacity for pollutants (check MAP:PET ratio. If the ratio is low – the system is likely to be sensitive to pollution. See MacFarlane *et al.* (2008) for tabulated values of wetland vulnerability based on MAP:PET).
- If areas of open water are present (versus wetlands with no open water) – these systems are prone to algal blooms.
- Systems with naturally short, heterogeneous vegetation are likely to be more sensitive to pollutants than those that have dense stands of *Phragmites, Typha* or *Cyperus* (Kotze, D. *pers. comm*. 2007).
- Wetlands in naturally nutrient-poor catchments (e.g. fynbos, or with sandstone-derived catchment) are more sensitive to water quality impacts, especially increased nutrient loads.
- Peat wetlands are especially sensitive to elevated sulphates, e.g. as found in acid mine drainage (Zak *et al.,* 2009).

Characteristics that make a system important for WQ amelioration:

- If a wetland is a diffuse rather than a channelled system (i.e. if the residence time of water in the wetland is long), it is likely to be important for WQ amelioration (Kotze *et al.,* 2008).
- If vegetation biomass and coverage is high and there is extensive contact between the wetland vegetation and the water, it is likely to be important for WQ amelioration (Kotze *et al.,* 2008).

Step 3b: Define the Reference Condition

As wetlands are highly variable in terms of water quality, many have been degraded and due to a paucity of historical WQ data, it may be impossible to define the WQ conditions that would have occurred in the natural state. Possible ways to infer qualitatively, if not quantitatively, what the WQ may have been like before development in the catchment are:

- If the wetland has a river running in or out of it, it may be possible to source RC data from a suitable DWA WQ monitoring station.
- From groundwater data (if available) and if this is a major source of water to the wetland, and the groundwater is considered to be unimpacted.

In the future it may be possible to establish historical WQ from diatom skeletons examined from substrate cores. This approach requires further research and may only be suitable for higher levels of Reserve determinations.

Step 3c: Establish the PES for WQ

The standard procedure for establishing wetland WQ PES is presented below. This is followed by variations to be applied depending on the HGM type.

Standard procedure:

1. Complete the Landuse/WQ spreadsheet by entering the approximate areal extent of different landuses in the catchment (Table A7.1). Use expert judgement to answer the questions at the bottom of the WQ model (Table A7.2) in order to obtain a *tentative PES category* (A-E/F; where an A category indicates natural/least-impacted WQ and an F category indicates extreme contamination).

Table A7.1: The landuse scoring sheet to determine water quality PES for wetlands. Users are required to fill in the highlighted yellow cells.

ASSESSMENT OF PES WATER QUALITY USING LANDUSE																
WETLAND NAME:																
DATE:																
ASSESSOR:																
		Contaminants default scores (change if data available)														
		pH	SALTS					Sediments		TOXICS						
	Landuse (in wetland and catchment)	pH	SO4	K	NaCl	P	N	Clastic	Organic	(All toxins score equally. Max impact score = 5)	SUM OF IMPACT RATING SCORES	Adjusted for weighting	Default ratings	% AREA (MAJOR LAND USES ONLY)	AREA WEIGHTED SCORES	RATING
Infrastructure	Housing (sewered)					2	2	2	1	1	8	14	2		0	0
	Housing (unsewered)					4	4	2	4	3	17	29	3		0	0
	Industrial (or mixed industrial/residential)		3	5	5	5	5	1	5	5	34	49	5		0	0
															0	0
Agriculture	Non-irrigated croplands					4	1	4		2	11	20	2		0	0
	Irrigated croplands				2	3	2	3		2	12	20	2		0	0
	Non-irrigated pasture			1	1	3	1	4		1	11	18	2		0	0
	Irrigated pasture			2	1	4	1	4		1	13	22	3		0	0
															0	0
Commercial plantations	Commercial plantations					3		3		1	7	13	2		0	0
	Dense alien trees/shrubs					3		2			5	11	2		0	0
Natural vegetation	Natural vegetation (and low-intensity grazing)					1		0			1	3	0		0	0
															0	0
Other	Sports fields					1	2	2			5	9	1		0	0
	Gardens					1	2	2			5	9	1		0	0
															0	0
																0
												TOTAL AREA (MUST EQUAL 100%)		0		A

Table A7.2: Adjustments to the initial PES indicated by landuse alone can be made according to the guidelines below.

ADJUSTMENT OF PES CATEGORY	YES/NO?	ALTERED RATING SCORE
1. Is the wetland well-buffered by natural vegetation? Then **improve** PES score by 1 category		FALSE
2. Are there point-sources of pollutants discharging directly into the wetland or immediately upstream? Then **lower** PES score by 1 category		FALSE
3. If there is mining or power generation activity in the catchment, **lower** PES score by half a category		FALSE
3. Is there intensive agriculture within the wetland itself? Then **lower** PES score by 1 category		FALSE
4. Has flow been significantly altered from natural? Then **lower** PES score by half a category		FALSE
5. Is the areal extent of urban landuse > 50% of catchment? Then **lower** PES score by 1 category		FALSE
	PES SCORE	FALSE
	PES CATEGORY	#N/A

GUIDELINES FOR COMPLETING THE CATCHMENT LANDUSE/WATER QUALITY SPREADSHEET

1. For each landuse (irrigated cropland, etc.) the contaminants likely to be generated as runoff are rated in terms of the likely impact on the WQ of the wetland. The impact scores range from 0 (no impact) to 5 (major impact). Expert judgement was used to establish these scores, but if additional information is available, they can be altered at the user's discretion.
2. A rough estimate of the extent major landuses is made (as % of the total catchment area) and filled in (yellow column). The total landuse must equal 100%. A tentative PES category (A-E) is generated by the spreadsheet model.
3. Note is made of other factors, e.g. the presence of a vegetation buffer around the wetland, presence of significant point sources of pollution in the catchment, that can be used to alter the tentative PES category obtained in 2. above. The questions are answered "YES" or "NO" in the lower yellow column.
4. The final PES category is then calculated by the spreadsheet model. Note though that this can still be modified if additional data (e.g. diatom SPI scores, or WQ data) are available as described in the protocol.

2. If diatom samples were collected in the field, the resultant Specific Pollution sensitivity Index (SPI) score, based on the diatom community present at the site, can be used to help assess WQ status (see Appendix 1: Rapid methodology for inferring wetland water quality based on diatom analysis).

3. If surface water is present, take a WQ sample in the field and measure electrical conductivity, pH, and temperature. If time and budget permit, send off a sample for nutrient analyses. (See under specific HGM types for guidelines on where the samples should be taken). It should be noted that since wetland WQ is highly variable, once-off sampling (unlike biomonitoring) is not particularly useful. However the measurements will give some preliminary indication of the WQ and whether the wetland is acidic/alkali, freshwater/saline. These results will also ultimately add to data collected under a monitoring programme (see Step 8) and hence result in a better understanding of the system.

4. Assemble any other available relevant sources of WQ data (i.e. measurements of variables) as listed in Step 2 (e.g. from literature, geohydrochemistry, riverine WQ), and calculate the median[4] values for WQ variables. Adjust the tentative PES WQ category obtained in **1.** above (from the assessment of landuse). If there are any additional WQ data, assess and adjust the tentative PES WQ category accordingly.

[4] Because our understanding of WQ in wetlands is in its infancy, it is difficult to know what statistical parameters are most appropriate for describing the WQ data. For example, should the median value (50%ile) or the 95%ile (as is used in rivers) be used for a salt such as sulphate? Until further research has been conducted on this topic, the median values should be used as this statistic is commonly used to describe WQ data since it is relatively insensitive to outliers.

Note:
i) If bioassessment using diatoms was carried out, WEIGHT THESE RESULTS HIGHER TO DETERMINE THE PES as this is a “direct measurement” rather than an indirect measurement inferred from landuse.
ii) For a few wetlands, long-term WQ data may be available. At the moment not enough is known about the range of concentrations naturally occurring in unimpacted wetlands to be able to categorise wetlands (into A-F PES categories) based on such data. Some idea, however, of the degree of impairment can be obtained from Malan and Day (2005), who analysed the WQ data from several hundred wetlands ranging from impacted to pristine. Results were presented as the range and median values for different WQ constituents including phosphate, electrical conductivity, nitrate and pH, for different wetland types.

Variations in the WQ method for different wetland types:
A pragmatic approach has been taken in developing this method. Thus, if the wetland is largely riverine, i.e. for most of the time water is confined within a channel, then the well-established rivers method (Kleynhans *et al.,* 1995; DWA *in prep*.) should be used to determine the PES. For example, the Nylsvlei wetland floods outside its channel only (approximately) 3 years out of 10 (Higgins *et al.,* 1997), so the rivers method can be followed. In the case of valley bottom wetlands with a channel, if the width of wetland fringing the channel is relatively narrow (see Table A7.3), then the rivers method should also be used. Table A7.3 shows variations to the standard approach for determining the PES WQ depending on the wetland type.

Table A7.3. Variations in the method for determining the PES for water quality according to wetland type.

Wetland type		**Variations**
Flood-plain		If over-bank flooding occurs **less than once per year**, use the rivers method. If more frequent, use the standard wetland approach. **Sample both at inflow and outflow and middle of wetland.**
Valley bottom (with channel)		If the average width of the fringing wetland is **less than twice** the channel width, use the rivers method for the channelized section of the wetland. If > than the above, use the standard wetland approach. **Sample both at inflow and outflow of wetland.**
Valley bottom (without channel)		Use the standard wetland approach **Sample both at inflow and outflow of wetland.**
Seep		No WQ component. Use vegetation to assess and monitor ecological condition (and possibly after further research, diatoms).
Depression	**Pan** (i.e. relatively shallow)	Use the standard wetland approach **Sample exposed water at edge of pan**
	Lake	Needs an Intermediate or Comprehensive Reserve **Intermediate or Comprehensive sampling strategy needs to be implemented**

Table A7.4: Linking the Diatom Index Score (SPI), general water quality condition and WQ category.

Diatom Index Score (SPI)	General WQ condition	WQ category
>17	High quality	A
13-17	Good quality	B
9-13	Moderate quality	C
5-9	Poor quality	D
< 5	Bad quality	E/F

A7.4 EWR Determination

STEP 4: QUANTIFY ECOLOGICAL RESERVE REQUIREMENTS

Step 4a: Set WQ ecological specifications

At the moment, because of the lack of understanding linking concentrations of chemical constituents (both in the water column and in the substrate) with ecological response, it is not possible to provide quantitative EcoSpecs for WQ variables (e.g. a range in concentrations of Total Inorganic Nitrogen that should not be exceeded) as it is for rivers. Several more qualitative approaches are suggested:

1. Use can be made of narrative ecological specifications:

e.g. “*Phragmites/Typha* (or other problematic plant) should not extend more than a given percentage area of the open water surface” or, “the wetland should remain in the same trophic state or ecological category”.

2. Ecological specifications can be set using biological (diatom) data:

e.g. “the diatoms (as given by the SPI) should remain in the same ecological category (A-D)”. Changes in ecological category indicate a modification of diatom community composition which is usually accompanied by a change in water quality. These changes (both in category and community composition) can be used to directly track/indicate water quality impacts. Table A7.4 shows the linkages between the diatom (SPI) score, general WQ condition and WQ category.

3.Tentative default values for ecological specifications are given in Malan and Day (2005).

These values, however, represent a low level of confidence and require validation in the field.

A7.5 Additional inputs to Reserve study

STEP 5: DETERMINE THE CONSEQUENCES OF OPERATIONAL SCENARIOS

Give the likely consequences of operational scenarios

Due to the limited understanding of WQ and wetlands this step can only be considered in a qualitative manner. In future it may be possible to undertake modeling to predict the WQ consequences of changes to hydrology or contaminant loading. When determining the likely consequences of operational scenarios, it is important to consider any changes to water inputs and outputs as well as alterations in pollution loading to the system. Issues that should be considered when predicting the likely consequences of operational scenarios are listed below.

Issues to consider (under future planning / development scenarios)

- A *reduction* in water volume: This may result in changed hydroperiod, reduction in the dilution capacity, and an increase in residence time of the water.
- An *increase* in water volume: This may lead to a change in hydroperiod, decreased salinity, decreased residence time and consequent changes in biotic character. The quality of the increased volume of water should also be considered. Although more water can lead to higher dilution of contaminants, higher volumes of poor quality water can also increase levels of pollutants.
- Alterations to nutrient loads (P and N): This may result in external and internal eutrophication (Boers *et al.,* 2006). Internal eutrophication occurs when previously unavailable nutrients become liberated from the wetland substrate due to changes in physico-chemical conditions (e.g. due to changes in hydrology).
    - N in organic matter can be liberated when water levels drop, the substrate becomes aerated and decomposition rates increase.
    - P can be liberated when naturally fluctuating water levels are stabilized, for example, by the construction of a dam or weir. The substrate then becomes anaerobic and chemically-bound P may be released from the sediments into the water column.
    - P can be released into the water column when surface water rich in sulphates (for example from Acid Mine Drainage) is supplied to wetlands (Zak *et al.,* 2009).

STEP 6: DWA ECOLOGICAL CATEGORY DECISION MAKING PROCESS

No input from the WQ specialist is require here, other than the results obtained from the previous steps, which will enable the decision-making process.

STEP 7: DEFINE THE RESERVE, INCLUDING RESOURCE QUALITY OBJECTIVES (RQOs) AND MONITORING PROTOCOLS

In this step the major output with regard to WQ is setting the WQ objectives and designing a monitoring programme to ensure that the ecological condition of the wetland is monitored. This is especially important for wetlands as so little is known about them and there is an urgent need to build the knowledge base. It is important that there is good liaison with SANBI so that data collected can ultimately be added to the attributes database for the National Wetlands Inventory (when finalized).

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APPENDIX A8

HYDROLOGICAL METHODS FOR WETLANDS

Author: Stephen Mallory

A8.1 WATER BALANCE FOR WETLANDS

The simplest way to assess hydrological flow pathways and quantities within wetlands is to use a Water Balance model. Water balances *per se* have not been carried out on previous estuary and river reserves, but typically a yield analysis or water resources model is set up for detailed Reserve estimates. These models carry out a 'water balance' although this is typically carried out at a monthly time step and the mean or average condition is not necessarily reported on. It is noted that rapid and desktop **river** Reserve methodology do not require that a water balance be undertaken, but that it has been decided that water balances must be carried out for Wetland Reserves on selected wetland types (where there is a need to understand the effects of altered flow provisions). Water balance models would be required even at a Rapid level; albeit with low confidence results.

Several different types of wetlands have been identified, but many aspects of the water balance approach will be the same regardless of the wetland type. The water balance methodology has therefore been described firstly in generic terms which apply to all wetland types (as well as rivers and estuaries) and then the methodology is refined for each identified wetland type. The detail of this refinement for each wetland type is discussed in the relevant Appendix on hydrological methods.

Where possible the water balance methodology has been adapted to use simple spreadsheets since these are generally easier to use than complex models. However, in some cases water resources models will be required and the Reserve team undertaking these more complex Reserve determinations will need to have the necessary hydrological modelling skills in their team.

A8.2 GENERIC WATER BALANCE METHODOLOGY

A8.2.1 Natural flow

The flow that is entering a wetland under natural conditions can be derived from natural flow time series which were estimated by the Water Research Commission (Midgley et al., 1994). These natural flow time series have now been updated and for the purposes of this report referred to as the WR2005 natural flow database. It important to note that these natural flow time series are based on quaternary catchments (as defined in the WR90 reports) and should the area upstream of the wetland consist of several quaternary catchments, it is necessary to add these natural time series so as to obtain the total natural inflow into the wetland. There are two suggested approaches for doing this;

- Spreadsheet
- Water resources model

For simple systems with not too many upstream quaternary catchments (say up to 10 catchments) it is recommended that a spreadsheet be used to create a total inflow time series. Spreadsheets capable of adding flows for up to a maximum of 10 quaternary catchments have been setup and form part of the tools provided by this study. In most cases the wetland under consideration will not fall at the outlet of a quaternary catchment and hence the full flow from a quaternary catchment might not necessarily contribute 100% to the flow into the wetland. The suggested methodology is to determine the surface area of the wetland (at the point of inflow) which is contained in the quaternary catchment and hence determine the scaling factor to be applied to the time series. An example of this is provided in the worked spreadsheet example.

Should the wetland under consideration be located lower in a large catchment, i.e. with many upstream quaternary catchments, the recommended approach is to use a water resources model to sum the natural flows up to the inflow point of the wetland. The choice of model to use should be left up to the water resources modeler, but recommendations in this regard are given in section 2.4.

A8.2.2 Current day flow

While the procedure described above gives an indication of what the flow regime into the wetland would be under natural conditions, it is also important to know what the flow is under current conditions. Under most circumstances, there will not be a gauge at the inlet to the wetland and therefore the current day flow needs to be estimated by other means.

In determining the current day inflows, it is first and foremost necessary to estimate the water use upstream of the wetland. Sourcing reliable information on water use is always problematic but for rapid assessments the following procedures are recommended:

- Ascertain if a detailed water resources or hydrological study has been done in the catchment in which the wetland is located. DWAF's Directorate of National Water Resources Planning is the best source of this information.
- If there are no detailed reports, the WARMS data for the catchment must be obtained from the relevant DWAF regional office and used to calculate the water use in the catchment. The summarised data from WARMS must be compiled into a short report which must be made available to the relevant DWAF Regional office to confirm that the WARMS data has been correctly interpreted. The DWAF Regional office, via the RDM office, must be requested to comment on the WARMS data and either confirm the water use or indicate the shortcomings in the information. A qualitative statement as to the accuracy of the data should be obtained from the Regional Office.
- The water resources specialist involved in the study must do a field visit to the catchment and carry out a reality check of the water use information.

Having obtained a reasonable estimate of the water requirements, these must be expressed in terms of time series. This task will need to be carried out by a water resources specialist.

The current day inflow time series can now be generated by subtracting the water use time series from the natural flow time series. If the catchment consists of a simple single catchment configuration, i.e. a single quaternary catchment, then this can either be done on a spreadsheet or with the aid of the Yield feature contained in SPATSIM. However, if the catchment is more complex, consisting of more than one quaternary catchment, then the use of a water resources model is recommended.

A8.2.3 Water use within the wetland

In almost all cases, the wetland itself alters the water balance. While this is a natural process, the upstream activities of man as well as activities within the wetland can alter the natural process of the wetland. Generally, wetlands alter the water balance by exposing the water in the catchment to a larger evaporative area than would occur in a river channel. Evaporation can be either directly from the water surface or through evapo-transpiration from wetland flora, or a combination of both. The exposure of a large area to evaporation will not necessarily lead to a water loss since the wetland's water body will also capture rainfall. The suggested approach for determining the local water balance is as follows:

- Determine the storage-volume relationship of the wetland
- Determine the area which is vegetated and the area which is open water
- In determining the evaporation from the wetland, assume the following:
    - o Evapo-transpiration from the vegetated area is calculated using A-pan evapo-transpiration and a crop factor of 0.8, but only when these vegetated areas are not inundated with water.
    - o When the vegetated areas are inundated, assume a crop factor of 1.0
    - o Calculate evaporation from open water areas using S-pan evaporation. Do not make any adjustment for lake evaporation. It is assumed that wetlands are shallow enough to exhibit the same evaporation characteristics of a Symons Pan.
- In determining the volume gain by rainfall assume the following:
    - o Rainfall on the open water body is converted directly to volume.
    - o Rainfall on the vegetated area is assumed to experience an interception loss of 3 mm. Using monthly rainfall data (as is recommended for the Rapid approach) the methodology used in the Pitman Model (Pitman, 1974) is recommended to determine the interception loss in monthly terms. The methodology is described in Appendix A.

A8.2.4 Modeling procedures

It is clear from the above description of evaporation losses and gains due to rainfall that time series modeling will be required to estimate the temporal changes to the water surface area of the wetland. The can be done using a spreadsheet for simple single catchment wetlands. A pro-forma spreadsheet has been developed for use in these instances.

In addition to modeling the inflow into the wetland, the outflow also needs to be modeled. Unlike a dam which has a specific full supply capacity, which, if exceeded, results in spillage, i.e. flows to the downstream catchment, the outflow from a wetland is better described by means of a stage-discharge relationship. This relationship will need to be determined by a hydraulician. Modeling outflow by means of a stage-discharge relationship using a monthly time step could be problematic and a few test cases will need to be modeled to ascertain whether or not this approach is feasible or not.

A8.2.5 Scenario analysis

Having determined the natural and present day water balance of the wetland, decisions as to whether or not to issue a license for water use within or upstream of the wetland will be based on how these water uses impact on the wetland. The loss of water per se is not the problem but rather the following:

- Permanent reduction in wetted area
- Reduction in frequency of flooding

The proposed water balance methodologies aim to address these two aspects.

A8.3 OTHER CONSIDERATIONS

A8.3.1 Time step

While it might not be particularly accurate to model wetlands using a monthly time step (as opposed to a daily time step) natural flow time series in South Africa is readily available at a monthly resolution, while more difficult to obtain on a daily basis. It is therefore recommended that a monthly time step be used for rapid wetland Reserves, but that daily models be developed for comprehensive Reserves.

A8.3.2 Model choice

The choice of which model to use to carry out water balance should be based firstly on the level of complexity of the wetland. As far as possible it is recommended that the spreadsheet model be used since this is easy to use and can be easily understood. Those that are familiar with the SPATSIM licensing tool can use this as an alternative to the spreadsheet.

Only if the catchment becomes large and complex should the use of water resources models be considered. The main criterion in selecting a model should be availability. If a model has already been set up and verified for a particular catchment, then it should be used in preference to setting up a new model. The other criterion is the modeler's knowledge of the modeling system. The two models recommended for water balance modeling are DWAF’s Water Resources Yield Model or Water for Africa’s Water Resources Modeling Platform.

A8.4 CASE STUDY ON DETERMINATION OF THE INUNDATION PATTERN OF A PAN

Author: Mark Rountree

Source: Fluvius Environmental Consultants, Report No. 022/2007.
Rapid Ecological Reserve Determination for Parkhaven Pan, Gauteng.

The identification and description of the pre-development hydrology or flooding pattern of a seasonal pan was determined in a study undertaken on behalf of DWAF in 2007. It was necessary to determine the predevelopment inundation patterns of a seasonal pan on the Highveld as a primary management objective was to maintain, as closely as possible, the pre-development hydrological (seasonal flooding) pattern of the pan. A number of rare biota located in the pan were known to be dependent on the habitat provided by seasonal pans.

Using LandSat™ satellite imagery, the timing and extent of the pan inundated over a ten year period was examined in relation to rainfall (rainfall data were obtained from a nearby weather station). Unfortunately the intervals between available imagery (sourced though DWAF) were erratic, with a number of years having extremely limited coverage (Figure A8.1 – A).

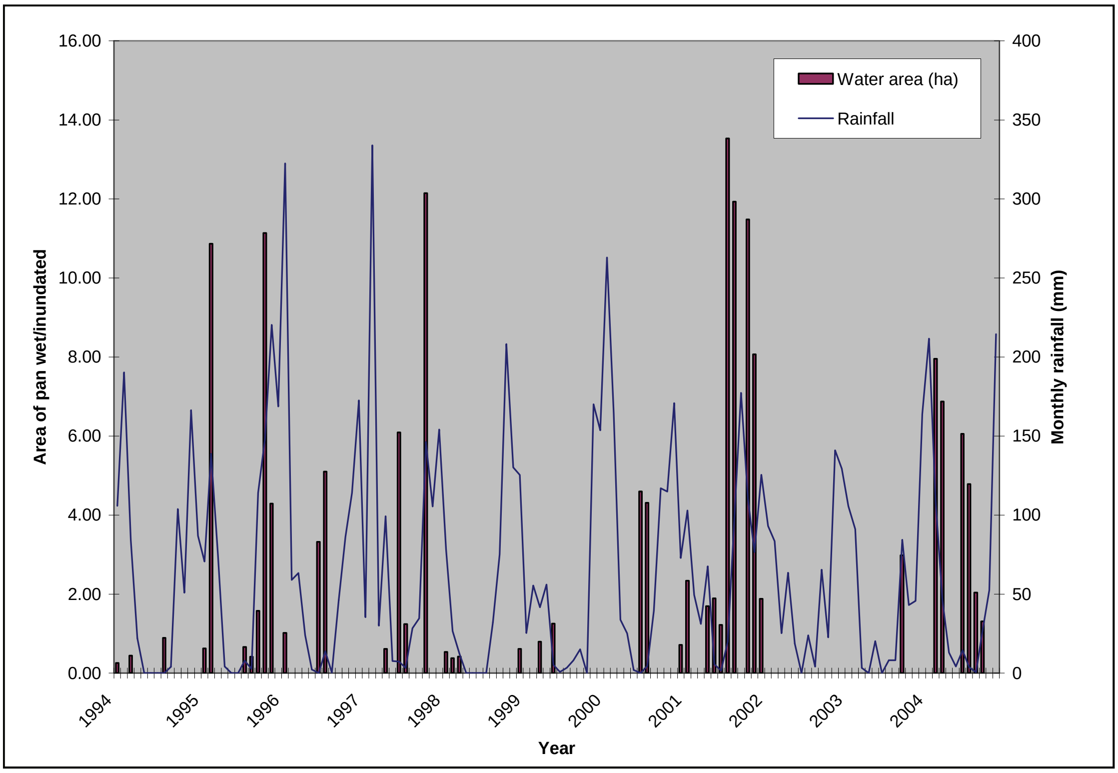

Figure A8.1 – A. The distribution of monthly rainfall versus (where data were available) the inundated area of the pan for a ten year period.

Initially the relationships between the area of the pan inundated at a particular time interval (month) and the rainfall of the preceding 2, 3, 4, 6, and 12 months were examined to determine if any correlation could be identified, but these proved to be extremely weak (Figure A8.1 – B). However the relationship between annual rainfall for the hydrological year (September of the preceding year to the next August) and the extent of inundation (if any) at the end of the dry season (August/September) of that year was examined, and a good correlation between rainfall and the inundated extent of the pan was identified (Figure A8.1 – C). This correlation accounts for approximately 86% of the variability in the data between annual rainfall and pan inundation area at the end of the dry season (R^2 = 0.738).

The elucidation of this relationship – between annual rainfall and pan area of inundation at the end of the dry season – allowed for, as part of a Water User Licence, conditions to be set whereby the natural patterns of inundation of a seasonal pan can be predicted and therefore managed in a developing catchment.

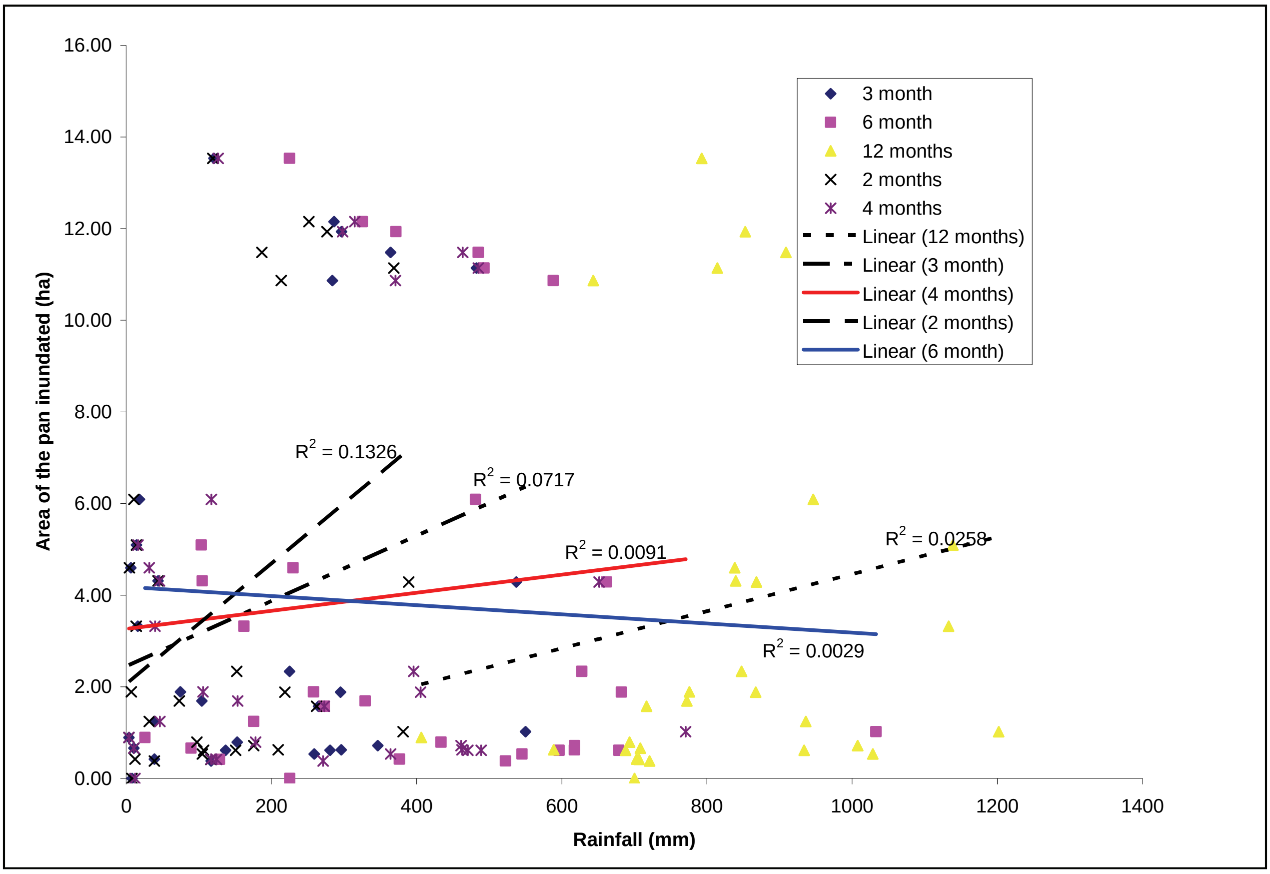

Figure A8.1 – B. The weak correlations between rainfall (at 2, 3, 4, 6 and 12 month intervals) and area of the pan which is inundated.

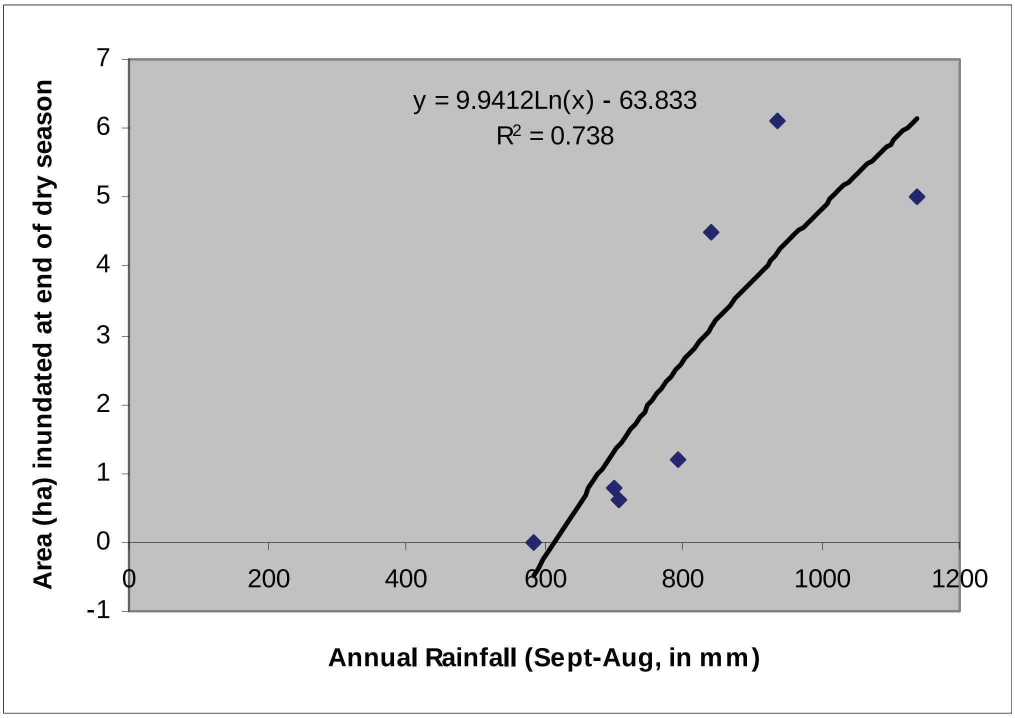

Figure A8.1 – C. The correlation between annual rainfall and area of the pan inundated at the end of the dry season.

APPENDIX A9

HYDRAULIC METHODS FOR WETLANDS

Author: Angelina Jordanova

A9.1 Introduction

An assessment of the ecological Reserve for wetlands requires the determination of Environmental Water Requirements (EWRs) for protection of wetland ecosystems. Wetlands are essential features for wildlife and vital to the water cycle. Abundant water makes wetlands the most biologically diverse ecosystem.

EWRs are used to quantify the water needs of the various biotic components in terms of the relation between flow magnitude and timing. The relationships that drive the ecological Reserve for wetlands include the frequency, duration, timing and rate of change of flows, and the specification of flows. These relationships aim to replicate these important aspects of the natural hydrological regime.

The purpose of hydraulic modelling for the wetlands is to provide a stage-discharge rating curve. In order to develop stage-discharge relationships based on one set of observed rating data there is a need for an understanding of flow resistance in natural wetland systems.

This technical memorandum is for the proposed methods for a Rapid Reserve determination for unchannelled valley bottoms, channelled valley bottoms, meandering floodplains type of wetlands.

A9.2 Unchannelled Valley Bottom wetlands

The ability to quantify vegetation resistance is essential for environmental management of wetland systems as well as wetland Reserve studies. The influence of aquatic vegetation on flow resistance is determined by the morphology of the individual vegetation stems and characteristics of the whole wetland bed. Plant characteristics such as stem diameter, stem height, the distribution of leaves and branches influence the drag imposed on the flow. These influences also vary seasonally according to the plant growth (James et al., 2001; James et al., 2004). The resistance coefficient does not vary much with flow depth, and can be expected to apply over a wide range of conditions.

Two methods for development of a stage-discharge curve for the unchannelled valley bottom type wetland are proposed. The proposed method 1 is for a site where there is no an appropriate cross-section for flow measurement while method 2 is for a site where discharge can be measured.

A9.2.1 Proposed method 1

If a selected site **does not have an appropriate cross section** for flow measurement, located either upstream or downstream of the wetland, two alternative methods are proposed for discharge estimation namely, Surface Velocity and Direct Approach.

Method 1.1 – Surface Velocity

This method is based on an assumption that the resistance coefficient does not vary much with flow depth, and therefore the flow velocity will not vary much with flow depth either. During the field survey flow velocities in different type of vegetation can be estimated by measuring the surface velocities and then be applied over a wide range of conditions for development of a stage-discharge curve.

Field survey

- Select EWR cross section;
- Measure flow depth along cross-sectional line in an appropriate interval;
- Identify different vegetation zones; and
- Measure surface velocities in different type of vegetation (V_s).

Stage-discharge development

- Calculate flow area from cross-sectional survey (*A)*;
- Calculate average velocities (*V*) in different type of vegetation using correction coefficient, *k*=0.85 (Gordon et at, 2004);
- Calculate discharge (*Q)* as *Q* = *VA*; and
- Develop stage-discharge curve.

Method 1.2 – Direct Approach

If a selected site **does not have an appropriate cross section** for flow measurement an iterative procedure developed for routine conveyance estimation for practical stage-discharge determination for waterways with emergent vegetation is proposed to be used (Jordanova et al., 2006; Jordanova and James, 2007).
Conveyance through extensive, uniform vegetation can be described by a resistance equation which accounts for the integrated interactions at the stem and leaf scale through a resistance coefficient (*F*), which can be determined empirically from measurements.

Field data required

During the field trip the following data needs to be obtained:

- Average stem diameter (*D*) of vegetation;
- Average stem spacing (*s*);
- Bed slope (*S*); and
- Average height of stems from the bed to the first leaf.

Stage-discharge development

- For a specified flow depth assume a flow velocity (*V*);
- Calculate the Reynolds number in terms of the stem diameter (*D*);
- Depending on the flow depth (*y*) of interest in relation to the height of the first leaf, estimate the drag coefficient (C_D) according to the degree of foliage from Figure A9.1;
- Calculate resistance coefficient (*F*);
- Calculate flow velocity (*V*);

- Compare the calculated velocity with the initially assumed one, and if there is a difference, repeat the procedure until the assumed and calculated velocities are the same;
- Calculate the discharge per unit width (q) for the nominated flow depth; and
- Develop stage-discharge curve.

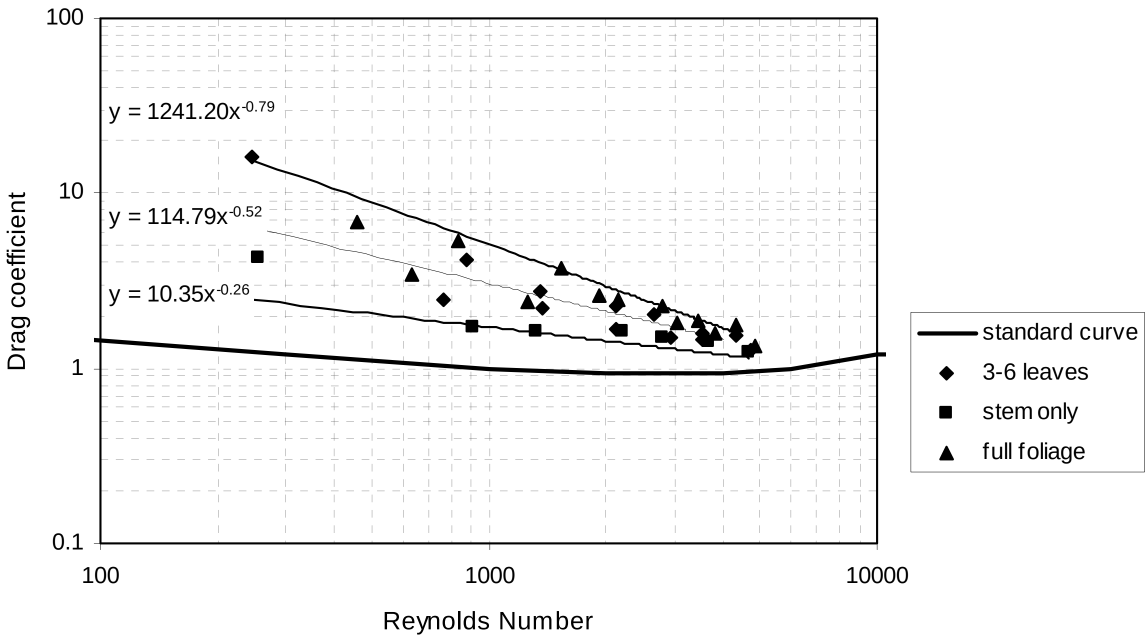

Figure A9.1: Variation of drag coefficient with degree of foliage

Calculate the Reynolds number in terms of the stem diameter (D) as:

$$\mathrm{Re} = \frac{VD}{\upsilon} \qquad (1)$$

where : υ *the kinematic viscosity (1.14x10^{-6} m^2/s for water at a temperature of 15° C)*

Calculate resistance coefficient (F) as:

$$F = 1.885\left(\frac{s}{D}\right)^{-0.65}\left(\frac{D}{y}\right)^{0.07} C_D^{\;0.48} \qquad (2)$$

The resistance coefficient (F) does not vary much with flow depth, and the calibrated equation (2) can be expected to apply over a wide range of flow depth conditions for development of a stage-discharge curve (James et al., 2001).
Calculate flow velocity (V) as:

$$V = \frac{1}{F}\sqrt{S} \qquad (3)$$

Calculate the discharge per unit width (q) for the nominated flow depth:

$$q = yV \qquad (4)$$

A9.2.2 *Proposed method 2*

If an **appropriate cross-section for discharge measurement is available** the following procedure should be applied.

Field data

During the field trip the following measurements have to be performed:

- Measure discharge (Q);
- Survey one wetland cross-section; and
- Survey bed slope (S).

Stage-discharge development

- Calculate average flow velocity as:

$$V = \frac{Q}{A} \tag{5}$$

Where: A is the flow aria

- Calculate site specific resistance coefficient (F):

$$F = \frac{\sqrt{S}}{V} \tag{6}$$

- Develop stage-discharge curve.

A9.3 Channelled Valley Bottom wetlands

Channelled valley bottoms wetlands are characterise by greater local resistance by vegetation and by retarding flow in adjacent clear water zones. Under these conditions discharges can be calculated separately for the vegetated and clear zones of a cross section, and added together to obtain the total discharge (James and Makoa, 2006). The effects of flow interaction between the zones can be quantified for this purpose through recognition of an apparent shear stress at the zonal interface. This effect of flow interactions tends to resist flow in the clear channel (Jordanova and James, 2007). The flow contribution of the vegetated zones is usually small and may often be ignored. The conveyance estimation method for the clear channel zone (James and Makoa, 2006; Jordanova and James, 2007) is proposed for the channelled valley bottoms wetland.

A9.3.1 *Proposed method*

A clear channel between vegetated sides can be considered as one of composite roughness, with different roughness on the sides (n_s) and the bed (n_b). Various equations (Horton, 1933; Pavlovski, 1931; Lotter, 1933; and Colebatch, 1941) that are based on different assumptions have been proposed for estimation of the equivalent value of Manning's n (n_e). Here the Pavlovski (1931) approach is proposed for use:

$$n_e = \left(\frac{\sum_{i=1}^{N} \left(P_i \, n_i^{\,2} \right)}{P} \right)^{1/2} \qquad 7$$

where n_e : the equivalent Manning resistance coefficient for the whole cross section and

P : the total wetted perimeter.

Field data required

During the field trip:

- Measure discharge in clear channel (Q);
- Survey one cross-section;
- Survey bed slope (S); and
- Measure flow depth in vegetated areas (y_v).

Modelling approach:

- From field data calculate the equivalent Manning resistance coefficient (n_e);
- Estimate Manning resistance coefficient for the bed (n_b);
- Calculate Manning resistance coefficient for sites (n_s) from equation (7); and
- Develop stage-discharge curve.

A9.4 Meandering floodplains

Hydraulic modelling for the meandering floodplains wetland type requires information on channel-floodplain connectivity and identification of flood requirements for the vegetation.

Field data

The following field survey will be required for the meandering floodplains wetland:

- Survey one cross-section to provide information on channel-floodplain connectivity;
- Survey specific points that provided vegetation flood requirements;
- Survey specific points that indicate permanent, seasonal and temporarily wet sections; and
- Measure discharge.

Stage-discharge development

Stage-discharge development for the meandering floodplains wetland type is similar to modelling of high flows for rivers for Rapid Reserve determination and this approach should be applied.

A9.5 General comment

The hydraulics of wetland is very complex and current knowledge is limited. There are a lot of uncertainties regarding understanding of relationship of hydraulics and wetlands. Even for the same type of the wetland the hydraulic approach could vary depend on a selected site. It therefore critical to test these methods' performance for hydraulics of wetlands in the field to determine a better understanding of what field data has to be collected during field work. This data can them be correlated with the hydraulic parameters that are required for modelled and those required by other scientists.

A9.6 Recommendations

- Hydraulic field survey for wetland Rapid Reserve determination requires more time that for the river Rapid Reserve determination. It is recommended that at least 6 hours should be allocated for field work;
- It is recommended that the position of the EWR cross section should be located after discussion with all the biologists specialist' team members;
- It is recommended that all hydraulics features important for vegetation and aquatics scientists be measured, surveyed and plotted on the cross-sectional profile; and
- 'Surface Velocity' method for development of a stage-discharge curve for the **unchannelled valley bottom type wetland** is proposed. The method was tested and a good result was obtained. To improve the application of the 'Surface Velocity' method, it would be valuable to carry out extensive field-based measurements (using a sensitive flow meter such as a two-dimensional Doppler) of velocity in different type of wetland vegetation that could be used in Rapid Reserve wetland studies.
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Rapid Reserve Determination for the Bedford Wetland (C81A)

Rapid Reserve Determination for the Bedford Wetland (C81A)

This part documents the Rapid Ecological Reserve Determination study undertaken on the Bedford Wetland in catchment C81A and contains a summary main report with appendices which detail the approaches and findings of each specialist assessment undertaken.

The study was undertaken jointly by a team of wetland experts which included:

Team member	***Affiliation***	***Role in project***
Mark Rountree	Fluvius Environmental	Project leader, Geomorphology
Heather Malan	University of Cape Town	Water Quality
Angelina Jordanova	Golder and Associates	Hydraulics
Stephen Mallory	IWR Water Resources	Hydrology
Shael Koekemoer	Koekemoer Aquatic Services	Diatoms
Jackie Jay	DWA: RDM	Client
Colleen Todd	Independent Consultant	Aquatic Invertebrates
Allan Batchelor	Wetland Consulting Services	Water Quality
Donovan Kotze	University of KwaZulu-Natal	Vegetation
Nonkanyiso Zungu	DWA: RDM	Client

ACKNOWLEDGEMENTS

Funding for the development and testing of Rapid Reserve Determination methods for Wetlands has been jointly funded through the Water Research Commission (WRC) and the Chief Directorate of Resource Directed Measures (CD:RDM) in the Department of Water Affairs. The establishment of this project began in 2005 when severe limitations with the then available approaches became apparent. Dr Steve Mitchell from the WRC and Ms. Barbara Weston from the Department of Water Affairs (CD: RDM) were instrumental in enabling this research and testing of environmental flow methods for wetlands to be undertaken.

Mr Peter Nelson (Eskom), the Ingula Conservation Manager, provided invaluable assistance on site at the Bedford Wetland as well as detailed insight into the pumped storage scheme and operation. Mr Alastair Campbell (Nature Conservation Corporation), the Environmental Control Officer at the Ingula Pumped Storage Scheme, kindly assisted with logistical support in the field and sourcing of monitoring data for the wetland. Their generous and patient assistance was highly appreciated.

Contents

APPENDICES

TERMS AND ACRONYMS

CD: RDM	Chief Directorate: Resource Directed Measures
DWA	Department of Water Affairs
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
HGM	Hydro-Geomorphic Unit
MRU	Management Resource Units
NWA	National Water Act
PES	Present Ecological State
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
RU	Resource Unit
SANBI	South African National Biodiversity Institute
ToR	Terms of Reference
Wetland IHI	A tool for determining an Index of Habitat Integrity of a wetland (DWAF, 2007)
WET-Health	A tool for determining the health of a wetland (MacFarlane et al., 2008).
WULA	Water User Licence Application (as related to Section 21 of the National Water Act, Act 36 of 1998).

1 INTRODUCTION

A new pumped storage scheme is being developed by Eskom Holdings Limited to store excess baseload energy in order to generate additional peak power for the South African grid. Two dams (Figure 1) are being constructed for this purpose. These are:

1) The lower reservoir, the Braamhoek Dam (26.3 Mm^3) in the Braamhoekspruit, a tributary of the Tugela River, and
2) The upper reservoir, the Bedford Dam (22.3 Mm^3) in Bedford wetland, a tributary of the Wilge River that in turn forms part of the Upper Vaal catchment.

These dams, 4.6 km apart, are connected by underground waterways and an underground powerhouse which will house four 333MW pump turbines. During times of peak energy consumption, water will be released from the upper dam through the pump turbines to the lower dam to generate electricity. During times of low energy demand the pump turbines will be used to pump the water from the lower dam back up to the upper dam.

Figure 1: The Braamhoek pumped storage scheme is located in the Drakensberg, east of Harrismith.

A once-off take of 27 Mm^3 from the Braamhoekspruit (Tugela catchment) for the purposes of filling the reservoirs and then an annual take of 2 Mm^3 from the Braamhoekspruit for the purposes of operating the dams are proposed. There are many wetlands within and downstream of the study areas, but downstream of the Bedford (upper) dam site in particular there is an extensive wetland along this tributary which joins with the floodplain wetland of the upper Wilge River (Figure 2). Although theoretically no net off-take is proposed in the Bedford catchment, the presence of the dam and diurnal fluctuating storage will impact on the pattern of flow downstream of the dam. Eskom, in their Water User Licence application, have proposed a minimum release pattern to maintain the downstream wetland, but these flows were not determined using Reserve Determination approaches.

The purpose of this study was to undertake a Rapid Reserve Determination for the Bedford wetland (Quaternary catchment C81A) downstream of the proposed Bedford dam, and in doing so

- Determine the Reserve for the Bedford Wetland,
- Determine if the minimum flows that have been proposed by Eskom would be sufficient to maintain the wetland the desired ecological category, and
- Test the methods for Rapid wetland Reserve (environmental flow) assessments that have been developed by the joint WRC/DWA:RDM study which funded this study;

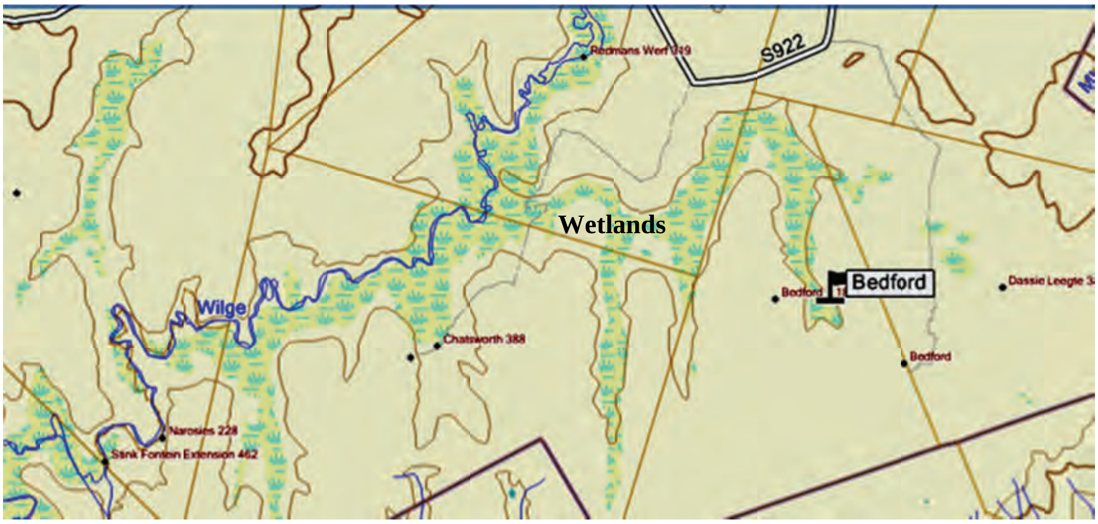

Figure 2: Extensive wetlands are present below the Bedford Dam wall (indicated as "Bedford" in the above figure). These wetlands extend down into the Wilge floodplain.

2 APPROACH

To facilitate easier linkages between RDM studies of different water resource types (rivers, estuaries, groundwater and wetlands), a generic 8 step procedure (Figure 3) has been developed for all Reserve determination studies. The procedural steps within Reserve Determination studies for different water resource types are thus similar to facilitate integration of the results, although the technical tools and methods are specific to each water resource type. For the detailed technical methods for the Rapid level of Reserve determination for wetlands, please refer to Rountree (ed), 2010.

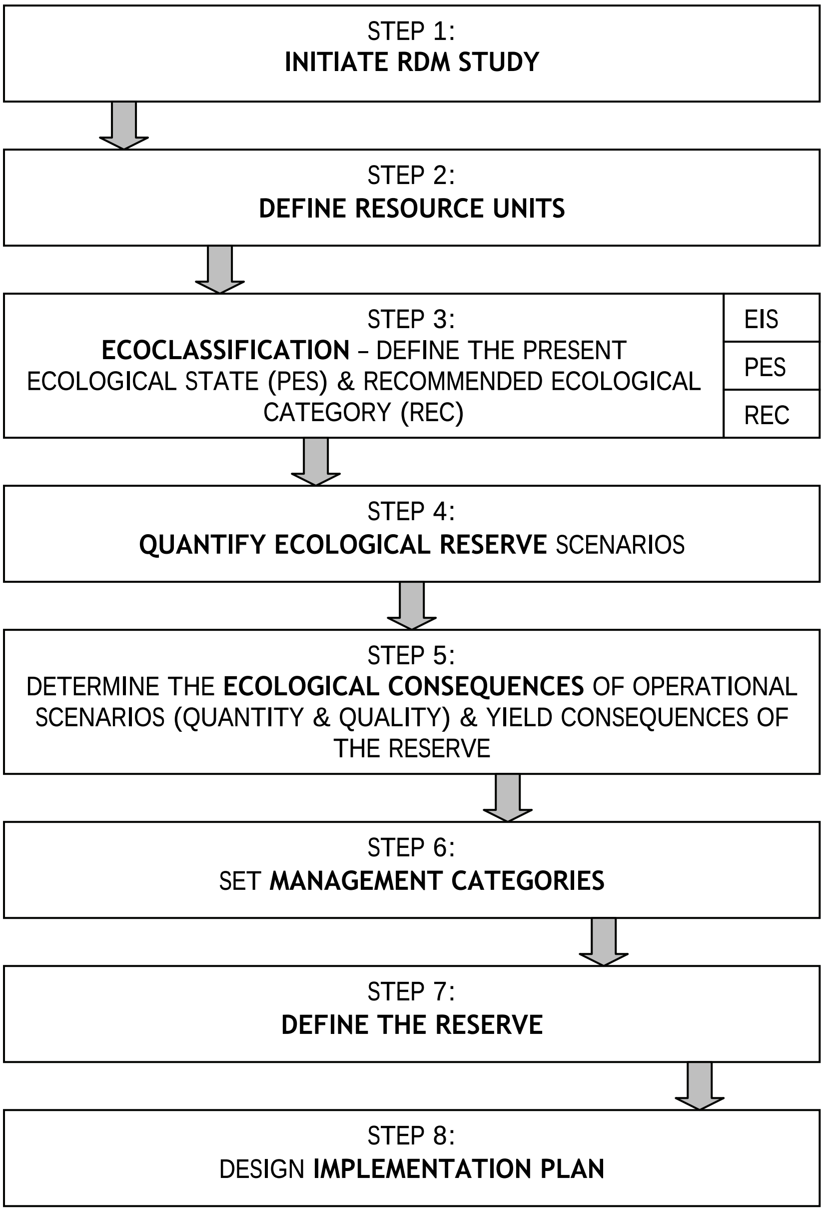

Figure 3: The generic 8 step procedure for Reserve Determination studies

The study was initiated by the DWA, CD:RDM, after receiving a Water User Licence application for the above-mentioned pumped storage scheme, which is expected to affect water yield and the ecological integrity of downstream rivers and wetlands.

A Comprehensive Reserve Determination study is currently underway on the rivers of the Upper Vaal Water Management area (within which the Bedford Dam is located) and Reserve studies have been previously undertaken for the Tugela catchment (where the Braamhoek Dam is located). However, no wetland Reserve had previously been determined for the Bedford wetland. No Reserves exist for any similar wetlands nearby, so extrapolation was not possible, and a new study was thus required. The approach employed in this Rapid wetland Reserve Determination followed the recently completed Rapid Reserve methods for wetlands (Rountree (ed), 2010). A Rapid Reserve Determination study was conducted for the following reasons:

- Funding and time were limited;
- Although the dam presents a potential large threat to the condition of the wetlands, Eskom has undertaken an extensive, protracted EIA and additional ecological investigations in order to mitigate its impact, and there is thus a wealth of existing information for the site;
- Although the wetland is in a very good condition, the size of the wetland is small and thus it would not be appropriate to conduct a higher confidence, more expensive study for such a small area. The wetland does not have any formal protection or provincial or national conservation status at present.

3 RESOURCE UNITS AND SITE SELECTION

3.1 Description and Classification of the wetland

Within the defined study area, the wetland/s should be described and classified (by HGM types) to enable Resource Units to be delineated. In the case of Rapid Reserve studies, the study area would generally be small and thus the number of Resource Units is not likely to be high.

The study area encompasses a reach from the site of the Bedford Dam until the wetland's confluence with the Wilge floodplain approximately 5km downstream. This is dominated by a long unchannelled valley bottom unit, with a short channelled section close the confluence and small seepage wetlands entering from the surrounding hillslopes (Figure 4). The unchannelled valley bottom HGM unit is located across the width of a relatively wide valley bottom and is dominated by grasses, sedges and *Phragmites* (Figure 5).

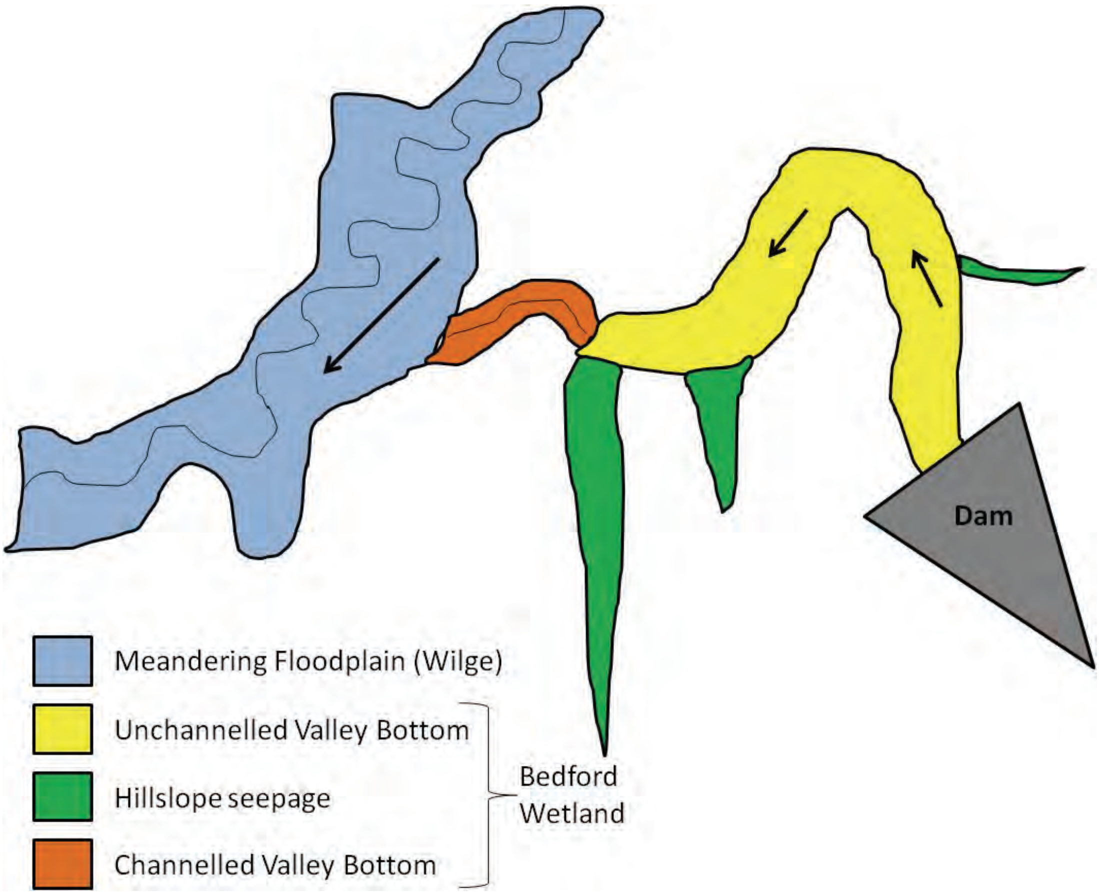

Figure 4: Sketch of the main HGM wetland units in the Bedford Wetland, with arrows indicating direction of flows. Also indicated is the downstream Wilge floodplain.

Field investigations strongly suggest that the wetland is maintained predominately by surface-water (overland flows and shallow interflow in the soil), and that groundwater (derived from underlying geology) contributions are minimal. The reasons for this are that:

- Peat formation in the reach is generally weakly developed[1], suggesting that groundwater contribution is not strong. Deep, highly organic peat deposits develop in wetlands which are driven by continuous groundwater inputs (such as the wetlands associated with dolomites elsewhere on the Highveld). Along the transect examined in this study, only shallow (0.5m depth) organic soils were found; and these had high clay content.
- Dam excavations indicate impervious clay layers below the Phragmites (Gerhardus Muller, *pers comm*.), and upper layers are also clay rich. This indicates that the wetland sits on an impervious clay bed (so groundwater entering from below would be impeded); whilst the mineral content of the upper horizons indicates surface flows or floods continuing to deposit sediment across the wetland.
- The river diversion that was constructed for the dam construction assumed that the material was peat (and therefore relatively pervious), but during construction it was clear that throughflow is very low due to presence of impervious clays in the wetland soils. Again, evidence for extensive peat development is not supported.
- Grouting of the dam is only going to be around the base of the dam wall, again suggesting limited groundwater inflows and limited pervious geology.
- Comments from Environmental Control Officer on the site indicated that vegetation vigour is strongly related to rainfall patterns. This indicates that a dependency (and dominance) of surface water (rainfall and surface runoff) rather than a strong groundwater supply.

Groundwater contributions therefore appear to be negligible for the reach of the Bedford Wetland below the dam site and were not considered further in this study.

3.2 Resource Units

Resource Units delineate reaches or zones of similar biophysical attributes such as geological, geomorphological and vegetation characteristics, as well as the type and intensity of catchment landuse which the system is exposed to. The following information sources are usually used to aid in the delineation of the Resource Units:

- 1:50 000 topographical maps;
- Google Earth and other high resolution imagery of the study area; and
- EcoRegions.

The study site encompasses a small area between the main impact site (the dam) and the confluence of the wetland with the very large Wilge Floodplain. This is about 5 kilometres long; most of which is dominated by a large unchannelled valley bottom

[1] It is important to note however, that at a localised area upstream of our site, shallow but old (13 000 year old) weakly developed peats have been found. Whilst the peats indicate permanent saturation, the role of groundwater was not considered responsible for the permanent wetland, but rather by high rainfall and storage of the wetland (Norstrom et al., 2009). Even so, this particular pocket of peat is located within the dam basin, and thus soon to be permanently drowned by the reservoir, so is not really relevant to the Resource Unit of this study.

unit. Landuse, Ecoregion and vegetation characteristics are the same throughout the reach. A single Resource Unit was thus identified for this study.

3.3 Focal wetland unit and EWR site selection

Within the Resource Unit, the main HGM wetland types are (Figure 4):

- Unchannelled valley bottom unit (dominant);
- Channelled valley bottom unit
- Hillslope seepage wetlands along tributary arms.

The unchannelled valley bottom unit would be most sensitive to the expected reduced flows associated with the new dam. This is because even small flows in this section of the wetland spread out and maintain a disproportionately wide area of permanent and seasonal wetland area (Figure 5). It is also the largest (dominant) HGM type within the Resource Unit. The unchannelled valley bottom unit was thus selected as the representative, focal HGM unit for more detailed field assessments.

Figure 5: The wide permanent wetland area is dominated by *Phragmites australis* reeds.

Within the large unchannelled valley bottom focal HGM wetland uni, a cross-section location (S28^{o} 13' 54.5", E29^{o} 34' 50.1") was selected which met the following criteria:

- Representative of the focal wetland unit (unchannelled);
- High diversity of wetland vegetation units present (to provide as many potential flow requirement cues as possible);
- Ability to generate reliable hydraulics from the site; and
- Access to the site is reasonable.

Selection of the site of the cross-section (Figure 6) is thus a trade-off between access to the site, reliability of hydraulics that can be generated at the site and the diversity and reliability of ecological cues for flow determination.


Figure 6: A cross-section (cleared path on the right) was surveyed through a section of the unchannelled valley bottom HGM unit. This site had a variety of vegetation units present.

4 PRESENT ECOLOGICAL STATE AND RECOMMENDED ECOLOGICAL CATEGORY

A single day of field assessments was undertaken on the 27th January 2010. Reference Conditions and Present Ecological State (PES) were assessed for each ecological component (Geomorphology, Hydrology, Water Quality, Vegetation and Diatoms) and the relevant Ecological Category identified (Table 1). A summary of the results is provided below. Detailed results from each component assessment are available in the specialist reports in the appendices. Importantly, this assessment was undertaken for the section of the wetland from the dam to the confluence with the Wilge floodplain (i.e. the wetland areas within the dam basin, which are to be lost as the reservoir fills, were not considered).

Table 1: Descriptions of the A-F Present Ecological State (PES) categories (after Kleynhans, 1996, 1999).

Ecological Category	PES % Range	Description of the Ecological Category
A	90-100%	Unmodified, natural.
B	80-90%	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	60-80%	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	40-60%	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	20-40%	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	0-20%	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

4.1 Geomorphology

The method used in this assessment is described in Rountree and Malan (2010), and detailed results are provided in Appendix

4.1.1 Description of the Reference Conditions

The reach (from the Bedford Dam wall to the confluence with the Wilge River) was historically a weakly channelled to unchannelled wetland with a short channelled wetland section close to the Wilge River.

4.1.2 Description of the Present Ecological State

PES was assessed using the WET-Health Level 1 assessment (MacFarlane et al., 2008). This indicated that the PES was in an A category; although due to erosion and incision associated with a headcut in the lower section of the wetland (Figure 7), it is felt that the PES is better categorised as an A/B category. The EC for

Geomorphology has thus been adjusted to an A/B. The headcut has been stabilised by engineering works and the trend is thus stable.

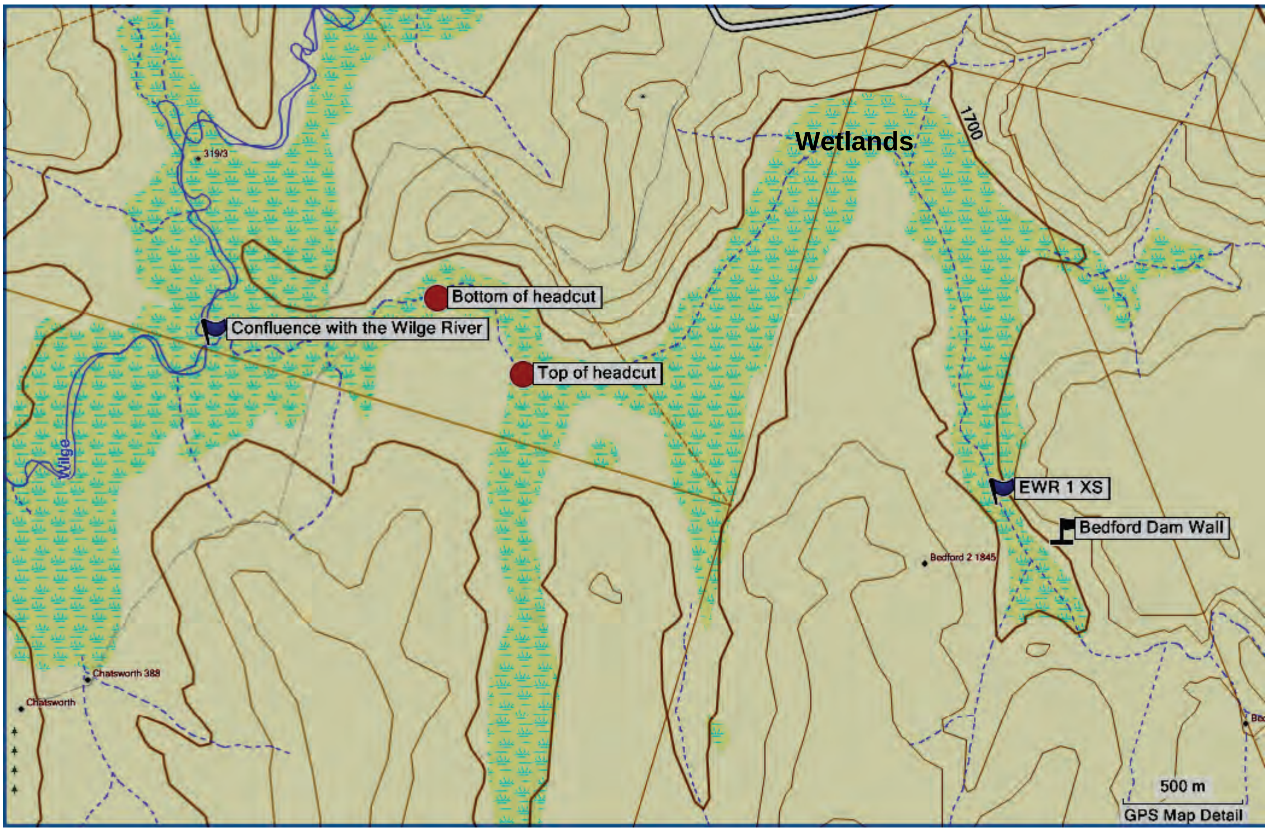

Figure 7: Map of the study area indicating the location of the dam wall; headcut (top and bottom) and cross-section (EWR 1 XS) locations. The shaded area indicates the wetland area.

4.2 Hydrology

The method used in this assessment is described in Rountree and Malan (2010),

4.2.1 Description of the Reference Conditions

This is primarily a surface-water driven wetland system – the wetland is maintained by water from rainfall, surface runoff and interflow in the soil. It is expected that groundwater contributions in the sections of the wetland below the dam are very limited. The catchment was grassland under Reference conditions and remains so currently.

4.2.2 Description of the Present Ecological State

PES was assessed using WET-Health Level 1 assessment (MacFarlane et al., 2008). This indicated that the PES was in an A category A. Whilst at the catchment level grazing may have increased flood peaks slightly, and within the wetland headcuts and the resultant incised channel have resulted in some drainage of the lower wetland, these impacts are localized and have not significantly altered the state of the overall wetland. The trend is stable, since the significant headcut within the wetland has been stabilised by a Working for Wetlands rehabilitation structure.

4.3 Water Quality

The method used in this assessment is described in Rountree and Malan (2010), and detailed results are provided in Appendix A6: WATER QUALITY.

4.3.1 Description of the Reference Conditions

No historical data are available to describe the Reference Condition water quality of the wetland itself. However, given the limited catchment landuse activities, the present day water quality of the system is considered to be little changed from the Reference Condition.

4.3.2 Description of the Present Ecological State

The water quality in the wetland is considered to be in an “A” category. Results from the diatom sampling largely support this result. The PES class as derived from diatoms was A/B (see below). An interesting discrepancy between the results was that the diatoms indicated acidic conditions, whereas the limited water quality data indicates that the streams supplying the wetland have neutral to alkaline conditions. The reason for this discrepancy is unknown and requires further investigation.

Paths and roads may have a minor impact on suspended load, but generally the current construction impacts are well-contained. The conditions are expected to remain stable, but this is dependent on good quality of water from the Bedford Dam (and thus from the Braamhoek Dam) being maintained.

4.4 Vegetation

The method used in this assessment is described in Rountree et al. (2010), and detailed results are provided in Appendix A4: VEGETATION ASSESSMENT.

4.4.1 Description of the Reference Conditions

The vegetation evolved under indigenous grazers and fire and is likely to have been entirely herbaceous, comprising mixed Phragmites and mixed sedge in permanent areas and a high diversity of sedges and grasses in seasonal areas. A fairly low abundance of pioneer plants and no alien species would have been present

4.4.2 Description of the Present Ecological State

There are several minor non-flow related impacts across the wetland, such as:

- A very slight increase in abundance of pioneer species due to previous heavy livestock grazing,
- A significant increase in abundance of pioneer species due to previous heavy livestock grazing and trampling. However many native hydric species still persist; and
- A significant increase in abundance of pioneer and terrestrial species around the desiccated area of the wetland affected by headcut erosion.

Despite this, the PES was calculated to be in an A category using WET-Health Level 1 (Macfarlane et al., 2008).

The trend is stable or slightly positive due to erosion stabilisation and the recently reduced grazing pressures in the catchment.

4.5 Diatoms

The method used in this assessment is described in Rountree and Malan (2010), and detailed results are provided in Appendix

4.5.1 Description of the Reference Conditions

It is expected that the majority of species would have an affinity for clean fresh waters with low electrolyte content and therefore species with sensitivity values above three would be expected in high abundance.

4.5.2 Description of the Present Ecological State

The PES was set at an A/B category. The biological water quality at this site was of high quality; dominant species all have a preference for oligotrophic, acidic to circumneutral waters with low electrolyte content (Taylor et al., 2007). The diatom based ecological water quality indicates that the water is acidophilous (water has a pH mainly below 7; for this site estimated at 6.1) with very little organically bound nitrogen and continuously high oxygen saturation. Salinity levels were very low and the site was oligotrophic and unpolluted. The majority of the species prefer the current conditions and it is evident that this site is very close to reference state. There were some species present that prefer increased levels of organics, nitrogen and phosphates, but these occurrences were very low and their presence is most probably attributed to natural wetland processes. Although *Hantzschia amphioxys* was present in very low abundance, this species usually occurs in crevices and rock ledges and therefore the presence of this species could indicate runoff from higher lying areas. The presence of *Achnanthes exigua*, albeit in very low abundance, may indicate that before the flood conditions (at the time of the site survey) the water was probably standing for some time.

4.6 Overall Weighted Score for Wetland PES

The PES scores for ecological components assessed all indicated that the site is close to natural conditions; with all PES scores in either A or A/B Ecological Categories (Table 2). A weighted average (weighting influenced by confidence) was determined to provide a PES score for the overall wetland condition. This indicated that the ***wetland is in an "A" Ecological Category***, meaning that the wetland is largely unmodified and can be considered to be in a natural condition.

Table 2: PES scores, methods and trends for the ecological components assessed, and weightings and result of the overall PES score.

Ecological Component	Weight (%)	PES estimation method	Trend	PES EC	Score (%)
Hydrology	100	WET-Health level 1	stable	A	95
Geomorphology	100	WET-Health level 1 (but adjusted down from A to A/B)	stable	A/B	91
Vegetation	100	WET-Health level 1	stable	A	93
Diatoms	50	Rountree et al., 2010	stable	A/B	90
Water Quality	50	Qualitative estimation (Rountree et al., 2010)	stable	A	95
				OVERALL PES SCORE (%):	**93**
				OVERALL PES EC:	**A**

5 IMPORTANCE AND SENSITIVITY

The Importance and Sensitivity assessment is undertaken to rank water resources in terms of:

- Provision of goods and service or valuable ecosystem functions which benefit people;
- biodiversity support and ecological value; and/or
- Reliance of subsistence users (especially basic human needs uses);

Water resources which have high values for one or more of these criteria may thus be prioritised and managed with greater care due to their ecological importance (for instance, due to biodiversity support for endangered species), hydrological functional importance (where water resources provide critical functions upon which people may be dependent, such as water quality improvement) or their role in providing direct human benefits (such as meeting some of the basic needs of poor people who depend directly on the water resource).

A rapid scoring system to evaluate

- Ecological Importance;
- Hydrological Functions; and
- Direct Human Benefits

has been developed to provide a scoring approach for assessing these aspects of importance and sensitivity of wetlands. These scoring assessments for these three aspects of wetland importance and sensitivity have been based on the requirements of the NWA, the original Ecological Importance and Sensitivity assessments developed for riverine assessments (DWAF, 1999), and the work conducted by Kotze et al. (2008) on the assessment of wetland ecological goods and services (the WET-EcoServices tool).

These rapid assessments were completed in a workshop environment using the expertise of the entire team. ***Importance and Sensitivity is HIGH*** primarily due to the hydrological and functional roles provided by the wetland (Table 3). It has moderate importance in terms of ecological importance and sensitivity, and a low value for direct human benefits.

Table 3: Importance and Sensitivity ratings for the Bedford Wetland

Bedford Wetland	**Importance Category**[1]	Confidence (1-5)
ECOLOGICAL IMPORTANCE & SENSITIVITY	**Moderate (2.3)**	2.8
HYDROLOGICAL/FUNCTIONAL IMPORTANCE	**High (3.4)**	3.0
DIRECT HUMAN BENEFITS	**Low (1.2)**	3.0

[1] **None** (0-1): Rarely sensitive to changes in water quality/hydrological regime;
Low (1-2): One or a few elements sensitive to changes in water quality/hydrological regime;
Moderate (2-3): Some elements sensitive to changes in water quality/hydrological regime;
High (3-4): Many elements sensitive to changes in water quality/ hydrological regime;
Very High (4): Very many elements sensitive to changes in water quality/ hydrological regime

5.1 Ecological Importance

The moderate Ecological Importance and Sensitivity can primarily be attributed to the presence of rare biota (Table 4). The Environmental Control Officer confirmed that the highly endangered White-winged flufftail birds have been heard on the site, and wattled cranes are known to utilize the wetlands and have recently breed successfully at the site. Altogether more than 200 bird species have been reported at the site.

Previous studies indicate that two red-data flowers (*Kniphofia spp.*) are likely to occur within the wetlands (Wetland Consulting Services, 2005), and the threatened Oribi antelope occurs on the site.

Whilst there is currently no formal protection status of the wetland, the land is to be protected though the establishment of the Bedford Wetland Park. The vegetation type is not endangered; and a number of similar, albeit generally smaller, wetlands are present in the area, so regional rarity is low.

Low flows are thought to maintain much of the extensive permanent unchannelled wetland areas, and they are expected to be moderately sensitive to nutrient inputs.

5.2 Hydrological and Functional Importance

The high hydrological and functional importance is attributed to the flood attenuation, sediment trapping and nitrate assimilation functions that this unchannelled wetland can provide (Table 5). It also plays a moderate carbon storage role.

5.3 Direct Human Benefits

The wetland has low importance in terms of direct human benefits (Table 6). There are no subsistence farmers dependent on the wetland, limited grazing or harvesting under the current ownership, but some education and tourism value is being developed.

Table 4: Ecological Importance and Sensitivity ratings for the Bedford Wetland

ECOLOGICAL IMPORTANCE AND SENSITIVITY			
Ecological Importance	Score (0-4	*Confidence*	**Motivation**
Biodiversity support	2.33	*3.00*	
Presence of Red Data species	4.00	*4.00*	White-winged flufftails have been heard on site; two red-data Kniphofia spp are likely to occur within the wetlands; Wattled cranes utilize the wetlands.
Populations of unique species	-	*2.00*	None known
Migration/breeding/feeding sites	3.00	*3.00*	White-winged flufftails use as migration site; Wattled cranes possibly breeding in lower sections
Landscape scale	2.30	*3.00*	
Protection status of the wetland	3.00	*4.00*	Eskom private land - protected as the Bedford Wetland Park
Protection status of the vegetation type	1.00	*3.00*	Lots protected; mostly used for pasture
Regional context of the ecological integrity	2.00	*2.00*	Other similar, good condition systems
Size and rareity of the wetland type/s present	3.00	*3.00*	Large for its type, but not rare
Diversity of habitat types	2.50	*3.00*	Unchannelled VB, seeps, some channelled sections
Sensitivity of the wetland	2.33	*2.33*	
Sensitivity to changes in floods	1.50	*2.00*	Not driven by floods
Sensitivity to changes in low flows/dry season	4.00	*3.00*	Low flows maintain the extensive permanent unchannelled wetland areas
Sensitivity to changes in water quality	1.50	*2.00*	Moderately sensitive to nutrient inputs
ECOLOGICAL IMPORTANCE & SENSITIVITY	**2.3**	*2.8*	

Table 5: Hydrological and Functional Importance ratings for the Bedford Wetland

HYDRO-FUNCTIONAL IMPORTANCE			Score (0-4)	*Confidence (1-5)*	Motivation
Regulating & supporting benefits		**Flood attenuation**	4	*5*	Diffuse flow through the extensive unchannelled wetland
		Streamflow regulation	2	*3*	Slow discharge
	Water Quality Enhancemer	*Sediment trapping/Erosion control*	5	*5*	Excellent sediment trapping abilities
		Phosphate assimilation	1.5	*2*	Very limited net removal.
		Nitrate assimilation	5	*4*	Very high potential for nitrate assimilation
		Toxicant assimilation	3	*3*	Metal-uptake would be high; herbicide and pesticide trapping would be high
		Carbon storage	3	*3*	Organic-rich soils (peats?) present in the wetland
	Hydro-Functional Importance		**3.4**	*3.0*	

Table 6: Direct Human Benefits ratings for the Bedford Wetland

DIRECT HUMAN BENEFITS		Score (0-4)	Confidence (1-5)	Motivation
Subsistence benefits	*Water for human use*	*1*	*2*	One homestead uses water from the lower wetland
	Harvestable resources	*1*	*3*	Grazing
	Cultivated foods	*0*	*4*	No cultivation within the wetland
Cultural benefits	*Cultural heritage*	*0*	*3*	None known
	Tourism and recreation	*3*	*3*	Birding, potential for tourism now that access is easy
	Education and research	*2*	*3*	Lots of research associated with the site, but mostly this is associated with the EIA and spinoff studies
DIRECT HUMAN BENEFITS		**1.2**	*3.0*	

6 RECOMMENDED ECOLOGICAL CATEGORY

The PES of the wetland (the reach downstream of the dam until the Wilge confluence) is in an A category and the trends; assuming careful flow management by the upstream dam operators; are stable. Importance and Sensitivity is High in terms of hydrological and functional aspects; and moderate for Ecological Importance and Sensitivity, whilst Direct Human Benefits are considered to be low.

The Recommended State is to attempt to maintain the PES of the remaining wetland areas below the dam (since all wetland areas within the upstream dam basin will be drowned and no longer functional). The REC is thus an “A” category.

7 ECOLOGICAL WATER REQUIREMENTS TO ACHIEVE THE REC

7.1 Determining Ecological Requirements for the REC

The objective of any Reserve determination is to estimate how much water, and of what quality, should remain in the system in order to maintain a particular desired state of the water resource.

A combination of hydraulic and hydrological approaches enabled ecological cues to be translated into volumetric water requirements. These were used to determine the flows required to maintain the Bedford wetland in its “A” REC.

7.1.1 Baseflow determination

Hydrological modelling was used to determine the wet and dry season baseflow requirements (the flows required to compensate for evaporative demand from the wetlands). The baseflows are required to maintain wet soil conditions in order to maintain the vegetation, which in turn stabilizes the sediment of the wetland and inhibits erosion and incision. If the wetland were to erode, then the biodiversity support and flood attenuation capacity of the wetland would be severely reduced.

The objectives of the dry season baseflows are to maintain saturated soils across the estimated 36ha of permanent wetlands between the Bedford Dam wall and the junction of the first major tributary – those wetlands which will be directly dependent on outflows of the dam; as no inflows from small tributaries will be able to mitigate the reduced flows. Even with the dam trapping the upstream runoff, more than half the catchment area of the Bedford wetland remains unimpacted and thus natural flow conditions exist for the large tributary wetlands and this would ameliorate the flow reduction changes resulting from the dam and thus ameliorate the impacts

These flows should also be able to maintain the breeding habitat required for wattled cranes (shallow inundated sections of the lower wetland in the dry season).
These water requirements were estimated using A-pan evaporation rates and hence represent a conservative estimate of the water requirements for this season. The flows identified from this approach are close to natural for the low flow season (Table 7).

Objectives for the wet season baseflows are similarly to maintain saturated soils and water in the channels; and to allow for saturation of both permanent and seasonal wetland areas and thus persistence of wetland vegetation. For wet season baseflows, the rainfall has been factored into the evaporation demands.

7.1.2 Flood flow determinations

At the EWR site, a cross-section through an unchannelled *Phragmites*-dominated section was surveyed (Figure 8) and discharge estimated at the time of the survey.

The discharge estimate was within 10% of the indicated discharge from the upstream dam.

This hydraulically rated cross-section was used to identify the flow requirements linked to ecological cues along the cross-section. Vegetation and soils were the primary ecological indicators.

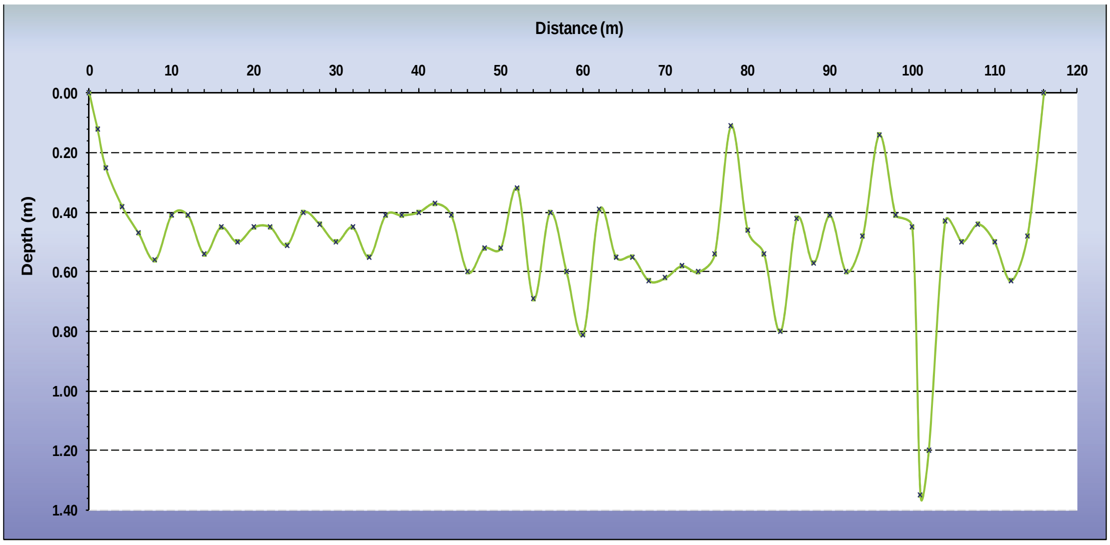

Figure 8: Cross- section of the Bedford Wetland at EWR 1 (depth indicates depth from water surface to bed at the time of the survey on 27 January 2010).

Two types of floods were identified as being required to maintain the current condition of vegetation and associated wetland habitats. These floods are required in addition to the baseflows, since their functions are not merely to offset evapotranspiration (as with the baseflows), but to achieve a level of wetland habitat maintenance (for the smaller inundation events) and to allow for some scour of the weakly developed channels (in the case of the larger, more infrequent flushing events).

Inundation events, the one-day floods of 1400 litres/s in November and again in January, were identified as being required to:

- Inundate and flood the wetland surface to create habitat suitable for critically endangered wetland associated biota such as White-winged flufftails – these birds prefer the shallowly inundated mixed sedge and transitional sedge/*Phragmites* habitats. An average of 1.4m^3/s is estimated to be sufficient to achieve this function.

A flood of this size should occur in October/November; and another to be provided in December/January. The duration of these flood events is one day each. During drought years these floods could be reduced to a single flood (i.e. either Oct/Nov or Feb/March).

The larger “flushing event” flood is required to:

- Flush and maintain the weakly-developed channels within the wetland;
- Maintain the heterogeneity of physical and vegetation habitats through localized scour and deposition.

- Possibly flush organic carbon out of wetland into downstream reaches where it can increase productivity.

These floods would only occur once in two to once in five years and would probably occur towards the end of the wet season when the catchments are saturated. These large floods would fill much of the valley bottom, and are likely to inundate the width of the valley bottom. We estimate that the magnitude of the flood associated with this flood class is approximately $4m^3/s$.

The baseflows and intra-annual floods expected to maintain the REC of an A (Table 7) for this wetland accounts for 65.6% of the natural MAR. Although this appears high, the unchannelled nature of the wetland requires relatively large discharges to maintain saturation, and small reductions in discharge would equate to large declines in wet areas due to the shallow, unchannelled nature of flow. It has been demonstrated that in small river tributaries a disproportionately large percentage of the MAR is required to maintain the PES, and we expect that the results of this study reiterate the similar findings in riverine EWR studies.

The larger (1:2 to 1:5 year return interval) floods have not been included in the EWR's. The occurrence of these events would be linked to the intense rainfall events within the subcatchment and it is assumed that these events would be released from the dam when these intense rainfall events occur.

Table 7: Baseflow and flood requirements for the Bedford Wetland downstream of the dam. The "Scenario" column represents the minimum flows that had been proposed in the WULA.

Month	NATURAL	RECOMMENDED ECOLOGICAL CATEGORY (A)					SCENARIO
		Base-flow	***Floods***		*% of monthly natural*	***Motivation for flow***	Release from Bedford Dam as proposed in the current WULA
			Size	Number, (duration)			
Oct	80	**22**			*27%*	Evapotranspiration offset to maintain wet soils	23
Nov	136	**100**	**1400**	1 (1 day)	*100%*	Flood and high baseflows required for vegetation and to create habitat for wetland-dependent birds and the invertebrates upon which they feed.	28
Dec	152	**130**			*85%*	High baseflows required to maintain the wide permanent wetland areas.	33
Jan	178	**130**	**1400**	1 (1 day)	*97%*	Flood and high baseflows required for vegetation and to create habitat for wetland-dependent birds and the invertebrates upon which they feed.	43
Feb	204	**130**			*64%*	High baseflows required to maintain the wide permanent wetland areas.	58
Mar	144	**19**			*13%*	Evapotranspiration offset to maintain wet soils	52
Apr	84	**17**			*20%*	Evapotranspiration offset to maintain wet soils	45
May	31	**14**			*45%*	Evapotranspiration offset to maintain wet soils	35
Jun	17	**12**			*71%*	Evapotranspiration offset to maintain wet soils	28
Jul	13	**13**			*100%*	Evapotranspiration offset to maintain wet soils	25
Aug	16	**16**			*100%*	Evapotranspiration offset to maintain wet soils	22
Sept	34	**22**			*65%*	Evapotranspiration offset to maintain wet soils	22

All discharges in litres per second, indicating mean monthly flows (note: floods in November and January reflect daily average flows in litres/s).

8 ECOLOGICAL CONSEQUENCES OF PROPOSED OPERATIONAL SCENARIO OF BEDFORD DAM

A Water User Licence (WULA) has already been granted for the proposed Bedford Dam. The proposed minimum releases included in that WULA (Table 4) were considered as a possible scenario for the future flows in to the Bedford wetland.

These proposed minimum releases (Table 7) do not make provision for any high flows or floods. Examination of the ecological cues at the site led the Reserve team to conclude that the prolonged absence of wet season high flow conditions (freshette floods of approximately 1.4 m^3/s) would cause some desiccation of the wetland and lead to a decline in the Present Ecological Condition of the wetland over a period of 5 to 10 years.

This risk of desiccation could cause

- A change in vegetation cover and decline of wetland species;
- An increased risk of erosion in the wetland due to reduced vegetation vigour and cover;
- An increased risk of fires if the organic-rich soils are not saturated; and
- A decline in wetland habitats favoured by red data bird species.

The scenario (i.e. the proposed releases as indicated in the existing WULA) would cause a decline in the PES to a B within 5 to 10 years, with expected associated declines in biodiversity support functions. ***The proposed flows as indicated in the existing WULA are thus insufficient to maintain the PES and achieve the REC.***

9 DWAF MANAGEMENT CLASS DECISION MAKING PROCESS

Until the CMA's are established, the REC should be proposed as the interim Reserve category.

10 ECOSPECS AND MONITORING

Ecological Specifications relating to the REC, and the monitoring procedures to assess these, are discussed below.

Monitoring of releases (daily with reviews on an at least annual basis):

- Monitoring of the daily discharges from the dam (from the stream diversion pipe at present and the dam discharges when construction is complete) should be implemented to ensure that the requested flows for the Ecological Reserve are provided.

Monitoring of channel condition (bi-annual):

- No erosion gullies (no incision of channels or headcuts) can be permitted to develop within the wetland. This is an unchannelled wetland and is very sensitive to erosion and incision.
    - To this end, suitable energy dissipation structures should be built below the dam to reduce scour and inhibit erosion in the wetland. These dissipation structures should ensure that the water released flows in to the wetland in a predominantly unchannelled fashion, since the promotion of concentrated or channelized flows (such as by the construction of notched weirs or piped releases) would be highly undesirable as these are likely to encourage channelization.

- Deposition of alluvial fans associated with excessive deposition of sediments is undesirable. This is a possible, probably low risk, consequence of elevated suspended sediments from the dam water.
- Monitoring of the permanent zone of the wetland to ensure that these soils remain saturated during the dry season

Monitoring of biota (at least bi-annual):

- Recommend generating a baseline wetland vegetation distribution map and then use this for monitoring with the aim of maintaining the proportions of reeds and sedges. *Phragmites* would possibly encroach if enhanced sediment deposition occurs associated with dam releases, and this risk needs to be monitored and prevented if beginning to occur.

- It is not recommended that invertebrate monitoring using the South African Scoring System (SASS) be used within wetlands. This monitoring tool was developed for riverine systems and is highly inappropriate for wetlands, since the more eroded (channelized or "riverine") the wetland becomes, the better the SASS scores that result. The tool thus presents a very misleading view of the ecological condition of the wetland.

- It would be useful if the monitoring programme for vegetation noted if the full extent of sedges along the EWR cross-section are indeed inundated during the wet season by the 1400 l/s freshette floods. This would then ensure that the expected physical habitat conditions are being provided by the requested flows.

11 RECOMMENDATIONS

The ***existing WULA*** for the Bedford/Braamhoek Dam ***should be revised or amended to include intra-annual floods*** identified in this study. These are required to maintain the wetland and thus to ensure that the REC can be achieved

Below the dam, suitable energy dissipation structures should be built to reduce scour and inhibit erosion in the wetland. These dissipation structures should ensure that the water released flows in to the wetland in a predominantly unchannelled fashion to minimise the risk of erosion in the wetland downstream of the dam.

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A1: HYDROLOGY AND WATER RESOURCES SCENARIO MODELLING

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Introduction

Eskom is in the process of constructing a pumped storage scheme in the vicinity of De Beers pass on the Natal Drakensberg escarpment located between the towns of Harrismith and Ladysmith. This scheme includes the construction of two dams, the Braamhoek Dam located at the bottom of the escarpment and the Bedford Dam located on the escarpment. The latter dam is located immediately upstream of an important pristine wetland and hence the impact of this dam (with its associated operating rule) needs to be assessed and recommendations made as to how the dam can be operated to limit these impacts to within acceptable levels.

Location of the study area

The Bedford Dam catchment is located on the Natal Drakensberg escarpment within the C81A quaternary catchment. See **Figure 1**. The elevation of the catchment is approximately 1 700 m above mean sea level. The catchment area of the dam is given in the report by the University of KwaZulu-Natal (Smithers et al.) as 12.6 km^2.

Hydrology of the study area

The catchment of the Bedford Dam, as well as the catchment of the downstream wetlands are ungauged and hence there will always be a high degree of uncertainty relating to the hydrology of this catchment. Two hydrological studies have been carried out on this catchment, one by the CSIR (CSIR, Undated) using the WRSM2000 model and the other by the University of KwaZulu-Natal (Smithers et al., 1998) using the ACRU model. The widely diverging hydrologies emanating from these two studies is indicative of the problems associated with predicting flow in ungauged catchments. See **Table 1.**

Table 4: Hydrological statistics of Bedford Dam catchment

Study	Mean Annual Precipitation (mm/annum)	Mean Annual Runoff	
		million m^3/annum	mm/annum
UKZN (Acru model)	960	8.8	699
CSIR (WRSM2000)	880	1.5	169

The UKZN study carried out a thorough analysis of rainfall data in the area and although there are no rainfall gauges within the catchment itself, they were able to deduce that rainfall within the Bedford Dam catchment is significantly higher than the average rainfall for the quaternary catchment. This is to be expected due to the catchment's high elevation relative to the quaternary catchment. The CSIR study, on the other hand, accepted the average MAP of the C81A catchment.

The approach taken in this wetland study was as follows:
The MAP derived as part of the UKZN study was accepted, but not their runoff of 699 mm/annum which is far outside of the runoff estimates based on calibration against observed records in the region. A graph of runoff vs. MAP for quaternary catchment in the region was prepared using WR2005v data from which a clear relationship is apparent. See **Figure 1.** Using this relationship and an MAP of 960 mm/annum, a runoff in the order of 230 mm/annum seem was selected as being a reasonable estimate. The WR2005 naturalise time series for the C81A quaternary catchment was then scaled in order to achieve this runoff from a

catchment area of 12.6 km^2. The hydrology derived in this manner is summarised in **Table 2** while the time of hydrology used in the study is provided in **Table 3**.

Table 5: Hydrological parameters

Parameter	**Bedford Dam**
Quaternary catchment	C81A
MAP	960 mm/annum
MAR (mm/annum)	230
Catchment area	12.6
MAR	2.8 million m^3/annum

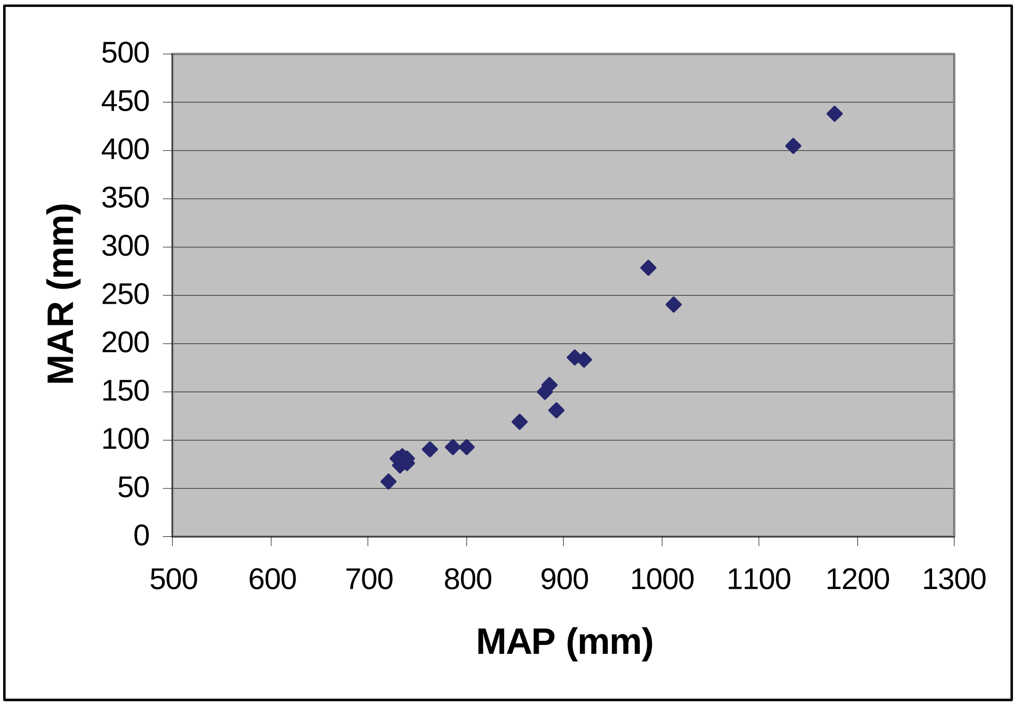

Figure 9: Rainfall/runoff relationship of Natal Drakensberg region (from WR2005)

From Figure 1, the runoff from the Bedford catchment is in the order of 230mm/annum. Based on a catchment area of 12.6 km2, this implies a MAR of 2.8 million m^3/annum. The WR2005 hydrology for the C81A catchment was scaled to provide a flow time series for the catchment. See Table 3.

Table 3: Hydrological parameters

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	0.89	0.45	0.04	0.06	0.36	0.51	0.19	0.02	0.02	0.02	0.01	0.02	2.59
1921	0.02	0.88	1.33	0.51	0.11	0.07	0.03	0.02	0.03	0.02	0.04	0.04	3.1
1922	0.63	1.39	1	0.61	0.69	0.33	0.02	0.02	0.04	0.04	0.03	0.01	4.81
1923	0.02	0.01	0.03	0.3	0.36	0.4	0.34	0.02	0.02	0.02	0.01	0.04	1.57
1924	0.09	0.41	0.44	0.13	0.12	1.7	1.68	0.1	0.04	0.02	0.02	0.02	4.77
1925	0.04	0.08	0.07	0.39	0.41	0.09	0.07	0.02	0.03	0.02	0.02	0.05	1.29
1926	0.08	0.12	0.18	0.16	0.24	0.23	0.05	0.02	0.01	0.03	0.03	0.01	1.16
1927	0.36	0.37	0.19	0.21	0.08	0.28	0.25	0.02	0.02	0.02	0.02	0.1	1.92
1928	0.14	0.06	0.29	0.4	0.2	0.21	0.16	0.03	0.09	0.12	0.06	0.84	2.6
1929	0.85	0.53	0.6	0.44	0.36	0.08	0.07	0.04	0.02	0.02	0.02	0.02	3.05
1930	0.03	0.02	0.08	0.76	0.73	0.07	0.06	0.05	0.02	0.03	0.02	0.01	1.88
1931	0.02	0.04	0.05	0.04	0.91	0.95	0.07	0.04	0.04	0.02	0.01	0.01	2.2
1932	0.01	0.04	0.1	0.09	0.05	0.08	0.06	0.03	0.01	0.02	0.01	0.01	0.51
1933	0.01	0.5	0.79	1.77	1.52	0.1	0.07	0.13	0.12	0.07	0.17	0.14	5.39
1934	0.09	0.78	1.53	0.81	0.06	0.33	0.33	0.04	0.02	0.02	0.01	0.02	4.04
1935	0.02	0.01	0.02	0.04	0.29	0.44	0.19	0.17	0.17	0.02	0.01	0.01	1.39
1936	0.04	1.12	1.14	0.56	0.8	0.3	0.03	0.01	0.01	0.01	0.01	0.01	4.04
1937	0.02	0.02	0.4	0.67	0.49	0.23	0.29	0.29	0.08	0.09	0.05	0.04	2.67
1938	0.33	0.34	0.33	0.63	1.02	0.71	0.04	0.05	0.05	0.12	0.14	0.04	3.8
1939	0.04	0.89	0.99	0.18	0.13	0.1	0.07	0.33	0.32	0.05	0.02	0.05	3.17
1940	0.07	0.26	0.54	0.92	0.86	0.28	0.21	0.19	0.02	0.02	0.02	0.02	3.41
1941	0.04	0.04	0.02	0.53	0.72	0.4	0.4	0.22	0.03	0.02	0.03	0.03	2.48
1942	0.06	0.49	1.01	0.94	0.4	0.09	0.78	0.76	0.07	0.22	0.33	0.15	5.3
1943	0.84	1.3	0.79	0.36	0.8	0.8	0.04	0.02	0.13	0.14	0.03	0.11	5.36
1944	0.41	0.36	0.06	0.02	0.18	1.07	0.91	0.06	0.02	0.02	0.01	0.01	3.13
1945	0.01	0.01	0.01	0.22	0.29	0.37	0.31	0.04	0.02	0.02	0.01	0.01	1.32
1946	0.44	0.74	0.31	0.03	0.4	0.69	0.35	0.05	0.03	0.03	0.02	0.02	3.11
1947	0.05	0.15	0.28	0.45	0.31	0.7	0.72	0.07	0.03	0.02	0.01	0.02	2.81
1948	0.03	0.04	0.02	0.37	0.4	0.08	0.07	0.05	0.02	0.02	0.01	0.02	1.13
1949	0.17	0.51	0.6	0.29	0.08	0.51	0.49	0.08	0.04	0.02	0.03	0.02	2.84
1950	0.04	0.05	0.28	0.29	0.07	0.06	0.06	0.07	0.04	0.02	0.02	0.02	1.02
1951	0.21	0.21	0.06	0.58	0.7	0.21	0.06	0.03	0.02	0.05	0.05	0.02	2.2
1952	0.02	0.06	0.08	0.07	0.73	0.75	0.07	0.05	0.02	0.02	0.02	0.01	1.9
1953	0.02	0.06	0.07	0.13	0.17	0.12	0.07	0.02	0.02	0.02	0.01	0.03	0.74
1954	0.05	0.18	0.2	0.46	1.16	0.76	0.06	0.03	0.02	0.02	0.01	0.01	2.96
1955	0.02	0.15	0.21	0.09	0.44	0.76	0.35	0.08	0.07	0.03	0.02	0.02	2.24
1956	0.18	0.4	1.58	1.56	0.24	0.07	0.06	0.02	0.02	0.26	0.3	1.65	6.34
1957	2.24	0.65	0.1	0.38	0.34	0.07	0.31	0.28	0.02	0.02	0.01	0.03	4.45
1958	0.06	0.26	0.61	0.54	0.2	0.06	0.15	0.56	0.44	0.04	0.02	0.01	2.95
1959	0.34	0.66	0.52	0.24	0.29	0.55	0.35	0.07	0.02	0.02	0.03	0.02	3.11
1960	0.15	0.17	0.74	0.76	0.06	0.04	0.4	0.42	0.09	0.04	0.02	0.03	2.92
1961	0.02	0.34	0.38	0.24	0.41	0.24	0.05	0.03	0.02	0.01	0.01	0.02	1.77
1962	0.02	0.06	0.07	0.94	0.93	0.05	0.06	0.04	0.06	0.08	0.05	0.01	2.37
1963	0.04	0.26	0.25	0.94	0.95	0.31	0.29	0.03	0.05	0.05	0.03	0.04	3.24
1964	1.17	1.21	0.15	0.37	0.29	0.03	0.06	0.06	0.04	0.04	0.04	0.03	3.49
1965	0.01	0.21	0.22	0.52	0.56	0.05	0.01	0.02	0.02	0.01	0.01	0.01	1.65
1966	0.02	0.05	0.45	1.21	1.61	1.08	0.29	0.08	0.04	0.02	0.02	0.02	4.89
1967	0.02	0.04	0.08	0.08	0.04	0.09	0.1	0.03	0.02	0.01	0.02	0.02	0.55
1968	0.01	0.02	0.06	0.09	0.09	0.31	0.31	0.11	0.08	0.03	0.02	0.01	1.14
1969	0.2	0.22	0.19	0.37	0.25	0.06	0.02	0.02	0.03	0.04	0.05	0.05	1.5
1970	0.08	0.07	0.05	0.41	0.42	0.07	0.18	0.2	0.08	0.03	0.02	0.01	1.62
1971	0.02	0.23	0.44	0.35	0.41	0.66	0.38	0.02	0.02	0.02	0.02	0.01	2.58
1972	0.02	0.07	0.07	0.06	0.46	0.43	0.04	0.03	0.01	0.01	0.09	0.12	1.41
1973	0.04	0.06	0.1	0.98	1.11	0.22	0.07	0.04	0.03	0.02	0.02	0.01	2.7
1974	0.01	0.93	1.26	0.98	1.85	1.2	0.07	0.03	0.02	0.02	0.01	0.27	6.65
1975	0.31	0.47	1.05	1.36	1.1	1.32	0.97	0.08	0.04	0.02	0.01	0.01	6.74
1976	0.5	0.81	0.53	0.62	0.43	0.07	0.06	0.03	0.02	0.01	0.01	0.04	3.13
1977	0.32	0.3	0.35	1.38	1.07	0.32	0.33	0.05	0.02	0.02	0.03	0.05	4.24
1978	0.13	0.11	0.36	0.36	0.45	0.46	0.04	0.03	0.02	0.05	0.54	0.56	3.11
1979	0.08	0.14	0.17	0.27	0.36	0.18	0.02	0.02	0.02	0.01	0.01	0.46	1.74
1980	0.47	0.14	0.15	0.66	1.41	0.79	0.07	0.03	0.02	0.02	0.04	0.04	3.84
1981	0.02	0.07	0.09	0.07	0.04	0.02	0.04	0.04	0.02	0.01	0.01	0.01	0.44
1982	0.36	0.39	0.05	0.06	0.06	0.04	0.03	0.02	0.02	0.02	0.01	0.01	1.07
1983	0.41	1.29	1.11	0.29	0.06	0.26	0.26	0.02	0.02	0.02	0.16	0.17	4.07
1984	0.06	0.07	0.05	0.41	1.03	0.64	0.03	0.02	0.01	0.01	0.01	0.01	2.35
1985	0.14	0.17	0.44	0.54	0.17	0.08	0.1	0.07	0.03	0.02	0.03	0.02	1.81
1986	0.34	0.38	0.11	0.09	0.07	0.26	0.25	0.02	0.02	0.02	0.05	1.2	2.81
1987	1.19	0.42	0.7	0.61	0.39	0.99	0.92	0.04	0.03	0.04	0.02	0.03	5.38
1988	0.3	0.32	0.25	0.26	0.89	0.88	0.05	0.02	0.04	0.03	0.02	0.01	3.07
1989	0.1	0.88	0.8	0.03	0.05	0.28	0.29	0.06	0.02	0.02	0.02	0.01	2.56
1990	0.03	0.03	0.06	0.58	0.75	0.37	0.29	0.16	0.02	0.02	0.01	0.01	2.33
1991	0.15	0.17	0.23	0.22	0.11	0.1	0.03	0.01	0.01	0.01	0.03	0.03	1.1
1992	0.02	0.3	0.31	0.04	0.06	0.09	0.07	0.03	0.01	0.01	0.01	0.01	0.96
1993	0.64	0.84	0.39	0.4	0.61	0.47	0.19	0.14	0.02	0.02	0.02	0.01	3.75
1994	0.01	0.01	0.04	0.08	0.14	0.17	0.09	0.03	0.02	0.01	0.01	0.01	0.62
1995	0.04	0.83	1.49	1.16	1.83	1.37	0.07	0.03	0.02	0.03	0.04	0.03	6.94
1996	0.68	0.82	0.35	0.22	0.02	0.41	0.57	0.37	0.24	0.06	0.04	0.05	3.83
1997	0.05	0.11	0.5	1.04	0.92	0.5	0.21	0.03	0.02	0.01	0.01	0.01	3.41
1998	0.02	0.78	1.13	0.67	0.39	0.36	0.32	0.05	0.02	0.02	0.01	0.01	3.78
1999	0.02	0.02	0.69	1.48	0.95	0.59	0.45	0.1	0.07	0.03	0.01	0.02	4.43
2000	0.38	0.64	0.31	0.06	0.32	0.42	0.17	0.06	0.02	0.02	0.03	0.04	2.47
2001	0.5	0.62	0.34	0.61	0.41	0.02	0.02	0.05	0.06	0.04	0.18	0.18	3.03
2002	0.03	0.02	0.42	0.45	0.21	0.22	0.05	0.02	0.02	0.02	0.02	0.01	1.49
2003	0.01	0.18	0.2	0.07	0.26	0.31	0.12	0.02	0.02	0.02	0.02	0.01	1.24
2004	0.02	0.05	0.46	0.92	0.6	0.27	0.17	0.03	0.02	0.02	0.04	0.03	2.63
Average	**0.21**	**0.35**	**0.41**	**0.48**	**0.50**	**0.38**	**0.22**	**0.08**	**0.04**	**0.03**	**0.04**	**0.09**	**2.84**

Impact of the Bedford Dam on the natural flow into the wetland

4.1 Introduction

The construction of the Bedford Dam will reduce the natural flow into the wetland immediately downstream of the dam with the severity of this impact depending very much on how the dam is operated.

4.2 Dam remains full

The water use licence issued to Eskom does not allow any water use out of the C81A catchment, hence as a worst case scenario it could be assumed that the dam remains full and the only loss is evaporative loss. This has been estimated at 0.6 million m^3/annum or 21% of the natural flow. The reason that this is so high (relative to the natural flow) is that the dam has a very large surface area relative to the catchment area and hence evaporation losses will be high.

4.3 Dam operated as pumped storage

The actual operation of the dam will be that water is pumped into the dam from the Braamhoek Dam during off-peak hours and then during peak energy demand water is released back into the Braamhoek Dam. Hence the dam will fluctuate from full to empty over a day. Spills will therefore only occur if the dam is left very near to full and there is an extreme rainfall event causing the dam to spill. Eskom will probably try and avoid this scenario as they will consider this to be water wasted which could be used to generate power.

Assuming this Bedford Dam is operated as pumped storage as designed, a release pattern from the dam must be established since it will rarely if ever spill if operated carefully. The primary purpose of these releases will be to sustain the wetland immediately downstream of the dam. The estimation of these releases was based on the following assumptions:

- Only the small area of wetland immediately downstream of the dam needs to be supported by releases since tributary inflows will support the remaining wetland. This area was estimated to be 36 ha.
- Evaporative losses were based on A-Pan evaporation derived from the UKZN report (Smithers et al., 2008).
- Rainfall accruals were not taken into account.

Based on the above assumptions, the following low-flow releases from the Bedford Dam are recommended.

Table 4: Maintenance flow release from Bedford Dam

Dry season maintenance flows (l/s)		**Wet season maintenance flows**	
March	19	Oct	22
April	17	Nov	100
May	14	Dec	130
Jun	12	Jan	130
Jul	14	Feb	130
Aug	19		
Sep	22		

Conclusions and recommendations

The releases required from the Bedford Dam to sustain the wetland downstream of the dam have been estimated. While these were determined from first principles and are not directly related to the natural runoff of the catchment, it is important to understand how these flows relate to the runoff of the catchment and how the wetland responds to these flows.

The recommended release pattern (maintenance and occasional flood release) represents approximately 70% of the assumed natural runoff. However, there is great uncertainty as to what the natural flow regime is and hence the following monitoring is strongly recommended in order to improve our understanding of this catchment:

The following data should be recorded on a daily basis;
Volume of water pumped into the dam
Volume of water released from the dam to Braamhoek
Volume of water released to downstream to maintain the wetland
Rainfall
Evaporation
Spills from the dam

Implicit in this recommendation is that a weather station be installed to measure rainfall and evaporation (Symons Pan). Also the spills and releases from dam need to be gauged. The construction of small crump weir capable of recording up to 4 m^3/s is recommended.

References

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CSIR, Environment. Undated. Braamhoek Pumped Storage Scheme: Hydrology.

A2: HYDRAULICS ASSESSMENT FOR THE BEDFORD WETLAND RAPID RESERVE DETERMINATION

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Affiliation: Golder and Associates

INTRODUCTION

Assessment of the ecological Reserve for wetlands required the determination of Environmental Water Requirements (EWRs) for protection of wetland ecosystems. EWRs tend to quantify the water needs of the various biotic components in terms of relations between flow magnitude and timing. These relations include the frequency, duration, timing and rate of change of flows, and the specification of flows for the ecological Reserve aims to replicate important aspects of the natural hydrological regime (Hirschowitz et al., 2007).

This technical memorandum is presenting tasks for the hydraulics assessment of the Rapid Reserve determination of the Bedford wetland situated downstream of the proposed Bedford Dam. The purpose of the Rapid Reserve determination study is to assess the flows which are required to maintain the Wilge River floodplain wetlands below the proposed Bedford Dam

DATA COLLECTION

During a site visit on 27 January 2010 a suitable EWR site was selected (Figure 10). The coordinates of the selected EWR site is given in Table 6. The advantages and disadvantages of the selected EWR site are given in Table 7.

Table 6: EWR site coordinates

Wetland	Latitude	Longitude
Bedford	S=28.29468	E=29.47579

Table 7: Advantage and disadvantage of the selected site

Wetland	Advantage	Disadvantage
Bedford	The site is accessible by 4x4	Extremely dense vegetation. There is no well-defined channel, upstream or downstream of the wetland, which could be used for discharge measurement. Not able to survey site using total station.

From Figure 10 it can be seen that vegetation is very high and dense, and survey of the site could not be therefore performed by using a total station. Furthermore there is not a well-defined channel, upstream or downstream of the wetland, which could be used for the discharge measurement.

Consequently a different approach has to be applied to survey the cross-sectional profile and to estimate discharge.

Figure 10: Belfast wetland EWR site view from left bank

The following approach was applied:

- EWR cross section was selected;
- Flow depth along the cross-sectional line was measured in 2m interval;
- Different vegetation zones were identified; and
- Surface velocity was measured in different type of vegetation.

The selected EWR cross-section is showed in Figure 11. Measured cross sectional flow depth is plotted in Figure 12. Information of surveyed vegetation is present in Table 8. Survey information regarding EWR cross section is listed in Table 9.

Table 8: Vegetation survey

Dominant Vegetation	Abundance (%)
Aristida junciformis	20
Themeda triandra	35
Tristachia leucothrix	15
Heteropogon contortis	10
Monosymbium ceresiformi	5
Eragrostis capensis	5
Andopogon apendicularis	5

Table 9: Survey information

Maximum depth (m)	Average depth (m)	Cross-sectional flow area (m^2)	Cross-sectional surface width (m)
1.35	0.49	56.94	116.00

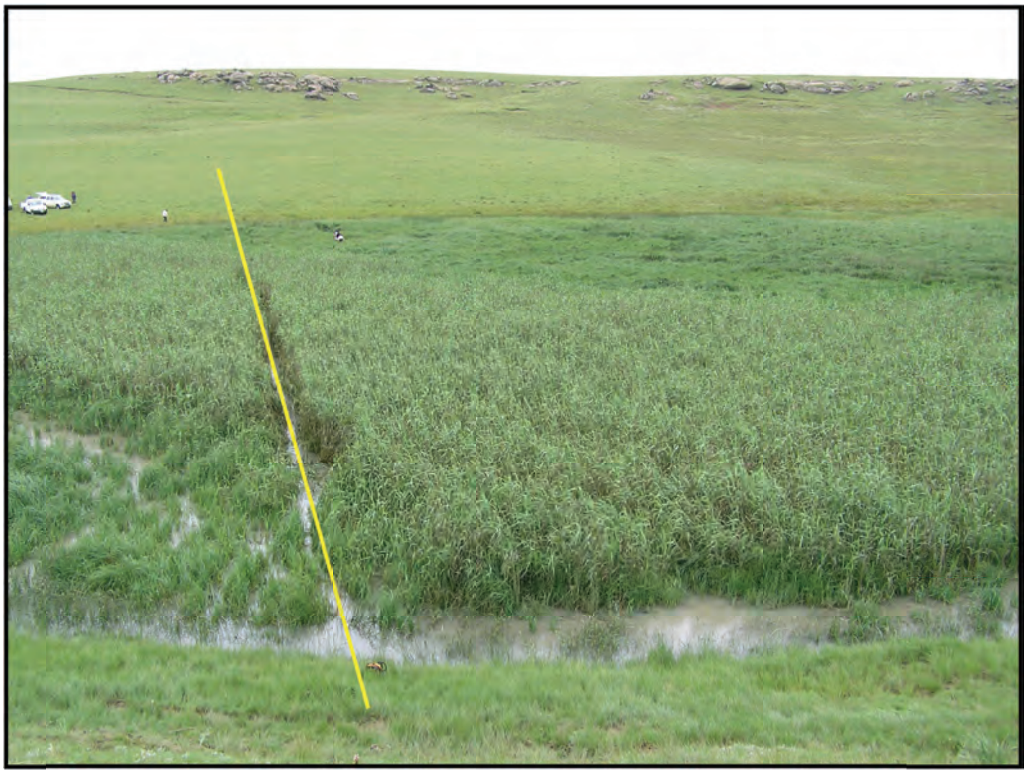

Figure 11: EWR cross section

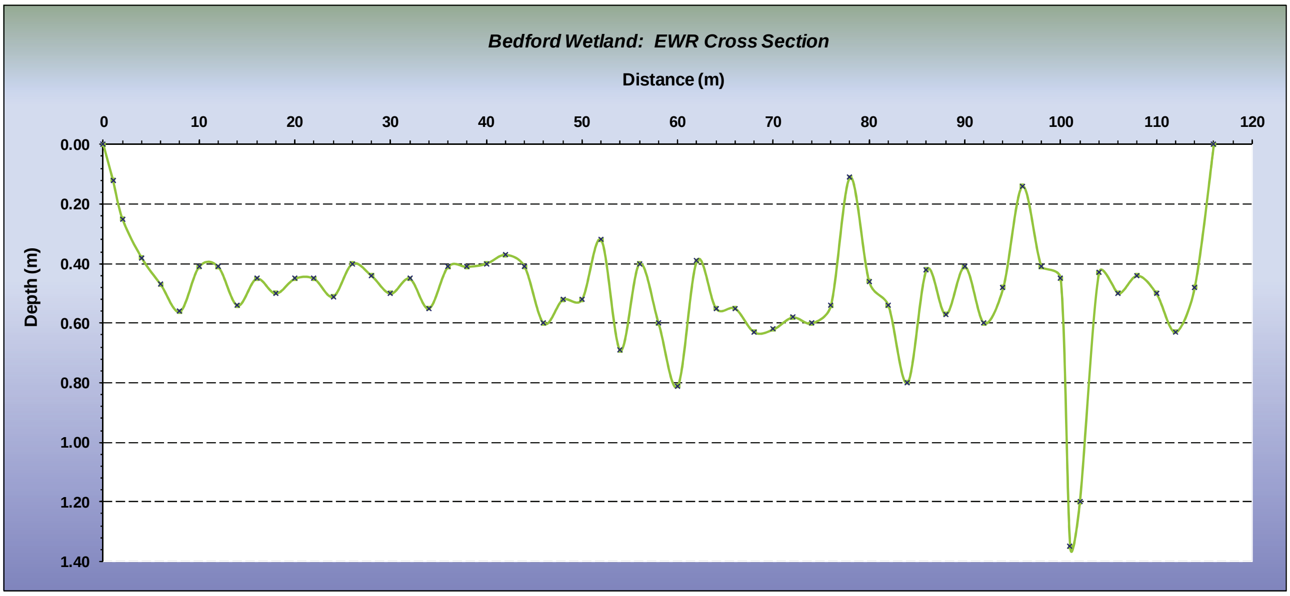

Figure 12: EWR cross-sectional profile as it was measured

Discharge estimation

As there was no well-defined channel where discharge could be measured using a flow meter two alternative methods were therefore applied for discharge estimation.

Method 1-Surface Velocity

- Surface velocities were measured in different type of vegetation;
- Since the surface velocity is higher than the average velocity, a correction coefficient, *k*=0.85 (Gordon et at, 2004) was applied; and

- Discharge, Q was calculated as $Q = VA$ where V = average velocity and A=flow area. Area was calculated from cross-sectional measurements.

Method 2-Direct Approach

Conveyance through extensive, uniform vegetation can be described by a resistance equation which accounts for the integrated interactions at the stem and leaf scale through a resistance coefficient, which can be determined empirically from measurements. Three vegetation zones were identified. For each vegetation zone a simple direct approach for resistance calculation (Jordanova et al., 2006) for discharge determination was applied:

- Flow velocity was assumed for measured depth;
- Reynolds number in terms of the stem diameter was calculated;
- Drag coefficient was estimated;
- The resistance coefficient was calculated;
- Flow velocity was calculated and compare with the assumed one;
- Procedure was repeated until the assumed and calculated velocities were the same; and
- Discharge, Q was calculated as $Q = VA$.

Discharges estimated using methods 1 and 2 are presented in Table 10.

Table 10: Estimated discharge

Method	Discharge (m^3/s)
1	3.78
2	3.38

It can be seen that the variability in performance of the two methods is about 11%.

MODELLING

Flow resistance in wetland is a function of stage and is determined by vegetation characteristics and does not vary much with flow depth (James et al., 2001; James et al., 2004). It has been assumed that flow velocity for the different water stages will be similar to the estimated during the site visit.
Modelled hydraulic data for the EWR site in 0.01 m depth interval are listed Table 11.

Table 11: Hydraulic results

Average depth (m)	Maximum depth (m)	Discharge (m^3/s)	Flow area (m^2)	Surface width (m)
0.03	0.70	0.15	2.23	64
0.03	0.75	0.18	2.81	64
0.04	0.80	0.25	4.06	72
0.06	0.85	0.35	6.12	108
0.12	0.95	0.80	13.02	112
0.21	1.05	1.51	23.55	113
0.30	1.15	2.25	34.42	114
0.38	1.25	3.01	45.49	115
0.49	1,35	3.78	56.94	116

During the Bedford Rapid Reserve workshop these hydraulics results were used to determine Reserve for the Bedford wetland.

CONCLUSSIONS AND RECOMMENDATIONS

- This study has tested a method proposed for Rapid Reserve determination for wetland.
- Average flow velocity in different type of vegetation was calculated from the measured surface velocity.
- Estimation of discharge was carried out using two methods (Surface Velocity and Direct Approach). The result shows a good correlation between the two values.

It would be valuable to carry out field-based extensive measurements (using a sensitive flow meter such as a two-dimensional Doppler) of velocity in different type of wetland vegetation that could be used in Rapid Reserve wetland studies.

REFERENCES

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Hirschowitz, P.M., Birkhead, A.L. and James, C.S. (2007) Hydraulic modelling for ecological studies for South African rivers, WRC Report no. 1508/1/07, Water Research Commission, Pretoria.

James, C. S., Birkhead, A. L., Jordanova, A.A,, Kotschy, K. A., Nicolson, C. R. and Makoa, M. J. (2001) Interaction of reeds, hydraulics and river morphology, WRC Report No. 856/1/01, Water Research Commission, Pretoria.

James, C. S., Birkhead, A. L., Jordanova, A. A. and O'Sullivan, J. J. (2004) Flow resistance of emergent vegetation, Journal of Hydraulic Research, Vol. 42, No. 4, 390-398.

Jordanova, A. A., James, C. S. and Birkhead, A. L. 2006. Practical resistance estimation for flow through emergent vegetation, Journal of Water Management of ICE Proceeding, Vol.159, issue WM3, 173-181.

A3: GEOMORPHOLOGY

Author: **M. W. Rountree**
Fluvius Environmental Consulting

This report documents the data collected for the Bedford Wetland Rapid Reserve study in January 2010. The methodology related to this assessment is described in Rountree and Malan (2010).

1. EWR 1

1.1 Data availability

A rapid site assessment was undertaken on the 27th January 2010. Available maps, Google Earth imagery, conversations with Environmental Officers at the field sites and data collected in the field were used to determine the EcoStatus and identify required flows. It is recommended that historical photographic imagery be used to assist in the geomorphology assessments; although in this case the near-Reference condition of the site did not require this. No other data on the condition of geomorphology were available at this time.

1.2 Reference condition

The reach (from the Bedford Dam wall to the confluence with the Wilge River) was historically a weakly channelled to unchannelled wetland with a short channelled wetland section close to the Wilge River.

1.3 PES

PES was assessed using the WET-Health Level 1 assessment (MacFarlane *et al.*, 2008). PES was categorised into an A category; although due to erosion and incision associated with the lower gully, it is felt that the PES is better categorised as an A/B category.

PES	CAUSES	SOURCES	FLOW / NON -FLOW RELATED
A/B	Natural except for lower incised gully	Possibly as a result of cattle grazing and increased runoff and trampling.	Non-flow related

1.4 Trend and reasons

Stable at present. The headcut has been stabilised some years ago through a large Working for Wetlands structure.

PES	TREND	RESULTING PES	TIME	REASONS
A/B	Stable	A/B	10 years	Headcut has been stabilised and no other erosion impacts under current conditions

A4: VEGETATION ASSESSMENT

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1.1 Data availability and collection

The vegetation PES of the resource unit (the Bedford wetland from immediately below the dam wall to its junction with the Wilge River floodplain) was undertaken based upon a rapid field visit on 27 January, 2010, using an approach adapted from the vegetation component of WET-Health assessment (Macfarlane et al., 2008). Level 2 of WET-Health was applied to the sample site and Level 1 to the overall wetland.

A primary site (Appendix A4-1), located approximately 1 km below the Bedford Dam currently under construction, was selected as representative of a reach of the wetland with minimal lateral tributary input. Specifically at this site, vegetation, soil morphology and water table depth were described at five points along a transect running approximately perpendicular to the wetland.

The vegetation was described in a few minutes per sample point based upon the identification of the more abundant species. In those samples with inherently low plant diversity, the description was close to complete.

The vegetation described at the sample points were compared with what one would expect in a reference site (see Section 1.2) based on the author's field experience, and A4-2 was then used to subjectively allocate an *intensity of impact score* that reflects the degree to which each disturbance class deviates from the reference conditions (Appendix A4-1).

The confidence that can be placed in the rapid assessment of the vegetation at the sample site was assigned a score of 3 on a scale of 0 [no confidence] to 5 [high confidence]) given the manner in which the vegetation was described and how the score allocated (as described above).

A low confidence estimate (score = 2) was undertaken of the vegetation PES in the overall wetland. This was based upon observation of the wetland from various vantage points and with reference to the Level 1 default scores given in WET-Health for different land-use types (Macfarlane et al., 2008).

1.3 Reference condition

The Bedford wetland evolved under grazing by indigenous herbivores and fire, and in its reference state comprises a variety of herbaceous vegetation types, including the following:

- *Phragmites australis* marsh, with a high abundance of *Phragmites australis*, as well other sub-dominant species, including *Carex acutiformis* and *Leersia hexandra*.
- Mixed sedge marsh, including *Cyperus fastigiatus*, *Carex acutiformis*, *Schoenoplectus corymbosus* (confined mainly to the preferential flow areas on the margin of the wetland).
- *Carex acutiformis* marsh, dominated strongly by *Carex acutiformis*

- *Scleria* spp. meadow, dominated strongly by *Scleria* spp.

- Mixed sedge meadow, including a high diversity of short (<1m) hydric sedge (e.g. *Bulbotsylis shcoenoides*) and grass species (e.g. *Hemathria altissima*)

- Hygrophilous grassland, including a mix of the hydric sedge and grass species given above as well as grass species occurring widely in non-wetland areas (e.g. *Themeda triandra*).

Alien plant species are totally lacking and indigenous pioneer species (notably Eragrostis plana) occur at low abundances (<10% cover).

1.3 PES

Based on the extent of the different disturbance units in the overall wetland and intensity of impact in these units (Table 1) the overall magnitude of impact on the vegetation was determined as 0.74, which, according to Appendix A4-2, is an A category

1.4 Trend (trajectory of change)

The advance of the gully erosion in the outlet of the wetland has been successfully halted by an erosion control structure built at the headcut of the gully, and therefore no further desiccation of the wetland is anticipated. The stocking rate has decreased and attempts are being made to reduce fire frequently and confine burning mainly at the end of the end of winter/ early spring, and thus catchment-related impacts are likely to continue to remain lower than in the past. Thus, the PES is likely to remain stable or improve slightly.

Table 1: Present Ecological State (PES) of the vegetation in the overall wetland

Disturbance unit	Extent (%)[1]	Impact intensity[2]	Impact magnitude[3]	Causes[4]	Source/s of the problem/s[5]	Flow / non-flow related[4]
Marsh	~80 %	0.5	0.4	-	-	Non-flow related
Sedge meadow	~6	1	0.06	Very slight increase in abundance of pioneer species	Past heavy livestock grazing	Non-flow related
Hygro-philous grassland	~10	1	0.1	Very slight increase in abundance of pioneer species	Past heavy livestock grazing	Non-flow related
Hygrophilous grassland – pioneer dominated	~2	3	0.06	Significant increase in abundance of pioneer species but many native hydric species still remain	Past heavy livestock grazing, with localized concentration of livestock with high levels of trampling	Non-flow related
Desiccated wetland	~2	6	0.12	Significant increase in abundance of pioneer and terrestrial species but some native hydric species still remain	Gully erosion in the outlet of the wetland, which is inherently vulnerable to erosion. Heavy grazing pressure and exposure from frequent early winter burning probably resulted in increased surface runoff, which, in turn, increased the erosive potential of storm events, combined with onsite trampling of cattle	Non-flow related
Overall magnitude			**0.74**			

[1]Extent is expressed as a % of the overall area of the wetland
[2]Impact intensity is rated on a scale of 0 (none) to 10 (critical). See Appendix A4-2.
[3]The magnitude of impact is calculated as Intensity X Extent/100 and ranges from 0 (none) to 10 (critical).
[4]The causes refer to the problem/s that have caused the site to change from Reference conditions.
[5]This refers to whether the problem is as a result of flow changes or other factors (such as adjacent land-use, etc.).

1.5 Ecological Flow Requirements

A flow rate of 1.3 $m^3 sec^{-1}$ is recommended for the wet season (October to February). This is the lowest discharge required to (shallowly) inundate most of the valley floor, which according to the soil descriptions along the profile is permanently saturated. The motivation for this discharge is as follows:

- **Maintenance of habitat for endangered species.** Shallow inundation of the valley floor, particularly within those parts of the valley floor supporting mixed sedge marsh, provides potentially suitable habitat for the critically endangered White winged flufftail.
- **Maintenance of wetland functionality.** The resulting shallow inundation of most of the valley floor is also likely to create favourable conditions for the functioning of the wetland and the provision of ecosystem services because it results in flow being spread across the valley floor, thereby maximizing contact between the water column and the wetland sediments. This, in turn, promotes the effectiveness of the wetland in improving water quality by assimilating pollutants. Flows of significantly less than1.3 $m^3 sec^{-1}$ are likely to be much less spread out across the wetland, significantly reducing the contact between the water column and the wetland sediments and vegetation, and therefore significantly reducing the assimilative capacity of the wetland.
- **Maintenance of semi-natural flow patterns.** In the absence of an understanding of the flow requirements of most species present in the wetland a precautionary approach is adopted, whereby it is assumed that the current biodiversity value is best maintained through flows that approximate the natural flow patterns as closely as possible, considering, of course, the practical constraints to achieving these flows.

1.6 References

Macfarlane DM, Kotze DC, Ellery WN, Walters D, Koopman V, Goodman P and Goge M. 2008. WET-Health: A technique for rapidly assessing wetland health. WRC Report No. TT 340/08. Water Research Commission, Pretoria.

Appendices

Appendix A4-1: Sample points described at the sample site

Pt no.	Veg type	Location	Soil morphology description and water table depth	Vegetation description	Impact rating
1	Phragmites australis marsh	S 28 13.922 E 29 34.823	0-10: amorphic peat with abundant roots, 10-30: organic clay 3/<0.5, >30 clay 3/0. Water 54cm deep	Phragmites australis 40%, Carex acutiformis 40%, Leersia hexandra 30%, Mentha 1%	0.5
2	Mixed sedge marsh	S 28 13.935 E 29 34.786	0-50: amorphic peat with abundant roots, 55-60: organic clay, 60-100: clay, chroma <0.5, no mottles. Water 50cm deep	Leersia hexandra 50%, Carex acutiformis 20%, Cyperus fastigiatus 10%, Persicaria slaisifolia 25%, Mentha aquatica 1%	0.5
3	Mixed sedge marsh	S 28 13.911 E 29 34.832 (approx. location)	0-45: amorphic peat with abundant roots, 45-50: organic clay loam, >50 clay, chroma <0.5, no mottles, Water 60 cm deep	Carex acutiformis 30%, C cognata 25%, P australis 15%, C fastigiatus 10, Leersia hexandra 5%	0.5
4	Cyperus fastigiatus marsh (mixed sedge)	S 28 13.908 E 29 34.835	0-30: loam, 7.5YR 5/0.5 with 6/1 bloches, few low contrast olive mottles, 30-90: as above but no mottle, >90 clay loam. Water depth 30 cm	Cyperus fastigiatus 40%, Eragrostis plana (margin) 10%, Persicaria salisifolia <1	1.5
5	Sedge meadow	S 28° 13.944' E 29° 34.775'	0-20cm: 7.5 YR3/0.5, loamy clay, Many high contrast orange/yellow mottles (mainly along root channels), 30-40cm, 7.5 YR3/1, loamy clay, 40-80cm 7.5 YR 3/0.5 with 5/1 blotches, loamy clay+ Dark patches visible, abundant intermediate contrast, mainly yellow, mottles, 80cm - 1.1m, 2.5 YR, 8/1 loam*, weathered sandstone; few low contrast yellow mottles	Penisetum thunbergei 15%, Aristida junciformis 15%, Tristachia leucothrix 5%, Hermarthria altisima 10%, Agrostis eriantha 10%, Eragrostis capensis 5%, Paspalum digitalum 3%, Andopogon apendicularis 10%, Harpochloa falx 5%, Pycerus sp.10%, Monopsis desipiens 5%, Eleochoris dregeana 3%, Bulbostylis schoenoides 15%, Ledebouria cooperi 1%, Commelena sp. 1%, Stiburis cf. aleopecuroides 5%	1

Pt no.	Veg type	Location	Soil morphology description and water table depth	Vegetation description	Impact rating
6	Hygrophilous grassland/non-wetland transition	S 28° 13. 947' E 29° 34.771'	0-10cm: 7.5 YR 3/1, fluffy loam, 30-40cm: 7.5 YR4/2, loam, 40-50cm: 2.5 YR 3 with 2 chroma blotches	Aristida junciformis 20%, Themeda triandra 35%, Tristachya leucothrix 15%, Heteropogon contortis 10%, Monocymbium cerisiformi 5%, Eragrostis capensis 5%, Andropogon appendicularis 5%, etc.	1.5

Appendix A4-2: Impact categories for assessing the intensity of impacts on vegetation integrity within disturbance classes (from Macfarlane et al., 2008)

IMPACT CATE-GORY	DESCRIPTION	INTENSITY OF IMPACT SCORE
None	Vegetation composition appears entirely natural.	0.5
Small	A very minor change to vegetation composition is evident at the site (e.g. abundance of ruderal, indigenous invasive slightly higher than would be the case naturally)	1.5
Moderate	Vegetation composition has been moderately altered but introduced; alien and/or increased ruderal species are still clearly less abundant than characteristic indigenous wetland species.	3
Large	Vegetation composition has been largely altered and introduced; alien and/or increased ruderal species occur in approximately equal abundance to the characteristic indigenous wetland species.	5
Serious	Vegetation composition has been substantially altered but some characteristic species remain, although the vegetation consists mainly of introduced, alien and/or ruderal species.	7
Critical	Vegetation composition has been almost totally altered, and in the worst case aall indigenous vegetation has been lost (e.g. as a result of a parking lot)	9

Appendix A4-3: Impact scores and categories of Present State (from Macfarlane et al., 2008)

IMPACT CATEGORY	DESCRIPTION	IMPACT SCORE	PES CATEGORY
None	Unmodified, natural.	0-0.9	A
Small	Largely natural with few modifications. A slight change in ecosystem processes is discernable and a small loss of natural habitats and biota may have taken place.	1-1.9	B
Moderate	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact	2-3.9	C
Large	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota and has occurred.	4-5.9	D
Serious	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable.	6-7.9	E
Critical	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8-10	F

A5: RAPID DIATOM ASSESSMENT

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This report documents the data collected for the (Bedford) Rapid Reserve study in November 2009. The methodology related to this assessment is described in the section following.

Summary information for EWR 1

1.1 Data availability

Available data are limited. A diatom assessment was done in the Wilge River (Braamhoek) downstream of the Bedford wetland during 2008 as part of the Upper Vaal Comprehensive Reserve determination. Three samples were analysed which included a sample from an oxbow lake. Confidence in data availability is moderate to high as the 2008 data was analysed by the same diatomologist which undertook the current study and the results were checked by Dr J. Taylor. There is also a good understanding of the catchment.

Confidence: 3.8

1.2 Reference condition

It is expected that the diatom community would consist of diatom species with an affinity for clean fresh waters, with low electrolyte content (up to 30 mS/m). Therefore species with sensitivity values above three is expected in high abundance (Lecointe *et al*., 1993). No to very slight pollution levels will be present. SPI scores would be between <17-20.

1.3 PES

The PES was set at an A/B category. The biological water quality at this site was of high quality with a SPI score of 17.9. The dominant species all have a preference for oligotrophic, acidic – circumneutral waters with low electrolyte content (Taylor *et al.*, 2007b). The diatom based ecological water quality indicates that the water is acidophilous (water has a pH mainly below 7; for this site estimated at 6.1), with very little organically bound nitrogen and continuously high oxygen saturation. Salinity levels were very low and the site was oligotrophic and unpolluted. The majority of the species prefer the current conditions and it is evident that this site is very close to reference state. There were some species present that prefer increased levels of organics, nitrogen and phosphates e.g. *Nitzschia filiformis*, *Mayamaea atomus* var. *permitis* and *Navicula erifuga* (Taylor *et al.*, 2007b), but these occurrences were very low and their presence is most probably attributed to natural wetland processes. Although *Hantzschia amphioxys* was present in very low abundance, this species usually occurs in crevices and rock ledges and therefore the presence of this species could indicate runoff from higher lying areas. The presence of *Achnanthes exigua*, albeit in very low abundance, may indicate that before the flood conditions the water was most probably standing for some time.

PES	CAUSES	SOURCES	FLOW / NON -FLOW RELATED
A/B (17.9%)	Anthropogenic activities	Land use activities in the vicinity.	NF

1.4 Trend and reasons

PES	13 TREND	RESULTING PES	TIME	REASONS
A/B	Stable	A/B		

1.5 Flow Scenarios

Modelled flow scenarios include increased base flows and no floods. Under these conditions it is envisaged that there will be no significant change in the current diatom EC. Elevated base flows will dilute any pollution entering the system. During dry season in the absence of floods it is estimated that water temperatures will rise as well as mineral content. This will impact slightly on the current EC and the PES may deteriorate to a high B but will recover during rain events.

Diatom Assessment – specialist appendix report

INTRODUCTION

BACKGROUND

Diatoms are of great ecological importance because of their role as primary producers, and form the base of the aquatic food web. They usually account for the highest number of species among the primary producers in aquatic systems (Leira, 2005). Diatoms are photosynthetic unicellular organisms and are found in almost all aquatic and semi-aquatic habitats.

Diatoms are a siliceous class (*Bacilariophyceae* of the phylum *Bacilariophyt*a) of algae. A remarkable aspect of diatoms is their silicon dioxide cell walls. The cell walls are perforated and ornamented with many holes, which are arranged in defined and unique patterns. Identification is based on the nature of these perforations as well as their orientation and densities.

Recent studies, as well as studies in progress, have identified diatoms as useful organisms to include in the suite of biomonitoring tools currently used in South Africa (Bate *et al*., 2002; De la Rey *et al*., 2004; Taylor, 2004) both for assessments of current water quality and for establishing historical conditions in rivers in South Africa (Taylor *et al*., 2005a).

Diatoms have been shown to be reliable indicators of specific water quality problems such as organic pollution, eutrophication, acidification and metal pollution (Rott, 1991; Tilman *et al*., 1982; Dixit *et al*., 1992; Cattaneo *et al.,* 2004), as well as for general water quality (AFNOR, 2000). The reasons why diatoms are useful tools for biomonitoring are listed by Round (1993):

- Diatoms have a universal occurrence throughout all rivers;
- Field sampling is rapid and easy;
- Cell cycle is rapid and they react quickly to perturbation;
- Diatoms are relatively insensitive to physical features in the environment;
- Cell counting by microscopic techniques is rapid and accurate;
- Cell numbers per unit area of substratum are enormous, making random counts excellent assessments of diatoms;
- The ecological requirements of diatoms are in many cases better known than those of any other group of riverine organisms;
- Permanent records can be made from every sample;
- Diatoms do not have specific food requirements, specialised habitat niches, and are not governed to a major extent by stream flow.

The specific water quality tolerances of diatoms have been resolved into different diatom-based water quality indices, used around the world. In general, each diatom species used in the calculation of the index is assigned two values; the first value reflects the tolerance or affinity of the particular diatom species to a certain water quality (good or bad) while the second value indicates how strong (or weak) the relationship is. These values are then weighted by the abundance of the particular diatom species in the sample. The diatom index used in the present study is known as the Specific Pollution sensitivity Index (SPI; Coste in CEMAGREF, 1982), one of the most extensively tested indices in Europe.

Diatom-based water quality indices have recently been evaluated for rivers and implemented in South Africa (Taylor, 2004; River Health Programme, 2005). De la Rey *et al*. (2004) and Taylor (2004) showed that diatom-based pollution indices may be good bio-indicators of water quality in aquatic ecosystems in South Africa by demonstrating a measurable relationship between water quality variables such as pH, electrical conductivity, phosphorus and nitrogen, and the structure of diatom communities as reflected by diatom index scores.

As there is a close association between diatom community composition and water quality inferences can be drawn regarding water quality. During 2008 a rapid method for inferring wetland water quality was developed by Dr Taylor (Rountree and Malan, 2010). This method was applied and tested during the site visit to the Bedford wetland.

TERMINOLOGY

Terminology used in this specialist appendix is outlined in Taylor *et al*. (2007a) and summarised below.

Trophy	
Dystrophic	Rich in organic matter, usually in the form of suspended plant colloids, but of a low nutrient content.
Oligotrophic	Low levels or primary productivity, containing low levels of mineral nutrients required by plants.
Mesotrophic	Intermediate levels of primary productivity, with intermediate levels of mineral nutrients required by plants.
Eutrophic	High primary productivity, rich in mineral nutrients required by plants.
Hypereutrophic	Very high primary productivity, constantly elevated supply of mineral nutrients required by plants.
Mineral content	
Very electrolyte poor	< 50 µS/cm
Electrolyte-poor (low electrolyte content)	50-100 µS/cm
Moderate electrolyte content	100-500 µS/cm
Electrolyte-rich (high electrolyte content)	> 500 µS/cm
Brackish (very high electrolyte content)	> 1000 µS/cm
Saline	6000 µS/cm
Pollution (Saprobity)	
Unpolluted to slightly polluted	BOD <2, O_2 deficit <15% (oligosaprobic)
Moderately polluted	BOD <4, O_2 deficit <30% (β-mesosaprobic)
Critical level of pollution	BOD <7 (10), O_2 deficit <50% (β-ά-mesosaprobic)
Strongly polluted	BOD <13, O_2 deficit <75% (ά-mesosaprobic)
Very heavily polluted	BOD <22, O_2 deficit <90% (ά-meso-polysaprobic)
Extremely polluted	BOD >22, O_2 deficit >90% (polysaprobic)

METHODS

SAMPLING

Diatom samples were taken at two of the current Ingula monitoring sites:

- The Nek which is the current Wetland Reserve site.
- Approximately 700 m upstream of the Dlamini monitoring site.

Details of the sampling sites are given in Table 2.1.

Table 0.1 Site information

Site name	Co-ordinates	
	Latitude	**Longitude**
The Nek	S 28° 13' 56.64"	E 29° 34' 46.5"
Dlamini (700m upstream)	S 28° 13' 20.41"	E 29° 33' 13.42"

During sampling at both sites epiphyton[1] was sampled. The flows were very high due to excessive rain in the area and it was expected that diatom densities of the prepared slides would be low. Therefore two samples were taken at The nek from *Phragmites* and *Cyperus* spp. respectively. At the Dlamini site only *Cyperus* spp. was sampled as *Phragmites* could not be accessed due to high flows.

ANALYSIS

The epiphyton sampled were processed as outlined in the methods designed as part of the Rapid Reserve Determination method for wetlands (Rountree and Malan, 2010). Samples were not processed in situ, due to heavy rain experienced during the field trip.

A Nikon Eclipse E100 microscope with phase contrast optics (1000x) was used to identify diatom valves. The aim of the data analysis was to count diatom valves to produce semi-quantitative data from which ecological conclusions could be drawn (Taylor *et al*., 2007a). However the samples collected from The Nek could not be analysed as the diatom valve densities were too low. The sample collected and processed from Dlamini was analysed although it must be noted that diatom densities were also low, and a valve count of only 250 could be made. The nomenclature followed Krammer and Lange-Bertalot (1986-91). Diatom index values were calculated in the database programme OMNIDIA (Lecointe *et al.*, 1993) for epilithon data in order to generate index scores to general water quality variables.

RESULTS

An epiphytic diatom sample was taken at the site during January 2010 and analysed with the aim to provide biological water quality information for conditions on the day, and providing additional input to the physico-chemical component of the study as a response variable.

DIATOM ASSEMBLAGE

The diatom species assemblage and abundances of the sample are provided in Table 3.1.

[1] Diatoms that are attached to macrophytic plants (emergent plants).

Table 0.2 Diatom species assemblage and abundances of the Dlamini site

Species	**Abbr.**	**Abundance**
Achnanthes spp.	ACHS	4
Achnanthes exigua Grunow	AEXG	1
Aulacoseira crassipunctata (Ehrenberg) Simonsen	AUCS	2
Cymbella aspera Ehrenberg	CASP	2
Cymbella cymbiformis Agardh	CCYM	1
Cocconeis pediculus Ehrenberg	CPED	1
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	CPLE	2
Eunotia bilunaris (Ehrenberg) Mills	EBIL	27
Eunotia minor (Kützing) Grunow	EMIN	17
Encyonopsis leei Krammer var. *sinensi*s Metzeltin & Krammer	ENLS	1
Eunotia pectinalis var. *undulata* (Ralfs) Rabenhorst	EPUN	7
Eunotia rhomboidea Hustedt	ERHO	3
Encyonema silesiacum (Bleisch) DG Mann	ESLE	1
Fragilaria construens Ehrenberg	FCON	2
Fragilaria pinnata Ehrenberg	FPIN	2
Fragilaria parasitica W Smith	FPSC	1
Frustulia saxonica Rabenhorst	FSAX	53
Frustulia vulgaris (Thwaites) De Toni	FVUL	16
Geissleria acceptata (Hustedt) Lange-Bertalot & Metzeltin	GACC	4
Gomphonema exilissimum Lange-Bertalot & Reichardt	GEXL	3
Gomphonema parvulum var. *parvulius* Lange-Bertalot & Reichardt	GPPA	11
Hantzschia amphioxys (Ehrenberg) Grunow	HAMP	2
Mayamaea atomus var. *permitis* (Hustedt) Lange-Bertalot	MAPE	2
Navicula cryptotenella Lange-Bertalot	NCTE	2
Navicula erifuga (OF Müller) Bory	NERI	2
Nitzschia filiformis (W Smith) Van Heurck	NFIL	1
Nitzschia fonticola Grunow	NFON	1
Nitzschia hantzschiana Rabenhorst	NHAN	1
Navicula notha Wallace	NNOT	31
Nitzschia species	NZSS	6
Pinnularia borealis Ehrenberg sensu lato	PBOR	1
Pinnularia divergens W Smith	PDIV	23
Pinnularia subcapitata Gregory	PSCA	13
Pinnularia viridis (Nitzsch) Ehrenberg	PVIR	4
Total valve count		**250**

- Shaded blocks indicate dominant species.

DIATOM BASED WATER QUALITY SCORE

The European numerical diatom index, the Specific Pollution sensitivity Index (SPI) was used to interpret results. De la Rey *et al.* (2004) concluded that the SPI reflects certain elements of water quality with a high degree of accuracy due to the broad species base of the SPI. The interpretation of the SPI scores is given in Table 3.2 and the SPI for the sample in Table 3.3.

Table 0.3 Adjusted class limit boundaries for the SPI index applied in this study

SPI score	Class	Ecological Category
>17	HIGH QUALITY	A
13-17	GOOD QUALITY	B
9-13	MODERATE QUALITY	C
5-9	POOR QUALITY	D
< 5	BAD QUALITY	E

Table 0.4 **SPI scores for the different samples**

Site	No species	SPI score	Category	Class
Dlamini	34	17.9	High quality	A/B

The diatom based ecological classification for water quality is given in Table 3.4.

Table 0.5 **Generic diatom based ecological classification**

Diatom based ecological classification						
Site	**pH**	**Salinity**	**Organic nitrogen**	**Oxygen levels**	**Pollution levels**	**Trophic status**
Dlamini	Acidophilous	Fresh	Very small levels of organically bound nitrogen	Continuously high (> 100% saturation)	Unpolluted	Oligotrophic

DISCUSSION

The dominant species in the diatom samples for the site are given in Table 4.1 and the diatom assemblages are discussed. Note: Species contributing 5% or more to the total count were classified as dominant species.

Table 0.6 **List of dominant diatom species, expressed as a percentage of the total sample.**

Diatom species	Abbr.	Dlamini
Frustulia saxonica Rabenhorst	FSAX	21
Navicula notha Wallace	NNOT	12
Eunotia bilunaris (Ehrenberg) Mills	EBIL	11
Pinnularia divergens W Smith	PDIV	9
Eunotia minor (Kützing) Grunow	EMIN	7
Frustulia vulgaris (Thwaites) De Toni	FVUL	6
Pinnularia subcapitata Gregory	PSCA	5

REFERENCE CONDITIONS

No reference condition information was available for the area. However this site was selected as it represents an unimpacted pristine type wetland environment.

SPI scores would be between <17-20. It is expected that the diatom community would consist of diatom species with an affinity for clean fresh waters, with low electrolyte content (up to 30 mS/m). Therefore species with sensitivity values above three is expected in high abundance (Lecointe *et al*., 1993). No to very slight pollution levels will be present. SPI scores would be between <17-20.

PES

The PES was set at an A/B category. The biological water quality at this site was of high quality with a SPI score of 17.9. The dominant species all have a preference for oligotrophic, acidic – circumneutral waters with low electrolyte content (Taylor *et al.*, 2007b). The diatom based ecological water quality indicates that the water is acidophilous (water has a pH mainly below 7; for this site estimated at 6.1), with very little organically bound nitrogen and continuously high oxygen saturation. Salinity levels were very low and the site was oligotrophic and unpolluted. The majority of the species prefer the current conditions and it is evident that this site is very close to reference state. There were some species present that prefer increased levels of organics, nitrogen and phosphates e.g. NFIL, NCRY, MAPE and NERI (Taylor *et al.*, 2007b), but these occurrences were very low and their presence is most probably attributed to natural wetland processes. Although HAMP was present in very low abundance, this species usually occurs in crevices and rock ledges and therefore the presence of this species could indicate runoff from higher lying areas. The presence of AEXG, albeit in very low abundance, may indicate that before the flood conditions the water was most probably standing for some time.

The two-monthly Ingula monitoring data for The Nek and Dlamini indicates that the SPI scores range from 14.8-18 which relates to a range of an A-B Category. From the monitoring data it is evident that the biological water quality deteriorates slightly during February-April. This may be due to dry season conditions, when and wetland processes (which results in elevated organics, nutrients and deteriorated saturated oxygen levels) are translated by OMNIDIA as elevated pollution.

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A6: WATER QUALITY

Authors: **Malan, H., Batchelor, A., and Zungu, N.**

This report documents the data collected for the Bedford Wetland Rapid Reserve study in January 2010. The method used in this assessment, is described in Rountree and Malan (2010).

1. EWR 1

1.1 Data availability

The following data sources were used in this study:

- Landuse taken from 1:50 000 maps; Google Earth; observations made during the site visit.
- Anecdotal information from personnel involved in construction of the pumped storage scheme (PSS) and from environmental managers for the Bedford wetland.
- Background information from Wetland Consulting Services (2006).
- Limited data collected during the initial EIA for the pumped storage scheme (Batchelor 1998), although this was for the streams above the dam site and thus is not completely representative of the Bedford wetland.
- Vaal Comprehensive Reserve determination (EWR site 7) water quality (WQ) data. Note that this site is upstream of the confluence with the Bedford wetland, and subject to some farming impacts. Thus, it is also not completely representative of WQ in the Bedford wetland.

An additional source of information was available, namely biomonitoring data collected for the environmental monitoring programme for the Braamhoek pumped storage scheme (PSS) from the EWR site. This data was NOT used in the initial EcoClassification. This is because a major objective of this project was to trial the recently-developed method for setting the wetland WQ Ecological Reserve (Malan et al., 2008). Detailed monitoring data will not normally be available when determining the WQ Reserve for wetlands. Thus, this data was only used to verify the conclusions drawn (see section 1.7).

The confidence in the ecoclassification (RC and PES) is considered to be **MEDIUM**, (and with the additional biomonitoring data, section 1.7, **HIGH**).

The conclusions with regard to WQ apply to the EWR site but also apply to the lower end of the wetland (at the confluence with the Wilge R) and all the wetland in between. This is because there are no significant impacts in terms of water quality between the two points (the catchment is unimpacted) and thus the entire wetland can be considered as a single WQ resource unit (i.e. broadly the same WQ throughout).

Consideration also needs to be given to the source(s) of water feeding into the wetland and the pattern of flow through the system, since this will influence WQ. From discussions with personnel from the PSS, the absence of true peat in the upper part of the wetland (discovered during excavations for the dam basin) indicates that the primary water source, at least to the upper arm of the wetland where the EWR site is located, is likely to be surface water rather than groundwater. The drainage pattern is exorheic (i.e. water drains through the system) as the hydromorphic type is unchannelled (and in some areas channelled) valley bottom wetland.

1.4 Reference condition

No historical data are available to describe the reference condition (RC) WQ of the wetland itself. However, the present day WQ of the system is considered to be little changed from RC.

1.3 PES

Water quality data from scoping studies conducted prior to initiation of the dam construction activities are shown in the table below.

Table 1; WQ in two streams supplying the Bedford wetland and the Braamhoekspruit (Batchelor 1998)

Determinant	Bedford 1	Bedford 2	Braamhoek
Nitrate	0.03	0.0	0.0
Chloride	3.6	4.0	4.0
Alkalinity	7.0	10.0	29.0
pH	6.5	6.8	7.5
Turbidity	0.9	9.8	11.4
TDS	32	52	76
Potassium	0.4	0.4	0.8
Sodium	1.6	2.4	4.4
Magnesium	0.08	0.25	2.14
Calcium	0.5	1.1	5.4
Hardness	1.7	3.8	22.3

As noted previously the data for the two Bedford streams is not directly representative of the present day WQ in the wetland. This is because, firstly it is taken from upstream of the wetland, secondly this is a riverine rather than wetland ecosystem and thirdly the data were from before the construction activities started. Nevertheless, in the absence of any other more representative data, they are useful for inferring the WQ of the wetland. The data show that the water supplying the wetland is of good quality with low levels of nutrients (nitrates) and salts and low Total Dissolved Solids (TDS). The pH is around neutral, although the environmental management personnel who monitor the site noted that on occasions the water in the tributaries supplying the wetland (i.e. in the upper Bedford catchment) is higher than 8.0.

Landuse changes have occurred in the catchment but these are considered to have exerted an insignificant impact on water quality. These are:

- infrastructure development associated with construction of the PSS above the dam wall.
- limited infrastructure (roads, homesteads, livestock paths) in the catchment, downstream of the dam wall.

The WQ impacts likely to arise from the above primarily relate to increased sediment mobilisation. However, there is evidence from the landscape (landslips etc.) that this is a catchment that is naturally sensitive to erosion and that to a large extent this has been a natural process (although accelerated in the past by activities such as over-grazing and construction of roads). The upstream water source flowing into the Bedford Dam is presently reticulated. Thus sediment generated by the construction activities appears to be contained within the construction site and is not released into the wetland. Sewage from the construction site is treated on site and discharged into the ground. This is well-contained, not linked to a drainage line and therefore unlikely to be a pollution source to the wetland.

The grazing that currently takes place in the catchment is of low-intensity. It is considered to be equivalent to the grazing pressure that would have been exerted by browsing wildlife (ungulates) under natural conditions.

The wetland WQ method calls for a consideration of any factors that might mitigate for the impacts of detrimental landuse. The entire wetland is surrounded by natural vegetation, and is thus well-buffered and protected from the entry of diffuse pollutants into the wetland.

From the above, in addition to data from the Vaal Comprehensive Reserve determination (EWR site 7), the WQ in the wetland is considered to be in an **"A" CATEGORY**. Results from the diatom sampling largely support this result. The PES class as derived from diatoms was A/B (Koekemoer S., pers. com. Jan 1010). An interesting discrepancy between the results was that the diatoms from the indicated acidic conditions, whereas the limited data indicates that the streams supplying the wetland have neutral to alkaline conditions. The reason for this discrepancy is unknown and requires further investigation.

Table 2: Summary of the Present Ecological State (PES)

PES	CAUSES	SOURCES	FLOW / NON -FLOW RELATED
A (WQ)	No sig. Impact	None	Not applicable
A/B (diatoms)			

PES: "A category" and 95% score.

CAUSE: No problems, only insignificant impacts arising from construction activities and road infrastructure. The system is considered to be close to Reference condition.

SOURCE: Not applicable

FLOW/NON-FLOW RELATED: Not applicable

1.4 Trend and reasons

It is considered that the WQ at the site is currently stable and the impacts are insignificant. There may in future be impacts associated with the commissioning of the dam and pumped storage scheme. This would include raising of the pH due to leachate from the cement infrastructure. However this is likely to be transient as the cement cures and also mitigated for by the fact that the pH from the tributaries supplying the dam is naturally neutral to slightly alkaline. (> 8.0 at Wilge River EWR site 7 and see section 1.3 above) and thus any disturbance of the pH balance is unlikely to be a significant impact and will be short-lived.

Landuse is likely to remain the same, or become more natural in the catchment since the Bedford wetland and surrounding area (effectively the entire catchment) will become a nature reserve (as prescribed in the Record of Decision). There are plans to persuade the remaining homesteads to relocate to housing outside of the catchment. The remaining cattle will be replaced with wildlife (Peter Nelson, Eskom, pers. com. Jan 2010).

A stable trend in WQ will however be dependent on the good quality of water from the Bedford Dam (and thus from the Braamhoek Dam) being maintained.

Table 3: Summary of likely WQ trend

PES	14 TREND	RESULTING PES	TIME	REASONS
A	Stable	A	20	Conservation of the catchment (Bedford Wetland Park)

1.5 Alternative ECs

The WQ consequences of the flows proposed as dam releases are discussed below:

The major threat in future to the WQ of the wetland arises from the fact that water will be released downstream to the system that is derived from the Braamhoek Dam (via the pumped storage scheme). Batchelor (1998) report that the WQ of both systems is largely similar in terms of chemistry (as is to be expected since both systems arise from the same geology), although, the Braamhoek system does have higher levels of calcium, magnesium and sodium ions, and consequently alkalinity and hardness are higher (Table 1). The lower dam is also likely to be higher in suspended sediments, which will be pumped into the Bedford Dam. It is not clear to what extent the sediments will settle out on the bottom of the Bedford Dam. The dam is relatively deep and a dissipation weir will be constructed downstream of the dam wall which are both features that will lower suspended sediment load. On the other hand, the water will be pumped between the two dams twice daily which may keep the sediment in suspension. Water discharged for baseflow maintenance is a very small volume and sediment is unlikely to be a problem. However during flood releases sediment loads will be higher, and it is not clear to what extent it will be retained behind the dissipation weir. Wetlands in general accumulate sediment, but on the other hand the reworking of sediments and maintenance of small channels at the EWR sites were identified by ecologists as important processes for maintaining plant diversity. Thus the potential ecological consequence of possible higher sediments loads being supplied to the wetland are unclear. This variable, in conjunction with the other suite of WQ variables listed in Malan et al. (2008), should be monitored in future and interpreted in relation to changes in vegetation patterns within the wetland.

Another potential WQ impact is the discharge of water from the dam of a significantly different temperature to that of the wetland. In this case, however, the volume of water discharged for baseflow maintenance is likely to be very small (e.g. mean monthly flow of 204 litres in February, the highest flow month – Mallory pers. com. Jan 2010 Braamhoek Reserve workshop) and will first be retained within the dissipation weir. Furthermore, when the pumped storage scheme is in operation, the water is likely to be well-mixed. Thus altered water temperature is unlikely to impact on the wetland greatly during supply of baseflow or of floods.

1.6 Deviations from the present wetland WQ method

The spreadsheet model of landuse-contaminant generation was not used because the extent of landuse change was so small it was considered unnecessary.

1.7 Verification of ecoclassification with the "extra" biomonitoring data

The relevant data collected as part of the environmental monitoring programme for the PSS is shown below. The diatom biomonitoring data for the EWR site support the PES ecoclassification of "A" to "A/B."

EWR site ("The Neck"). Data supplied by Graham, M. Jan 2010

Site	Sampling Date	SASS score	No. Families	ASPT	Diatom SPI
The Neck	24/04/2008	NS	NS	NS	16.2
	07/08/2008	NS	NS	NS	17.4
	14/11/2008	NS	NS	NS	17.4
	19/02/2009	NS	NS	NS	16.3
	29/04/2009	NS	NS	NS	14.8
	16/09/2009	NS	NS	NS	18.0

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A7: AQUATIC INVERTEBRATES

Macroinvertebrates are good indicator organisms of freshwater resources because they integrate driver-related conditions over space and time. Macroinvertebrate assessment methods are well-developed for lotic systems in South Africa, namely the South African Scoring System Version 5 (SASS5), but no local methods currently exist for assessments in wetlands. As there are no appropriate sampling or EcoStatus methods, and the expected sensitivities of invertebrates found in wetlands can be expected to be low, invertebrate assessments were not included as part of this study.

However, it is possible to make assumptions regarding expected macroinvertebrate communities in the wetland as they relate to habitat types available according to depth or frequency duration of inundation. Macroinvertebrate communities occupy available aquatic habitats as they relate to sediment, the water column and submerged and emergent vegetation. Vegetation is required by certain adult insects for resting sites, some damselflies require vegetation for egg-laying sites, whilst some require vegetation for food and refugia. Vegetation is often a food source as it relates to the conversion to detritus which is then utilized by macroinvertebrates.

The study area is from the Bedford Dam to the confluence with the Wilge River. The wetland is predominantly an unchannelled valley bottom wetland, with a minor section that is channelled. An existing monitoring site exists in the lower, channelled reaches of the wetland, called “Dlamini’s Drift”. At the time of this assessment, extremely high flows were present due to very high rainfall in the catchment, which would have influenced macroinvertebrate communities. Dlamini’s Drift site was completely inundated and therefore unable to be assessed. However, considering existing SASS5 data collected at the site by Ground-Truth Consulting from April 2008 to September 2009, the ***site is in an overall good ecological condition***. The suitability of this site as a SASS5 site could generally not be assessed at the time of the study as it was completely inundated as explained above.

It would be expected that the wetland is stable under current conditions. The recommended flows should sustain the macroinvertebrate communities occurring in the wetland, according to the hydraulic profile across the wetland as it relates to available habitat per monthly discharge, including the recommended floods in November and January of 1500 l/s accordingly.

If no flooding occurs over the mixed sedge marsh, this would impact negatively on the macroinvertebrate food supply for the White-winged Flufftail.