Prioritisation of wetlands for water security in priority dam catchments in the Western Cape Water Supply System

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Table of Contents

LIST OF FIGURES

No table of figures entries found.

LIST OF TABLES

Glossary of Terms

Term	Explanation
Biodiversity	The wide variety of plant and animal species occurring in their natural environment (habitats). The term encompasses different ecosystems, landscapes, communities, populations and genes as well as the ecological and evolutionary processes that allow these elements of biodiversity to persist over time.
Catchment	The area where water from atmospheric precipitation becomes concentrated and drains downslope into a river, lake or wetland. The term includes all land surface, streams, rivers and lakes between the source and where the water enters the ocean.
Delineation	Refers to the technique of establishing the boundary of a resource such as a wetland or riparian area.
Conservation planning	An approach to conservation that prioritises actions by setting quantitative targets for biodiversity features such as broad habitat units or vegetation types. It is premised on conserving a representative sample of biodiversity pattern, including species and habitats (the principle of representation), as well as the ecological and evolutionary processes that maintain biodiversity over time (the principle of persistence).
Ecosystem	An ecosystem is essentially a working natural system, maintained by internal ecological processes, relationships and interactions between the biotic (plants & animals) and the non-living or abiotic environment (e.g. soil, atmosphere). Ecosystems can operate at different scales, from very small (e.g. a small wetland pan) to large landscapes (e.g. an entire water catchment area).
Ecosystem goods and services	The goods and benefits people obtain from natural ecosystems. Various different types of ecosystems provide a range of ecosystem goods and services. Aquatic ecosystems such as rivers and wetlands provide goods such as forage for livestock grazing or sedges for craft production and services such as pollutant trapping and flood attenuation. They also provide habitat for a range of aquatic biota.
Function/functioning/functional	Used here to describe natural systems working or operating in a healthy way, opposed to dysfunctional, which means working poorly or in an unhealthy way.
Threatened ecosystem	In the context of this document, refers to Critically Endangered, Endangered and Vulnerable ecosystems.
Threat Status	Threat status (of a species or community type) is a simple but highly integrated indicator of vulnerability. It contains information about past loss (of numbers and / or habitat), the number and intensity of threats, and current prospects as indicated by recent population growth or decline. Any one of these metrics could be used to measure vulnerability.
Wetland	Refers to land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil (National Water Act, 1998).
Wetland catchment	The land upstream of the wetland, supplying water to that wetland.
Wetland type	This is a combination between wetland vegetation group and Level 4 of the National Wetland Classification System, which describes the Landform of the wetland.
Wetland vegetation group	Broad wetland vegetation groupings reflect differences in regional context such as geology, soils and climate, which in turn affect the ecological characteristics and functionality of wetlands.

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1 Introduction

1.1 Background to the study

The Nature Conservancy (TNC) is in the process of establishing the Greater Cape Town Water Fund (GCTWF). A key focus of the Water Fund will be the potential to make investments in nature-based solutions to address water security for the City of Cape Town. There is thus a need to establish the current understanding of the role that wetlands play in providing ecosystem services that contribute to water security, and to use this knowledge to prioritise important wetlands in this context.

While much conservation planning and policy has proceeded and directed investments towards wetland conservation and restoration globally, there is a recognized acknowledgment that much of this rests on generalizations about wetland functions. The literature suggests that wetlands do not provide services uniformly, so there is a need to establish current state of the science in order to inform planning for the Water Fund.

The Freshwater Research Centre, in collaboration with a CODA fellow at TNC and Anchor Environmental Consultants, was requested by TNC to undertake a desktop prioritisation of wetlands located within catchments upstream of the six major dams supplying water to the City of Cape Town – Steenbras Dams (Upper and Lower), Theewaterskloof Dam, Wemmershoek Dam, Berg River Dam and Voëlvlei Dam (see Figure 1.1) – in the Western Cape, based on our current understanding of the role wetlands play in ensuring water supply to communities. The objective of the prioritisation was to rank the wetlands in order of their perceived importance for the supply of ecosystem services relating to water security. In addition, the team was requested to briefly assess their condition, compile rehabilitation plans and determine the costs of their rehabilitation in order to either secure or improve their provision of these ecosystem services.

Anchor Environmental Consultants contributed to the study with additional information on the value of wetland ecosystem services, and a rapid, desk-top assessment of the return on investment for rehabilitation of the prioritised wetlands.

Definition of a wetland — land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil (from the South African National Water Act; Act No. 36 of 1998).

1.2 Project deliverables and spatial data

The project deliverables included:

- A set of prioritisation criteria and the rationale for using these criteria;
- A description of the databases used in order to apply the prioritisation criteria, and the rationale for their use;
- A ranked list of the top five wetlands, in order of priority for water security;
- A map of the prioritised wetlands;
- An assessment of the current condition, and ecological importance and sensitivity (EIS) of each of the priority wetlands;

- A determination of the cost of restoring the wetlands to improve their ability to supply water for human use, and
- An estimation of the return on investment for rehabilitation of a subset of prioritised wetlands.

Prioritisation of wetlands was performed on a sub-catchment level as well as on individual wetlands.

The study area for this wetland study included the 15 sub-quaternary (SQ4) or quinary catchments that include the six major supply dams in the WCWSS and their upstream catchments (Figure 1.1). These 15 catchments were delineated for the Turpie *et al.* (2017) study using the sub-quaternary or quinary catchment dataset generated by Maherry *et al.* (2013). However, the prioritisation criteria chosen for this wetland study utilised datasets nested within the SQ4 catchment data layer developed for the National Freshwater Ecosystem Priority Area project (NFEPA) (Nel *et al.*, 2011). This SQ4 layer was also used by Macfarlane and Atkinson (2015) in their national prioritisation of catchments for wetland rehabilitation (see Section 2). The NFEPA SQ4 layer showed general alignment with the dam catchments delineated by Turpie *et al.* (2017), and in all cases, SQ4 datasets were clipped to the Turpie *et al.* (2017) catchment boundaries.

Unfortunately, the National Inland Aquatic Ecosystem Inventory map was not completed at the time of completing this study. Ideally, the prioritisation done for this study should be repeated when this becomes available. The wetland data layer used for this study is a draft version of the Inventory of Inland Aquatic Ecosystems being developed for the National Biodiversity Assessment 2018 (version 5.4, SANBI, in prep.), with some additional wetlands delineated by this author in prioritised SQ4 catchments. The draft map has not been released to the public as yet, and so needs to be used with great caution (the map will be released for public use on the 1st July 2018). In the case of the top three prioritised wetlands, however, ground verification allowed for the improvement of the wetland map, and greater confidence in the mapping of the location and extent of wetlands in the SQ4 catchments prioritised by this study.

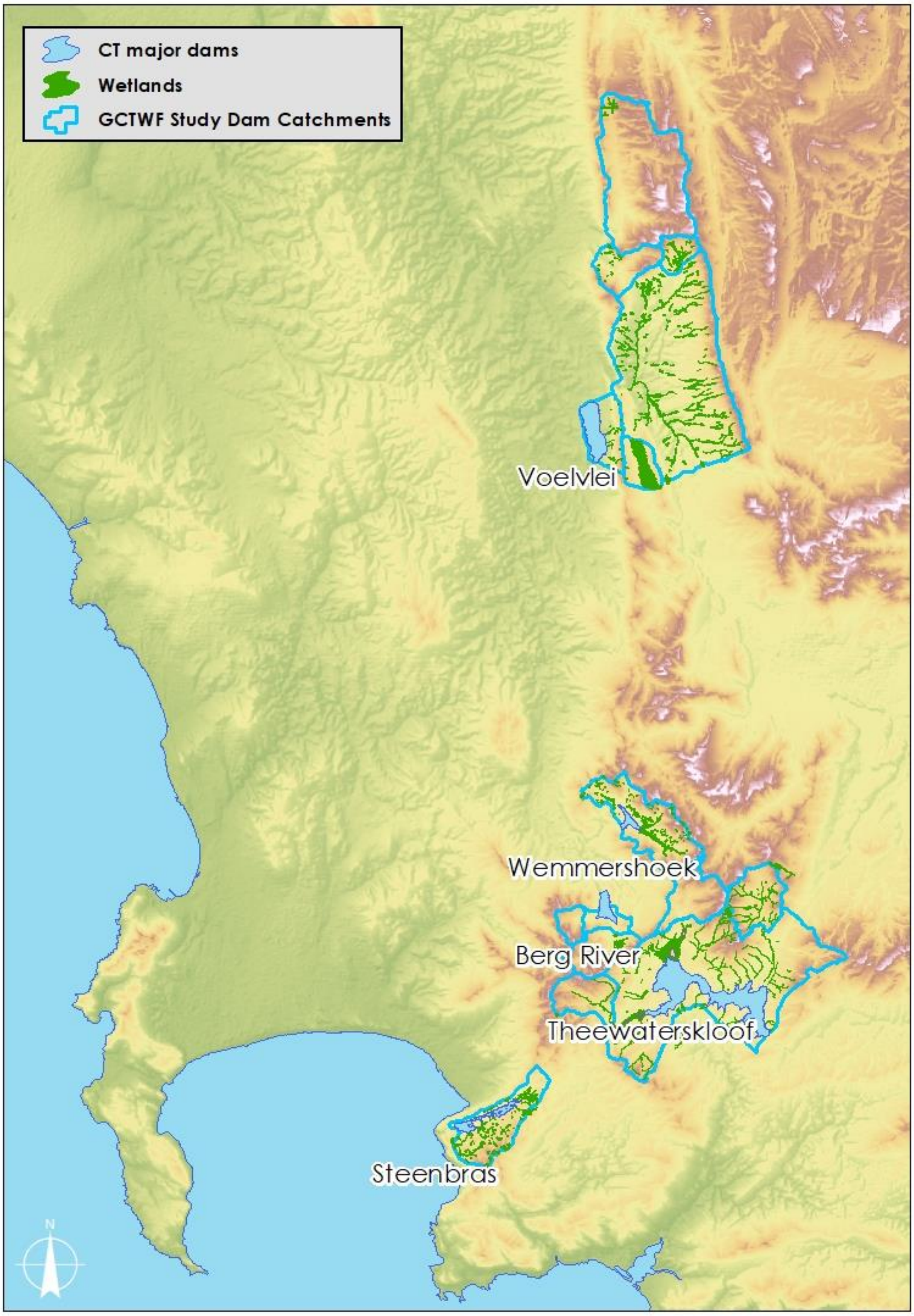


Figure 1.1 The six major dams supplying water to the City of Cape Town include Steenbras (Upper and Lower), Theewaterskloof, Berg River, Wemmershoek and Voëlvlei. The relevant dam catchments are delineated as blue outlines (from Turpie *et al.*, 2017), and wetlands are shown as green polygons, using draft data from the National Inland Aquatic Ecosystems map (version 5.4, SANBI, in prep.).

1.3 Wetlands and Water Security

Wetlands have a significant role to play in the hydrological cycle (Bullock and Acreman, 2003). Soils, topography, vegetation and climate are the combined determinants of the hydrological response in a catchment (Le Roux *et al.,* 2015), and a wetland is an expression of a combination of these drivers. Basically, wetlands form where there is a surplus of water at the ground surface (water input exceeds water output), and they occur at the interface between terrestrial and aquatic environments, and between ground- and surface-water systems (Ellery *et al.*, 2008). Due to their occurrence at these interfaces, wetlands are the complex product of a wide range of natural processes. It may be due to these complexities that there are many assumptions made about the ecosystem services that wetlands provide.

If a specific ecosystem service is looked at in isolation, the role that wetlands play in delivering that service may indeed be under- or over-emphasised. Similarly, examining the services that an individual wetland provides in isolation also does not reveal the full set of services that could be provided by the wetland in the context of its catchment. Understanding the role that wetlands play requires a more holistic approach, where the synergistic relationships between ecosystem services are examined in the context of the whole catchment. It seems to be uncontested that wetland ecosystem service provision is highest in undisturbed wetlands, and that rehabilitation of degraded wetlands improves their service provision (e.g. Meli *et al.*, 2014).

While wetlands have a significant role to play in the hydrological cycle, a knowledge gap exists about the hydrology of wetlands in Africa (Riddell *et al.,* 2013). As in other parts of the world, making generalizations about hydrologic processes across South African wetland types is difficult because the underlying geologic settings and site characteristics are so variable. (Riddell *et al.,* 2013), making it hard to find consistency in the way that hydrologic processes work. In addition, key differences between the southern African sub-continent and northern continents, where much research has been carried out, make it hard to translate what is known about wetland management from temperate northern climates. For instance, Africa has lower than average rainfall and high evapotranspiration demand (Ellery *et al.,* 2008). The high elevation of the southern Africa plateau distinguishes it from similarly arid regions of the world such as western Australia and northern Canada (Ellery *et al.,* 2008).

Water security is a major concern globally (e.g. Russi *et al.*, 2013), and increasingly so in parts of the world where supply is struggling to meet demand, as a result of either climatic or human pressures, or both. This has dramatically become the case for the City of Cape Town, South Africa, where the City faces the possibility of running out of water – a global first for a large city.

Water security is defined by the UN as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against waterborne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN-Water Task Force, 2013).

There has been much debate around augmentation options for water supply for Cape Town, and the focus has widened to examine nature-based solutions, in addition to the conventional engineered solutions for bulkwater supply, i.e. dams, inter-basin water transfers, groundwater abstraction and desalination. Turpie *et al.* (2017) found that the unit reference value of water[1] (in R/m^3, *sensu* van Niekerk and du Plessis (2013)) for the various water supply options for the City of Cape Town ranges from roughly R2 to R12.50/m^3, with dams being the "cheapest" option and desalination the "most expensive". Catchment

[1] From Turpie *et al.* (2017): The unit reference value (URV) compares water supply options, as a quantification of the present value of the life cycle costs of a water supply project, while also considering the present value of the water supplied by the project over its life cycle, with the assumption that the primary benefit supplied by the project can be directly measured as the quantity of water delivered (van Niekerk and du Plessis 2013).

restoration is listed as only marginally more costly than dams, with the main emphasis being on control of invasive alien plants (IAPs).

This project aimed at exploring the ecosystem services offered by wetlands, in the specific context of water security, in order to be able to put a cost to the rehabilitation of important wetlands that could be incorporated into the case for investment in ecological infrastructure in the Western Cape. Rehabilitation of specific ecosystem types, in this case wetlands, is significantly strengthened through sound catchment restoration and management - *healthy soils and vegetation in a catchment lead to healthy wetlands and rivers, that provide people with good quality water in sufficient quantities*.

Ecological infrastructure is defined as naturally functioning ecosystems that deliver valuable services, such as water and climate regulation, soil formation and disaster risk reduction, to people. Examples of this include healthy mountain catchments, rivers and wetlands, aquifer recharge zones, coastal dunes, and corridors of natural habitat. Ecological infrastructure provides cost-effective, long-term nature-based solutions to service delivery that can supplement or even substitute built infrastructure, especially in areas where the latter is limited or non-existent (SANBI, 2014).

1.4 Wetland ecosystem services

Ecosystem services are natural assets, produced by the environment and used for human needs (Maltby and Acreman, 2011). The Millennium Ecosystem Assessment (MEA, 2005) categorised ecosystem services as provisioning, regulating, cultural and supporting. As demand for water grows due to increasing human populations and the complexities of climate change, the ecosystem services that wetlands provide are being looked to as “nature-based solutions” that can contribute to water security and offset the need for costly built infrastructure. However, relatively few studies have documented evidence of whether and how wetlands perform the ecosystem services they are credited with, and those that have find wide variation in the direction and magnitude of the services provided.

The potential for wetlands to provide ecosystem services is increasingly important as climate change and population growth threaten water security. Water security depends on a number of ecosystem services, and Nature Based Solutions (NBS) can contribute to water security by improving water availability and quality while at the same time generating social, economic, and environmental co-benefits and reducing water related risks like floods and droughts (UN World Water Development Report, 2018). In many cases, NBS can work alongside and complement built or “grey” infrastructure to help provide sustainable solutions for water demands.

The report focuses on provisioning and regulating services, in relation to water security.

1.4.1 Provisioning services

The provisioning services of wetlands cover the products that are derived directly from wetlands, such as cultivated and wild animal and plant foods, raw materials such as reeds and sedges (e.g. Kotze and Traynor, 2011), fuel, clay, peat, medicinal plants and grazing for livestock. The provision of grazing for livestock and wild game and the cultivation of wetlands are particularly important in dryland environments, especially during dry periods or seasons (e.g. Fynn *et al*., 2015). The provision of genetic resources is also included as a provisioning service.

1.4.2 Regulating services

Regulating services are the process benefits that people receive from wetlands. These include the regulation of streamflow, groundwater recharge, flood attenuation, sediment transport and trapping, water quality regulation and carbon storage.

1.4.2.1 Streamflow regulation, flood attenuation and sediment retention

Wetlands provide a range of services that are linked to hydrology and sediment – their capacity to maintain base flows, attenuate floods, and retain sediment. Surface flows are attenuated due to the roughness and water retention capacity of the wetland, reducing downstream damage (e.g. flooding, erosion) from high energy flows. Eroded sediments from the catchment can be retained within the wetland, preventing sedimentation of downstream land and dams.

Wetlands do not supply additional water in catchments, but rather moderate downstream flows by temporarily storing water and releasing it slowly, maintaining low flows throughout drier periods. These low flows can effectively increase the total capacity throughout the year of reservoirs that are unable to capture all water flowing out of the upstream catchment. However, a number of wide-ranging reviews of the role of wetlands in catchment hydrology have presented conflicting results, with some concluding that in the majority of cases wetlands increase flood peaks, reduce dry season baseflows, and lose water through evapotranspiration at a rate higher than terrestrial landscapes (e.g. Bullock and Acreman, 2003; Kotze *et al.*, 2009; Grundling *et al*,. 2015).

In a more recent review, Kadykalo and Findlay (2016) found that, although few empirical studies met their requirements for inclusion, generally wetlands "…reduce the frequency and magnitude of floods and increase flood return period; augment low flows; and decrease runoff and streamflow." All reviews, however, have found that since it is hard to predict with any certainty the level of services from a wetland without site specific information, and so any valuation of those benefits, economic or otherwise, will be compromised by uncertainty.

The way in which wetlands regulate or change flows depends upon the balance of water entering and leaving the system. A general model for the hydrological balance of wetlands includes surface water and groundwater inflows. Other inputs are rainfall, with losses including interception and evapotranspiration (Figure 1.2).

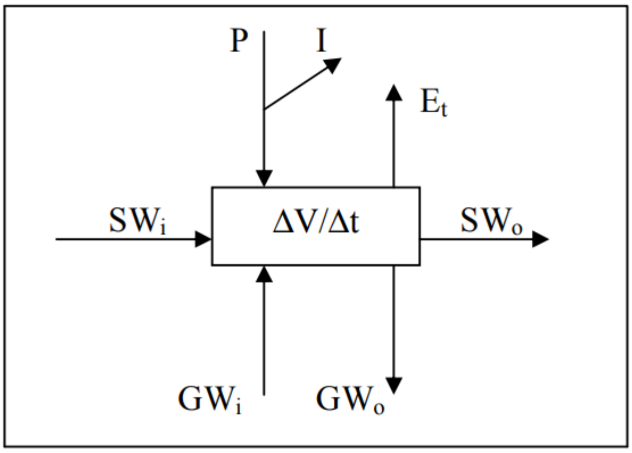


Figure 1.2 Basic hydrological balance model for a wetland, where SW indicates surface water inflow (i) and outflows (o), GW includes groundwater inflows and outflows, Et represents total evaporation (including plant transpiration), P is gross precipitation, I is interception losses and ΔV/Δt is the change in storage volume over time (Source: Gray 2011).

Evaporation rates are highly dependent on the shape and size of the wetland, how much open water is present, soil moisture levels and the wetland vegetation communities (species, age, height, rooting depth, etc) present. Transpiration rates of different vegetation types can differ significantly in various settings. Generally, wetland vegetation transpires more than surrounding dryland vegetation types, however this may not be true for some alien vegetation (Table 1.1).

While a wetland can potentially transpire more water than the surrounding dryland fynbos, if the wetland is allowed to degrade and the vegetation community is replaced with dense alien vegetation, the transpiration rates (and therefore water losses) could potentially increase. Furthermore, a review by von der Heyden (2004) found that evapotranspiration losses from wetlands were higher in grasslands, but in miombo woodland, the latter transpires at a higher rate than the local wetland vegetation. The summaries in Table 1.1 highlight the fact that the difference in terms of transpiration rates are not clear-cut between indigenous, wetland or alien vegetation and that more site-specific research is required to be able to accurately assess the impact of a change in vegetation type on transpiration rates in wetlands.

Table 1.1. Summary of some estimates of transpiration rates (mm/a) of different wetland components and riparian vegetation communities from a variety of different local sources.

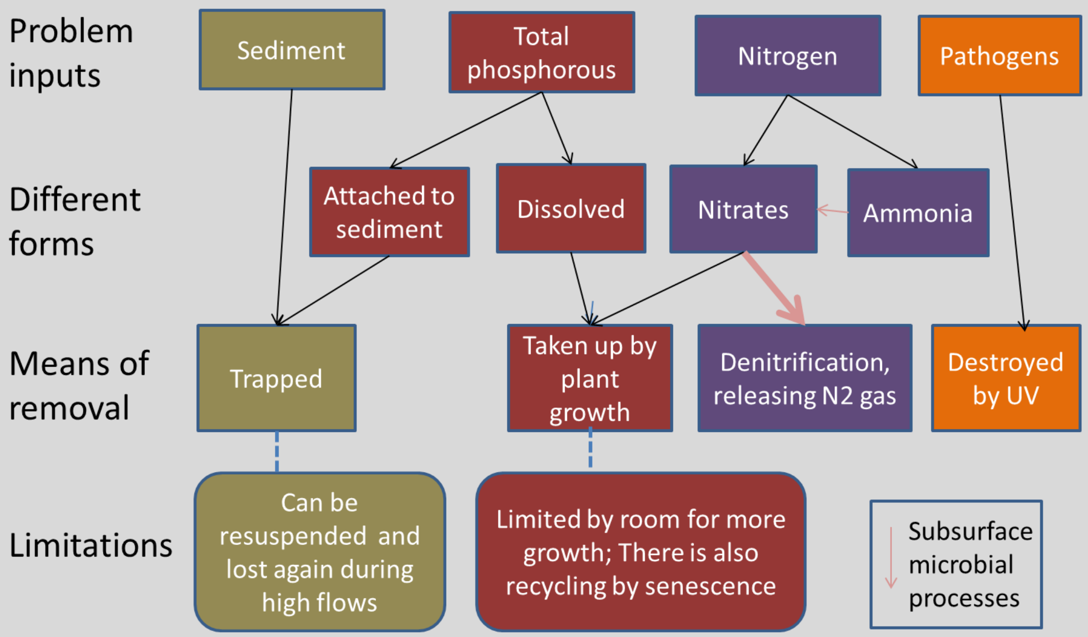
Plant or setting	Transpiration rates (mm/a)	Source
Indigenous riparian montane	1037	Measured transpiration rates from the Berg catchment – summarised in Görgens (2016)
Indigenous riparian lowland	820	
Black wattle riparian	1277	
Longleaf wattle riparian	1283	
Eucalyptus riparian	1347	
Palmiet wetlands	1042-1623	Rebelo (2012) – MODIS and Landsat
Phragmites (common reed)	1174	Dye *et al.* (2008)
Fynbos riparian	1332	Dye *et al.* (2001)

1.4.2.2 Water quality enhancement

Water entering wetlands from developed catchments generally has elevated concentrations of sediments, nutrients and pollutants from catchment activities, natural processes such as erosion, industrial effluents, treated and untreated sewage and other wastes. In less developed catchments we would expect lower amounts of these nutrients and pollutants, but probably still present. Excess phosphates and nitrates stimulate algal growth in freshwater ecosystems and dams, which can lead to deterioration in ecosystem health and capacity to deliver ecosystem services. Toxic algal blooms, heavy metals and pathogens pose a risk to human health. Thus the services provided by wetlands can save on water treatment costs and/or human health costs. The way in which aquatic ecosystems perform this service is outlined in the box below.

Water quality enhancement by wetlands

There are a number of different process through which wetlands remove sediments, nutrients and pollutants from the inflowing water. Nutrients that are introduced in dissolved form can be taken up directly by plants and incorporated into plant tissue as they grow. Most of the phosphorus that is introduced to wetlands is attached to sediment and settles to the bottom, where it can remain inactive (Brinson, 2000). However, if sediments are stirred up then some of this phosphorous can go back into solution and become available for use by plants. The uptake of dissolved phosphorous will continue as long as there is room for further plant growth (in terms of space, oxygen or plant size limits), after which the system will reach some kind of equilibrium in which the uptake is balanced by the senescence, death and rotting of plant material which reintroduces nutrients into the water column (remineralisation). At this point there would be no further net uptake of nutrients by the wetland unless nutrients are being exported out of the system (e.g. by harvesting plants or dredging and removal of sediments), or unless there is a natural process of peat formation.



Summary of water quality amelioration services by natural systems (Source: Turpie, 2015)

Nitrogen is removed in wetlands mainly by the nitrification–denitrification process (Saunders and Kalff 2001). Nitrification is the microbially-mediated oxidation of ammonium (NH_4) to nitrite (NO_2) and then nitrate (NO_3). This process consumes oxygen and thus occurs in aerobic areas of the wetland. Nitrate then diffuses to anaerobic areas of the wetland where it may be denitrified. This is the rate-limiting step in the removal of nitrogen from flooded systems. In the denitrification process nitrate (NO_3) is reduced to gaseous nitrous oxide (N_2O) and nitrogen gas (N_2), which are then released to the atmosphere (Mitsch and Gosselink 1993). This occurs mainly in sediments with abundant organic matter that provides a carbon source for denitrifying bacteria. Bacteria concentrations are reduced in wetlands by exposure to UV-light. The degree to which this occurs is linked to the duration of water retention within the system.

The ability of wetlands to perform water quality amelioration services depends on their area and type of vegetation as well as to their overall health and management. Hydraulic efficiency, which is the degree to which a wetland disperses inflow over its area, is also important (Jordan *et al.,* 2003). This maximizes contact area and it can be assumed that it serves to increase detention time as well. There is an upper limit to the amount of pollution that a wetland can remove, as well as to the amount of pollution that can be added to a wetland without having a significant impact on its functioning and biodiversity. At high phosphorus loading rates wetlands may eventually become a phosphorus source rather than a sink (Tilton and Kadlec, 1979, Forbes *et al.,* 2004). This also varies seasonally. Wetlands are thought to be better at removing total suspended solids, phosphorus and ammonia during high flow periods (when sediment loads entering the wetland increase), but better at removing nitrates during low flow periods (Johnston *et al.,* 1990, McKee *et al.*, 2000).

1.4.3 Wetlands in the WCWSS Dam Catchments

The 15 sub-catchments that define the study area boundary for this study are located within the Groot Winterhoek and Boland Mountain ranges of the Western Cape. These catchments lie primarily within two Cape Folded Mountains ecoregions (*sensu* Kleynhans *et al.*, 2005) – the Western Folded Mountains and Southern Folded Mountains – with small overlap with the South Western Coastal Belt and Western Coastal Belt (see Table 1.2 for summary details of the ecoregions).

In terms of vegetation bioregions, the study area lies entirely within the Cape Floristic Region, specifically the Southwest Fynbos bioregion. This bioregion has been shown to support wetlands with a high diversity and density (number of wetland plants per hectare of wetland) of wetland plants, especially in those wetlands occurring at high altitudes (Sieben *et al.*, in prep.). The Southwest Fynbos bioregion also supports the highest level of endemism of wetland plant species in the whole country – the bioregion lies, after all, in the Cape Floristic Region (CFR), with 69% of the CFR's plant species endemic to the CFR (Linder *et al.*, 2010; de Moor and Day 2013), and 56% of all aquatic taxa, resulting in the CFR being classified as one of the World's 200 significant Freshwater Ecoregions (Thieme *et al.,* 2005). Sieben *et al.* (in prep.) have also found that the diversity and level of endemism of wetland plants are positively correlated with rainfall – thus, the wetlands that occur in South Africa's high rainfall/high runoff catchments tend also to be the most diverse, with the highest occurrence of range-limited plant species.

The wetlands within the study area are generally associated with rivers – starting as seeps at high altitude that feed into narrow valley-bottom wetlands located within valley floors between high mountains, and then flowing into wider valley-bottom wetlands lying on flatter slopes in the foothills. As the rivers reach the lowlands, the wetlands are generally floodplain wetlands with some wetland flats towards the coast. There is currently much debate about the extent to which the wetlands in the Cape Folded Mountains are dependent on groundwater – either from shallow short return-time interflow in the vadose (unsaturated) zone, or from the deeper long return-time aquifers. It seems uncontested, however, that groundwater plays an important role in wetland hydrology, and that wetlands have a significant influence on catchment hydrology, by having an impact on the catchment water balance and the way water moves through the landscape.

Table 1.2 Main attributes of the ecoregions that intersect with the study area (from Kleynhans *et al.*, 2005).

Ecoregion	Terrain morphology	Dominant vegetation types	Altitude	Mean Annual Precipitation	Rainfall seasonality
South Western Coastal Belt	Moderate relief plains; Closed hills; Mountains	West Coast Renosterveld; Sand Plain Fynbos; Mountain Fynbos	Mainly 0-300 mAMSL; hills up to 900 mAMSL	0 to 1500 mm/year	Winter
Southern Folded Mountains	Closed hills; Mountains; Moderate and High Relief	Mountain Fynbos, Grassy Fynbos and Little Succulent Karoo predominant	Mainly 300-1900 mAMSL	100 to 1500 mm/year	Very late summer to winter to all year
Western Coastal Belt	Plains; Low Relief	Lowland Succulent Karoo	Mainly 0-700 mAMSL	0 to 200 mm/year	Winter
Western Folded Mountains	Closed hills; Mountains; Moderate and High Relief	Mountain Fynbos predominant	Mainly 300-1700 mAMSL	100 to 1500 mm/year	Winter

2 Prioritisation of sub-quaternary catchments

A national-level catchment prioritisation was completed by Macfarlane and Atkinson (2015) to inform the national strategic planning of the Working for Wetlands programme, and also to inform long-term rehabilitation intervention planning at the provincial level. The aim of the prioritisation was to look at the opportunities and needs for rehabilitation at the scale of sub-quaternary (SQ4) catchments (NFEPA SQ4 catchments, Nel *et al.*, 2011) nation-wide, while taking into account some of the socio-economic factors that impact on or are impacted by rehabilitation activities. Broadly, their approach assessed the rehabilitation potential of wetlands for the maintenance of biodiversity and enhancement of wetland functionality. Existing partnerships were also taken into account, in order to focus rehabilitation efforts towards areas where good partnerships are likely to ensure the long-term success of rehabilitation activities. Strong partnerships tend to lead to better management and monitoring of interventions, thus securing the long-term gains envisaged during rehabilitation planning.

The national prioritisation dataset of Macfarlane and Atkinson (2015) is extremely useful as a means to determine the relative biodiversity value and demand for wetland functions in SQ4 catchments. While their assessment of the relative biodiversity value of the wetlands within each of the catchments is not relevant for this project, the following sections provide a summary of their approach used for the assessment of the demand for wetland functions, amongst which are water quality enhancement, sediment retention and streamflow regulation, all of which are important for water security. The datasets used, and some summary information for each, are also provided in Table 2.1.

2.1 Functional value

Macfarlane and Atkinson (2015) used a number of datasets relating to the **demand** for regulating and supporting services provided by wetlands. These datasets[2] included:

2.1.1 Streamflow regulation

Areas that are important for streamflow tend to be those which generate the highest volumes of water – these areas are known as Strategic Water Source Areas (SWSAs)[3]. Transpiration and evaporation collectively reduce the amount of surface water supplied to downstream areas, and wetlands have been shown to have a higher evapotranspiration rate than surrounding terrestrial areas, especially during the growing season. The following datasets were used:

- **Mean annual runoff**: The range in MAR for the SQ4s was used to assign each SQ4 to a class, and scored.
- **Transpiration losses**: The expected risk of transpiration losses was calculated as a combination of frost occurrence (mean number of heavy frost days) and rainfall seasonality. SQ4s in summer rainfall areas, where there is a significant die-back of vegetation during winter, are expected to be least susceptible to transpiration losses.
- **Catchments feeding large dams**: There is a heavy reliance on surface water for water supply in South Africa, and so there is a significant demand for good water quality and sediment retention in the catchments that supply water to dams. For the national prioritisation, a dataset of

[2] A more comprehensive description of input datasets is available in the national catchment prioritisation report (Macfarlane & Atkinson, 2015).
[3] Strategic Water Source Areas have been identified nationally and are those areas that supply a disproportionate amount of mean annual runoff to a geographical region of interest. These areas were identified based on mean annual runoff (MAR) data initially captured at a quaternary catchment scale and then disaggregated to a 1 x 1 minute grid resolution (Nel et. al., 2013).

those SQ4 catchments that lie upstream of dams was generated and all SQ4's were scored accordingly.

- **Rural water provision**: The reliance of communities on water supply directly from natural sources (rivers, springs, natural pools) was mapped based on information from StatsSA. This information was scaled to the level of the SQ4 catchment, through area-weighting and determination of a number of classes based on the number of households per hectare.

2.1.2 Water quality enhancement

This component reflects the demand for ecosystem services that improve water quality. The datasets included:

- **Degree of physico-chemical modification**: Levels of physico-chemical impacts on water resources was subjectively assessed at a SQ4 catchment scale as part of the desktop PES/EIS assessment coordinated by DWS (DWS, 2014). This therefore provides a coarse indication of levels of water contamination in a catchment.
- **Eutrophication of dams**: The eutrophication potential of dams was assessed using the data from DWS's National Environmental Monitoring Programme (2012 – 2013 monitoring period – 166 monitoring sites). This information gives an indication of the extent of nutrient enrichment in a waterbody and is an indicator of trophic status. The data were up-scaled to the quaternary catchment level.
- **Toxic contaminants**: This dataset provides the levels of toxic contaminants sampled by DWS in rivers, and includes data for B, Cd, Cr, Cu, Fe, Hg, Mn, Pb, V and Zn over the period 1979 to 2014. Levels of contamination of these elements were converted into categories of low, medium or high pollution risk. The data were up-scaled to quaternary catchment.
- **Catchments feeding large dams**: See above.
- **Rural water provision**: See above.

2.1.3 Sediment retention

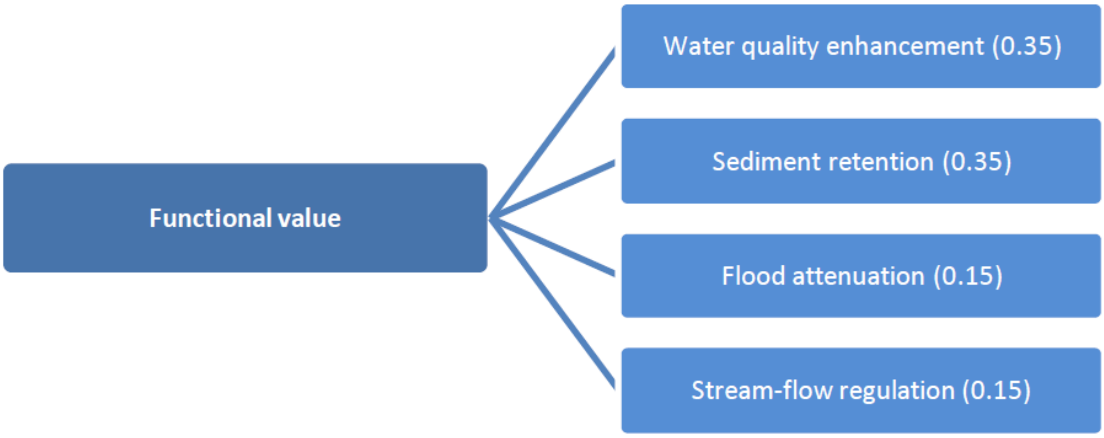
- **Sediment yield:** Actual sediment yield data are available for selected quaternary catchments (from a WRC-funded research project). SQ4 catchments that fell within these were assigned scores from 0 to 1, based on the relative yield in comparison with the calculated maximum of 1114 tonnes/km2 per annum.
- **Erosion hazard**: This dataset provides an indication of water erosion potential of South Africa and reflects the relative ability of earth material to resist erosion. It takes into account factors such as rainfall erosivity, soil erodibility, topography and vegetation cover (Msadala et al., 2010). A number of erosion hazard classes were devised and an area-weighted score calculated for each quaternary based on the % cover of each hazard class within each quaternary catchment. This was down-scaled to SQ4s as proportional to the maximum value.
- **Evidence of gully erosion**: A gully location map is available at a national scale (Mararakanye and Le Roux, 2012), which provides an indication of wetland degradation in the form of erosion, as well as a predictor for further erosion and sediment loss. The % cover of gully erosion within each SQ4 was calculated by summing the area occupied by gullies and dividing this by the area of the SQ4. The ranges in % cover were assigned to a number of classes, and scored.
- **Levels of land degradation**: Land degradation is another useful predictor of soil loss and associated increases in sediment loads in water resources. SANBIs 2009 mosaic land cover dataset was used to map land degradation within each SQ4. The % cover of land degradation in each SQ4 was calculated by summing the area of degradation and dividing this by the area of the SQ4. The ranges in % cover were assigned to a number of classes, and scored.
- **Catchments feeding large dams**: See above.
- **Rural water provision**: See above.

Table 2.1 Datasets used for the national prioritisation for wetland rehabilitation of Macfarlane and Atkinson (2015).

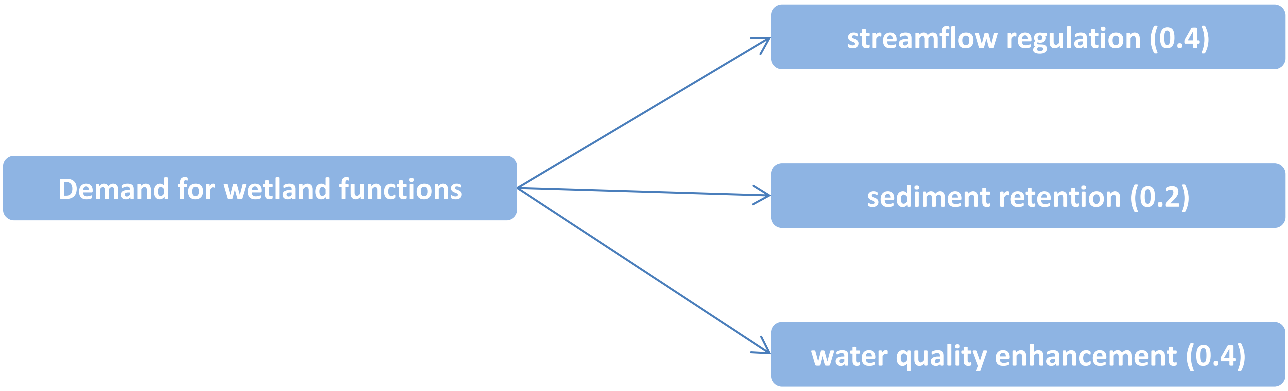
Component	Criterion	Risk vs Demand	Detail	Dataset used	Weighting for each dataset
FUNCTIONAL VALUE	**Water quality enhancement**	**DEMAND**	Degree of physico-chemical modification	Derived from DWS PES/EIS data (2014)	0.2
			Eutrophication (dams)	NEMP (DWS) 2010 - 2013	0.5
			Toxic contaminants	DWS data up to 2014	0.3
		RISK	Wetlands upstream of major dams	ARC / DWS	Max
			Rural water provision	StatsSA 2013 – number of households/ha	Max
	Sediment retention	**RISK**	Sediment yield	Actual sediment yield for selected dam catchments, from WRC project (Msabdala *et al.*, 2010)	0.3
			Erosion hazard	Erosion hazard (Le Roux) at quaternary catchment scale	0.4
			Gully erosion	Gully map of Mararakanye and Le Roux, 2012 – extent of gully area within SQ4 catchments	0.2
			Land degradation	Extent of land degradation classes (SANBI's landcover of 2009)	0.1
		DEMAND	Dam catchments	See above	0.7
			Rural water provision	See above	0.3
	Stream-flow regulation	**RISK**	Mean annual runoff or Water supply	Strategic Water Source Areas (2013) – using MAR classes	0.75
			Transpiration losses	Frost and rainfall seasonality	0.25
		DEMAND	Dam catchments	See above	0.3
			Rural water provision	See above	0.7

2.2 Weighting

Macfarlane and Atkinson (2015) weighted the components of wetland functional value as follows:



For this study, flood attenuation was not taken into account as this service does not have a direct influence on water security and also due to the low demand for this service in upper catchments, and the weighting of the remaining components was adjusted to reflect the focus on water supply (see below). The streamflow regulation and water quality enhancement components were weighted most heavily, as these components have an important bearing on water quantity and quality. Sediment retention was weighted as 0.2, due to the relatively low levels of clastic (Job, 2014) and anthropogenic sediment in Cape rivers in middle to upper catchments.



2.3 Results of catchment prioritisation

The final score for the demand for wetland functions within the SQ4 catchments was calculated by summing the individual, weighted scores for the three components used in this analysis, so that:

$$\begin{aligned} &Functional\ value \\ &\quad = (streamflow\ regulation\ \times 0.4) + (water\ quality\ enhancement\ \times 0.4) \\ &\quad + (sediment\ retention\ \times 0.2) \end{aligned}$$

The catchments were then ranked as follows:

- 81 - 100% = rank 1
- 61 – 80% = rank 2
- 41 – 60% = rank 3
- 21 - 40% = rank 4
- 0 – 20% = rank 5

The results of the catchment prioritisation for wetland functions are shown in Figure 2.1 and Figure 2.2. The results are shown separately for streamflow regulation, water quality enhancement and sediment retention, and also collectively for overall demand for wetland functions related to water supply.

The SQ4 catchments that rank highest (ranks 1 and 2) in terms of the overall demand for wetland functionality related to water supply are located upstream of the Steenbras Dams, Theewaterskloof, Wemmershoek and the Berg River Dam.

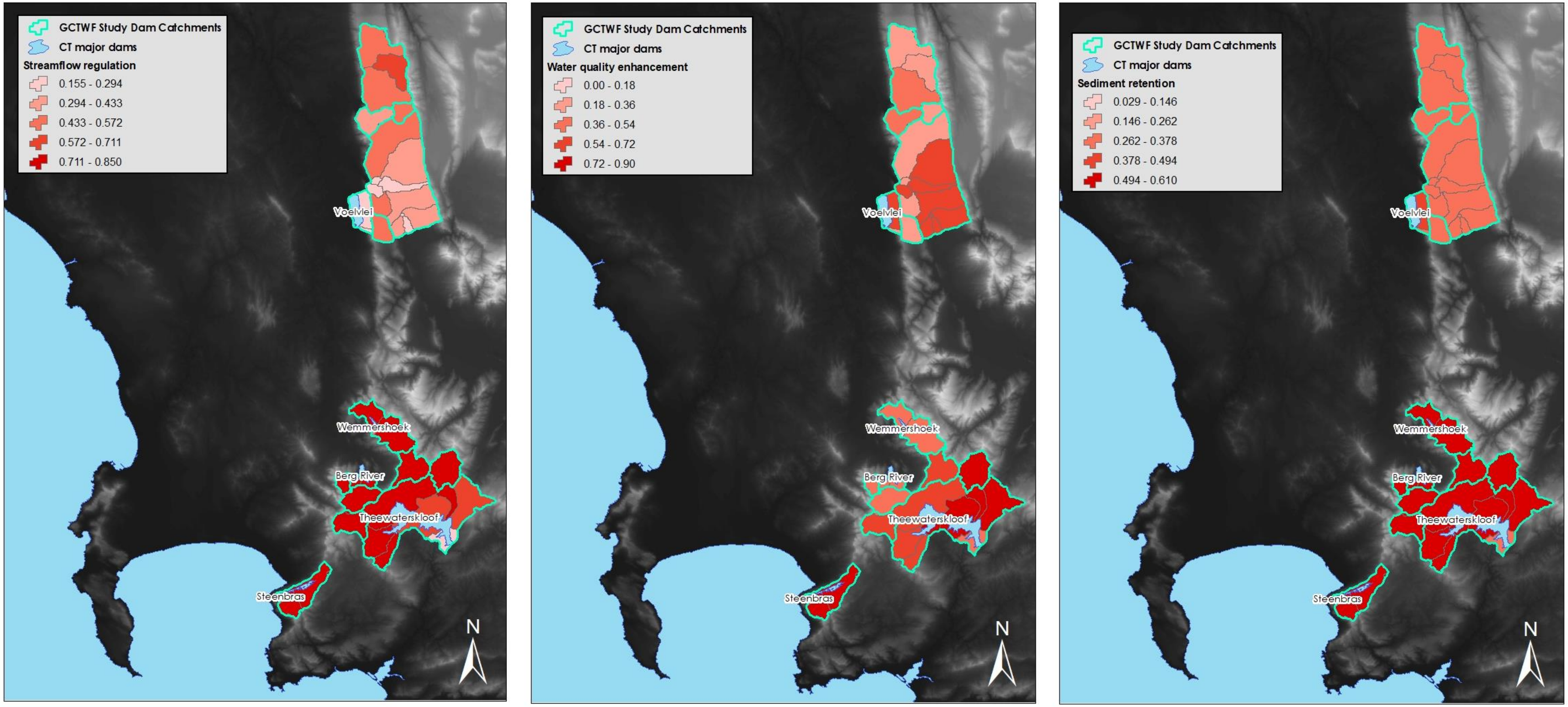


Figure 2.1 Prioritisation of sub-quaternary catchments for demand for streamflow regulation (left), water quality enhancement (middle), and sediment retention. Data used are from Macfarlane and Atkinson (2015).

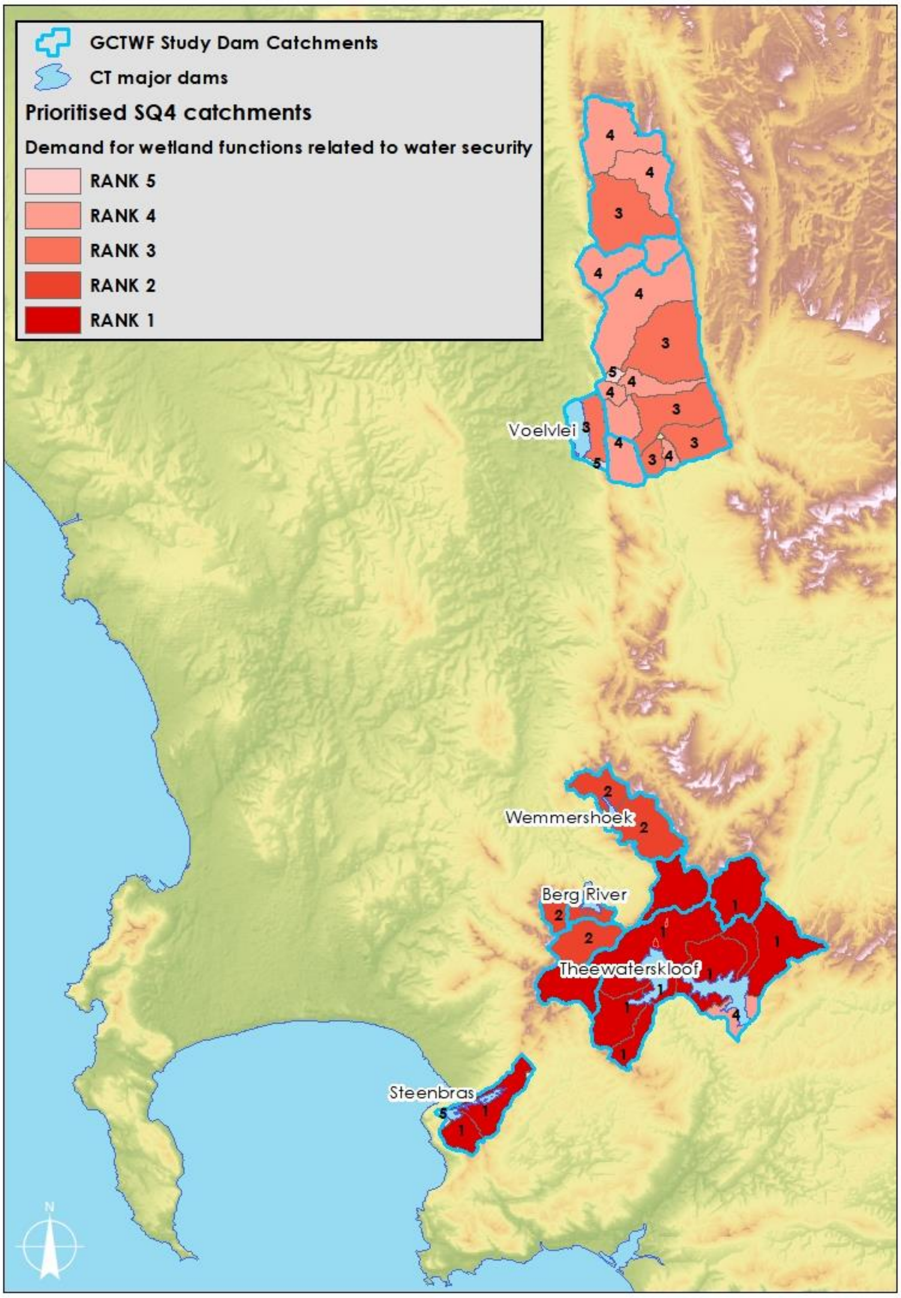


Figure 2.2 Prioritisation of sub-quaternary catchments for overall demand for wetland functions relating to water security. Data used are from Macfarlane and Atkinson (2015).

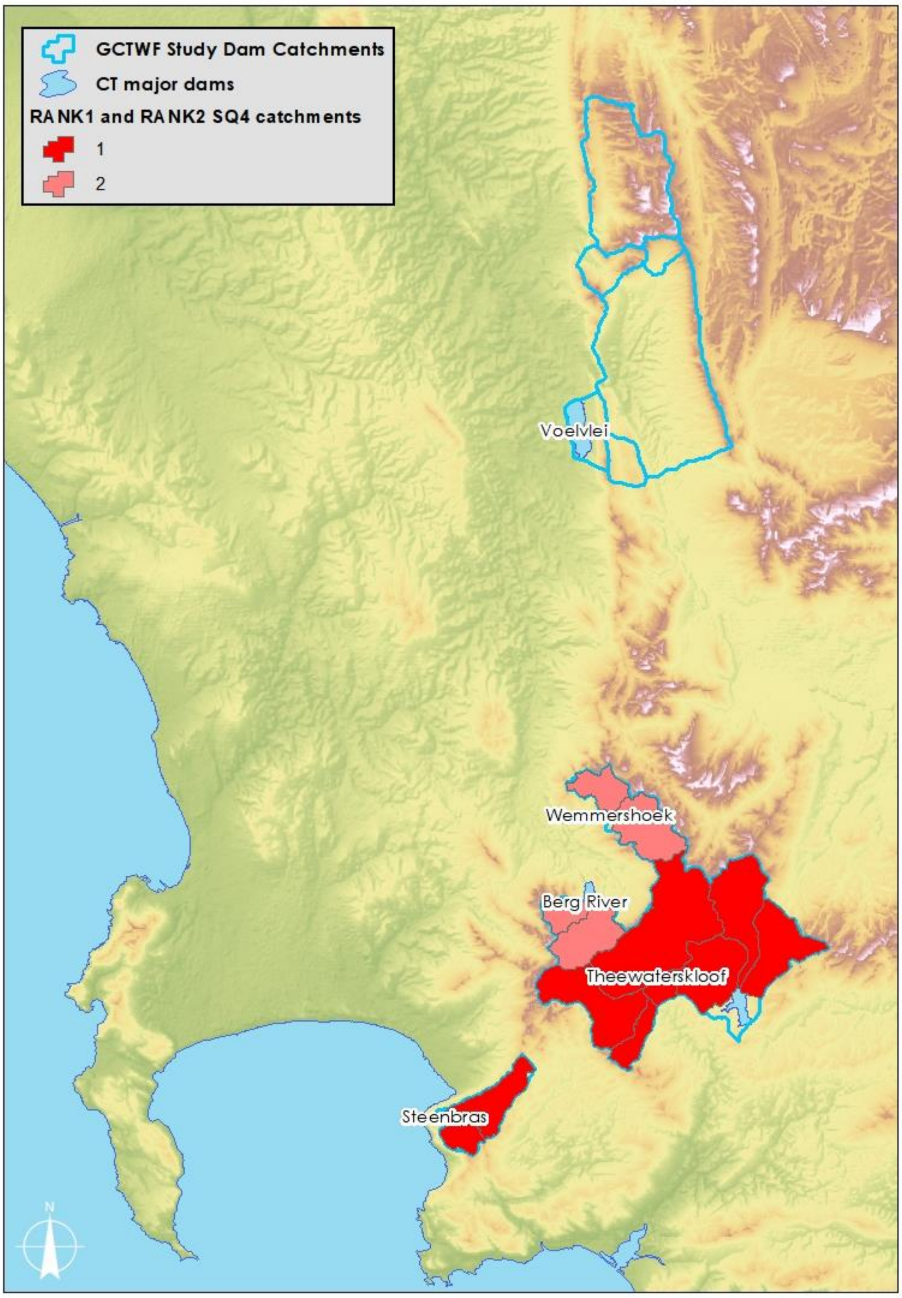


Figure 2.3 Map of sub-quaternary catchments prioritised as Rank 1 or 2 for the demand for wetland functions relating to water security (using data from Macfarlane and Atkinson, 2015).

3 Prioritisation of wetlands

The high ranking (ranks 1 and 2) SQ4 catchments were taken further into the next step, which was to prioritise wetlands within the catchments. A number of criteria were selected as a means of ranking the wetlands themselves in order of importance for water security for the City of Cape Town.

3.1 Prioritisation criteria

As stated above, drivers such as soils, topography, vegetation and climate are the combined determinants of hydrological response in a catchment (Le Roux *et al.*, 2015). In addition, there are a number of wetland characteristics, such as size, hydrogeomorphic (HGM) type, presence and extent of hydrological zones, fluvial connectivity etc, which are likely to influence the manner in which water moves into, through, and out of these systems, and so have an impact on the quantity, timing and quality of water exiting the wetlands. A brief review of the literature enabled the selection of catchment drivers and wetland characteristics that can be used as criteria for prioritising individual wetlands for water security. A sub-set of these criteria could be applied to the wetlands within the prioritised catchments, due to limitations in time and data availability.

Table 3.1 Catchment drivers and wetland characteristics that have been used as criteria for the prioritisation of wetlands for water security.

Characteristic	Reason for consideration for prioritisation	Assumption regarding water security	Included for wetland prioritisation?	Dataset used
Wetland size	• Size relative to catchment infers flood (NB not base-flow) retention and attenuation – this is related to the total capacity of a wetland to retain water (Kotze *et al.*, 2009). • Small wetlands act as a better nutrient sink than larger ones because a greater percentage of their water touches soil either on the bottom or on the shoreline, a factor which is key in the assimilation of excess nutrients and preventing them from making their way to downstream water bodies (Cheng and Basu, 2017). Cheng and Basu (2017) state that "…10 one-hectare wetlands have a greater impact on water quality than one 10-hectare wetland." • In addition, the greater the size of a wetland relative to the wetland's catchment, the greater the relative contribution of sub-surface to surface flows.	• It can be assumed that larger wetlands are more efficient in terms of contributions to surface flows, and the capacity to retain flood and base flows. • It is difficult to map size relative to wetland catchment area, so the following categories were used for this study (from Macfarlane *et al.*, 2014): ○ Small: < 0.5 ha ○ 0.5 – 5.0 ha ○ Intermediate: 6 – 50 ha ○ Large: 51 – 300 ha ○ Very large: > 300 ha	✓	Draft National Inland Aquatic Inventory (SANBI, in prep.), 2018
Hydrogeomorphic type	• The hydrogeomorphic type (HGM) of wetland infers the way water moves through the wetland. For instance, both flood and baseflows move as diffuse flow through an unchannelled valley-bottom wetland, whereas, base flows move through the channels in a channelled valley-bottom wetland or floodplain. • Although the evidence is equivocal, some researchers have found that seep wetlands are more likely to be fed by	• Hillslope seeps have the highest likelihood of connectivity with subsurface flows; floodplain wetlands are the least likely. Valley-bottom wetlands are intermediate. • It is proposed here that a combination of seeps feeding into valley-bottom wetlands located upstream of dams would be the best combination for water supply.	✓	Draft National Inland Aquatic Inventory (SANBI, in prep.), 2018

Characteristic	Reason for consideration for prioritisation	Assumption regarding water security	Included for wetland prioritisation?	Dataset used
	groundwater than are floodplain wetlands (Macfarlane *et al.*, 2014; Maherry *et al.*, 2016). • In an eastern Maine catchment, groundwater-fed headwater seeps contributed 40 – 80% of surface water to first order streams during summer base flows (Morley *et al.*, 2011).			
Fluvial connectivity	• Wetlands that are connected to the river network are far more likely to contribute to streamflow than isolated systems (Bullock and Acreman, 2003; Kotze *et al.*, 2009).	• Non-isolated wetland types contribute to streamflow – this includes non-isolated seeps, valley-bottom wetlands and floodplain wetlands. Isolated depressions and wetland flats can be discounted.	✓	1:50 000 NGI rivers map
Presence of important aquatic ecosystem OR water resource downstream	• Wetlands that are providing important ecosystem services (water supply, sediment trapping, water quality enhancement, etc) to important water supply resources (these can be natural, such as important estuaries, or man-made, such as dams - in this case, the CoCT major dams) immediately downstream assume a greater importance than those downstream of these water resources.	• In this case, wetlands located immediately upstream of the major City of Cape Town dams assume greater importance for water supply.	✓	NGI dams layer
Surface roughness	• Surface roughness (e.g. presence of particular plant species, plant roots and plant growth forms) influences the rate at which water moves through the wetland, by increasing retention time and the contact between water, soils and vegetation (Kotze *et al.*, 2009).	• Vegetated wetlands have a higher surface roughness, and so can be expected to be more effective at slowing water down and improving water quality.	✘	n/a
Hydrological zones present	• Saturated soils convey water more quickly to the downstream river, so if soils remain saturated, runoff will be greater from a saturated wetland/soil than from an	• Wetlands that have both seasonal and perennially saturated/inundated zones will more effectively retain water, and assimilate nutrients.	✘	n/a

Characteristic	Reason for consideration for prioritisation	Assumption regarding water security	Included for wetland prioritisation?	Dataset used
	unsaturated wetland/soil (Bullock and Acreman, 2003). • The presence of permanently and seasonally saturated (or inundated) zones in a wetland increases total annual nitrate / phosphate assimilation (Kotze *et al.*, 2009). For instance, denitrification requires prolonged soil saturation that leads to anaerobic conditions, but appears to occur extensively in soils that are alternately aerobic and anaerobic – i.e. seasonally saturated.			
Vegetation type and extent of vegetation cover	• Deeper-rooting plants tend to have a higher transpiration rate than shallower rooting plants as they have greater access to deeper water[4], which will lead to a greater loss of water through evapotranspiration. • Vegetation provides habitat around its roots for the microbes that assimilate nutrients and other pollutants, and also an important supply of soil organic matter that the microbes require (Kotze *et al.*, 2009). Plants are also responsible for some direct uptake of nutrients (Kadlec and Knight, 2003). The more sparse the vegetation, the lower the assimilation of nutrients and pollutants.	• Wetlands with shallower-rooting vegetation will contribute more water to downstream water resources, due to a lower evapotranspiration rate. • Well vegetated wetlands are more likely to have a higher nutrient/pollutant assimilation rate.	✘	n/a
Pattern of low flows within the wetland	• Most of the assimilation of nutrients and pollutants occurs during periods of low flow and not flood flows. This is due to the fact that at this time residency time is longer and waters are shallower, which allows the wetland a greater opportunity to take up	• Seeps and unchannelled valley-bottom wetlands are more likely to have diffuse flow, and an improved retention of water and assimilation of nutrients.	✘	n/a

[4] This is dependent on several factors and not a simple relationship. For instance, the availability of water at certain depths has a significant impact on transpiration rates.

Characteristic	Reason for consideration for prioritisation	Assumption regarding water security	Included for wetland prioritisation?	Dataset used
	nutrients and pollutants (Kadlec and Kadlec, 1979). • Diffuse flow (i.e. seeping slowly through soil / vegetation) also increases the retention time by slowing down flow, and increasing contact time between water, soil and vegetation (Kotze *et al.*, 2009). • For example, both flood and baseflows through a seep or an unchannelled valley-bottom wetland are diffuse, while flow through a floodplain is channelled.			
Spread of stormflows across the wetland area	• The frequency with which stormflows are spread across the wetland will have an impact on flood attenuation, and so the retention of sediment. If flows spread at a frequency higher than once a year, then effectiveness is high. • The sinuosity of the channel (if there is one present) flowing through a wetland will also influence the speed of flow through a wetland, whereby a more sinuous channel will drop out more sediment in the channel and across the wetland.	• A gentler slope and sinuous channel (if present) will increase the effectiveness of attenuating floods, retention of sediment during periods of high flow.	✘	n/a
Contribution of sub-surface vs surface flows	• It has been documented that the removal of nitrates is more efficient from diffuse sub-surface flows than from surface flows – thus the greater the contribution of sub-surface flows the greater the assimilation of nutrients (Kotze *et al.*, 2009).	• Wetlands located in areas of groundwater discharge are more likely to be more efficient at nitrate assimilation.	✘	n/a
Runoff potential of the soils	• The higher the runoff potential (i.e. infiltration and permeability) of a soil, the slower will be the rate of infiltration and the greater the runoff intensity. • Deep, well drained sands have a low	• Wetlands on soils that have a low runoff potential (deep, well-drained sands) are more likely to have a higher infiltration rate, recharge of groundwater and less flashy flows exiting the system.	✓	Generalised soil map (Agricultural Research Council, Department of Agriculture, Institute

Characteristic	Reason for consideration for prioritisation	Assumption regarding water security	Included for wetland prioritisation?	Dataset used
	runoff potential, and clay soils, or soils with a permanently high water table, have a high runoff potential.			for Soil, Climate and Water), 2003
Soil type – especially presence of soils high in organic content, such as peat	• The structure of soils rich on organic material (e.g. peat) means that these soils can store significant quantities of water. Evidence of the role that these soils play in streamflow regulation, especially contributions to dry season base flows, remains equivocal, with one study finding that peatlands contribute up to 55% of streamflow during the dry season in Alaska (Gracz *et al.*, 2015), while other studies have shown that peatlands do not significantly regulate streamflow. • Fibrous peat increases the water storage capacity of the soil in a wetland, while still allowing water to flow freely through the substrate. Amorphous peat (comprising finer particles, and few fibres) also stores water but has a much lower hydraulic conductivity (like clay), which limits the release of water.	• The presence of fibrous peat (and to a lesser extent amorphous peat) is likely to increase the capacity of the wetland to store water and ensure infiltration of water into groundwater (should the geology allow). Water is more likely to be released slowly throughout the year. • Permanently saturated palmiet peat wetlands in the Cape Fold Mountains are known to slow down surface flows which may improve the ability of these ecosystems to replenish water stores in a downstream dam throughout the year.	✓	Research reports
Slope	• Slope influences the rate at which water moves through the wetland, and so has an impact on retention time (and so retention capacity) and contact time between water, soil and vegetation (Kotze *et al.*, 2009). This will influence the assimilation of nutrients and other pollutants.	• Wetlands on a gentler slope are likely to more effective in terms of the attenuation of flows, retention of water over time, and filtration of water into the ground (should the soils and geology allow).	✓	Environmental Potential Atlas of South Africa (ENAPT), 2011
Geology / hydrogeology	• The aquifer types of Colvin *et al.* (2007) may be used to infer groundwater	• Wetlands lying on geological formations known to contain aquifers are more likely to be fed by	✗	n/a

Characteristic	Reason for consideration for prioritisation	Assumption regarding water security	Included for wetland prioritisation?	Dataset used
	connectivity (also Kotze, in prep.). For instance, the Table Mountain Group aquifer, specifically the Nardouw Aquifer, has a high probability of feeding surface seeps and streams. • Groundwater discharge zones will be areas of high ground- to surface-water interactions.	groundwater. This will only occur, however, at groundwater discharge sites (e.g. faults and springs) and zones.		
Total rainfall	• Wetlands play an important role in slowing water flow over the ground surface, and so generally improving filtration into groundwater from surface, and water provision to downstream surface water resources (including dams).	• Wetlands located in areas of high total rainfall are likely to be more important in terms of the demand for services relating to attenuation of flows, streamflow regulation and infiltration into groundwater.	✓	Catchment dataset, WR2012
Rainfall intensity (an expression of the rate at which rain falls, usually expressed as mm/hour)	• The intensity of rainfall is as or possibly more important than total rainfall, as it provides information about the rate at which water falling as rainfall is accommodated on land, and the speed with which that water flows overland. Wetlands play an important role in slowing water flow over the ground surface, and so generally improving filtration into groundwater and the perenniality of water provision to downstream surface water resources. • A water supply system will benefit from catchment areas that assist in ensuring that rainfall does not flow in great volume over a short period of time into downstream dams, possibly exceeding dam capacity and leading to dam overflow and "loss" of water downstream and out of the supply system.	• Wetlands located in areas of high rainfall intensity are likely to be more important in terms of the demand for services relating to attenuation of flows, streamflow regulation and infiltration into groundwater.	✓	Rainfall intensity map, MacFarlane *et al.* (2014) adapted from Schulze (2007)

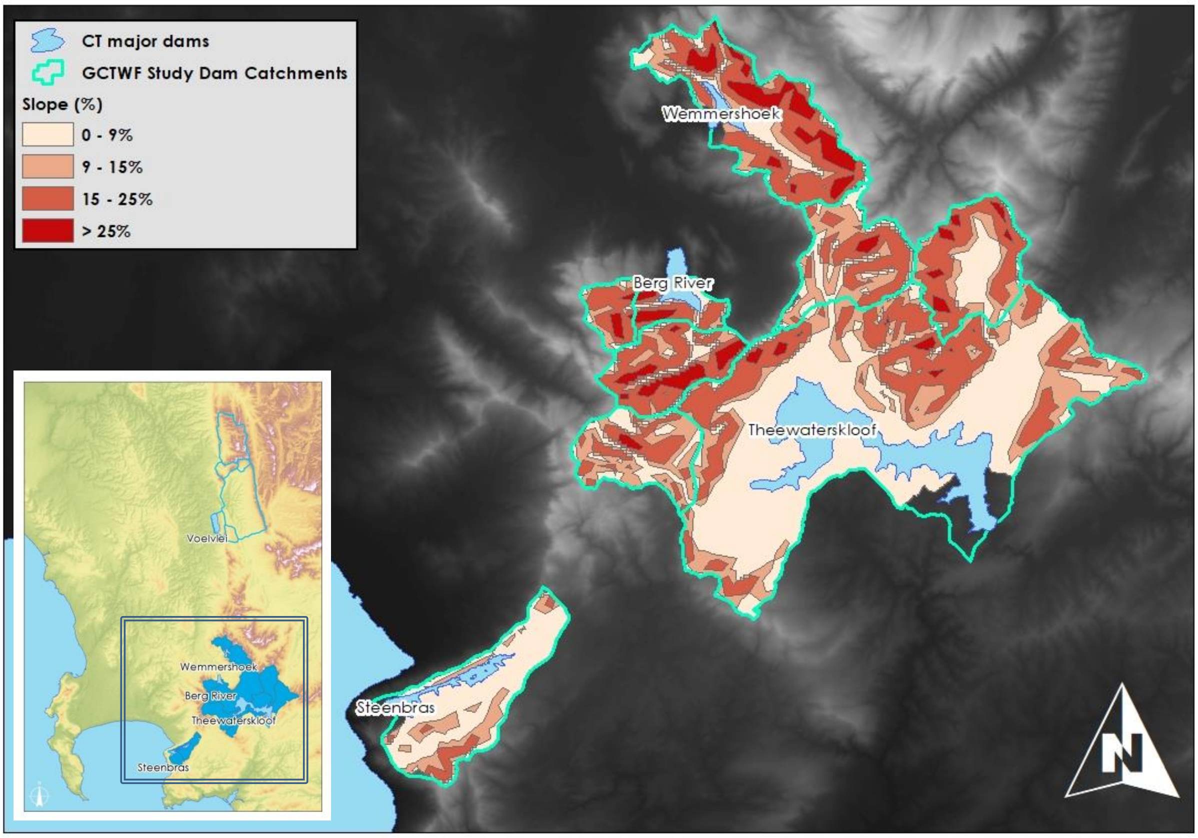


Figure 3.1 Slope categories (see legend) within the prioritised SQ4 catchments.

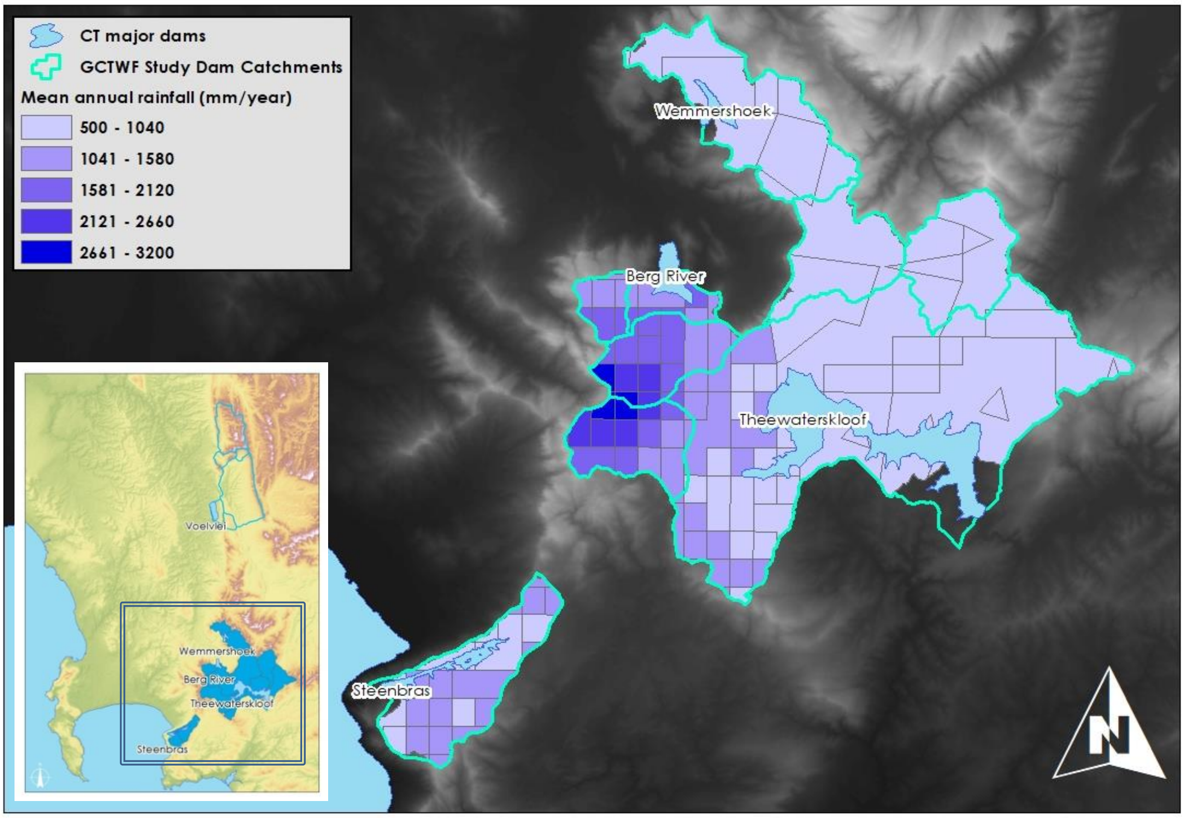


Figure 3.2 **Mean annual rainfall (see legend) within the prioritised SQ4 catchments prioritised.**

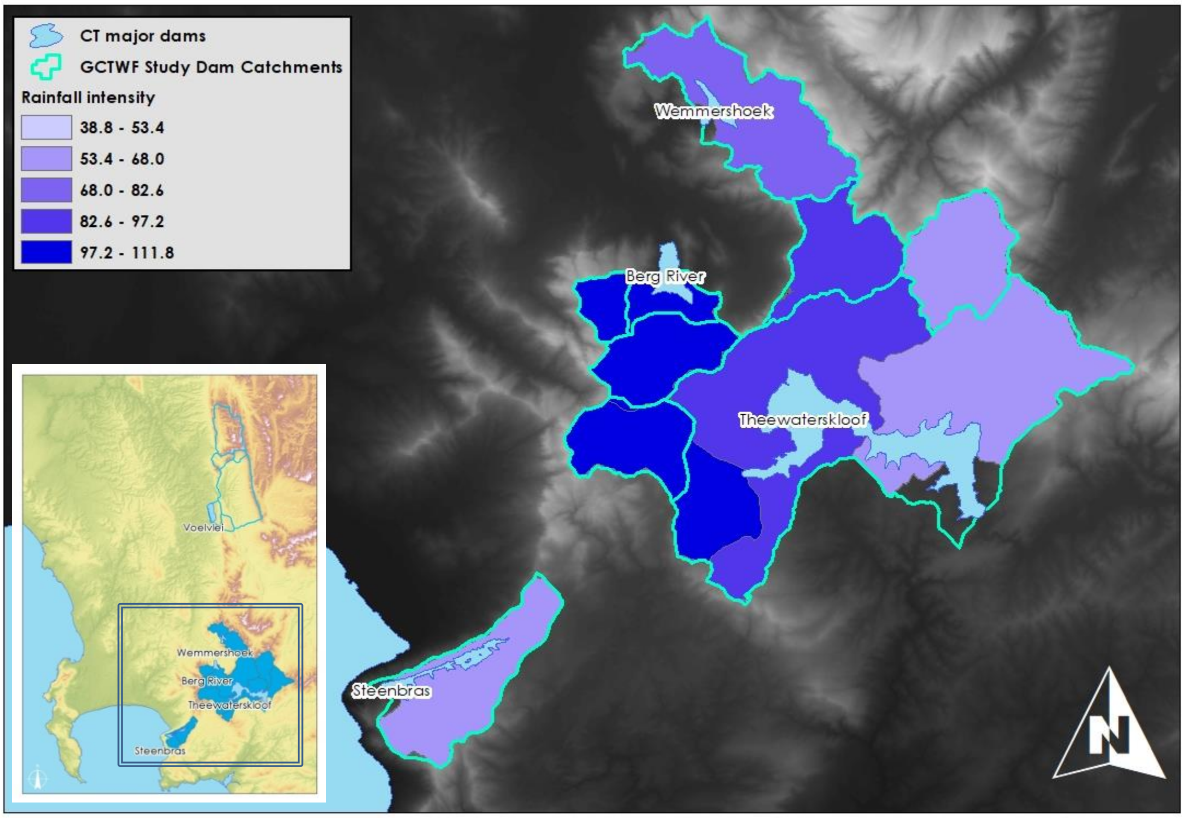


Figure 3.3 **Rainfall intensity (see legend) within the prioritised SQ4 catchments. Data from Macfarlane *et al.* (2015) – the rainfall intensity was modified from Schulze *et al.* (2007), and uses the 1-day design rainfall over a two year period.**

3.2 Results of wetland prioritisation

The results of the prioritisation of individual wetlands are presented in Table 3.2. It should be noted that should more time be allowed for a prioritisation of wetlands at a future date, more criteria could be added to this list, as more databases can be sourced and included in the assessment, and also through ground-verification of wetlands. For instance, ground-verified data on the vegetation communities within wetlands would be useful for determining whether there is a dominance of deeper-rooting species.

Table 3.2 Wetland characteristics that were used to prioritise individual wetlands for water security. The criteria were applied in the order that they appear in the table, and followed a process of elimination. Criteria were not weighted.

Characteristic	Selection criteria	Results
Wetland size	Area > 50 ha (upper two categories of Macfarlane *et al.*, 2014)	18 wetlands in the prioritised SQ4 catchments have an area > 50 ha
Hydrogeomorphic type	Seeps or valley-bottom wetlands	All of the wetlands selected above for size are seeps, or channelled or unchannelled valley-bottom wetlands
Fluvial connectivity	Wetlands that are connected to rivers	All of the wetlands selected above for size are connected to significant rivers in the region
Presence of important water resource downstream	Wetlands located immediately upstream of dams	Of the 18 wetlands selected for their overall size, three were identified as being immediately upstream of major dams in the WCWSS – Upper Riviersonderend, Du Toits River wetland (these last two feed into Theewaterskloof Dam), and the Olifants River wetlands feeding into Wemmershoek Dam.
Runoff potential of the soils – sand vs clay, and soil depth	Wetlands located on sandy loams and sandy soils, preferably where soils are moderately deep to deep	All three of the wetlands identified above lie on sandy loams or sandy soils. Only the Upper Riviersonderend feeding into Theewaterskloof Dam is located on moderately deep soils.
Soil type – especially presence of soils high in organic content, such as peat	Permanently saturated palmiet peat wetlands in the Cape Fold Mountains	The Upper Riviersonderend and Du Toits River wetlands are both permanently saturated palmiet peat wetlands in the Southern Folded Mountains ecoregion.
Slope	Slope category of < 9%	All three wetland systems identified above important dams are located on slopes < 9%
Total rainfall	Total rainfall	The three wetlands are all situated in high rainfall catchments: Upper Riviersonderend: 2141 mm/year Du Toits River wetland: 1241mm/year Wemmershoek: 1306 mm/year
Rainfall intensity	High rainfall intensity areas	The three wetlands are all situated in high rainfall intensity catchments (the maximum for South Africa is 140 mm): Upper Riviersonderend: 112 mm Du Toits River wetland: 86 mm Wemmershoek: 72 mm

Based on the criteria presented above in Table 3.2, three wetlands satisfied all the criteria – the Upper Riviersonderend, Du Toits River wetland, and the Wemmershoek wetland. In terms of organic content, runoff potential of soils, and the catchment rainfall intensity, the Upper Riviersonderend wetland emerges as likely to be the most critical wetland for the supply of important wetland functions relating to water security, while also being located in a part of the catchment where there is a high demand for such services. For instance, although water quality data were not consulted for the prioritisation (water chemistry is currently not monitored in the catchment by any government authorities), the Vyeboom area is an area of intense agriculture, with known point and non-point sources of nutrients and other pollutants. The wetland thus provides essential water quantity enhancement services, filtering out nutrients and pollutants before the water enters Theewaterskloof.

Dam storage capacity was not used as a prioritisation criterion, as this alone does not reflect the importance of a specific dam and dam catchment, due to the fact that the dams are located within a complex system of supply pipelines and transfer schemes (see Figure 3.4). Water is transferred between dams and catchments according to demand and supply. Theewaterskloof Dam has the largest storage capacity within the WCWSS, providing 41% of storage capacity within the WCWSS.

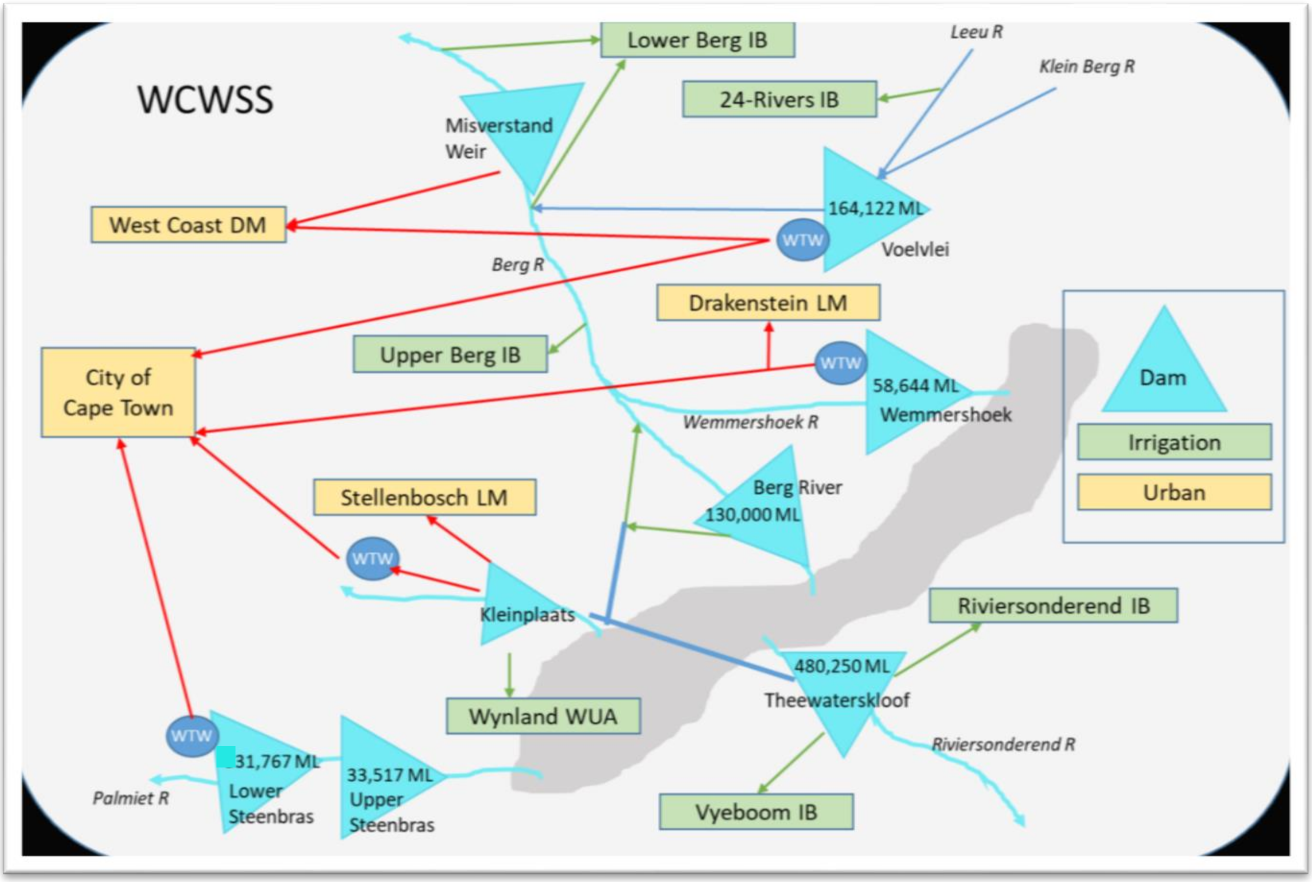


Figure 3.4 The Western Cape Water Supply System (from Turpie *et al.* (2018), based on DWS (2017)).

The brief for this study was to identify five priority wetlands, thus it is proposed that the seep and valley-bottom wetlands located immediately upstream of Steenbras Dam and the Berg River Dam, should be added. There is little difference in importance for water security between the latter two systems, although the Steenbras wetlands are located on a gentler slope compared to the Upper Berg River.

It must be noted that the lack of a high confidence wetland map for all of the prioritised catchments may have led to large or important wetlands being missed in this analysis. For this reason, it was decided that the extensive Zuurvlak wetland located on the Waterval River should be added to the list of prioritised wetlands. It was not mapped by the South African Inventory of Inland Aquatic Ecosystems, and the catchment in which the wetland lies was not prioritised according to demand for wetland function (this was largely due to the relatively lower rainfall and rainfall intensity within the catchment, and slightly lower runoff). However, the Zuurvlak wetland meets several of the wetland prioritisation criteria – see Table 3.3 – and it is located within a strategic water source area.

Table 3.3 Wetland characteristics for Zuurvlak wetland.

Characteristic	Selection criteria	Zuurvlak
Wetland size	Area > 50 ha (upper two categories of Macfarlane *et al.*, 2014)	The broad wetland is over 900 ha in size
Hydrogeomorphic type	Seeps or valley-bottom wetlands	Zuurvlak comprises seeps and channelled valley-bottom wetland
Fluvial connectivity	Wetlands that are connected to rivers	The wetland feeds the Waterval River.
Presence of important water resource downstream	Wetlands located immediately upstream of dams	The Waterval River confluences with the Klein Berg that supplies water to Voëlvlei Dam.
Runoff potential of the soils – sand vs clay, and soil depth	Wetlands located on sandy loams and sandy soils, preferably where soils are moderately deep to deep	The soils in the Zuurvlak wetland are sandy but relatively shallow (< 450 mm) on rock.
Soil type – especially presence of soils high in organic content, such as peat	Permanently saturated palmiet peat wetlands in the Cape Fold Mountains	There may be organic-rich soils but probably minimal peat (not confirmed however, as this wetland has not been sampled for peat). Portions of the wetland do support palmiet however, and remain permanently saturated.
Slope	Slope category of < 9%	Zuurvlak lies on a slope that is < 9%.
Total rainfall	Total rainfall	Total rainfall is 764 mm/year
Rainfall intensity	High rainfall intensity areas	Zuurvlak: 55 mm

3.3 Summary features of prioritised wetlands

Wetland name	Quaternary catchment	Wetland type (hydrogeomorphic unit)	Area
Upper Riviersonderend	H60A	Channelled valley-bottom	222 ha
Du Toits River	H60B	Channelled valley bottom	679 ha
Wemmershoek	G10B	Channelled valley bottom	323 ha
Steenbras	G40A	Seeps and channelled valley-bottom	77 ha
Upper Berg River[5]	G10A	Seeps and channelled valley-bottom	93 ha
Zuurvlak	G10E	Seeps and channelled valley-bottom	925 ha

[5] The greater area of wetlands mapped in the Upper Berg River catchment *versus* those in the Steenbras River catchment may be due to the Berg River mapping being done at a fine-scale using aerial photography with some ground verification (for Working for Wetlands Phase 1 planning), whereas the wetlands in the other catchments were copied from the draft National Inland Aquatic Ecosystem map (SANBI, in prep.).

4 Assessment of prioritised wetlands

4.1 Methods

4.1.1 Assessment of wetland functioning

To quantify the level of functioning of the prioritised wetland systems, and to highlight their relative importance in providing ecosystem benefits and services at a landscape level, WET-EcoServices (Kotze *et al.,* 2007) assessments were performed for all the prioritised wetland systems identified above.

The WET-EcoServices assessment technique focuses on the extent to which a benefit is being supplied by the wetland, based on both:

- The opportunity for the wetland to provide the benefits; and
- The effectiveness of the particular wetland in providing the benefit.

Ecosystem services, which include direct and indirect benefits to society and the surrounding landscape, were assessed by rating various characteristics of the wetlands and their surrounding catchments, based on the following scale:

- Low (0);
- Moderately Low (1);
- Intermediate (2);
- Moderately High (3); and
- High (4)

The scores obtained from these ratings for the wetland systems were then incorporated into WET-EcoServices scores for each of the fifteen ecosystem services (Table 4.1).

Table 4.1 Ecosystem services supplied by wetlands (Kotze *et al.,* 2007).

Ecosystem services supplied by wetlands	**Indirect benefits**	**Regulating and supporting benefits**		Flood attenuation	The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream
				Stream flow regulation	Sustaining stream flow during low flow periods
			Water quality enhancement benefits	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
				Nitrate assimilation	Removal by the wetland of nitrates carried by runoff waters
				Toxicant assimilation	Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters
				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
	Direct benefits	**Biodiversity maintenance**			Through the provision of habitat and maintenance of natural process by the wetland, a contribution is made to maintaining biodiversity
		Provisioning benefits		Provision of water for human use	The provision of water extracted directly from the wetland for domestic, agricultural or other purposes
				Provision of harvestable resources	The provision of natural resources from the wetland, including livestock grazing, craft plants, fish, etc.
				Provision of cultivated foods	The provision of areas in the wetland favourable for the cultivation of foods
		Cultural benefits		Cultural heritage	Places of special cultural significance in the wetland, e.g. for baptism or gathering of culturally significant plants
				Tourism and recreation	Sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife
				Education and research	Sites of value in the wetland for education or research

4.1.2 Assessment of wetland condition/integrity

To determine the level of ecological integrity, a WET-Health assessment (MacFarlane *et al.*, 2009) was performed for the prioritised wetland systems. The WET-Health assessment technique gives an indication of the deviation of the system from the wetlands' natural reference condition for the following biophysical drivers:

- Hydrology - defined as the distribution and movement of water through a wetland and its soils;
- Geomorphology - defined as the distribution and retention patterns of sediment within the wetland; and
- Vegetation - defined as the vegetation structural and compositional state.

The impacts on the wetlands, determined by features of the wetlands and their catchments, were scored based on the impact scores and then represented as Present State Categories (PES) as outlined in WET-Health (Table 4.2). Either a Level 1 or Level 2 WET-Health assessment was completed for all wetlands, depending on the amount of detail available for the assessment.

Table 4.2 Impact scores and present state categories for describing the integrity of wetlands. (MacFarlane *et al.*, 2009).

Impact Category	Description	Impact Score Range (0-10)	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 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**

The scores for hydrology, geomorphology and vegetation were simplified into a composite impact score, using the predetermined ratio of 3:2:2 (MacFarlane *et al.,* 2009) respectively for the three components. The composite impact score was used to derive a health score that then provided the basis for the calculation of hectare equivalents (also referred to as functional area), which can be described as the health of a wetland expressed as an area (Kotze and Ellery, 2009).

4.2 Results of assessment

4.2.1 Wetland functioning

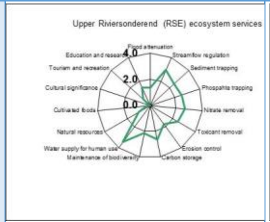
Biodiversity maintenance and hydrological / functional importance were of greatest importance in all of the wetlands (Table 4.3). In terms of biodiversity, all of the wetlands are located close to or within conservation areas, providing important habitat for a number of wetland species. Most of the hydrological / functional importance services were considered to be of intermediate to high importance, with the exception of flood attenuation and erosion control. All of the wetlands are located in upper catchments and so flood attenuation is less important than in wetlands lower down the catchment on gentler slopes.

In terms of provisioning services, all of the wetlands assessed are considered important for direct water supply, due to the importance of their downstream dams in the Western Cape Supply System. All of the wetlands scored highest for this function. The remaining cultural and supporting services were considered to be of low to negligible importance for all the wetlands, due to their location close to conservation areas, and not being located in communal areas where harvesting and grazing is more likely to occur in the wetlands.

Table 4.3 Assessment of current wetland ecosystem services for the prioritised wetlands.

Ecosystem Service		Upper Riviersonderend	Du Toits	Wemmershoek	Steenbras	Upper Berg	Zuurvlak
		Importance Score	Importance Score	Importance Score	Importance Score	Importance Score	Importance Score
Regulatory and Supporting Services	Flood Attenuation	1.3	1.3	1.6	1.3	1.5	1.4
	Stream Flow Regulation	3.0	2.7	2.7	2.7	2.7	2.3
	Sediment Trapping	2.5	2.5	2.9	2.9	2.5	0.8
	Phosphate Trapping	2.5	2.5	2.1	2.1	2.1	1.5
	Nitrate Removal	2.7	2.7	2.3	2.5	2.7	2.2
	Toxicant Removal	2.5	2.5	2.8	2.8	2.8	2.0
	Erosion Control	1.8	1.8	1.9	1.9	1.9	1.8
	Carbon Storage	2.7	2.3	2.0	2.3	2.3	1.7
Overall hydrological /functional importance		**2.32**	**2.29**	**2.29**	**2.31**	**2.31**	**1.71**
Biodiversity	Biodiversity Maintenance	**2.6**	**2.2**	**2.5**	**2.5**	**2.7**	**2.3**
Provisioning Services	Water Supply	3.4	3.4	3.4	3.4	3.4	3.4
	Harvestable Natural Resources	1.0	1.0	0.6	0.8	0.8	0
	Cultivated Foods	0.2	0.2	0.0	0.2	0.0	0
Cultural Services	Socio-Cultural Significance	0.0	0.0	0.0	0.0	0.0	0
	Tourism and Recreation	1.7	0.7	1.0	1.4	1.9	1.6
	Education and Research	2.0	1.5	1.3	1.5	3.0	2.0
Overall direct human benefits		**1.38**	**1.13**	**1.05**	**1.22**	**1.52**	**1.17**

2.3

<table>
<tr><th rowspan="2">Ecosystem Service</th><th>Upper Riviersonderend</th><th>Du Toits</th><th>Wemmershoek</th><th>Steenbras</th><th>Upper Berg</th><th>Zuurvlak</th></tr>
<tr><th>Importance Score</th><th>Importance Score</th><th>Importance Score</th><th>Importance Score</th><th>Importance Score</th><th>Importance Score</th></tr>
<tr><td>Web diagrams of ecosystem services</td>
<td>
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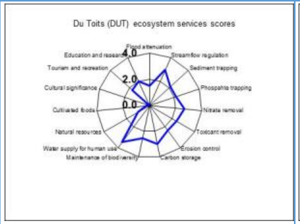
<td>
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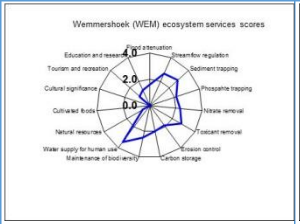
<td>
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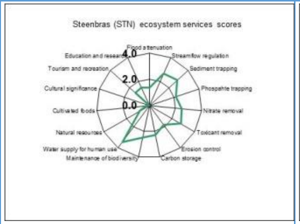
<td>
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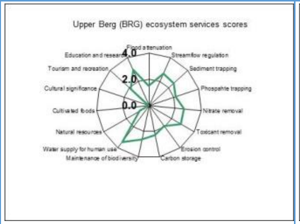
<td>
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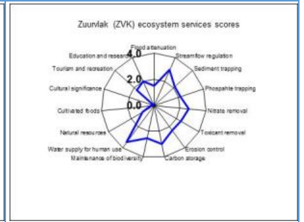
<td>
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4.2.2 Wetland condition

The Upper Riviersonderend, Steenbras and Zuurvlak wetlands are all in a largely modified state and this is primarily due to altered hydrology as a result of agricultural practices, IAP encroachment (past and/or present) and afforestation. The other three wetlands are moderately modified, for the same reasons.

In terms of geomorphology, the wetlands are not greatly altered, with the exception of the Upper Riviersonderend, where erosion of channels in the wetland has changed the cross-sectional shape of the system.

The assessed condition for all the wetlands is relatively poor, but this might be exaggerated due to the consideration of each wetland or group of wetlands (in the case of Steenbras and Upper Berg) as a whole and not as individual disturbance units. The former approach, used here, tends to lower the overall condition score and over-emphasise modifications, but the latter approach requires more time, and was not possible within the time and budget constraints of this project.

Table 4.4 Current wetland impact scores and Present Ecological Status categories for the prioritised wetlands.

Wetland name		Upper Riviersonderend	Du Toits	Wemmershoek	Steenbras	Upper Berg	Zuurvlak
Hydrology	**Impact Score**	6.0	6.5	4.0	7.0	6.5	6.5
	PES Category	**E**	**E**	**D**	**E**	**E**	**E**
Geomorphology	**Impact Score**	3.1	1.6	1.6	0.9	0.9	1.0
	PES Category	**C**	**B**	**B**	**A**	**A**	**A**
Vegetation	**Impact Score**	3.0	2.0	2.0	4.0	3.0	5.2
	PES Category	**C**	**C**	**C**	**D**	**C**	**D**
Overall	**Impact Score**	4.3	3.8	2.7	4.4	3.9	4.5
	PES Category	**D**	**C**	**C**	**D**	**C**	**D**

5 Rehabilitation plans

The prioritised wetlands were visited during the months of May and June 2018, in order to investigate opportunities for rehabilitation. Opportunities were found only in the Upper Riviersonderend, Du Toits River wetlands and Zuurvlak. Zuurvlak was identified as a Working for Wetlands priority in 2014, and rehabilitation planning was completed for this wetland in 2014. These costs have been inflated to 2018 rates.

5.1 Rehabilitation aims and objectives for the project area

It is important to set aims and objectives for the planned rehabilitation, as recommended in WET-RehabPlan (Kotze *et al.*, 2009); those identified for rehabilitation of prioritised wetlands for water security for Cape Town are presented in Table 5.1.

Table 5.1 Aims and objectives of rehabilitation for water security for Cape Town.

Aim	Objective
Prevent further erosion and loss of wetland soils and vegetation	Stabilise head-cut and bank erosion to prevent further erosion
Stabilise base-flows flows in order to reduce erosion within the wetland	Slow down and dissipate the energy of base flows to reduce incision and head-cut erosion
Allow build-up of sediment within the wetlands in order to return the systems to depositing instead of eroding systems	Trap sediment and slow down flow
Remove existing populations of IAPs and prevent further encroachment into wetland and rivers, in order to reduce evapotranspiration losses	Remove IAPs from the wetlands and river channels and revegetate with appropriate plant species

5.2 Rehabilitation plan for the Upper Riviersonderend

5.2.1 Description of the wetland

The Upper Riviersonderend wetland system is a weakly channelled valley-bottom wetland (see Kotze, 2015) that flows into the Theewaterskloof Dam near the agricultural settlement of Vyeboom. The river rises on the Groot Drakenstein and Franschhoek mountains, and joins the Breede River 20km west of Swellendam (Kotze, 2015). The wetland occupies an area of 222 ha, which incorporates both private and public land. The upper end of the wetland lies within a CapeNature Reserve, the Hottentots-Holland Nature Reserve, while a portion of the wetland immediately upstream of the full supply level (FSL) of Theewaterskloof Dam, lies within a World Heritage Site. Theewaterskloof Dam itself is owned and managed by the Department of Water and Sanitation (DWS).

The sub-catchment in which the wetland lies has been identified as a FEPA catchment, due to the good condition of the river. The upper reaches of the Riviersonderend are known to provide sanctuary to the endangered Giant Redfin, *Pseudobarbus skeltoni* (J. Shelton, pers. comm.), which is endemic to the Breede River. It is possible that this is one of the three last remaining populations of this newly described species (Chakona and Swartz, 2013). Most of the wetland has been classified as an aquatic Critical Biodiversity

Area (CBA) in the Western Cape Spatial Biodiversity Plan for the Theewaterskloof Municipality (Pool-Stanvliet *et al.*, 2017). The management objective for aquatic CBAs is to maintain these ecosystems in a natural or near-natural state, with no further loss of natural habitat, degraded aquatic CBAs should be rehabilitated and only low-impact, biodiversity-sensitive land uses are appropriate in and around these ecosystems.

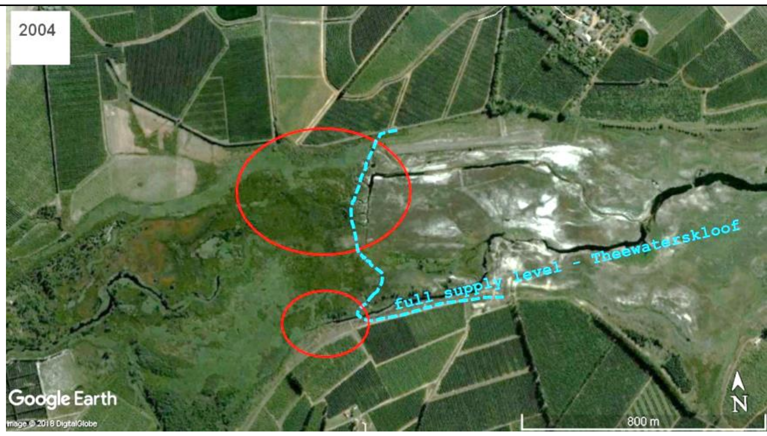
The vegetation type throughout the wetland is the critically endangered Elgin Shale Fynbos, and the bioregion is Southwest Fynbos (Rebelo *et al.*, 2006). The vegetation in the wetland is dominated along much of the length of wetland by dense stands of palmiet, *Prionium serratum*. This obligate wetland plant has been described as an "ecosystem engineer" due to its ability to block water flow where the plant proliferates, leading to the accumulation of organic material and the development of wetland conditions (Sieben, 2012; Job, 2014). The organic content of the soils in the Upper Riviersonderend wetland has been sampled on a number of occasions in the past (Job and Reeler, 2013; Kotze, 2015). The average depth of soils with a high organic content (> 20% carbon content) was found to be 0.54 m, with an estimated total of 383 153 m^3 (Kotze, 2015).

The WWF's Ecosystem Carbon Project initiated extensive IAP clearing in 2015/2016. This has been largely effective, with some patches of scattered individuals remaining.

5.2.2 Modifications within the wetland

As presented above (Section 4.2), the wetland was assessed as being largely modified, returning overall a Category D WET-Health assessment (Section 4.2.2). This is largely due to modifications in wetland hydrology within the wetland, as summarised in Table 5.2.

Table 5.2 Modifications to wetland hydrology encountered in the Upper Riviersonderend wetland, with accompanying photographs.

<table>
<tr><th>Wetland problem</th><th>Photos</th></tr>
<tr><td>Erosion of organic soils and loss of wetland vegetation, leading to channelisation of flows in erosion gullies. This leads to the draining and desiccation of wetland areas and further erosion.</td><td>
</td></tr>
<tr><td>Rapid changes in water level around the margins of Theewaterskloof Dam (and drying out of soils during the current dry period) trigger head-cut erosion into the wetlands feeding the dam</td><td>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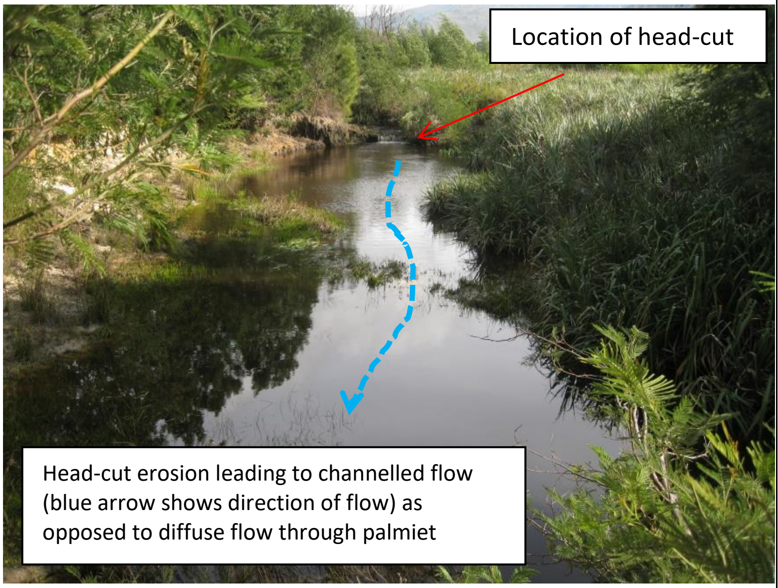
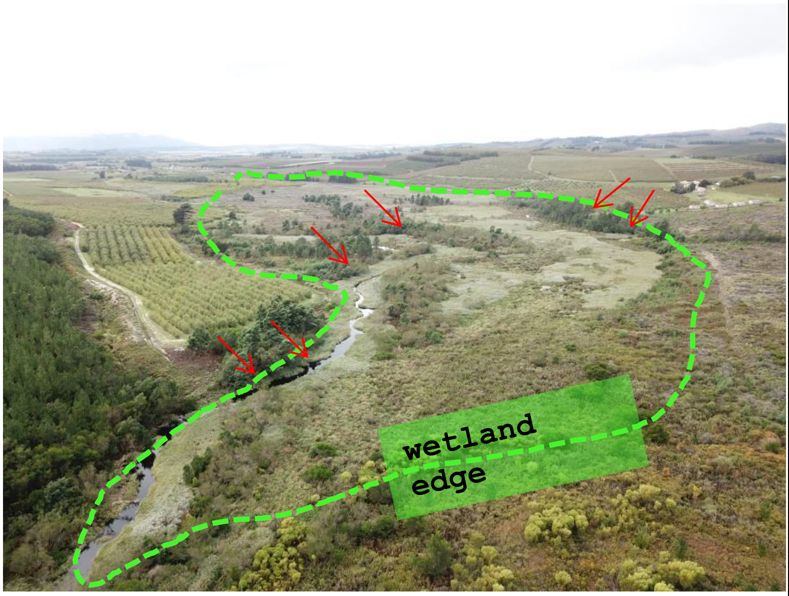
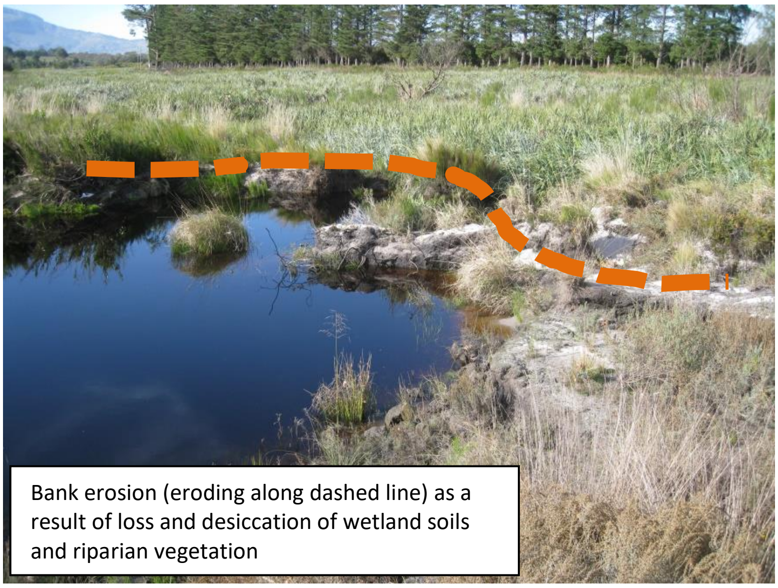
Wetland problem	Photos
Head-cut erosion which has changed the manner in which low flows move through the wetland – these now flow as channelled flow rather than diffuse flow through beds of palmiet	
IAP encroachment (red arrows) into the wetland area – leading to evapotranspiration losses that are higher than that attributed to indigenous vegetation	

Wetland problem	Photos
Discharge of channelled flows into the wetland from agricultural drains, changing flow patterns and causing erosion	

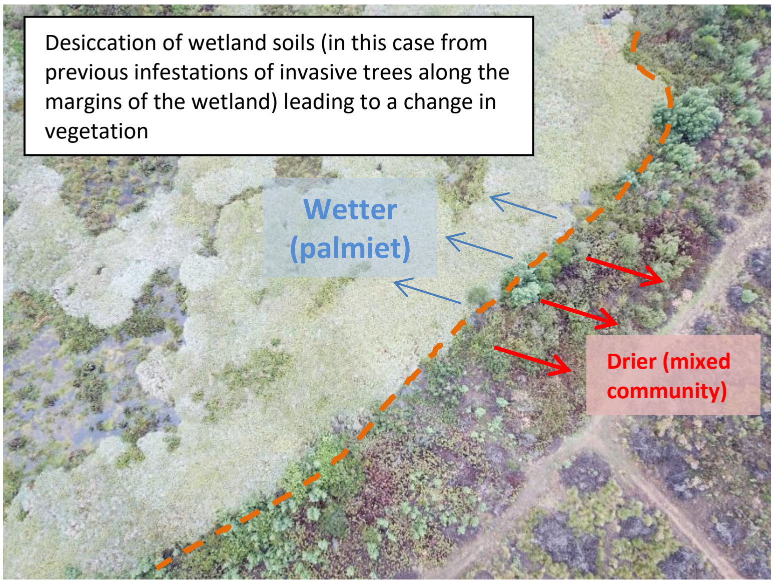
Table 5.3 Modification to wetland geomorphology in the Upper Riviersonderend wetland.

Wetland problem	Photos
Bank erosion as a result of loss and desiccation of wetland soils and vegetation	 Bank erosion (eroding along dashed line) as a result of loss and desiccation of wetland soils and riparian vegetation

In addition there have been modifications to the geomorphology of the wetland, largely due to the changes in hydrology mentioned above, but also directly as a result of the loss or desiccation of wetland soils as a result of draining of wetlands and the replacement of indigenous riparian and wetland vegetation with orchards and IAPs. Destabilised banks are eroding particularly in one area of the wetland immediately downstream of a road bridge that concentrates surface flow at one point, thus increasing the erosive force of the water. The wetland has been drained along the left-hand bank and a sports field constructed through infilling. The desiccated wetland soils are now eroding along this bank (see Table 5.3).

In terms of vegetation within the wetland, there are a few areas where the dense palmiet stands that should occur have been replaced either by vegetation that grows in slightly drier conditions (Table 5.4), as a result of desiccation of the wetland soils, or by IAPs, where soils have been disturbed. Desiccation of wetland soils occurs where there has been IAP encroachment in the past – these exotic tree species (primarily black wattle (*Acacia mearnsii*) and pines (*Pinus pinaster*)) transpire at a higher rate than the indigenous wetland vegetation – or where the wetland has been drained through channel formation (through erosion or man-made channelisation) (see Table 5.4).

Table 5.4 Modifications to wetland vegetation in the Upper Riviersonderend wetland.

Wetland problem	Photos
Encroachment of IAPs into the wetland area	IAPs (mostly black wattle) into the Upper Riviersonderend wetland. (Photo courtesy of Heidi Nieuwoudt) 
Drying out of wetland soils leading to a change in vegetation community from a drier, facultative wetland to a wetter, obligate wetland community	

The plant communities inhabiting parts of the wetland that are not dominated by palmiet include a number of indigenous species, such as those presented in Table 5.5.

Table 5.5 Plant species occurring in the Upper Riviersonderend wetlands

Plant species	Wetland category (facultative/obligate)
Erica lutea	Non-wetland
Watsonia aletroides	Facultative
Willdenowia sulcata (restio)	Facultative
Cliffortia graminea	Facultative
Elegia tectorum (restio)	Facultative
Pteridium aquilinum (bracken)	Facultative
Zantedeschia aethiopica (arum lily)	Facultative
Metrosideros angustifolia	Riparian tree species
Isolepis spp	Depends which *Isolepis* spp: could be either
Hellmuthia membranaceae (sedge)	Obligate
Carpha glomerata	Obligate
Juncus kraussii (rush)	Obligate
Juncus lomatophyllus (rush)	Obligate
Juncus punctorius (rush)	Obligate
Leucadendron salicifolium, L. xanthoconus	Obligate
Paspalum distichum (grass)	Obligate
Pennisetum macrourum (grass)	Obligate
Platycaulos major (restio)	Obligate
Prionium serratum (palmiet)	Obligate
Wachendorfia thyrsiflora (blood/red root)	Obligate

5.2.3 Proposed rehabilitation strategy

A number of rehabilitation interventions, all of which are considered to be "soft" engineering options, are recommended for the Upper Riviersonderend. The rehabilitation planning was done with the guidance of two environmental engineers from Groundtruth, KwaZulu-Natal. The interventions are listed in Table 5.6. It must be noted that costing of the various interventions has been done at private contractor rates. Detailed design drawings are provided in Appendix 1.

The costs include the following:

- Implementer fees
- Professional fees
- Training and capacity building
- Community facilitation
- Marketing

- Administration
- Wages paid in terms of the EPWP
- Non-EPWP salaries
- Materials and equipment
- Transport: project management
- Transport: operational
- Transport: contractors
- VAT

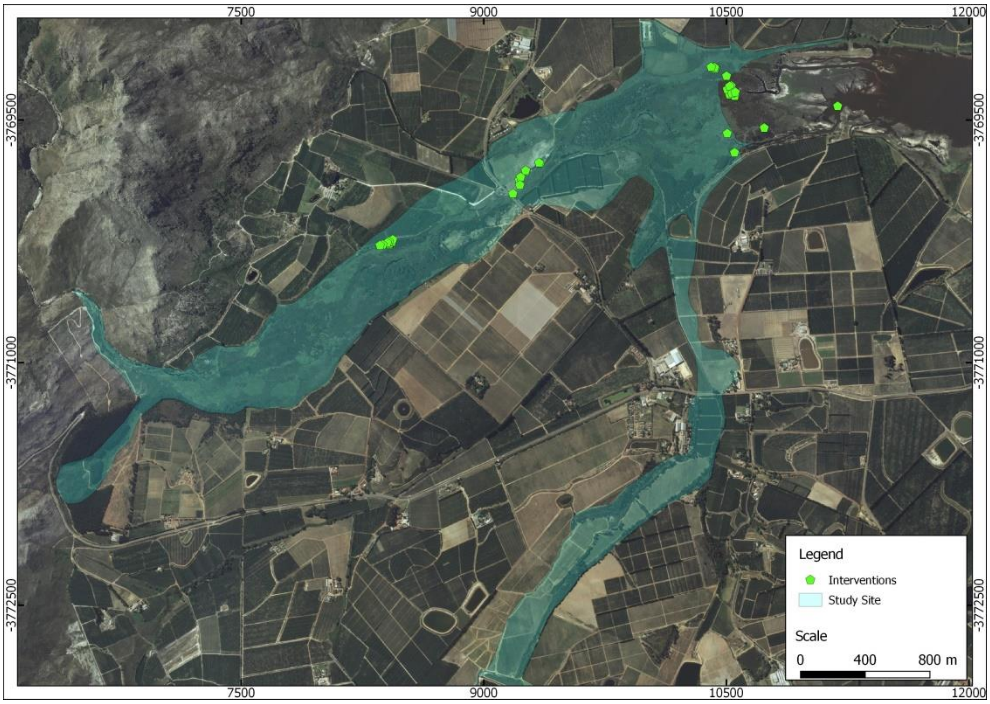


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Figure 5.1 Overview of the Upper Riviersonderend wetlands (WfWet ID: H60A-01) and its associated interventions

Table 5.6 Interventions proposed for the Upper Riviersonderend wetland (WfWet ID: H60A-01).

Intervention No.	Description of intervention	Rehabilitation objectives	Cost Estimate (R)
H60A-01-201	Geo-cell concrete chute	Stabilise the head-cut and prevent further erosion and soil mobilisation	R53 377
H60A-01-202	Rockpack	Reduce high energy flow through the channel and prevent further erosion of the head-cut	R5 228
H60A-01-203	Sloping with bio-jute blanket and backfilling depressions, as well as revegetation along bank	To stabilise the banks in order to prevent further erosion and soil mobilisation	R335
H60A-01-204	Sloping with bio-jute blanket and ecologs, as well as revegetation along bank	To stabilise the banks in order to prevent further erosion and soil mobilisation	R11 900
H60A-01-205	Rockpack	To reduce high energy flows through channel and prevent further erosion of the head-cut	R2 766
H60A-01-206	Rock Masonry Chute	To stabilise the head-cut and prevent further erosion of the wetland	R17 958
H60A-01-207	Extension of an existing earthen berm	To prevent any lateral erosion into the channel and divert water into a controlled re-entry point	R4 781

Intervention No.	Description of intervention	Rehabilitation objectives	Cost Estimate (R)
H60A-01-208	Sloping of the left bank and installation of groynes as well as revegetation with Palmiet along the toe of the bank	To stabilise the bank and prevent further erosion as well as to divert water to the right of the channel	R248 320
H60A-01-209	Sloping of the right bank and active revegetation with Palmiet along toe of banks	To prevent further erosion along the right bank	R22 226
H60A-01-210	Sloping with rockpack	Stabilise the head-cut and prevent further erosion and soil mobilisation	R6 119
H60A-01-211	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R272 431
H60A-01-212	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R215 902
H60A-01-213	Geocell chute and backfilling of adjacent headcut	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R220 421
H60A-01-214	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R317 534
H60A-01-215	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R368 189
H60A-01-216	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R202 931
H60A-01-217	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R105 367
H60A-01-218	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R17 089
H60A-01-220	Geo-cell concrete chute	Stabilise the head-cut that is threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam	R116 753
H60A-01-221	Sloping and revegetation of bank	To stabilise the banks in order prevent further erosion and soil mobilisation	R1 089
TOTAL			**R2 210 717**

5.2.3.1 IAP control

In addition to the engineering rehabilitation interventions proposed above, there are parts of the wetland that still need to be cleared of IAPs. These areas amount to a total area of 48 hectares, at a cost of approximately R904 000 in the first year.

The total cost was broken down per block of IAPs identified in the Upper Riviersonderend (details provided in Appendix 2). There are a number of methods that are applied, each with different cost implications. They can be summarised as follows:

- **Frilling:** a number of overlapping cuts is made through the bark into the soft wood of the tree around the entire stem, using an axe, panga, or bush knife, approximately 0.5 m above the ground surface. The herbicide is then applied into the cuts, ensuring that it reaches and is retained in the cambium layer.
- **Cutting and stacking**: trees are cut using a chainsaw, and stacked on site. Herbicide is applied to cut stumps.
- **Cutting and logging**: trees are cut using a chainsaw, cut into smaller sizes, and removed from the wetland or riparian zone. Herbicide is applied to cut stumps.

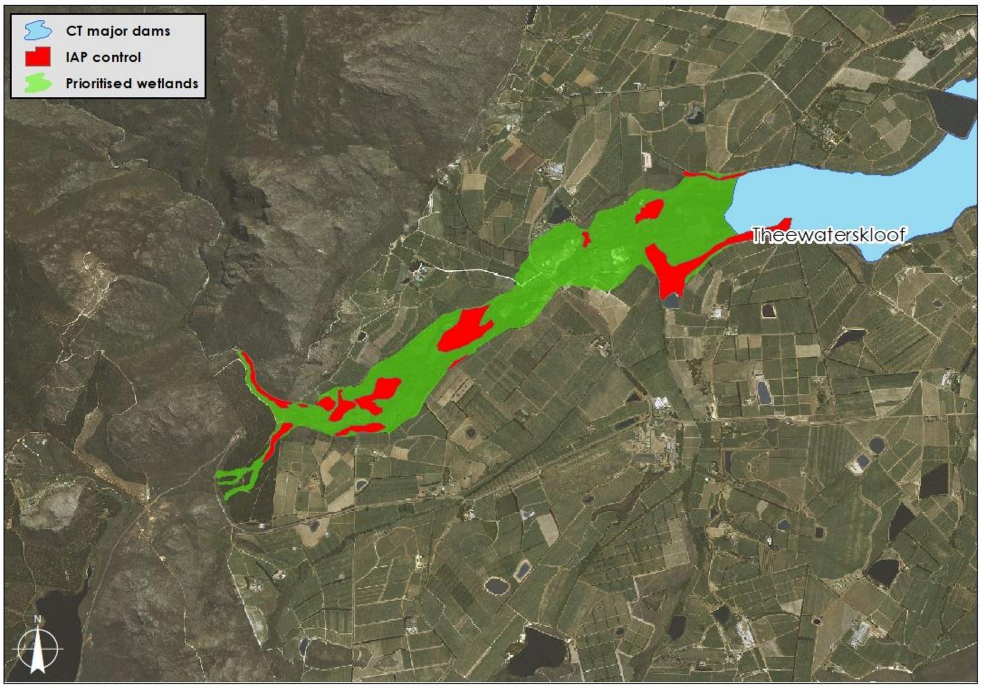

Figure 5.2 Blocks of IAPs (mainly pines and black wattle) that still need to be cleared in the Upper Riviersonderend wetland.

5.2.3.2 Partnerships

Existing initiatives that should be taken into account in order to strengthen the rehabilitation strategy presented here include:

- **WWF's Ecosystem Carbon Project** – WWF has done some extensive clearing of IAPs in the Upper Riviersonderend as part of this project. There are substantial quantities of dead branches that remain in the wetland, however, and this needs to be removed as a matter of urgency as this will block flow and shade out indigenous plants.
- **Working for Wetlands (WfWet)** – the Upper Riviersonderend has been identified as a priority for rehabilitation planning (Nieuwoudt, 2015), and environmental authorisation has been

obtained for work in this area. It is recommended that a partnership should be formed with WfWet, so that the rehabilitation strategy presented here can be taken forward within the conditions of the authorisation, and contributing to WfWet's goals and targets.

- **CapeNature** – CapeNature manage aspects of the World Heritage Site, thus access to the intervention sites close to the dam will require consultation with CapeNature.

5.2.4 Rehabilitation gains

A comparison between the current condition of the wetland and its condition with and without rehabilitation allows for the rough calculation of the number of hectares of wetland that will be gained or secured through rehabilitation. In addition, the delivery of ecosystem services by the wetland can also be compared between the current state and a predicted state with rehabilitation (Table 5.7).

Table 5.7 Rehabilitation gains for the Upper Riviersonderend wetland. The table includes only those ecosystem services that will influence water security.

	Total wetland area influenced	Number of hectare equivalents gained or secured	% increase in streamflow regulation	% increase in nitrate removal	% increase in erosion control	% increase in carbon storage
Upper Riviersonderend	222	77	0	0	33	25

5.3 Rehabilitation plan for Du Toits River wetland

5.3.1 Description of the wetland

The Du Toits River wetland is located on the north-western margin of Theewaterskloof Dam. The wetland is an extensive weakly channelled valley-bottom wetland, dominated by plant communities that are very similar to the Upper Riviersonderend wetland. Palmiet grows in large, dense stands, with more mixed plant communities inhabiting other portions of the wetland, especially where there has been disturbance in the past. During the early 2000s, there was an erosion event in the catchment that led to the deposition of considerable sediment in the wetland (Kotze, 2015). The wetland has largely recovered from this impact, with a mixed plant community growing quite rapidly over the deposited sediment. There has been extensive IAP removal over the past few years, and the vegetation now appears to be in good condition.

The Du Toits River wetland was sampled for organic content of the wetland soils by Job and Reeler (2013) and Kotze (2015) – they found that the organic soils (carbon content > 20%) were deeper than those in the Upper Riviersonderend wetland, extending on average to 0.93 m, with a total volume of organic material of 1 095 733 m^3 (Kotze, 2015). Fortunately, the erosion gully that extended into the wetland during the early 2000s, is located upstream of the organic stores in the wetland, and is thus not perceived as a threat to the ability of the wetland to store carbon.

The Du Toits River wetland lies almost entirely within the Theewaterskloof World Heritage Site and is managed by CapeNature.

5.3.2 Modifications within the wetland

Wetland problem	Photos
Scattered IAPs	

5.3.3 *Proposed rehabilitation strategy*

There are no major impacts within the wetland area that are considered to be threatening the ability of the wetland to perform ecosystem services that relate to water security (and incidentally, carbon storage). The rehabilitation strategy for the Du Toits wetland is follow-up IAP clearing.

5.3.3.1 IAP control

IAPs in the Du Toits River wetland are scattered, and can be removed by frilling.

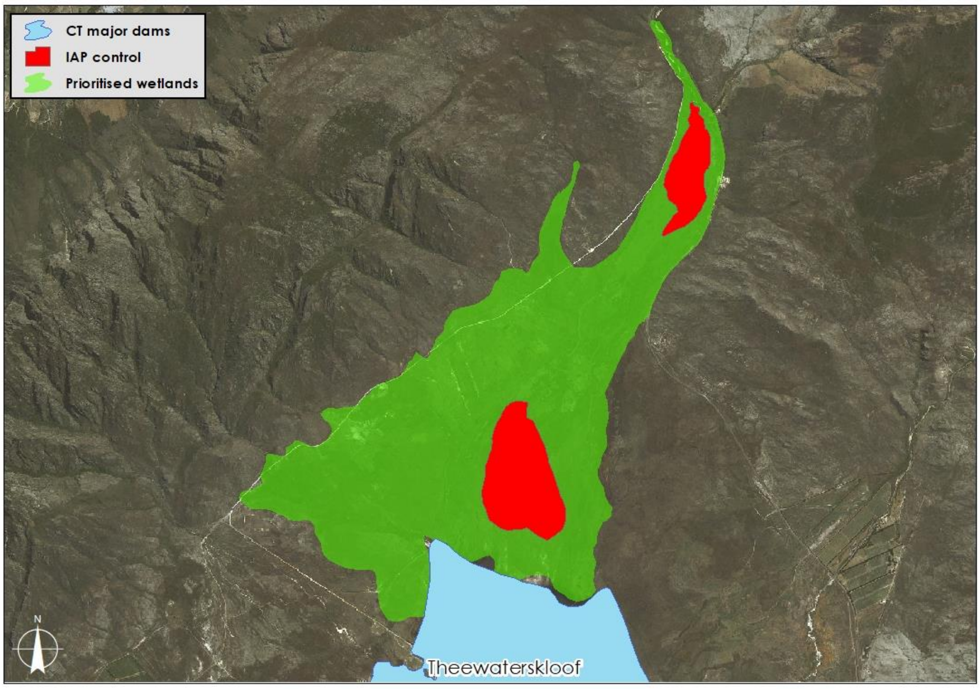

Figure 5.3 Areas in the Du Toits River wetland that should be cleared of scattered IAPs.

A total area of approximately 82 ha requires IAP clearing (Figure 5.3), at an estimated cost of R525 000 in the first year.

5.3.3.2 Partnerships

- **CapeNature** - the wetland is managed as part of the Hottentots-Holland Nature Reserve, so any work in the wetland should follow on from consultation with CapeNature.

5.3.4 Rehabilitation gains

A comparison between the current condition of the wetland and its condition with and without rehabilitation allows for the rough calculation of the number of hectares of wetland that will be gained or secured through rehabilitation. In addition, the delivery of ecosystem services by the wetland can also be compared between the current state and a predicted state with rehabilitation (Table 5.7).

Table 5.8 Rehabilitation gains for the Du Toits River wetland. The table includes only those ecosystem services that will influence water security.

	Total wetland area influenced	Number of hectare equivalents gained or secured	% increase in streamflow regulation	% increase in nitrate removal	% Increase in erosion control	% Increase in carbon storage
Du Toits River wetland	680	56	0	0	6	11

5.4 Rehabilitation plan for Zuurvlak

5.4.1 Description of the wetland

Zuurvlak is located on the Waterval River, a tributary of the Klein Berg River, which supplies water to Voëlvlei Dam. Until approximately a decade ago, the wetland was completely under SAFCOL pine plantations, managed by MTO, but the pines have been systematically cleared since the early 2000's. MTO signed off on the site in 2014, and the site was returned to the Department of Agriculture, Forestry and Fisheries (DAFF) and then the Department of Public Works (DPW). A 30-year lease was signed in September 2015 between DPW and a private renewables company, SFWECO (Pty) Ltd, who have plans to construct a wind, solar or possibly a pumped storage scheme on the site.

The wetland is quite unique in its location on a gently sloping valley floor or plateau, with seeps and streams feeding into it from the side slopes. Overall, the wetland is classified as a seep, but there are areas of valley-bottom wetland associated with the stream channel. A high (approximately 30 – 40 m) waterfall separates the wetland plateau from downstream, leading to the isolation of this plateau from the rest of the catchment. This is likely to have had an influence on species diversity and speciation. The wetland is a known location of at least 3 Red Data Book Proteaceae species and populations of *Galaxias zebratus* and *Sandelia capensis* (Cape kurper).

The sub-catchment incorporating the Zuurvlak wetland has been prioritised as a FEPA sub-catchment, due to the relatively good condition of the river reaches in the catchment. A small seep in the north-western corner of the plateau has been identified as a wetland FEPA, and is in pristine condition.

The vegetation type across the whole wetland plateau is Hawequas Sandstone Fynbos, which is least threatened and well protected (Rebelo *et al.*, 2006). The soils here are very sandy and well leached, with sometimes a thin layer of dark organic matter at the surface, where the soils are wetter for longer.

Figure 5.4 Panoramic photo of the upper section of Zuurvlak (2014), showing the main ring road around the wetland in the foreground. This upper section has been cleared of pines for some time and is in good condition

Figure 5.5 View of the lower end of Zuurvlak (2018), showing regrowth of pines. These pines were cleared in 2013/2014.

Figure 5.6 Red List plant species located in Zuurvlak wetland. Top left: *Serruria* sp., top right: *Sorocephalus imbricatus* (critically endangered); Bottom left: *Diastella myrtifolia* (critically endangered).

5.4.2 Modifications within the wetland

Wetland problem	Photos
Erosion around plantation roads, exacerbated by afforestation with pines, and their subsequent removal. Erosion gullies (arrow) are leading to the draining of seeps feeding into the main wetland	
Erosion subsequent to recent fires. Hot fires have burnt down into the sandy soils, which are now subsiding, causing erosion gullies to form	
Persistent regrowth of pine trees, and also black wattle in and around the river and in previously cleared blocks	

5.4.3 Proposed rehabilitation strategy

The rehabilitation interventions proposed to address some of the wetland problems outlined above are listed in Table 5.9. The interventions were planned, designed and costed as part of the West Coast Working for Wetlands Rehabilitation Plan (2014). A map of the interventions is provided in Figure 5.7.

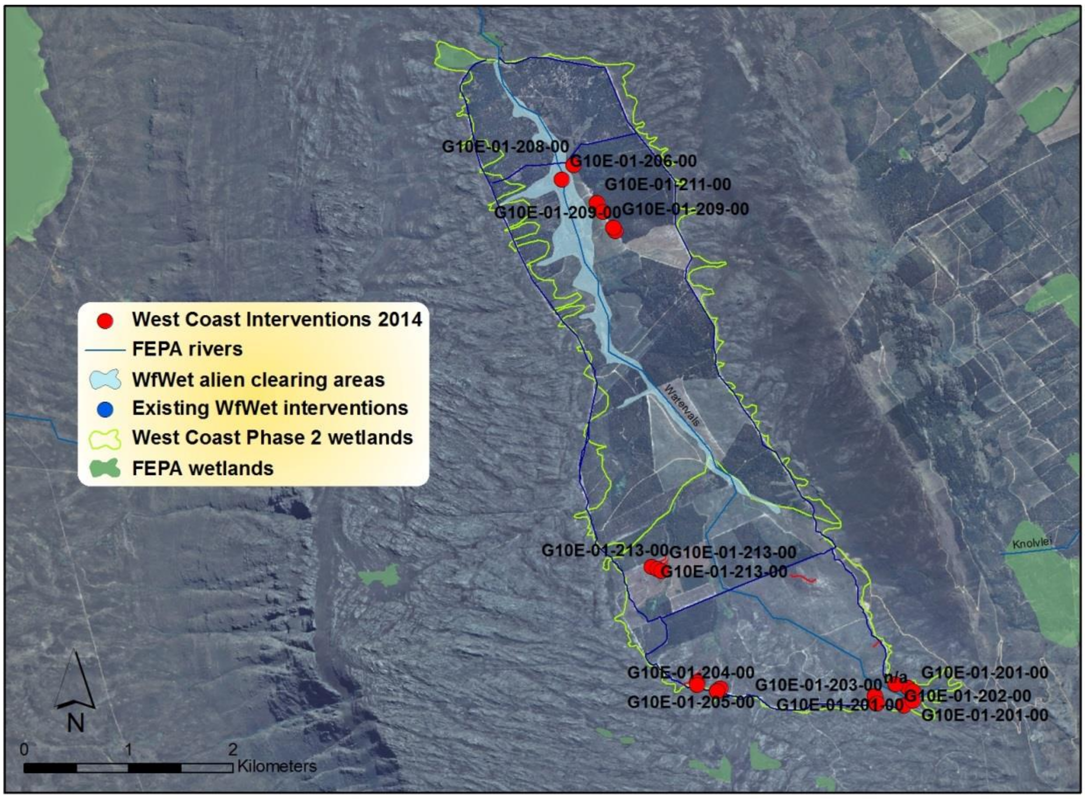

Figure 5.7 Location of interventions proposed by Working for Wetlands for the Zuurvlak wetland (G10E-01) in 2014. See Table 5.9 for descriptions of the interventions.

Table 5.9 Details of interventions planned for the Zuurvlak wetland (WfWet ID: G10E-01).

Intervention No.	Description of intervention	Rehabilitation objectives	Cost Estimate (R)
G10E-01-202-00	Road closure and brush packing along steeper sections of road, plus instalment of ecologs or micro-catchments every few metres with ripping in between. Fix gully with rock packs tied into the sides of the road, placed every few metres, plus geofabric	• Rationalise the road network, in order to minimise the fragmentation of the wetland resulting from the criss-crossing of roads and tracks through and around the wetland, and reduce the impacts on surface and sub-surface flow of water in the upper catchment. • Stabilise erosion gully along old forestry roads, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic	R105000

Intervention No.	Description of intervention	Rehabilitation objectives	Cost Estimate (R)
		water source area and IBA.	
G10E-01-203-00	Replace road crossing with a drift, stabilised with gabions. Series of sediment fences and rock packing every few metres, and rock packing where gully is shallower and narrower.	• Stop erosion in and around old forestry roads and stabilise gully and encourage re-wetting of surrounding wetland, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R225 000
G10E-01-204-00	Small gabion drop inlet weir immediately below the road, followed by sediment fences and rock packing every few metres.	• Stabilise gully and encourage re-wetting of surrounding wetland, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R120 000
G10E-01-205-00	Series of rock packs placed every few metres, and rock packing where gully is shallower and narrower.	• Stabilise gully and encourage re-wetting of surrounding wetland, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R4 000
G10E-01-208-00	Road closure, plus rock packs and small berms across the road	• Rationalise the road network, in order to minimise the fragmentation of the wetland resulting from the criss-crossing of roads and tracks through and around the wetland, and reduce the impacts on surface and sub-surface flow of water in the upper catchment. • Stabilise erosion gully along old forestry roads, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R10 000
G10E-01-209-00	Rock packing of small erosion gully and head-cut. Breach berm in a few places	• Stabilise head-cut in road, and prevent further erosion, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA. • Allow spread of flow across road, rather than channelised flow that causes further erosion.	R1000
G10E-01-210-00	Rock packing of small erosion gully and head-cut	• Stabilise head-cut in road, and prevent further erosion, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect	R4 000

Intervention No.	Description of intervention	Rehabilitation objectives	Cost Estimate (R)
		a strategic water source area and IBA.	
G10E-01-211-00	Rock packing of small erosion gully and head-cut	• Stabilise head-cut in road, and prevent further erosion, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R2 000
G10E-01-212-00	Rock packing on one side of road, gully extends for approximately 50 m	• Stabilise head-cut next to road and fix erosion gully, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R8 000
G10E-01-213-00	Sediment fences and rock packs placed every few metres.	• Stabilise gully and encourage re-wetting of surrounding wetland, in order to assist the natural recovery of the wetland from historical pine plantations, to improve biodiversity value, to protect Red Data Book plant and fish species, and to protect a strategic water source area and IBA.	R70 000

5.4.3.1 IAP control

An area of 574 ha requires IAP clearing in Zuurvlak, at an approximate cost of R4 625 000 in the first year.

5.4.3.2 Partnerships

- **Working for Wetlands (WfWet)** – the Upper Riviersonderend has been identified as a priority for rehabilitation planning, and environmental authorisation has been obtained for work in this area. It is recommended that a partnership should be formed with WfWet, so that the rehabilitation strategy presented here can be taken forward within the conditions of the authorisation, and contributing to WfWet's goals and targets.
- **CapeNature** – the Zuurvlak wetland is surrounded by the Watervalsberg Nature Reserve, which is managed by CapeNature. Access to the site is across CapeNature land.

5.4.4 Rehabilitation gains

A comparison between the current condition of the wetland and its condition with and without rehabilitation allows for the rough calculation of the number of hectares of wetland that will be gained or secured through rehabilitation. In addition, the delivery of ecosystem services by the wetland can also be compared between the current state and a predicted state with rehabilitation (Table 5.7).

Table 5.10 Rehabilitation gains for the Zuurvlak wetland. The table includes only those ecosystem services that will influence water security.

	Total wetland area influenced	Number of hectare equivalents gained or secured	% increase in streamflow regulation	% increase in nitrate removal	% Increase in erosion control	% Increase in carbon storage
Zuurvlak wetland	925	227	8	8	0	25

5.5 Summary of rehabilitation gains

	Total wetland area influenced	Number of hectare equivalents gained or secured	% increase in streamflow regulation	% increase in nitrate removal	% increase in erosion control	% increase in carbon storage	% increase in biodiversity maintenance
Upper Riviersonderend	222	77	0	0	33	25	23
Du Toits	680	56	0	0	6	11	16
Wemmershoek	323	0 (no rehab opportunities currently identified)	n/a	n/a	n/a	n/a	n/a
Zuurvlak	925	227	8	8	0	25	32

6 Return on investment

6.1 Introduction

Estimating the return on investment (ROI) in wetland rehabilitation requires the estimation of the benefits of restoration in physical or monetary terms. Where there are multiple types of benefits, as would be the case for wetlands, the ROI would best be expressed in monetary terms. This requires the estimation of changes in ecosystem attributes, productivity and processes in physical terms (changes in supply of ecosystem services), and then the valuation of the benefits derived from these services.

Wetlands generate a range of ecosystem services, which can be broadly classified into provisioning, regulating and cultural services. Provisioning services comprise the supply of harvested resources such as fish and reeds, the value of which is classified as “direct use value”. Regulating services are those associated with ecosystem functions that generate benefits off-site, such as water quality amelioration and sediment retention. These values are classified as “indirect use values”. Cultural services include both direct use values such as recreation and ceremonial use, and the more intangible “non-use values” such as the satisfaction that people derive from knowing that the wetlands and their biodiversity are conserved.

These values vary in terms of the ease with which they can be valued. There are various commonly-used and widely-accepted ecosystem valuation techniques including using market prices, replacement costs, damages avoided, revealed preference, stated preference and benefit transfer methods, each of which is suited to different types of value. As such, rarely do valuation studies manage to attribute monetary values to the full suite of ecosystem services and their benefits. In these cases it is important to recognise that an economic valuation may just form a portion of the total value of the system (Figure 6.1). In this section, we briefly outline the way in which wetlands are typically valued. Then, given that this study was a rapid desktop assessment, we devise an order-of-magnitude estimation of the value of restoring priority wetlands in the study area, using the information to hand, and calculate the potential return on investment, based on the estimated rehabilitation costs.

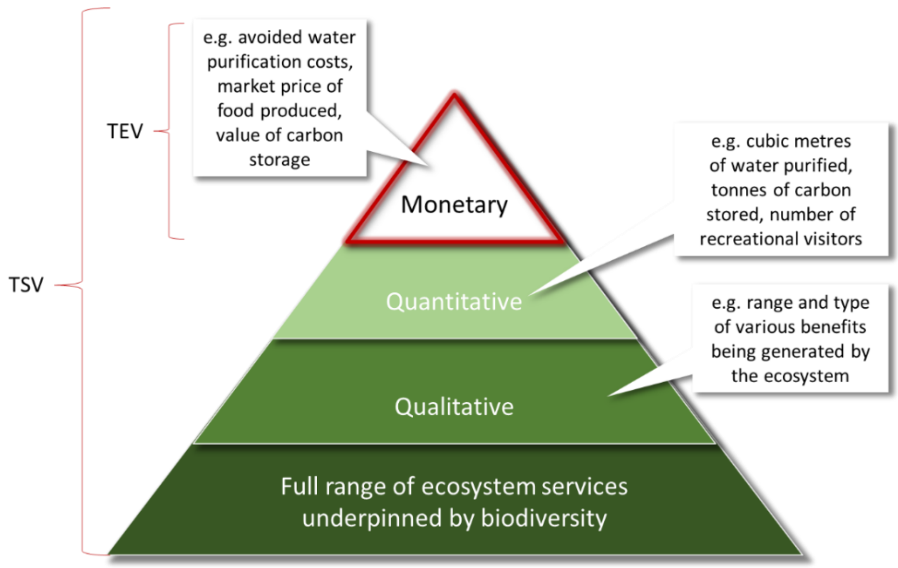

Figure 6.1. The benefits pyramid and Total Economic Value versus Total System Value (Source: TEEB 2009).

There was not enough information on the prioritised wetlands to allow an in-depth ecosystem service valuation within the time available. Using broad assumptions and transferring understanding and values from other settings, we have provided a "back of the envelope" type of assessment to give an indication of the potential value of some of these services, and the potential gains associated with rehabilitation. These are based on the estimated changes in ecosystem services from Section 5. Caution is advised when interpreting these estimates, and further research would be required to improve the confidence in our estimates.

6.2 Estimated gains in the value of wetland ecosystem services

6.2.1 Provisioning Services

Wetland valuation studies generally rely on monitoring data and/or social surveys to quantify the direct use of wetland resources (e.g. Lannas and Turpie, 2009). Provisioning services are usually valued based on market prices of the harvested output as well as the inputs. These values can be high in areas where there are large numbers of poor households that are dependent on wetlands, such as in the densely-populated communal land, and in poor peri-urban areas (Lannas and Turpie, 2009).

However, the priority wetlands in the study area are relatively remote and inaccessible and are far from the types of areas described above. As such it is unlikely that these wetlands are being used to the same extent as those in peri-urban environments. The wetlands for which there might be value in terms of provisioning resources are the Upper Riviersondered wetland, which is surrounded by a matrix of agricultural land. The other wetlands are unlikely to provide many resources to local inhabitants as they are less accessible and surrounded by mainly natural land in Protected Areas. It is possible that some people travel to these wetlands to collect resources, but it is unlikely that this use is significant. Interviews or surveys with people living in the vicinity of these wetlands would be necessary to confirm this.

Provisioning value includes genetic resources. We do not expect there to be significant value associated with bioprospecting in these regions, nor much potential from the genetic material found in these wetlands. In this study we have therefore estimated that rehabilitation would have negligible benefit in terms of provisioning services.

6.2.2 Regulating services

The value of regulating services offered by wetlands is not only dependent on their capacity to supply the services, but also on the demand for services. In this case, the prioritised wetlands are all upstream of major dams, which means that there is probably a relatively low demand for their flood attenuation services, due to the capacity of the dam itself to provide this service. The dams themselves create the demand for base-flow maintenance, sediment retention and water quality enhancement, however. Base-flow maintenance throughout the year should extend the hydrograph into the dry season, Sediment retention by wetlands prevents sediments from entering the dams and leading to a loss of capacity. Nutrient retention by wetlands prevents the proliferation of algae in the dam, which would otherwise need to be removed in the water treatment process using chemical flocculants. These services and their potential values are explored in more detail below.

6.2.2.1 Streamflow regulation

In order to assess whether or not a particular wetland is contributing to a net water loss or gain for the catchment involves understanding the balance between all these inflows and outflows (see Figure 1.2). This requires site-specific data collection and understanding of the overall hydrology of the catchment including surface and groundwater in- and out-flows. These factors can also often vary between seasons and years. It is therefore very difficult to assess this service as it is not static. Although the presence of a wetland in a catchment may incur some yield losses through increased evapotranspiration, the cost of this loss may be negated by the value of increased downstream base flows, which in some contexts may be more valuable. Estimation of these processes can be achieved by creating wetland water balance models (e.g. Grundling *et al.*, 2015) or through adapting catchment models such as ACRU or SWAT to include specific wetland components (e.g. Gray, 2011). This type of modelling generally has large data requirements.

While streamflow regulation can be an important service provided by many wetlands, in the case of the priority wetlands this service may not necessarily be in demand, due to the large capacity of the downstream dams to store water, and therefore may not hold much economic value. The dams in the Western Cape rarely operate at full capacity, often due to planned releases of water for downstream use, and rarely suffer from the inability to capture storm flows (e.g. by overtopping the dam wall). As such, any additional streamflow regulation helping to limit storm flow and maintain base flows is unlikely to have an effect on the ability of the dams to catch water or maintain flows below the dam. Modelling stream flow regulation of the wetland itself is therefore unlikely to yield significant values given the lack of demand and is not recommended given the high data and time needs to conduct properly.

Even if this service is enhanced through rehabilitation, there is no direct economic return as a result. Only rehabilitation of Zuurvlak is expected to show any increase in the ability to perform this service with rehabilitation. Even then, the increase is only minimal at 8% (Table 5.10). For the wetlands that do not empty directly into a dam and maintain stream baseflows (e.g. Zuurvlak and Upper Berg), these wetlands may hold more value in terms of streamflow regulation through maintaining base flows. This value however does not have expected economic returns, but rather helps maintain the biodiversity of a stretch of river between the wetlands and the dams.

6.2.2.2 Water quality enhancement

A number of studies have been carried out on the waste treatment function in natural and created aquatic habitats (e.g. Peltier *et al.,* 2003, Thullen *et al.,* 2005, Batty *et al.,* 2005), but most research has been carried out in treatment wetlands. In South Africa there are data on the capacity of artificial wetlands to treat wastewater (e.g. Rogers *et al.,* 1985), but little information exists on natural systems, which are generally less efficient. Turpie *et al.* (2017) were able to generate a relationship between treatment cost and inflowing water quality into a dam in eThekwini Municipality (KwaZulu-Natal), however, processes identified in some systems may not be transferable to the systems of the Western Cape, which tend to have lower nutrient levels and colder temperatures.

Turpie *et al.* (2010) conducted a preliminary study on the role of wetlands in determining water quality in a selection of 100 sub-catchments in the Western Cape (none of which were however those containing the priority wetlands). Wetlands in these catchments were found to play a significant role in the reduction of nitrates, nitrites, and ammonium, but not dissolved phosphorus or suspended solids (which carry most of the phosphorus), probably due to the temporal nature of the study. Estimated removal rates ranged from 307 to 9 505 kg N/ha/y, with an average of 1 594 ± 1 375 kg N/ha/y.

Further research is required to better understand this service and its resource value. In order to construct a more robust model, data collected from the sub-catchments within which the priority wetlands lie would be used to generate a relationship between the instream water quality, wetland area and other land-uses within the catchment. This relationship would estimate the removal of different water quality components (nitrates, TSS, orthophosphates, ammonium) that affect downstream treatment costs. In addition, a cost model relating the treatment costs of the water to the water quality would need to be generated specifically for the treatment plants that treat the water downstream of the wetlands.

Data required for complete analysis include:

- Time series of water quality and flow data above and below the wetland of interest,
- Time series data of water quality within dam near intake for treatment, and
- Time series data of water treatment costs from treatment plants downstream of wetlands and dams of interest.

In addition to nutrients, wetlands can also assimilate and store toxins and pollutants, these are however expected to be low given the mostly undeveloped nature of the catchments. Similar to other nutrients these can be re-suspended and re-enter the system under certain conditions. The extent to which this is likely should be quantified for each wetland before attributing economic value to this function.

In the absence of water quality monitoring data and data on recent treatment costs we can only make a rough estimation of the value of the water treatment service based on the study by Turpie *et al.* (2010) for wetlands in the Cape region. We have to assume that the costs data are transferable to our study catchments and that treatment costs have only increased following CPI. We can then use the relationships from this study to estimate nutrient removal rates and treatment costs avoided through the presence of wetlands in the catchments. We also assume that the cost of removal of ammonium nitrogen (NH_4) are reflective of estimated increases in nitrate removal efficiency estimated in Section 5.

To carry out this valuation first we applied the relationship generated in Turpie *et al.* (2010) to generate N removal rates for wetlands related to the sub-catchment landcover using the following relationships:

$$N(NO_3 + NO_2)\ (mg.s^{-1}) = 334.82 + 18.458\%I - 43.76*\%W \text{ and}$$

$$N(NH_4)\ (mg.s^{-1}) = 74.95 + 9.52*\%DV - 22.13*\%W - 1.89*\%DA$$

Where %I is the percentage of irrigated lands (including orchards, vineyards, pastures, parks and gold courses) in the sub-catchment, %W is the percentage of wetlands in the sub-catchments, %DV is the percentage of degraded veld in the sub-catchment and %DA is the percentage area of dryland agriculture in the sub catchment. Applying these equations (including +/- standard errors for each term) with and without wetlands gave the likely range in marginal change in N removal by having the wetlands present. This was then converted into a removal rate of kg/ha/yr for each catchment, which was then applied to the wetland of rehabilitation interest. We then applied the cost of water treatment per kg NH_4 removed using costs from Turpie *et al.* (2010) and updated to 2018 Rands using CPI.

We used spatial data from the 2013-2014 National Landcover (NLC) to estimate these percentages of dryland and irrigated agriculture. We also used the NLC 2009 to estimate the area of degraded veld as the newest NLC dataset does not contain a "degraded" class, however, we also estimate the degraded veld using the NLC 2013/2014 counting both the "bare ground" class, and plantation classes (extensive areas of plantation have recently been removed in all these catchments, leaving disturbed soils and recovering vegetation). Within the sub-catchments of the priority dams the % areas are presented in Table 6.1.

Table 6.1 Percentage of catchment under different land cover classes for each of the wetlands used to estimate N removal rates for wetlands within each catchment based on equations in Turpie *et al.* (2010). Degraded veld was taken as the maximum of either NLC 2009 degraded class, or NLC 2013-2014 bare ground or plantation classes.

Wetland sub-catchment	Irrigated lands (% catchment)	Degraded veld (% catchment)	Dryland agriculture (% catchment)	Wetlands (% catchment)
Upper Riviersonderend	19	1-6	0	4
Du Toits	5	0-1	0	21
Wemmershoek	0	5-6	0	3
Zuurvlak	0	3-4	2	39
Upper Berg	0	0-6	0	4
Steenbras	0	9-18	0	9

Applying these values to each of the priority wetlands gives the following annual removal rates and their potential increases in value as a result of rehabilitation (Table 6.2). This preliminary analysis suggests that rehabilitation of the Zuurvlak wetland could save treatment costs in the order of **R472 000-937 000** per year. This large range in values highlights the need to collect more site-specific data.

Table 6.2 Estimated NH_4 removal for each priority wetland (kg/year), potential treatment cost avoided (R/year), potential increase in the N removal service and the potential increase in the treatment cost avoided through this rehabilitation. Potential increases in services were taken from Section 5.

Wetland sub-catchment	NH^4 removal (kg/yr)	Potential treatment cost avoided (R/yr)	Potential increase in service (%)	Potential increase in treatment cost avoided (R/year)
Upper Riviersonderend	14 000-28 000	646 000-1 284 000	-	-
Du Toits	24 000-48 000	1 104 000-2 193 000	-	-
Wemmershoek	36 000-71 000	1 640 000-3 258 000	-	-
Zuurvlak	128 000-254 000	5 894 000-11 708 000	8%	472 000-937 000
Upper Berg	10 000-20 000	472 000-938 000	-	-
Steenbras	6 000-11 000	263 000-523 000	-	-

6.2.2.3 Sediment retention

In order to undertake a rigorous assessment of this service and the effects of rehabilitation, it would be necessary to undertake empirical or modelling studies to estimate the sediment yield of the catchment and the extent to which the wetlands are able to remove excess sediments generated by human activities. It would also be necessary to estimate the changes in the sediment volume entering the downstream dams, and the impact that this might have on dam yields, dredging costs or the timing of future water supply infrastructure developments.

A wetland's ability to trap sediments is a dynamic function of size, soil moisture holding capacity, holding capacity, and vegetative "roughness" and state of wetness or inundation. Note that while wetlands can trap excess sediments generated by human activities in the catchment, the accumulation of these trapped sediments may ultimately reduce the integrity of the wetland itself, by changing it from its natural condition. Without intermittent scouring events, the accumulation of sediments may also ultimately reduce the capacity of the wetland to supply this service.

For most of the priority wetlands, there are few anthropogenic sources of sediment in their catchments such as farming, forestry or unpaved roads. However, future activities, including fires and the clearing of IAPs may generate sediments that could end up in dams.

In the absence of detailed data on the sediment trapping ability of the priority wetlands, we made a ball-park estimate of the sediment trapping ability by estimating the holding capacity of the wetlands and estimating the cost of replacing that holding capacity by building a check dam. Holding capacity was estimated using the following volumetric equations from DWAF (2010):

Valley bottom: $V = 1/3 \times (d_{water} + d_{soil}) \times area$ (triangular prism), $d_{water} = 0.5$ m
Seeps and Flats: $V = (d_{water} + d_{soil}) \times area$ (disc), $d_{water} = 0$ m

Soil moisture storage depths were estimated for individual wetlands by intersecting wetlands with the South African Atlas of Climatology and Agrohydrology layers (Schulze and Horan, 2007) to determine topsoil and subsoil depths and porosities, while maximum surface water depths were assumed to be constant for each wetland type.

Table 6.3. Estimated holding capacity of the six priority wetlands, the replacement value of storage based on the annualised capital costs of building dams of the same capacity and the likely increases in storage capacity with rehabilitation. Potential increases in services were taken from Section 5.

Wetland	Estimated Volume (m^3)	Potential storage capacity 20-40% volume (m^3)	Potential replacement value of storage (R/year)	Potential increase in erosion control service (%)	Potential increase in replacement value of storage (R/year)
Upper Riviersonderend	595 000	119 000-238 000	496 000-992 000	33%	164 000-328 000
Du Toits	2 312 000	462 000-925 000	1 928 000-3 857 000	6%	116 000-232 000
Wemmershoek	805 000	161 000-332 000	672 000-1 343 000	-	-
Zuurvlak	2 770 000	554 000-1 108 000	2 310 000-4 621 000	-	-
Upper Berg	122 000	24 000-49 000	102 000-203 000	-	-
Steenbras	201 000	40 000-80 000	168 000-335 000	-	-

Seasonal variations in water stored in wetlands play a determining role in flood attenuation capacity. Large recurrence interval floods typically occur after days, or even weeks of wet conditions when catchments are saturated. For these reasons, it was conservatively assumed that between 20% and 40% of total wetland volume is available for flood attenuation/sediment retention storage. This includes the sediment already stored in the wetland now being held in place by current vegetation.

The most practical way to value this function is using the replacement cost method, using simple assumptions to estimate values within a plausible range. In this case the engineering solution to replace the service would be the construction of dams of equivalent attenuation capacity. The cost of doing this was estimated based on data from DWAF on the annualised capital replacement costs of dams (R4.17/m^3 in 2018 Rands; N = 272 dams for which capacity data were available, DWS, unpublished data, March 2008).

This analysis suggested the potential value of the holding volume of the priority wetlands could be in the order of R5.68-11.35 million per year, and that the increases in this service due to rehabilitation could be in the order of **R280 000-560 000** per year (Table 6.3).

6.2.3 Carbon storage

Wetlands are often cited as being carbon stores due to their ability to form and accumulate peat (soils with usually >50% carbon content). However, peat-forming wetlands are quite rare in South Africa, only occurring in specific contexts (Grundling *et al.* 2017). It is more common for wetlands tend to form "organic soils", which typically have a carbon content of about 10-50%. Palmiet wetlands (such as the Upper Riviersonderend and Du Toits wetlands) can accumulate organic soils and are sometimes colloquially referred to as "peat-forming". However, this is not the case for all Palmiet wetlands, where carbon content can be less than 2.5% (Mills and Hunter 2018). Nevertheless, Grundling *et al.* (2017) found much higher levels of carbon than recorded in Mills and Hunter (2018), and recorded carbon contents of 10-41% for Cape Fold Mountain peatlands. While the rehabilitation of palmiet wetlands would not necessarily lead to significant carbon sequestration (Mills and Hunter 2018), the restoration of the wetlands will reduce the loss of organic soils through continued erosion. This highlights the need for wetland-specific assessments to be able to yield accurate and reliable valuation of the benefit of restoration. Assessing the carbon content of the wetlands would require mapping their extent, determining the depths of organic soils and their bulk density.

In the absence of site-specific data from most of the priority wetlands, ball-park estimates in value were made using estimates from the literature. For Upper Riviersonderend and Du Toits wetlands the actual volume of organic soils had been estimated at 383 153 m^3 and 1 095 733 m^3 respectively (Kotze, 2015). For these two wetlands the average percentage of carbon and range of bulk densities were taken from Grundling *et al.* (2017). For all other wetlands, assumptions were made about the organic soil depths, % carbon and bulk densities and extent of area containing organic soils.

Table 6.4. Estimated carbon soil stock of priority wetlands, their associated social costs incurred to South Africa and the rest of the world and the estimated increases as a result of rehabilitation. Potential increases in services were taken from Section 5. Wemmershoek wetland was estimated to not contain organic soils (K. Snaddon, pers. comm).

Wetland	Conservative estimate of potential organic carbon stocks (T C)	Potential value of carbon to South Africa (R/year)	Potential increase in service (%)	Potential increase in value of carbon to South Africa (R/year)
Upper Riviersonderend*	10 000-40 000	71 000-282 000	25%	18 000-71 000
Du Toits*	28 000-114 000	202 000-807 000	11%	22 000-89 000
Wemmershoek	-	-	-	-
Zuurvlak^	5 000-74 000	38 000-521 000	25%	10 000-130 000
Upper Berg^	1 000-4 000	8 000-31 000	-	-
Steenbras^	2 000-7 000	13 000-51 000	-	-

* actual data for extent of organic soils, using average carbon values (26%) and bulk densities between 0.1-0.4T/m^3 from Grundling *et al.* 2017.
^ assuming 15%, 30% and 60% of wetland area contains organic soils and average organic soil depths (0.15m), average carbon values (26%C) and bulk densities between 0.1-0.4T/m^3 from Grundling *et al.* 2017.

The value of this carbon storage was estimated by converting the T Carbon into Equivalent T CO_2, using the global social cost of carbon (Nordhaus 2017, updated to 2018 Rands) and estimating South Africa's share of this cost based on proportional GDP contribution and vulnerability index (Turpie *et al.* 2017b). This provides an estimate of the economic costs avoided by sequestering or avoiding the loss of carbon. This analysis suggested that retaining current carbon stocks is worth R332 000-1 692 000 per year, the value of increased damages avoided through rehabilitation are only likely to be in the order of **R50 000-290 000** per year to South Africa (Table 6.4).

This large range of potential values highlights the need to collect site-specific data of organic soil parameters in order to refine these values.

6.2.4 Recreation and tourism

The aesthetic and recreational value of wetlands is influenced by the extent to which they are accessible and visible to people. These values are normally estimated using revealed preference methods such as hedonic pricing (based on property values) and travel cost methods (based on visitor behaviour). These methods can be extended to yield both the producer and consumer surplus that need to be estimated to understand economic implications of policy decisions.

The wetlands in the study area are relatively far from population centres, and some are relatively inaccessible due to their location on private land. However, some of the wetlands may contribute to tourism value in the area, through their aesthetic qualities and wildlife, especially those within public nature reserves.

We estimated the tourism value of the priority wetlands using the national tourism value map generated by Turpie *et al.* (2017b). Their study estimated the proportion of total tourism expenditure spent on visiting attractions (as opposed to visiting family, etc.), then utilised the density of geo-referenced photographs uploaded to the Google *Panoramio* site to map this value. For this study, we extracted these values to estimate the tourism value for each of the priority wetlands (Table 6.5). The granularity of the grid on which this analysis was conducted (0.025 degrees, roughly 2.75 km x 2.4 km) means that the values incorporated the surrounding natural areas of the wetland. Based on this, it can be seen that wetlands in accessible places where they can be seen (e.g. near major roads such as the N2 – Steenbras) have a much higher average value per ha than those in more remote locations or surrounded by private land (Table 6.5).

Table 6.5. Estimated tourism value of each wetland and the estimated increases as a result of rehabilitation. Potential increases in services were taken from Section 5.

Wetland	Tourism value per wetland (R/year)	Potential increase in tourism services (%)*	Potential increase in value with rehabilitation (R/year)
Upper Riviersonderend	93 000-312 000	-	-
Du Toits	34 000-153 3000	-	-
Wemmershoek	39 000-145 000	-	-
Zuurvlak	49 000-129 000	20%	10 000-26 000
Upper Berg	50 000-75 000	-	-
Steenbras	650 000-919 000	-	-

6.2.5 Other cultural values

Wetlands in the study area contribute to the maintenance of biodiversity in the region as a whole. This includes the provision of habitat for endangered fish species like the Giant Redfin, *Pseudobarbus skeltoni* and provision of aquatic connection corridors through the landscape. People derive value merely from the knowledge that nature exists and that it can be enjoyed by future generations. The existence value of nature is often related to attributes of ecosystems such as rarity, beauty and diversity. These values can only be estimated using stated preference methods such as the contingent valuation method (CVM). Turpie (2003) estimated the existence value of South Africa's biodiversity using a CVM study. This study found that the aggregate willingness to pay for conservation of biodiversity in the Fynbos Biome was in the order of R6.29 million (updated to 2018 Rands). This translates to a value of R8.90/ha/year, if it is simplistically assumed that the value is evenly spread. Applying this value to the priority wetlands yields a total value for each wetland in the order of R1 000 to R8 000/year. No gain in cultural significance is expected under rehabilitation (Section 5). However, these wetlands are expected to increase their biodiversity value by 16% to 32% which may confer some increased value. The impact of these biodiversity increases on existence value are however unknown and have not been estimated here.

6.3 Potential return on investment

The preliminary analyses above suggest that through rehabilitation of the priority wetlands, the economic gains in terms of ecosystem services could be in the order of **R0.81-1.35 million**/year (Table 6.6).

Table 6.6. Summary of potential costs avoided through rehabilitation of priority wetlands for wetlands for which rehabilitation was costed (R'000s per year).

Wetland	Increase in water quality amelioration benefits	Increase in sediment retention benefits	Increase in carbon benefits	Increase in tourism value	Total gain (R'000s/yr)
Upper Riviersonderend	-	164-328	18-71	-	182-399
Du Toits	-	116-232	22-89	-	138-321
Zuurvlak	472-937	-	10-130	10-26	492-628
Total	472-937	280-560	50-290	10-26	812-1348

In order to calculate the return on investment for rehabilitation of these priority wetlands we calculated the present values of the costs avoided through rehabilitation and the present value of the rehabilitation costs over a 30 year time frame using a 6% discount value. We assumed that the capital costs were spent in the first year with ongoing maintenance costs of 2% per year (based on an average of costs reported in literature for wetland rehabilitation works (e.g. Armitage *et al.*, 2013, Morales Torres *et al.*, 2015). We assumed IAP clearing reduced after clearing 30% each year (Heidi Nieuwoudt, pers. comm).

The results indicate a range of return on investment (ROI) values from 0.65-6.38 (Table 6.7). This range of values indicated that, for the most part the ROI was greater than one. However, for Upper Riviersonderend whether or not the ROI was greater than one, depended upon whether the lower end or upper end of costs avoided are used. At the upper end of the estimates all wetlands showed positive ROIs. Du Toits wetland showed the highest ROI compared to the other two wetlands, this is due to the lower rehabilitation costs, even though the costs avoided through rehabilitation were the lowest of the three wetlands.

Table 6.7. Preliminary estimates of present values of costs avoided through rehabilitation and costs of rehabilitation as well as the potential range of return on investments.

Wetland	Present value of ES gains (6% discount rate over 30 years)		Present value of rehabilitation costs (6% discount rate over 30 years)	Return on Investment	
	Lower bound	Upper bound		Lower bound	Upper bound
Upper Riviersonderend	2 496 000	5 478 000	3 842 000	0.65	1.43
Du Toits	1 898 000	4 406 000	691 000	2.75	6.38
Zuurvlak	6 757 000	8 636 000	6 744 000	1.00	1.28

It should further be noted that these preliminary estimates take into account the increase in services using the methods outlined in Section 4.1 and based on available information without extensive modelling or new data collection. These value estimates could be substantially improved upon with further research, modelling and data. Additionally, further quantification of the likely future risks involved in letting wetlands degrade would likely see these values increase. Values not captured in this analysis include the value of biodiversity, which in itself is an argument for wetland rehabilitation, even if the case is not an economic one.

7 Summary and Conclusions

As demand for water grows due to increasing human populations and the complexities of climate change, the ecosystem services that wetlands provide are being looked to as “nature-based solutions” (NBS) that can contribute to water security and offset the need for costly built infrastructure. However, relatively few studies have documented evidence of whether and how wetlands perform the ecosystem services they are credited with, and those that have find wide variation in the direction and magnitude of the services provided.

The potential for wetlands to provide ecosystem services is increasingly important as climate change and population growth threaten water security. Water security depends on a number of ecosystem services, and NBS can contribute to water security by improving water availability and quality while at the same time generating social, economic, and environmental co-benefits and reducing water related risks like floods and droughts (UN World Water Development Report, 2018). In many cases, NBS can work alongside and complement built or “grey” infrastructure to help provide sustainable solutions for water demands.

This study aimed to use spatial datasets to prioritise a number of sub-quaternary catchments, and then the wetlands within them, according to the risk and demand for wetland functions that relate to water security within the Western Cape Water Supply System. The criteria that were used for prioritisation of catchments were:

- Streamflow regulation: using datasets for mean annual runoff, transpiration losses, catchments feeding large dams and rural water provision.
- Water quality enhancement: degree of physico-chemical modification, eutrophication of dams, toxic contaminants.
- Sediment retention: sediment yield, erosion hazard, evidence of gully erosion, and levels of land degradation.

Within these catchments, six wetlands / wetland clusters ranked highest in relation to a number of criteria based on wetland characteristics that are likely to influence the manner in which water moves into, through, and out of these systems, and so have an impact on the quantity, timing and quality of water exiting the wetlands. These wetlands are the Upper Riviersonderend and Du Toits River wetlands, that feed into Theewaterskloof dam, the Olifants River wetlands suppling water to Wemmershoek Dam, a cluster of wetlands upstream of Steenbras Dam, and a similar cluster in the upper catchment of the Berg River, and the Zuurvlak wetland on the Waterval River, supplying water to Voëlvlei Dam.

These wetlands were assessed for condition and ecological importance and sensitivity, and also for opportunities for rehabilitation. Rehabilitation plans were developed for three of the six prioritised wetlands, and these were costed. The improvement in condition, areas of wetland secured, and the perceived increase in ecosystem service provision was calculated, in order to build the case for investment in these important wetland systems.

The preliminary analyses above suggest that through rehabilitation of the priority wetlands, the economic gains in terms of ecosystem services could be in the order of R0.81-1.35 million/year.

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Appendix 1

Design drawings from Groundtruth – separate document

Appendix 2: IAP clearing details

ID	Species	Difficulty rating (1 = easy access; 5 = in the wetland or river)	Area (m^2)	Area (ha)	Comment	Rate per ha	Total
RSE IAP 1	pines[6] and black wattle	3	27618.6	2.76		40000	R110 474
RSE IAP 2	pines and possibly black wattle	2	20690.1	2.07		30000	R62 070
RSE IAP 3	black wattle	2	23841.9	2.38		8000	R19 074
RSE IAP 4	black wattle (some isolated pines)	5	25969.5	2.60		8000	R20 776
RSE IAP 5	black wattle	5	57163.6	5.72	scattered	8000	R45 731
RSE IAP 6	black wattle	4	96976.7	9.70		8000	R77 581
RSE IAP 7	pines	1	5061.31	0.51		20000	R10 123
RSE IAP 8	black wattle	2	6632.64	0.66		30000	R19 898
RSE IAP 9	black wattle	2	155000	15.50		30000	R465 000
RSE IAP 10	black wattle	1	2312.74	0.23		30000	R6 938
RSE IAP 11	pines	1	13452	1.35		8000	R10 762
RSE IAP 12	black wattle	1	15220.4	1.52		8000	R12 176
RSE IAP 13	black wattle and isolated pines	5	28915.3	2.89		15000	R43 373
TOTAL				**47.89**			**R903 976**
DUTOIT IAP 1	black wattle and pine	5	261160	26.12	scattered	5000	R130 580
DUTOIT IAP 2	pines?	4	563419	56.34		7000	R394 393
TOTAL				**82.46**			**R524 973**
ZUUR IAP 1	pines and black wattle and port jackson	2	1126035	56.30	in riparian zone of Waterval River	15000	R844 526
ZUUR IAP 1b	pines and black wattle and port jackson	2		56.30	outside riparian	8000	R450 414

[6] All pines are assumed to be *Pinus pinaster*. This may be a generalisation, but this will be the case for most areas.

ID	Species	Difficulty rating (1 = easy access; 5 = in the wetland or river)	Area (m^2)	Area (ha)	Comment	Rate per ha	Total
ZUUR IAP 2	pines and black wattle and port jackson	2	46321	4.63	seep	8000	R37 057
ZUUR IAP 3	pines	2	129484	12.95	seep	8000	R103 587
ZUUR IAP 4	pines	1	241333	24.13	block - quite sparse	6000	R144 800
ZUUR IAP 5	pines	2	553080	55.31	block and including seep	6000	R331 848
ZUUR IAP 6	pines	1	363599	36.36	seep	8000	R290 879
ZUUR IAP 7	pines	1	913354	91.34	block	6000	R548 012
ZUUR IAP 8	pines	1	2218981	221.90	riparian and surrounding slopes - quite sparse across a broad area	8000	R1 775 185
ZUUR IAP 9	pines	1	50948	5.09	block	5000	R25 474
ZUUR IAP 10	pines	1	91534	9.15	seep	8000	R73 227
TOTAL				**573.47**			**R4 625 010**