# ECONOMIC VALUATION OF SELECTED WETLANDS IN THE BREEDE CATCHMENT

## Final Report

Report to the

**DEPARTMENT OF ENVIRONMENTAL AFFAIRS & DEVELOPMENT PLANNING (DEA&DP)**

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Project No. EADP 975

**2019**

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**This publication should be cited as: Department of Environmental Affairs and Development Planning, 2019. *Economic Valuation of Selected Wetlands in the Breede Catchment*, Cape Town, South Africa: DEA&DP**

## ACKNOWLEDGEMENTS

Funding for this study was provided by the Department of Environmental Affairs and Development Planning (DEA&DP). The maps in Figures 3-5, were produced by the Sub-Directorate Spatial Information Management, DEA&DP, Western Cape Government.

# Abstract

Wetlands which fall within the catchments of water supply dams have the potential to make important contributions in terms of water-related ecosystem services, particularly water quality enhancement. At the same time wetlands are facing growing threats and continued degradation. Despite this, there has been very limited valuation of the contribution of South African wetlands and their rehabilitation to water quality enhancement and other water-related ecosystem services. Thus, an assessment is being undertaken of three wetlands in the Theewaterskloof Dam, which makes a critical contribution to City of Cape Town as supplied by Western Cape Water Supply System. The three wetlands, namely Elandskloof, Vyeboom and Du Toits, represent a diversity of catchment contexts, functional capabilities and degradation pressures. The Elandskloof lies downstream of extensive orchards and Villiersdorp town, including an informal settlement and discharge from the town's wastewater treatment works, and there is a very high demand for water quality enhancement from this wetland. However, the wetland is currently degraded and its capability for dealing with this demand appears limited. Some potential for rehabilitation exists, but this is constrained because much of the wetland lies below the full supply level of the Theewaterskloof Dam. Vyeboom also has a moderately high demand for water quality-related services, which is largely matched by the current high capability of the wetland, although this capability is under imminent severe threat from active erosion, for which Working for Wetlands have begun implementing erosion control interventions to arrest any further degradation. The Du Toits wetland, which is currently still largely intact and not under any imminent threat, has a low demand for water quality-related services given that its catchment comprises largely natural vegetation. An economic valuation is being undertaken of the monetary value of key ecosystem services provided by these three wetlands, with each wetland assessed for both a degraded state compared with an intact (rehabilitated) state. The valuation encompasses the development of an economic valuation model, which includes a nutrient reduction (water quality enhancement) model, a sediment retention model, and a carbon storage model. In addition, a hydrology model has been set up to inform the nutrient reduction and sediment retention model. Furthermore, the quantified monetary assessment is supplemented by a qualitative assessment of the intrinsic value of the wetlands in terms of biodiversity conservation, which is not amenable to being assessed through economic valuation. The results of this valuation are presented and discussed in relation to the specific contexts of the three wetlands.

**Keywords**: Breede Valley, Theewaterskloof Dam, Wetland Service, Wetland Economic Valuation, Hydrological modelling

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# ACRONYMS AND ABBREVIATIONS

| Abbreviation | Meaning |
|---|---|
| Capex | Capital Expenditure |
| CBA | Critical Biodiversity Area |
| CPI | Consumer Price Index |
| DK | Du Toits Kloof Wetland |
| DTM | Digital terrain model |
| DWAF | Department of Water Affairs and Forestry |
| DWS | Department of Water and Sanitation |
| EK | Elandskloof Wetland |
| FEPA | Freshwater Ecosystem Protected Area |
| GIS | Geographic information systems |
| HGM | Hydrogeomorphic (features) |
| IAP | Invasive Alien Plants |
| IB | Irrigation Board |
| MAE | Mean annual evaporation |
| MAP | Mean annual precipitation |
| MAR | Mean annual runoff |
| MASL | Metres above sea level |
| Opex | Operational expenditure |
| PES | Present Ecological State |
| ROI | Return on investment |

| | |
|---|---|
| RSA | Republic of South Africa |
| SAPWAT | WRC software for estimation of crop irrigation requirements. |
| TC | Tonnes of Carbon |
| TEV | Total Economic Values |
| TSV | Total Value of Ecosystems |
| TWK | Theewaterskloof |
| VB | Vyeboom Wetland |
| WAAS | Water availability assessment study |
| WCWSS | Western Cape Water Supply System |
| WMA | Water Management Area |
| WR2012 | Water Resources of South Africa 2012 |
| WRPM | Water Resource Planning Model |
| WRSM2000 | Water Resources Simulation Model 2000, a.k.a. Pitman Rainfall Runoff Model |
| WRYM | Water Resources Yield Model |
| WTW | Water Treatment Works |
| WWTW | Waste Water Treatment Works |
| ZAR | South African Rand |

# 1. INTRODUCTION/ BACKGROUND

Wetlands ecosystems are vital ecological infrastructure that provide valuable services to people and are important biodiversity assets. Wetlands help to buffer flood waters, soak up water to release more gradually over time, filter sediments, purify water, and provide forage for livestock and refuge for numerous species. While remarkably resilient in many ways, wetlands are vulnerable to a range of direct, indirect and cumulative impacts.

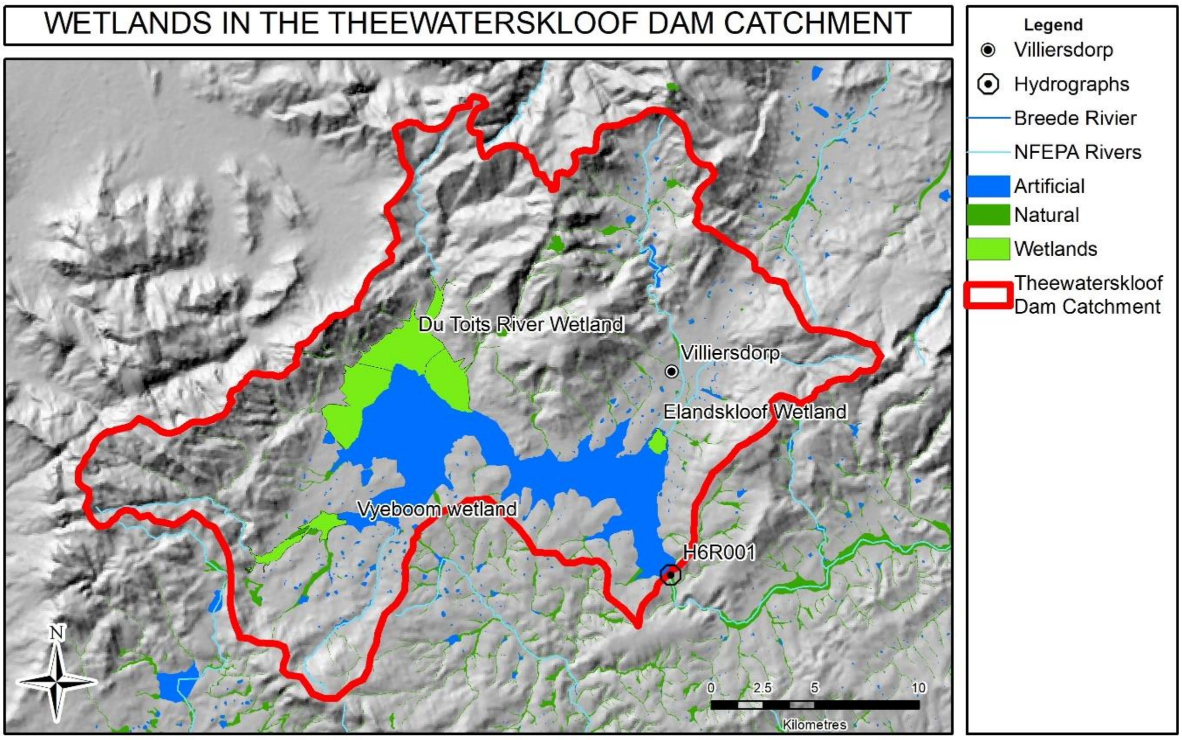


**Figure 1: Wetlands around Theewaterskloof**

Some of the wetlands in the Upper and Middle Breede River Catchment that feed into the Theewaterskloof Dam (See Figure 1) are under threat, predominantly from agriculture and invasive alien plants, and pollutants from both agriculture and urban settlement.

This study will focus on key wetlands in the Theewaterskloof Dam area, so as to compare the impacts of agriculture (Vyeboom), and urban settlement (and agriculture) (Elandskloof) with a pristine wetland (Du Toits). The Theewaterskloof Dam is an important source of water for the Western Cape, and as such it is important to establish the value of the wetlands through which water drains into this dam.

## 1.1 Concept methodology for valuation of wetland services

Figure 2 gives a diagrammatic representation of the methodology to be undertaken for the economic valuation of selected wetlands in the Breede catchment. This study would aim to focus on three key wetlands in the Theewaterskloof Dam area. This would include Vyeboom wetlands, as well as wetlands within the Du Toits River flowing from Franschhoek - both palmiet wetlands, and the Elandskloof Wetland, all of which flow into Theewaterskloof dam.

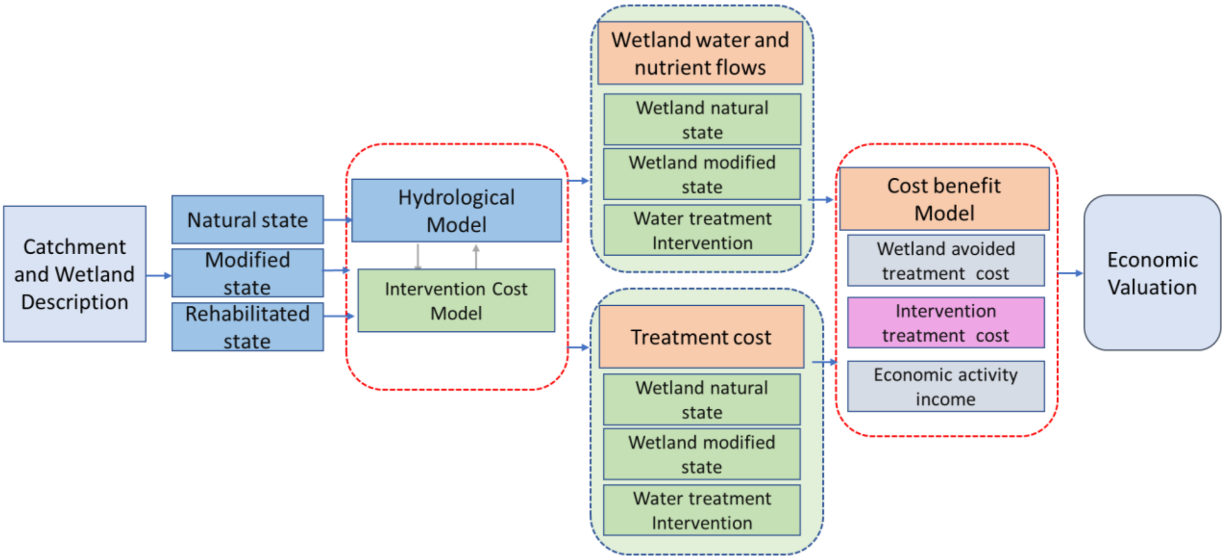


**Figure 2: Summary of Methodology**

# 2. DESCRIPTION OF THE THREE WETLANDS IN TERMS OF IMPACTS, PRESENT ECOLOGICAL STATE AND DEMAND AND REHABILITATION MEASURES.

## 2.1 Key attributes of, and impacts to, the three wetlands

The three wetlands are all valley bottom wetlands within a Table Mountain Group sandstone setting, but vary according to how strongly channelled they are and their predominant hydrological zones (Table 1). In particular, the Elandskloof is the most strongly channelled and has a considerably more limited extent of the permanently saturated zone than the other two wetlands (Table 1).

**Table 1: Key hydro-geomorphic (HGM) and hydrological features of the three wetlands**

| | Elandskloof | Vyeboom | Du Toits |
|---|---|---|---|
| HGM units, listed from upstream to downstream end of the wetland | Channelled valley bottom | 1. Weakly channelled/ unchanelled valley bottom | 1. Channelled valley bottom |
| | | 2. Channelled valley bottom | 2. Weakly channelled/ unchanelled valley bottom |
| | | 3. Weakly channelled/ unchanelled valley bottom | 3. Channelled valley bottom with multiple channels on a major alluvial fan and from tributaries feeding the fan |
| Hydro-geological type setting | All three wetlands and their catchments are underlain by Table Mountain Group (TMG) sandstone. Vyeboom HGM 1 and Du Toits HGM 2 would appear to have possible links with groundwater given the wide lateral extent of permanently saturated areas. However, this requires more detailed hydrological investigation to confirm. All HGM units are likely to be supplied by interflow, which is shallower and less sustained than the groundwater. | | |
| Predominant hydrological zones[1] | Predominantly temporary zone | Predominantly permanent zone in HGM 1 and 3 and good representation of temporary, seasonal and permanent zones in HGM 2 | Predominantly permanent zone in HGM 2 and good representation of temporary, seasonal and permanent zones in HGM 1 and 3 |
| Sediment type | Predominantly sandy sediments, with localized silty areas. Organic soil is absent. | Predominantly sandy sediments with organic soil deposits[1] especially in HGM 1 | Predominantly sandy sediments with organic soil deposits[1] especially in HGM 2 |

[1] The organic soil deposits, although containing some coarse fibric material and sand, are generally composed predominantly of relatively fine organic particles, which is likely to result in a relatively low hydraulic conductivity of the material. In Vyeboom the average depth of the organic soil deposit is about 0.5 m and in Du Toits it is about 0.9 m (Kotze, 2015).

The vegetation of Elandskloof contrasts markedly with the other two wetlands. Firstly, indigenous bulbous plants, restios and ferns are lacking (Table 2). Secondly, at the time of the first assessment within this project, prior to alien plant clearing, almost all (94%) of the commonly occurring plant species were either alien species or indigenous species which are favoured/tolerant of human disturbance, while in Vyeboom and Du Toits wetlands, such species constitute 38% and 26% respectively of the commonly occurring species (Table 2).

**Table 2: Plant species commonly occurring in the three wetlands**

| | Elandskloof | Vyeboom | Du Toits |
|---|---|---|---|
| Sedges/ rushes | Juncus effusus*<br>Juncus puctorius<br>Isolepis prolifera* | Carpha glomerata<br>Hellmuthia membranaceae<br>Isolepis prolifera*<br>Juncus lomatophyllus*<br>Juncus punctorius<br>Prionium serratum | Carpha glomerata<br>Cyperus thunbergii<br>cf Epischoenis gracilis<br>Isolepis prolifera*<br>Prionium serratum |
| Grasses | Cynodon dactyon*<br>Paspalum distichum*<br>Paspalum urvillei**<br>Phragmites australis* | Paspalum distichum*<br>Pennisetum macrourum | Merxmuelera cincta |
| Restios | - | Platycaulos major<br>Willdenowia sulcata | Elegia capensis<br>Restio paniculatus, |
| Bulbous plants | - | Watsonia aletroides<br>Wachendorfia thyrsiflora | Wachendorfia thyrsiflora |
| Herb | Conyza bonariensis**<br>Bidens pilosa**<br>Xanthium strumarium**<br>Persicaria lapathifolia** | | Laurembergia repens |
| Shrubs | Cliffortia strobilifera* | Cliffortia strobilifera* | Cliffortia strobilifera* |

| | | | |
|---|---|---|---|
| | Sesbania punicea**<br>Stoebe plumosa* | Rubus fructicosus**<br>Erica leutea | Rubus fructicosus** |
| Fern | | Pteridium aquilinum*<br>cf Thelypteris confluens | Pteridium aquilinum*<br>cf Thelypteris confluens |
| Trees | Acacia mearnsii**<br>Acacia saligna**<br>Salix fragilis** | Acacia mearnsii**<br>Leucadendron salicifolium<br>Metrosideros angustifolia<br>Pinus sp.** | Acacia mearnsii**<br>Psoralea aphylla<br>Psoralea pinnata<br>Brabejum stellatifolium<br>Searsia augustifolia |
| *Indigenous species tolerant of /favoured by high levels of human disturbance<br>**Alien species | | | |

The three wetlands vary greatly in terms of type and level of impact (Table 3). Elandskloof has been subject to the greatest variety of impacts and the highest impact severity, both directly within the wetland and arising from its upstream catchment (Table 3). The Du Toits wetland has the least severe impacts of the three wetlands, both directly and from the upstream catchment, and could justifiably be described as pristine, as would be borne out by the limited occurrence of alien species and indigenous species tolerant of /favoured by high levels of human disturbance, as reported in Table 2. Vyeboom is intermediate in terms of impact severity.

**Table 3: Anthropogenic impacts on the three wetlands**

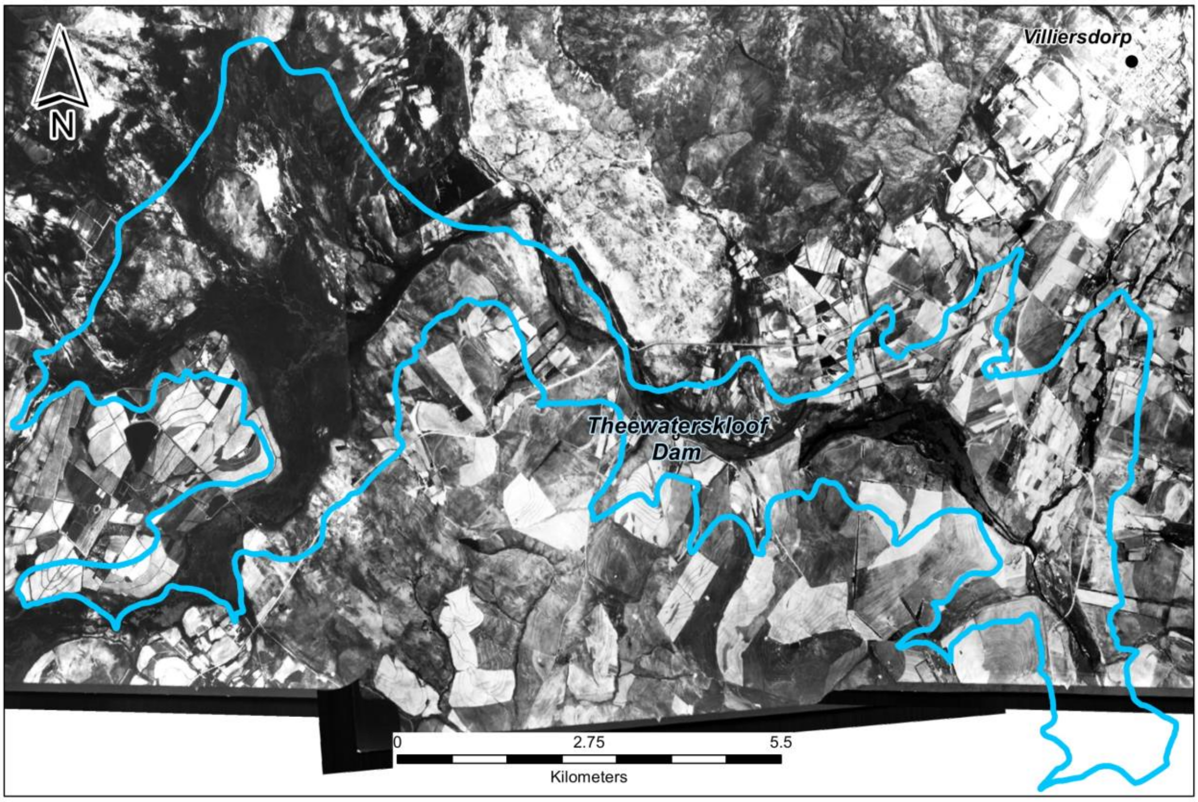
| Types of impact | Elandskloof | Vyeboom | Du Toits |
|---|---|---|---|
| Deep flooding by the dam | Takes place over a large proportion of the wetland | Confined to the lowermost toe of the wetland | Confined to the lowermost toe of the wetland |
| Erosional incision | Prior to recent clearing of IAPs was localized and limited in extent but increased in extent along the channel as a result of the destabilizing effects of the clearing | A single moderately active erosion headcut is present in HGM$^1$. Several very active erosion headcuts are present in HGM 31. | Localized and very limited in extent |
| Invasive alien plant (IAP) cover | ~25% aerial cover of the wetland prior to clearing, predominantly Acacia mearnsii and Salix fragilis trees | ~20% aerial cover of the wetland, predominantly Acacia mearnsii and trees | ~3% aerial cover of the wetland, predominantly Acacia mearnsii trees |

| | | | |
|---|---|---|---|
| Alterations to Mean Annual Runoff (MAR) from the wetland's catchment | MAR likely to be slightly reduced overall by IAPs in the upstream catchment, but countered by irrigation return flows and releases from Villiersdorp wastewater treatment works. | MAR likely to be reduced overall by IAPs and irrigation abstraction in the upstream catchment. | MAR likely to be slightly reduced overall by IAPs and tree plantations in the upstream catchment. |
| Alterations to the seasonal pattern of water supply [to be reviewed in the light of the hydrological assessment] | Irrigation return flows and wastewater treatment works releases likely to have increased dry season inputs. | Irrigation return flows likely to have increased dry season inputs | Little change anticipated. |
| Alterations to the quality of water [to be reviewed in the light of the hydrological assessment and water quality results] | Extensive orchards in the wetland's catchment as well as the urban area of Villiersdorp, including an informal settlement and wastewater discharge are likely to have significantly compromised water quality entering the wetland in terms of nutrients, biocides and E coli. | Extensive orchards in the slopes immediately adjacent to the wetland are likely to have contributed to increased nutrients and biocides. | The catchment is largely natural vegetation and impacts on water quality are anticipated to be negligible. |
| Extent of conversion of the wetland to orchards | Approximately 37% of the wetland has been converted to orchards | Approximately 25% of the wetland has been converted to orchards & farm dams | No orchards present in the wetland. |
| Level of historical disturbance of currently natural/ semi-natural areas [2] | Very high | Moderate | Generally low but moderate in HGM unit 3. |

[1] The destabilizing effects of the abundant wattle trees growing in the predominant water flow area through the wetland appears to have been an important factor contributing to the initiation of the headcut in HGM1, in the Vyeboom Wetland. As elaborated upon in the main text, the loss of vegetation in the downstream toe of the wetland, which is flooded when the Theewaterskloof Dam is at a high level appears to be the principle factor precipitating the erosion in HGM 3.

[2] Wetland maps of the region that have been developed through satellite imagery (Figure 5) have been compared with aerial photography images (Figure 3 and Figure 4). Theewaterskloof Dam did not exist in 1961 as seen in the aerial photo in Figure 3, as it was built in 1978. Very high level of disturbance

impacts can be noted in Elandskloof, moderate impacts in the Vyeboom while generally low impacts in the Du Toits wetlands over the historical period depicted in the images. The full extent of Theewaterskloof Dam is shown in the aerial photo of 1993, in figure 4, whereas the dam is in a period of drought in 2018, in Figure 5.



**Wetlands of Theewaterskloof Dam - 1961**

Scale: 1: 58.108

Date: 01 November 2019

Reference No: 2019_157

Data Source: WCG

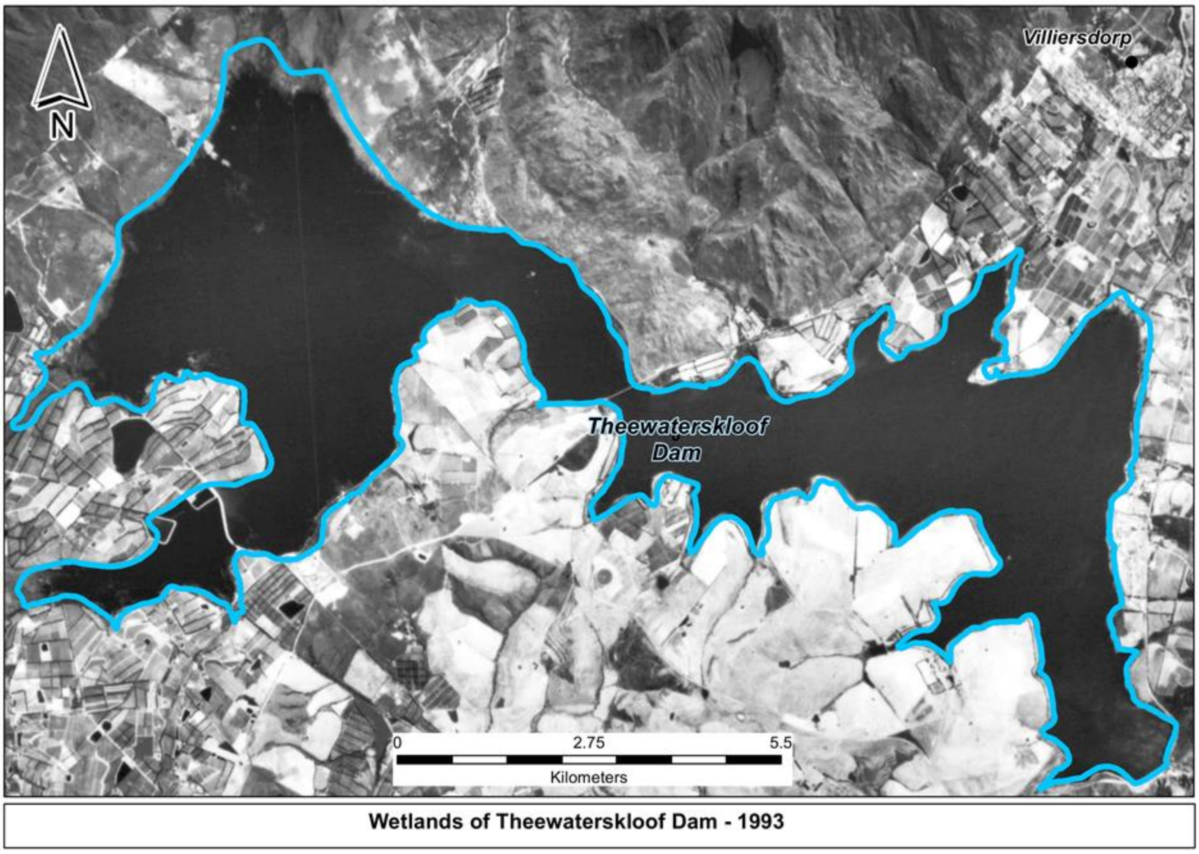
**Legend**

● Town_

∘ Wet_Dam

▭ Theewaterskloof_Dam

**Figure 3: Wetlands of Theewaterskloof Dam – 1961**



Scale: 1: 58.108

Date: 01 November 2019

Reference No: 2019_157

Data Source: WCG

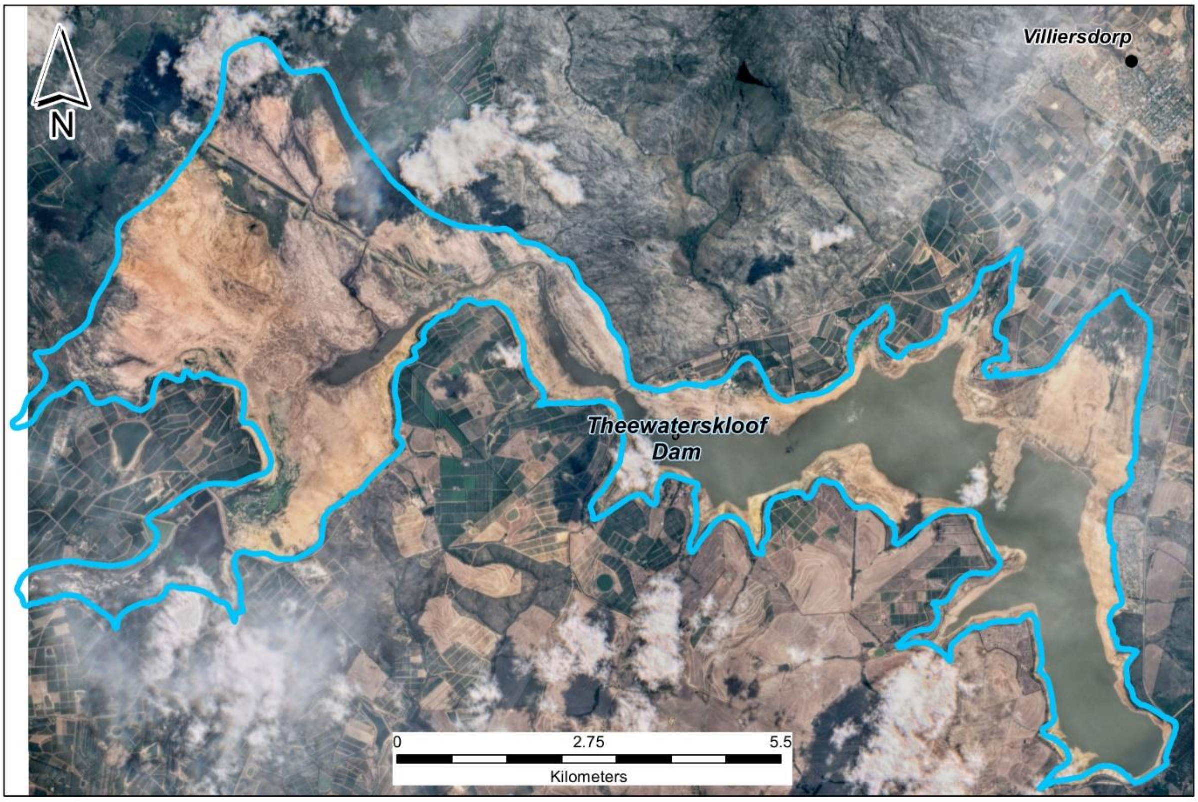
**Legend**

● Town_

∘ Wet_Dam

▭ Theewaterskloof_Dam

**Figure 4: Wetlands of Theewaterskloof Dam – 1993**



**Wetlands of Theewaterskloof Dam - 2018**

Scale: 1: 58.108

Date: 01 November 2019

Reference No: 2019_157

Data Source: WCG

**Legend**

● Town_

○ Wet_Dam

▭ Theewaterskloof_Dam

**Figure 5: Wetlands of Theewaterskloof Dam – 2018**

One of the key differences between the Elandskloof Wetland and the other two Wetlands, is that a large portion of the Elandskloof Wetland lies below the full supply level of the Theewaterskloof dam, whereas in the other two wetlands only a small portion at the downstream end of both of these wetlands lies below the dam's full supply level. Even so, in the case of the Elandskloof, the fluctuating level of the dam appears to have a potentially major wetland impact by precipitating head-ward erosion of an extensive area of wetland lying immediately upstream of the dam and extending below the full supply level of the dam. This begins during a period when the dam is full or near-full and the lowermost portion of the wetland becomes flooded, which in turn drowns the vegetation covering this area. When the level of the dam drops, which is often rapid, the downstream portion of the wetland is left without vegetation and exposed to erosion. Furthermore, the base level of the wetland, previously provided by the highwater level of the dam, is now often several metres below wetland, and therefore has no controlling influence over water flowing out of the wetland, further amplifying the vulnerability of the wetland to erosion.

Where the downstream portion of the wetland is unchanelled or weakly channelled (as is the case in the Vyeboom Wetland) it is particularly vulnerable to the destabilizing effect of a greatly fluctuating dam level, as is evidenced by the fact that the lower portion of the Vyeboom Wetland is currently actively eroding, and the main erosion headcut has advanced 390 m in 14 years based on comparison of the 2004 Google Earth image with that from 2018. Without any intervention it is likely to erode to at least the mid portion of the wetland. The Du Toit Wetland also includes such potentially vulnerable areas in its lower portion, but to date has shown little evidence of any advancing heacut/s. This is perhaps because the wetland is much broader and flow more widely dispersed at the interface with the dam than in the Vyeboom Wetland.

## 2.2 Present Ecological State (PES) of the three wetlands

The Present Ecological State (PES) of the three wetlands was assessed using WET-Health Level 1B (Macfarlane et al. 2018) with field verification[1]. This involved a two-step process, the first step being a land-cover based desktop assessment and the second step being an adjustment of the desktop assessment based primarily on field verification to identify any misclassification of land-cover classes and the presence of key point source impacts. Verification also included reference to Google Earth imagery and relevant reports, notably Görgens, (2016).

The primary basis for the WET-Health Level 1B assessment is a determination of the spatial extent of different land-use types in the wetland, its immediate buffer, the buffer surrounding any streams feeding the wetland and the remainder of the wetland's catchment. The method then combines the respective extent measures with predetermined impact intensity scores associated with different land-use types (given on a scale of 0 [no impact] to 10 [critical impact]). For example, the impact intensity score on hydrology for orchards in a wetland (which is typically associated with a high level of artificial drainage) is 7 while for semi-natural vegetation it is only 1. The WET-Health assessment also takes into account the hydrogeomorphic type of the wetland. For example, Vyeboom was identified as a channelled valley bottom with substantial lateral inputs and therefore the influence of the adjacent land-uses are automatically weighted relatively high compared with the distant upstream catchment.

In the Elandskloof Wetland, field verification in this study, showed that extensive areas of what was mapped as Natural/minimally impacted was, in fact, moderately degraded land, while in Du Toits wetland, a localized area mapped as Natural/minimally impacted was semi-natural drained. Within Vyeboom the key land-cover adjustment was changing a portion of the wetland mapped incorrectly as cultivated lands to orchards and vineyards (although of little consequence for the PES score as they have similar impacts on the wetland). In all three wetlands, the key adjustment made to land-cover in the wetland's catchment was to account for the high degree of under-mapping of invasive alien plants. The desktop land-cover based assessment did not include point-sources of pollution, and the impact on the water-quality component of Elandskloof wetland was adjusted to take account of the outflow from the Villiersdorp sewage works located 640 m upstream of the wetland.

The PES scores for the three wetlands, which take all of the field-verified land-cover and point source impacts into account, are presented in Table 4. These results demonstrate that the sites represent a gradation in ecological state from Elandskloof at the one extreme having a low PES and the second lowest possible ecological category, whilst Du Toits wetland at the other extreme having the highest PES category (confirming it to be aptly described as a pristine wetland) and finally, Vyeboom occupying

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[1] All GIS analyses for the WET-Health assessment were undertaken by Tumisho Ngobela of the Freshwater Consulting Group

an intermediate position.  Not surprisingly, the PES gradation from Elandskloof through Vyeboom to Du Toits shows inversely related occurrence impacts reported for these respective wetlands, displayed in the Table 3.

In terms of the different components of PES, Table 4 demonstrate that vegetation was consistently the lowest or close to the lowest scoring of the four components of PES, followed by hydrology and water quality, while geomorphology was consistently the highest scoring component of PES.

**Table 4: Present Ecological State of the three wetlands expressed on a scale of 100% (Pristine) to 0% (critically impacted) and ecological category expressed on a scale of A to F**

| | | Components of PES | | | | Combined overall PES |
|---|---|---|---|---|---|---|
| | | Hydrology | Geomorphology | Water quality | Vegetation | |
| Elandskloof | PES Score (%) | 36% | 64% | 40% | 15% | 38% |
| | Ecological category | E | C | E | F | E |
| Vyeboom | PES Score (%) | 52% | 74% | 55% | 57% | 59% |
| | Ecological category | D | C | D | D | D |
| Du Toits | PES Score (%) | 93% | 96% | 92% | 84% | 91% |
| | Ecological category | A | A | A | B | A |

## 2.3 Ecosystem services supply and demand

A preliminary scoping assessment of the supply and demand for a range of different ecosystem services was undertaken for the three wetlands.  This was based on the guidance provided by WET-EcoServices (Kotze, et al., 2008), and consideration of key attributes of the wetlands and their particular catchment and landscape contexts.  The ecosystem services ratings are presented in Table 5 and the rationale underlying these ratings in Table 6.

**Table 5: Current supply and demand for different ecosystem services rated on a scale of very low (0) to very high (********) for the three wetlands**

| ECOSYSTEM SERVICE | | Elandskloof | | Vyeboom | | Du Toits | |
|---|---|---|---|---|---|---|---|
| | | Current supply | Current demand | Current supply | Current demand | Current supply | Current demand |
| REGULATING AND SUPPORTING SERVICES | Flood attenuation | **** | 0 | **** | 0 | ***** | 0 |
| | Stream flow regulation | * | * | *** | * | *** | * |
| | Sediment trapping[1] | ** | ******* | *** | **** | ****** | *** |
| | Phosphate removal | ** | ******** | **** | *** | ***** | * |
| | Nitrate removal | ** | ******** | ***** | ***** | ****** | ** |
| | Toxicant removal[2] | ** | ******* | ***** | ***** | ****** | ** |
| | E. coli removal | *** | ******** | ****** | *** | ****** | * |
| | Carbon storage | * | ******** | ***** | ******** | ******* | ******** |
| PROVISIONING SERVICES | Water supply | * | **** | ******* | ****** | ****** | ** |
| | Harvestable natural resources | *** | 0 | *** | 0 | | 0 |
| | Food for livestock | **** | *** | *** | 0 | *** | 0 |
| | Cultivated foods | ******* | ******* | ******* | ******* | 0 | 0 |
| CULTURAL SERVICES | Tourism & recreation | *** | *** | *** | ** | **** | ***** |
| | Education and research | * | ***** | ***** | ***** | ******* | ***** |
| | Cultural significance | * | ** | ** | ** | ** | **** |

[1] This also includes what would be described as erosion control

[2] This includes removal of biocides, heavy metals and other toxicants (not measured in this study)

[3] The high *Escherichia coli* (E. coli) levels periodically entering the Elandskloof Wetland are confirmed based on data supplied by the Breede Gouritz Catchment Management Agency of recent monthly sampling (June to August 2019) of E coli in the Elandskloof River shortly upstream of the Elandskloof wetland. Concentrations of up to 2200 cfu/100ml were recorded, which is considered unacceptable for swimming. Further confirmation is from sampling data from 2015 to 2018 from the outflow of the Villiersdorp wastewater treatment works (Marthinus, 2019), which indicates that the works was non-compliant in terms of Faecal coliforms for 75% of the samples taken.

**Table 6: Rationale for the ecosystem services ratings assigned to the three wetlands in Table 5**

| Ecosystem service | Rationale |
|---|---|
| Flood attenuation | All three wetlands have features generally conducive to the attenuation of floods, namely that the stream channels do not contain major flows but spill out across the wetland (especially frequent in Vyeboom and Du Toits), longitudinal slopes are gentle and the hydraulic resistance offered by the robust vegetation is generally high. This hydraulic resistance has reduced in the Elandskloof post alien clearing.<br>At all three wetlands, demand for these services (and streamflow regulation below) is minimal because of their specific location immediately upstream of a major dam with a level that remains almost permanently well below fully supply level, as argued for by Snaddon *et al,* (2018). |
| Stream flow regulation | In the case of Vyeboom and Du Toits it appears that the wetlands are sustained to some extent by groundwater (see Table 1), which in turn may contribute to streamflow. The contribution of water to the downstream environment has been moderately compromised by invasive alien trees in the Vyeboom Wetland and severely compromised in the Elandskloof Wetland, prior to alien clearing. |
| Sediment trapping | The features described above for the attenuation of floods (e.g. the frequent occurrence of channel overspill across the wetland, especially frequent in Vyeboom and Du Toits) also contribute to the effectiveness of the wetlands in trapping sediment. As described in Table 3, the trapping of sediment has been greatly compromised in both Elandskloof and Vyeboom as a result of erosion linked with the fluctuating level of the Theewaterskloof Dam.<br>For all three wetlands, the demand for sediment trapping is high given that the wetlands are located at inflows directly into the Theewaterskloof Dam, for which sediment entering the dam would contribute to a loss of dam storage capacity. The Theewaterskloof Dam, which has the largest storage capacity of all dams in the Western Cape Water Supply System (WCWSS), is critical for water supply for human use, primarily for domestic and industrial water supply to Cape Town metro as well as for irrigation more locally. |
| Phosphate removal | Phosphates and many toxicants are adsorbed to sediments. Thus, the greater the extent to which wetlands trap new sediment (see above) the greater will be the extent to which the wetland removes these associated pollutants (Hemond & Benoit, 1988).<br>The demand for phosphate removal is high for all three wetlands given the location of the three wetlands at major inflows directly into the Theewaterskloof Dam, which, as described above, is critical for water supply. Further adding to the demand for phosphate removal by Elandskloof Wetland is the fact that this wetland is fed by runoff from the urban area of Villiersdorp, including a sewage works and informal settlement, which are likely to contribute to elevated phosphate loads to the wetland. Some additional phosphates may also arise from the orchards in the catchments of Elandskloof and Vyeboom, but these sources are likely to be lower than from the |

|  |  |
|---|---|
|  | Villiersdorp sources, particularly as sediment-adsorbed phosphates would be the main source and sediment loss from the orchards appears relatively low. The close-to-completely-natural catchment of the Du Toits Wetland is taken as having very limited sources of phosphates, nitrates and toxicants. |
| Nitrate removal | The primary process by which nitrates are removed from runoff water in wetlands is denitrification, which requires prolonged soil saturation leading to anaerobic conditions (Sather and Smith, 1984; Reddy and Patrick, 1984). In this respect the much greater proportional extent of the wetter hydrological zones in the Vyeboom and Du Toits wetlands than in the Elandskloof are more favourable. Another important factor is the pattern of low flows. Much of assimilation by wetlands of nutrients/pollutants, particularly those not carried by sediment, takes place during low flow periods, when waters are shallower and residency times in the wetland longer, which affords the wetland greater opportunity to assimilate pollutants contained in the water. In addition, the more diffusely that flows are spread throughout the wetlands (vs. being concentrated by a channel in only a small portion of the wetland) then the greater is the contact of the water column with sediments and biologically active surfaces in the wetland ( (Kadlec & Kadlec, 1979); (Hammer, 1992)). Again, in this respect the much more diffuse flows in the Vyeboom and Du Toits Wetlands than in the Elandskloof are more favourable.<br>As for phosphate removal, the demand for nitrate removal is high given the location of the three wetlands at inflows into a dam which is critical for water supply. Further, the demand for nitrate removal by Elandskloof and Vyeboom Wetlands is likely to result from nitrates in the irrigation return-flows from the orchards in the wetlands' catchments, and in the case of Elandskloof additional nitrate sources from Villiersdorp town. |
| Toxicant removal | Toxicants are taken to encompass a wide range of chemicals, including biocides and metals (e.g. mercury) which are assimilated through a wide variety of processes. Given that many toxicants are adsorbed to sediments, sediment trapping is one of the key processes for toxicant removal. Many metals are adsorbed very effectively to in situ organic sediments, making the accumulation of soil organic material another key mechanism for removal of metals (Wieder and Lang 1986; (McCarthy & Venter, 2006). In addition many biocides are most rapidly degraded under anaerobic conditions (Gambrell and Patrick 1988). Thus, the much greater extent of the wetter hydrological zones and occurrence of organic soils (together with more diffuse flows) in the Vyeboom and Du Toits Wetlands are taken as key factors contributing to their being more effective than the Elandskloof in toxicant removal.<br>As for phosphates and nitrates, the demand for toxicant removal is high given the location of the three wetlands at inflows into a dam which is critical for water supply. Further adding to the demand for toxicant removal are the sources of toxicants in the catchments of the Vyeboom and Elandskloof Wetlands, especially biocides from all of the intensive agricultural operations with high levels of herbicide application in both catchments. In addition, Elandskloof is fed by runoff from the urban area of Villiersdorp, likely to contribute to elevated metals. |
| *Escherichia coli* removal | Key factors contributing to the removal of *Escherichia coli* are spreading of low flows across the wetland as shallow water with long residency times, which exposes the bacteria to predation, toxic substances such as root secretions and natural die back (Hemond & Benoit, 1988). The much more diffuse flows in the Vyeboom and Du Toits Wetlands than in the Elandskloof are therefore more favourable in terms of |

| | |
|---|---|
| | *Escherichia coli* removal. Nonetheless, low flows in Elandskloof are generally shallower compared with the predominantly narrower excavated channel leading from Villiersdorp town to the wetland, thereby contributing to *Escherichia coli* removal.<br>As for nutrients and toxicants, demand is high given the location of the three wetlands at inflows into a dam which is critical for water supply. Further adding greatly to the demand for *Escherichia coli* removal by the Elandskloof Wetland are: (1) the major sources of *Escherichia coli* from the Villiersdorp sewage works and informal settlement upstream of the Elandskloof Wetland; and (2) a high level of recreational water use by the yacht club which is located very close to the outflow of the Elands stream and would therefore have much less of a dilution effect from the Theewaterskloof Dam than would be the case for locations in the dam which were much further away from this outflow. |
| Carbon storage | There is a considerable global demand for carbon storage given the climate change implications and global social cost of carbon emissions (Nordhaus, 2017).<br>The globally important contribution of carbon sinks made by wetlands, particularly those supporting organic soils, is widely recognized (Mitsch, et al., 2013). Thus, a key factor considered in scoring the carbon storage of the three wetlands is the volume of organic soil present, which was estimated as 1 095 733 m$^3$ for the Du Toits 383 153 m$^3$ for Vyeboom (Kotze, 2015) but absent in the Elandskloof Wetland. Further confirmation of the much lesser importance of Elandskloof for carbon storage arises from its much lower level of wetness (and associated anaerobic conditions) than the other two wetlands. Prolonged anaerobic conditions promote the accumulation of organic matter by impeding its decomposition, and thus, for a given climate, those wetland zones subject to the most extended wet periods tend to have the highest amounts of organic matter (Tiner & Veneman, 1988). |
| Water supply | The Vyeboom and Du Toits Wetlands, which appear to be sustained to some extent by groundwater (see Table 1) and support extensively permanently flooded areas, are much better than the Elandskloof Wetland in terms of direct water supply.<br>Currently the Du Toits and Elandskloof are not used for direct water supply. However, some of the farmers with orchards adjacent to the Vyeboom abstract water from the wetland, and the recent drying out of a portion of the wetland as a result of the draining effect of recent gully erosion has already begun to impact negatively on this service for the farmer directly affected (H Nieuwoudt 2019. Personal communication. Working for Wetlands, George) |
| Harvestable natural resources | In all three wetlands, particularly the Du Toits Wetland, there are natural resource (e.g. fynbos for the florist industry and restios and rushes for craft production) which could potentially be harvested to a limited extent. However, currently there is no harvesting taking place of these resources. |
| Food for livestock | The natural vegetation of Vyeboom and Du Toits has a relatively low value as livestock grazing. Portions of the Elandskloof which are not heavily invaded by *Acacia mearnsii* and *A. saligna* provide grazing of moderate value, mainly by the grass *Cynodon dactylon*. Currently only Elandskloof wetland is used for livestock grazing. |

| | |
|---|---|
| Cultivated foods | The contribution of the wetlands to cultivated foods was scored based on the fact that extensive areas of the Vyeboom and Elandskloof Wetlands have been converted to orchards but currently no cultivation takes place in Du Toits Wetland. |
| Tourism & recreation | Key features considered when scoring a wetland in terms of supplying a tourism/recreation experience are its scenic beauty and the presence of charismatic species. Du Toits was considered the most scenic, followed by Vyeboom and then Elandskloof, which was the least scenic at the time of the assessment, given the dense infestations of invasive alien plants and the presence of solid waste e.g. bricks and old tyres. The alien vegetation has now been cleared and it is hoped that in time indigenous vegetation will re-establish or the site will be rehabilitated. A positive feature at Elandskloof was the presence of the charismatic Cape clawless otter. For demand, a key feature is location in relation to tourism routes, with Du Toits located directly on a major tourism route between Franschoek and other tourist destinations such as Hermanus, but the other two wetlands are less directly linked to such a route. |
| Education & research | Key factors considered when scoring supply of the education this service were: (1) presence of existing studies, e.g. Rebelo (2017) and Rebelo et al. (2018); (2) the PES of the site in terms of providing a good representative of its type; and (3) the presence of organic sediment as a repository of information on past climates, vegetation etc. (Mulders, et al., 2017). Demand was scored in terms of the need for understanding of a critically endangered wetland type. |
| Cultural Significance | Based on limited available information no known cultural sites are present in the three wetlands, but one could argue that the orchards and fynbos in the wetlands form part of the local cultural landscape. Demand for cultural experience was rated somewhat higher for Du Toits given its closer links with a tourist route, and that cultural experience is a component of the overall tourism experience. |

A key overall trend seen in the ratings of supply and demand for ecosystem services for these wetlands in Table 5 is that the demand for water quality-related services is particularly high at Elandskloof, but the current capability of the wetland to deal with this demand (as expressed in the supply scores) is limited. Although lower than Elandskloof, Vyeboom also has a high demand for quality-related services, which is largely matched by the current high capability of the wetland, although this capability is likely to be substantially reduced in the absence of the “pre-emptive” rehabilitation measures, as described later in the report. Du Toits Wetland has a low demand for water quality-related services, and its greatest contribution to a specific service for which demand is currently high is that of carbon storage.

## 2.4 Intrinsic value of the three wetlands (and rehabilitation of these wetlands) for biodiversity conservation

Most of the Du Toits Wetlands falls within a formally protected area managed by Cape Nature. The small portion of the Du Toits Wetland falling outside of the protected area and most of the Vyeboom Wetland have been classified as aquatic Critical Biodiversity Areas (CBAs) in the Western Cape Spatial Biodiversity Plan (Pool-Stanvliet, et al., 2017). The vegetation type covering both the Du Toits and Vyeboom Wetlands is Elgin Shale Fynbos, which has been identified as critically endangered owing to the irreversible loss of natural habitat (Pool-Stanvliet, et al., 2017). The fact that in addition to representing a critically endangered type, Du Toits is a very large wetland in good condition and with high connectivity to other natural areas makes it intrinsically valuable from a biodiversity conservation perspective. Vyeboom also has a relatively high intrinsic value, but this is somewhat lower than Du Toits Wetland owing to its smaller size and lower ecological condition, as reported in the section on Present Ecological State (PES) of the wetlands.

The sub-catchment in which the Vyeboom Wetland lies has been identified as a Freshwater Ecosystem Protected Area (FEPA) catchment, and it not only supports a good condition river but also the endangered giant redfin, *Pseudobarbus skeltoni*, which is endemic to the Breede River (Snaddon, et al., 2018). It is possible that this is one of the three last remaining populations of this newly described species (Chakona & Swartz, 2013); (Snaddon, et al., 2018). Smallmouth bass (*Micropterus dolomieu*), an alien fish species with a potentially devastating impact on indigenous fish populations, occurs in Theewaterskloof Dam. However, it appears to be absent upstream of the Vyeboom wetland where the giant redfin is located, and it seems that the weakly channelled sections of the Vyeboom, where water flows are spread amongst dense palmiet beds are serving as an important barrier to the upstream movement of small-mouth bass in the dam (Snaddon K, 2019. Personal communication. Freshwater Research Centre, Cape Town). The active headcut erosion in the Vyeboom Wetland is causing the ingress into the weakly channelled palmiet beds of a much less obstructed channel. In the absence of rehabilitation, this ingress poses a considerable threat not only to vegetation habitat in the wetland (through its desiccation) but could indirectly threaten the giant redfin by allowing the smallmouth bass much less restricted access to the Upper Riviersonderend Stream. Therefore, it can be appreciated that in halting the headcut erosion, the rehabilitation will make a key contribution to sustaining the intrinsic biodiversity value of the wetland and its broader sub-catchment. Similarly, control of invasive alien plants, which pose a considerable long term threat to both the Du Toits and Vyeboom Wetlands, will make a key contribution to sustaining the intrinsic biodiversity value of these wetlands and their broader sub-catchments.

The intrinsic value of Elandskloof Wetland for biodiversity conservation is considerably lower than the Du Toits and Vyeboom. As reported for the PES of the wetland, the vegetation is in a very poor condition and was dominated by alien species and indigenous species which are generalists/pioneer. In addition, the area has been so dominated for several decades, and therefore the on-site seedbank of native plants is likely to be severely depleted. Therefore, although Elandskloof Wetland occurs within Elgin Shale Fynbos, it is an extremely poor representation of wetland vegetation of this type. Nonetheless, it is important to emphasize that despite its low contribution in terms of floristic conservation, this wetland has value for the conservation of wetland habitat more generally. It also has recognized value for wetland-dependent fauna. For example, the wetland supports Cape clawless otter (*Aonyx capensis*) which are categorized as a near threatened species, which although having a large distribution range, has a spatial area of occupied habitats which is much smaller and unknown, particularly due to the widespread habitat destruction and pollution problems (Jacques, et al., 2015). It should be noted further that at a local level the Elandskloof Wetland is one of a very few remaining natural/semi-natural wetland areas in the landscape, and although not very well connected to other natural/semi-natural wetland areas, it makes an important contribution to improving the connectivity of this landscape. The proposed rehabilitation interventions at Elandskloof, in particular the control of invasive alien trees, are anticipated to improve wetland and aquatic habitat provided by the wetlands, thereby enhancing the current intrinsic value for biodiversity conservation.

## 2.5 Rehabilitation interventions for the three wetlands: some preliminary suggestions

### 2.5.1 An overview of the rehabilitation interventions

Two main modes of rehabilitation are considered for the assessment.

- Rehabilitation of the existing natural/ semi-natural wetland areas by halting degradation and improving functioning of these areas.
- Rehabilitation of wetland already completely transformed to orchards by withdrawing the orchards from the wetland and returning as much functionality to the wetland as possible.

It is recognized that the opportunity costs associated with the latter are likely to be very high given the considerable capital investment in the development of these wetland areas as orchards. Furthermore, it is recognized that widespread withdrawal of orchards may threaten the viability of the fruit production operations as a result of the lost productive area. Thus, the latter mode of rehabilitation is considered only for very limited strategic areas within the selected wetlands.

In terms of rehabilitation of wetland already completely transformed to orchards within the three wetlands this study has identified areas which are currently under orchards and which if withdrawn would likely be most strategically located in terms of the interception of nutrients/pollutants from the upstream catchment, and these constitute a total 14.4 ha in the Elandskloof wetland and 6.1 ha in the Vyeboom wetland (Figure 6).

**Figure 6: Wetland areas currently under orchards identified as strategically located in terms of the interception of nutrients/pollutants from the upstream catchment if rehabilitated (outlined in green).**

In terms of rehabilitation of the existing natural/ semi-natural wetland areas, a few key rehabilitation objectives have been identified for the respective three sites based on the impacts and threats facing these respective wetlands (Table 4). As can be seen from Table 5, removal of invasive alien trees is required at all sites and Du Toit requires no further rehabilitation measures. In contrast, Vyeboom and Elandskloof require several additional rehabilitation interventions (Table 7 ).

**Table 7: Key overarching rehabilitation objectives for the existing natural/ semi-natural areas of the three wetlands (EK=Elandskloof, VB=Vyeboom, DK=Du Toits) and implications for wetland functioning**

| Key overarching objectives | Implications of the rehabilitation for wetland functioning | Wetland | | |
|---|---|---|---|---|
| | | EK | VB | DK |
| Remove invasive alien trees | The replacement of tall invasive alien trees with shorter shrubs and graminoids which have a much smaller transpiring leaf area, and therefore a much lower total evaporation from the wetland, which, in turn, increases the supply of water downstream.<br>Better protection of the soil.<br>Reduced level of uniform shading of the channel, leading to improved habitat. | ✓ | ✓ | ✓ |
| Promote robust herbaceous vegetation in the channel bed and banks | Favourable conditions for the enhanced assimilation of nutrients (through direct uptake and more importantly by creating microhabitat for microbes responsible for the assimilation such as denitrifying bacteria).<br>The accumulation of sediment in the channel will be promoted (see below for implications of this effect). | ✓ | ✓ | |
| Reduce channel incision and promote the accumulation of sediment in the channel | The capacity of the channel is decreased, thereby increasing the frequency and extent of bank overspill, which in turn increases the incidence of flooding across the wetland and the benefits associated with this flooding, in particular the trapping of sediment.<br>Reduced loss of sediment to the downstream environment. | ✓ | ✓ | |
| Halt the advance of headcut erosion threatening to alter diffuse flow portions of the wetland into strongly channelled portions | By preventing the conversion of diffuse flow portions of the wetland into strongly channelled portions the concentration of flows and drying out of these portions of the wetland would be prevented. In turn the loss of desiccated organic soil to mineralization would also be prevented.<br>Direct reduced loss of sediment to the downstream environment | | ✓ | |

### 2.5.2 A description of key interventions included in the rehabilitation

The rehabilitation interventions in the Elandskloof Wetland have been designed specifically taking into account the following impacts and constraints of the site:

- An extensive portion of the wetland is periodically flooded when the dam levels are high. In addition to precluding this wetland from ever being rehabilitated to anywhere near pristine condition, the direct influence of the dam mitigates against vegetation cover directly by the water being too deep for most species to tolerate. In addition, it acts indirectly through wave action by removing soil, in particular the topsoil, so that when the dam level drops a much less favourable growth medium to support plant growth remains.

- Several sections of stream channel are incised.
- One section of the stream channel has been artificially straightened.
- The site has been subject to widespread historical disturbance and the vegetation was previously dominated by alien species and pioneer indigenous species, but with the recent clearing of extensive stands of the alien tree species *Salix fragilis* and *Acacia mearnsii* located mainly adjacent to the streams, some recovery is anticipated in the future.
- Although highly modified, the Elands Stream has prior to alien clearing showed signs of aquatic fauna, including Cape clawless otter spoor and Malachite kingfisher diving after prey in one of the pools in the Elands Stream.

While impacting negatively on biodiversity and water conservation, the *Salix fragilis* trees appear to serve a useful ecological function by dissipating wave action when the dam levels are high, and therefore reducing disturbance of the area and loss of sediment in some of the wetland. Therefore, in terms of shoreline protection and soil conservation, with the removal of these trees it would probably be important to replace them with indigenous plants. *Morella serrata* and *Salix mucronata* are two indigenous tree species tolerant of prolonged flooding which are recommended.

Considering possible opportunities as well as taking into account the impacts and constraints described above for the Elandskloof Wetland, several wetland rehabilitation measures are proposed (Table 8).

**Table 8: Rehabilitation interventions proposed for the Elandskloof Wetland**

| Description of intervention | Specific objective of the intervention | Cost estimate |
|---|---|---|
| Anchored log boom lines/brush fences (constructed from cleared invasive alien trees) orientated at right angles to the shoreline and located in recently deposited sediment and stream outflow areas | Dissipation of wave energy and protection of the soil or recently deposited sediment | To be determined |
| Earthworks to close off the inflow and outflow to the artificially straightened section of channel. | Redirect flows into the original sinuous stream channel. No need to re-fill but left to increase depression storage capacity of the wetland. | To be determined |
| Two strategically located low weirs in the stream channel located in areas downstream of active incision of the channel. | Halt active headcut erosion and incision of the stream channel. | To be determined |
| Sloping of banks in some severely incised sections of channel and use of bio-jute blanket and ecologs, as well as revegetation along banks and toe of banks | Stabilize the banks and prevent further erosion and soil loss | To be determined |
| Lines of robust herbaceous wetland vegetation planted at right angles to | Protection of soil/sediment against wave energy, wash and wind. | To be determined |

| | | |
|---|---|---|
| the flow across recently deposited sediment and stream outflow areas. | Create more favourable conditions for the assimilation of nutrients. | |
| Removal of invasive alien trees | Reduce increased evaporative loss of water and improve habitat, both for aquatic life in the stream and for the wetland more generally. | To be determined |
| Planting of indigenous trees where *Salix fragilis* trees have been removed. | Dissipation of wave energy and protection of the soil or recently deposited sediment, especially in areas which would become exposed with the clearing of *Salix fragilis* | To be determined |

A rehabilitation plan with costing for all of the interventions in Vyeboom has been developed by (Snaddon, et al., 2018) and this provides the basis for the specific interventions given in Table 9. The estimate by (Snaddon, et al., 2018) of the extent of invasive alien plants in Vyeboom and du Toits Wetlands will also be used.

**Table 9: Rehabilitation interventions proposed for the Vyeboom wetland excluding the clearing of invasive alien plants (Snaddon, et al., 2018)**

| Description of intervention | Specific objective of the intervention | Cost estimate (R) |
|---|---|---|
| Sloping and use of bio-jute blanket and ecologs, as well as revegetation along banks and toe of banks | To stabilise the banks in order to prevent further erosion and soil mobilisation | R35 550 |
| Sloping with rock-pack | Stabilise the head-cut and prevent further erosion and soil mobilisation | R6 119 |
| Sloping of 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 |
| 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 |
| A series of geo-cell concrete chutes | Stabilise several head-cuts that are threatening the upstream wetland and prevent further erosion and soil mobilisation that would contribute to sediment loads entering Theewaterskloof Dam | R1 889 994 |

| | | |
|---|---|---|
| Rock Masonry Chute | To stabilise the head-cut and prevent further erosion of the wetland | R17 958 |
| Rock-pack | To reduce high energy flows through channel and prevent further erosion of the head-cut | R7 994 |
| TOTAL | | R2 210 717 |

Unlike the rehabilitation of the natural/semi-natural areas for which individual interventions have been costed, a much coarser estimate has been undertaken for the rehabilitation of wetland areas currently under orchards. These areas will require extensive blocking of artificial drains and reference is made to costs of comparable historical projects reported by Kotze et al. (2018) and accounting for inflation.

## 2.6 A comparison of key functional attributes of the three wetlands for "Without rehabilitation" and "With rehabilitation" scenarios

Having identified the rehabilitation measures to be undertaken in the natural/semi-natural wetland areas, and the specific objectives of these interventions (Table 8 and Table 9) a preliminary assessment was made of key functional attributes of the wetland for a "Without rehabilitation" scenario compared to a "With rehabilitation" scenario (Table 10).

**Table 10: A preliminary qualitative/semi-quantitative assessment of key functional attributes of the three wetlands for "Without rehabilitation" and "With rehabilitation" scenarios. Percentages given in the table refer to proportional extent of the wetland, and the most prominent differences between the "With rehabilitation" and the "Without rehabilitation" scenarios are highlighted in red.**

| | Elandskloof[1] | | Vyeboom | | Du Toits | |
|---|---|---|---|---|---|---|
| | Without rehabilitation | With rehabilitation | Without rehabilitation | With rehabilitation | Without rehabilitation | With rehabilitation |
| Pattern of low flows | | | | | | |
| Strongly channelled | 90% | 88% | 30% | 15% | 15% | 15% |
| Moderately channelled | 5% | 5% | 15% | 10% | 30% | 30% |
| Intermediate | 3% | 4% | 10% | 10% | 30% | 30% |
| Diffuse flow | 2% | 3% | 45% | 65% | 25% | 25% |
| Occurrence of high flows across the wetland | 1 in >5 years over most of the wetland | 1 in 3 years over most of the wetland | In most years, but excluding the strongly channelled portion | In most years, but excluding the strongly channelled portion | In most years, but excluding the strongly channelled portion | In most years, but excluding the strongly channelled portion |

| | | | | | | |
|---|---|---|---|---|---|---|
| Hydrological zonation | | | | | | |
| Temporary | 88% | 83% | 45% | 30% | 35% | 35% |
| Seasonal | 11% | 15% | 35% | 37% | 32% | 32% |
| Permanent | 1% | 2% | 20% | 33% | 33% | 33% |
| Extent of invasive alien trees | 50% | <0.1% | 40% | <0.1% | 6% | <0.1% |

[1] This refers to the situation when the level of the dam is such that the dam shoreline lies below the outlet of the wetland.

From Table 10 it can be seen that the degree to which functional attributes will be enhanced by rehabilitation is clearly greatest in Vyeboom, followed by Elandskloof, and much less in Du Toits, where it is associated with clearing of invasive alien trees alone. The most important contribution at Vyeboom Wetland is in diffuse flow occupying 20% more of the overall wetland area (a change from 45% to 65% of the wetland) and strongly channelled areas being correspondingly less prominent with rehabilitation than without. Rehabilitation would cause water flows to be much more spread out in the wetland, and therefore contribute greatly to increasing the contact between the water column and wetland sediments and vegetation of the Vyeboom Wetland. This would significantly increase the capacity of the wetland to assimilate nutrients and pollutants.

Given the overall size of the natural/semi-natural area of Vyeboom of 235 ha, then the 20% enhanced diffuse flow through rehabilitation, constitutes a total of 47 ha. In terms of modelling the effect of the rehabilitation on the assimilation of nutrients/pollutants, the key difference between the two scenarios is that 47 ha dominated by diffuse low flows, extensive permanent soil saturation and high levels of soil organic matter present in the "With rehabilitation" scenario is replaced with 47 ha of concentrated flow and predominantly temporary soil saturation and much lower levels of soil organic matter in the "Without rehabilitation" scenario.

In the 81 ha area of semi-natural vegetation in the Elandskloof wetland the "With rehabilitation" scenario results in only a 2 ha shift from strongly channelled to areas of intermediately to diffusely spread flows compared with the "Without rehabilitation" scenario, based on the change in flow patterns shown in Table 10.

A total of 37 ha of the Vyeboom Wetland which supports organic soil is under threat from actively advancing headcuts and associated erosion gullies. In the absence of any rehabilitation interventions it is likely that these erosion gullies will advance through these areas and have a strong draining effect on the organic soil material which they contain. Given the average depth of 0.5 m of organic material across this area, this translates into 185 000 m$^3$ of organic soil material under threat.

While Du Toits Wetland holds by far the greatest volume of organic soil material out of the three wetlands, estimated as 1 095 733 m$^3$ (Kotze, 2015), this is not under any immediate observable threat for which rehabilitation interventions have been planned. In the long term, control of wattle trees eliminates the threat to this organic material posed by the drying effect and destabilization of channels in the wetland posed by these trees in the absence of effective control.

The lower gullies of the Vyeboom Wetland feed directly into the Theewaterskloof Dam, and therefore all of the sediment eroded out of these gullies will be deposited in the dam. Although the eroding channel below the road crossing is currently not connected by a clearly defined channel to the outflow, at the current rate of advance of the main lower gully, this is likely to take place resulting in sediment eroding from this channel being readily transported into the Theewaterskloof dam. In contrast, sediment eroded from the upper erosion gully flows through a weakly channelled portion of the wetland (not threatened by gully erosion) before entering a well-defined channel carrying it directly into the Theewaterskloof. For the purposes of the economic assessment it is assumed that half of the sediment lost from the upper gully would be deposited in this weakly channelled area rather than being carried down into the Theewaterskloof Dam.

# 3. HYDROLOGICAL MODEL FOR THE THEEWATERSKLOOF DAM WETLANDS

## 3.1 Introduction

This section of the report will describe the development of a representative hydrological model for the Theewaterskloof Dam wetlands. The WRSM2000-Pitman Model has been:

- configured,
- calibrated at all the observed streamflow sites including the Theewaterskloof Dam inflow record, and
- used to simulate flows through the applicable wetlands for historical conditions and for the Present Day (2009) Development Level Scenario.

The following Sections of the report will provide an overview of the study area and the various sets of input data required to configure an integrated hydrological model for all areas upstream of the Theewaterskloof Dam, including all the wetlands. References are made to the sources of the data or assumptions made for each type of input data. The results from the model calibration will also be presented. Subsequently the three wetland balances are provided for a Present Day (2009) development level scenario.

## 3.2 Study area

The study area consists of three quaternary catchment areas that feed into the Theewaterskloof Dam, i.e. H60A, B & C. The Theewaterskloof Dam catchment consist of an enclosed valley with mountainous borders which surrounds approximately 80% of the catchment. The steep hills surround flat valley areas on which extensive irrigated agriculture, farm dams and the larger reservoirs can be found. Altitudes vary from 1500 meters above sea level (masl) in the South West to 320 masl at the Theewaterskloof Dam wall in the South East.

To more accurately determine the long-term wetland water balances, the quaternary catchments were further divided into quinary catchments as indicated in Figure 7.

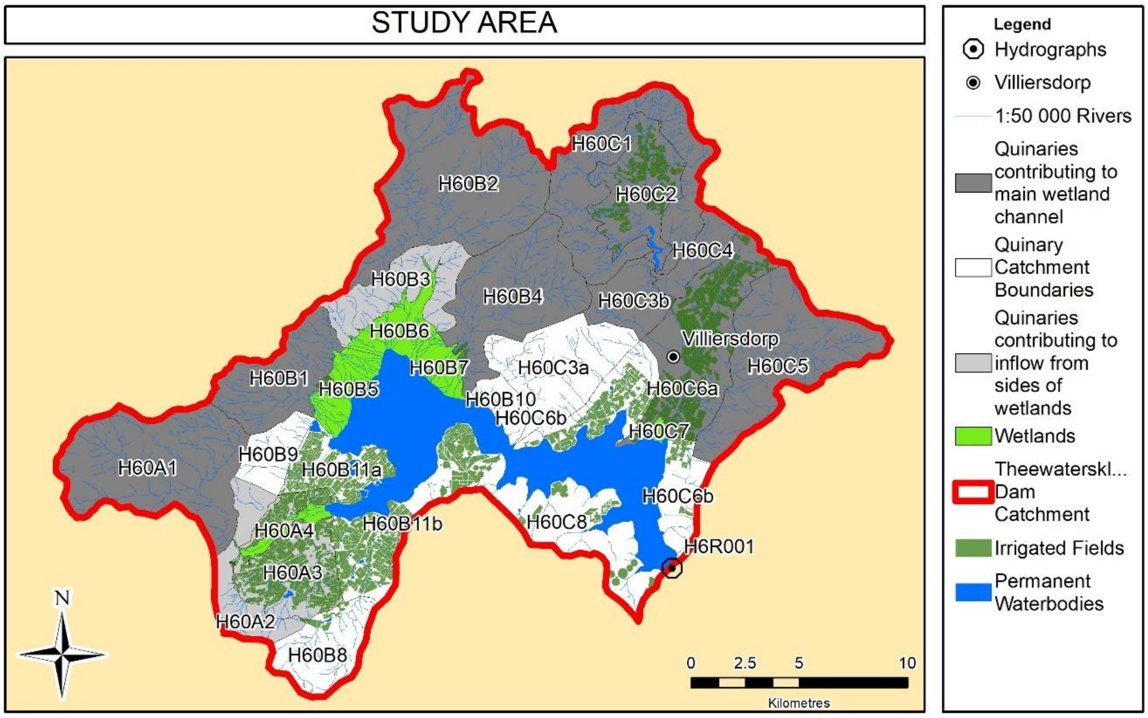


**Figure 7: Study area Map**

Table 11 provides the reference number, description, catchment area, Mean Annual Precipitation (MAP) and Mean Annual Evaporation (MAE) for each of the quinary catchments. The MAP for each of the quinary catchments were generated from the WR2012 source dataset (Dent, et al., 1987) and catchment boundaries were determined using 1:50 000 contour maps overlaid on Google Earth satellite images.

As can be seen from Table 11 the MAP for the catchment varies between 547 to 2329 mm/annum, which influences the demands in different parts of the catchment significantly. Table 11 also shows that 78% of the surface runoff generated upstream from Theewaterskloof Dam first flows through wetlands before reaching the dam. The Theewaterskloof Dam supplies approximately 36% of the Western Cape Water Supply System (WCWSS - Figure 8) Historical Firm Yield (Department of Water Affairs (DWA), 2012) which means that the wetlands in these 3 quaternary catchments filters approximately 28% of the entire WCWSS’s yield.

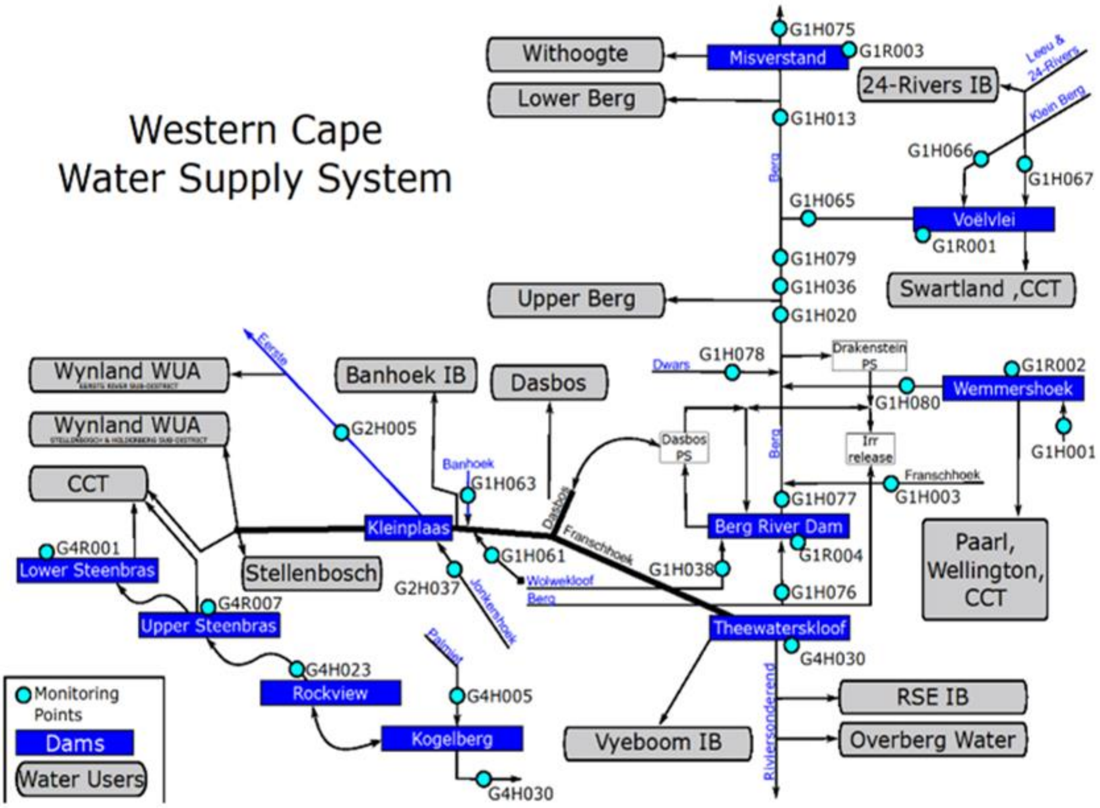


**Figure 8: Western Cape Water Supply System (WCWSS)**

**Table 11: Quinary areas in the Theewaterskloof Dam Catchment.**

| Catchment # | Description | Area (km$^2$) | MAP (mm/annum) | MAE: S-Pan (mm/annum) |
|---|---|---|---|---|
| H60A1 | Catchment for main channel inflow to Vyeboom Wetland (Gauged: H6H008) | 39 | 2329 | 1440 |
| H60A2 | Mountainous areas surrounding Vyeboom Wetland, causing lateral inflows | 11 | 1263 | 1440 |
| H60A3 | Irrigation upstream from Vyeboom Wetland, causing lateral inflows | 20 | 1016 | 1440 |
| H60A4 | Vyeboom Wetland | 2 | 976 | 1440 |
| *H60A Total* | | 73 | 1751 | 1440 |
| H60B1 | Catchment for main channel inflow to Du Toits Wetlands #1&2 | 18 | 1755 | 1465 |

|  |  |  |  |  |
|---|---|---|---|---|
| H60B2 | Catchment for main channel inflow to Du Toits Wetland #3 (Gauged: H6H007) | 46 | 1246 | 1465 |
| H60B3 | Mountainous areas surrounding Vyeboom Wetland, causing lateral inflows | 15 | 1081 | 1465 |
| H60B4 | Catchment for main channel inflow to Du Toits Wetland #4 | 28 | 1280 | 1465 |
| H60B5 | Du Toits Wetland #1 & 2 | 7 | 1099 | 1465 |
| H60B6 | Du Toits Wetland #3 | 8 | 907 | 1465 |
| H60B7 | Du Toits Wetland #4 | 5 | 744 | 1465 |
| H60B8 | High runoff mountainous area (south), contributing to irrigation downstream from Vyeboom Wetland | 14 | 1228 | 1465 |
| H60B9 | High runoff mountainous area (north), contributing to irrigation downstream from Vyeboom Wetland | 7 | 1399 | 1465 |
| H60B10 | High runoff mountainous area (east), flowing directly into Theewaterskloof Dam | 4 | 887 | 1465 |
| H60B11 | Irrigated areas not influencing the Vyeboom Wetland | 32 | 740 | 1465 |
| Dam B | Dam surface area in H60B | 27 | 690 |  |
| *H60B Total* |  | 210 | 1105 | 1465 |
| H60C1 | High runoff mountainous areas upstream from Elandskloof Dam | 32 | 1296 | 1470 |
| H60C2 | Irrigated areas upstream from Elandskloof Dam | 18 | 923 | 1470 |
| H60C3a | High runoff mountainous areas, not affecting Elandskloof Wetland | 21 | 1275 | 1470 |
| H60C3b | High runoff mountainous areas, upstream Elandskloof Wetland (1) | 10 | 1275 | 1470 |
| H60C4 | High runoff mountainous areas, upstream Elandskloof Wetland (2) | 6 | 814 | 1470 |
| H60C5 | High runoff mountainous areas, upstream Elandskloof Wetland (3) – Partly gauged by H6H010 | 33 | 850 | 1470 |
| H60C6a | Areas under irrigation upstream from Elandskloof Wetland | 29 | 693 | 1470 |

| | | | | |
|---|---|---|---|---|
| H60C6b | Areas under irrigation, not affecting the Elandskloof Wetland | 22 | 693 | 1470 |
| H60C7 | Elandskloof Wetland | 0.8 | 613 | 1470 |
| H60C8 | Areas under irrigation, not affecting the Elandskloof Wetland | 22 | 547 | 1470 |
| Dam C | Dam Surface area in H60B | 25 | 690 | 1470 |
| *H60C Total* | | 217 | 894 | 1470 |
| Theewaterskloof Dam Catchment Total | | 500 | 1108 | 1464 |

## 3.3 Rainfall

Long-term catchment-based rainfall time-series were generated for the Theewaterskloof Dam from patched point rainfall station data from within and surrounding catchment areas. The point rainfall data was obtained from WR2012-Study (Bailey & Pitman, 2015). Table 12 provides a summary of the rainfall stations used in determining the long-term catchment rainfall records.

**Table 12 : Point rainfall stations used for long-term catchment rainfall data input**

| Station # | Data Start | Data End | No. of Years | MAP (mm/annum) |
|---|---|---|---|---|
| 006031 | 1971 | 2007 | 37 | 3146 |
| 006065 | 1935 | 1970 | 36 | 1579 |
| 0021809 | 1930 | 1952 | 23 | 1489 |
| H1E007 | 1984 | 2009 | 26 | 1058 |
| 0022148 | 1977 | 2009 | 33 | 1881 |
| 022440 | 1953 | 1994 | 42 | 833 |

Most of the rainfall station used for this analysis are situated outside the catchment borders, and only two of the rainfall stations used were still open at the end of the simulation period. The declining number of rainfall stations will make future analyses less accurate and it is highly recommended that new rainfall stations are commissioned in the catchment to improve the measured distribution of rainfall both spatially and temporally.

The resulting catchment rainfall data generated from the point rainfall data was compared with other historical analyses done for this area. Figure 9 shows the cumulative annual rainfall deviation from the long-term mean annual rainfall for this analysis, as well as for the WR2012-Study and for the last detailed hydrological analysis done by DWS for the WCWSS, referred to as the Water Availability Assessment Study (WAAS) (Department of Water Affairs and Forestry (DWAF), 2008)

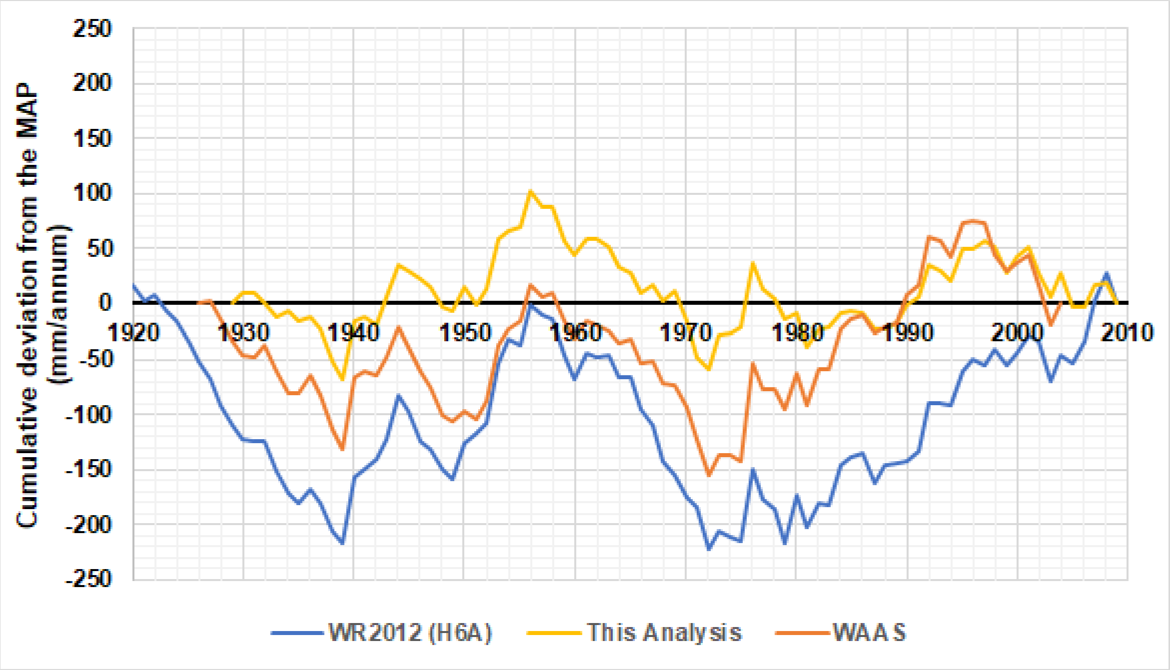


**Figure 9:Long-term cumulative annual catchment rainfall variation**

Figure 9therefore shows how the annual catchment rainfall fluctuated over time above and below the long-term mean on a cumulative basis. Descending parts of the line shows consecutive years of lower than average annual rainfall and ascending parts show consecutive year with above average rainfall. The previous comparative studies show large cumulative dry and wet periods up to 1975 and much smaller cumulative dry and wet periods post-1975. This artificial trend seen in the previous analyses are partly due to (a) making use of point rainfall data with long-term trends not supported by surrounding rainfall stations and (b) the inherent difference in how rainfall was monitored in South Africa pre-1975. Both these issues were resolved by careful selection of point rainfall station data record periods. The trends between all the studies still compares well in terms of dry and wet periods, however this study's annual rainfall pattern fluctuates more evenly around the mean, and do not show the usual discrepancy between pre- and post-1975 rainfall measurement.

## 3.4 Reservoirs

Detailed information on the Elandskloof and Theewaterskloof dams were obtained from DWS: Hydrological Services. This included latest survey data (for area-capacity relationship calculations) as well as the detailed daily water balance information for calibration purposes. The DWS: Dam Safety database were used to obtain capacity and surface area information for twenty six (26) registered dams in the Theewaterskloof Catchment. A relationship between the provided full supply area and capacities of the registered dam were determined and is provided in Figure 10. The figure therefore shows the known capacities and related full supply surface areas for several farm dams in the Theewaterskloof Catchment. Fitting an 2$^{nd}$ order polynomial trend line through the known area-capacity relationship produced an equation for dams in the Theewaterskloof Dam catchment.

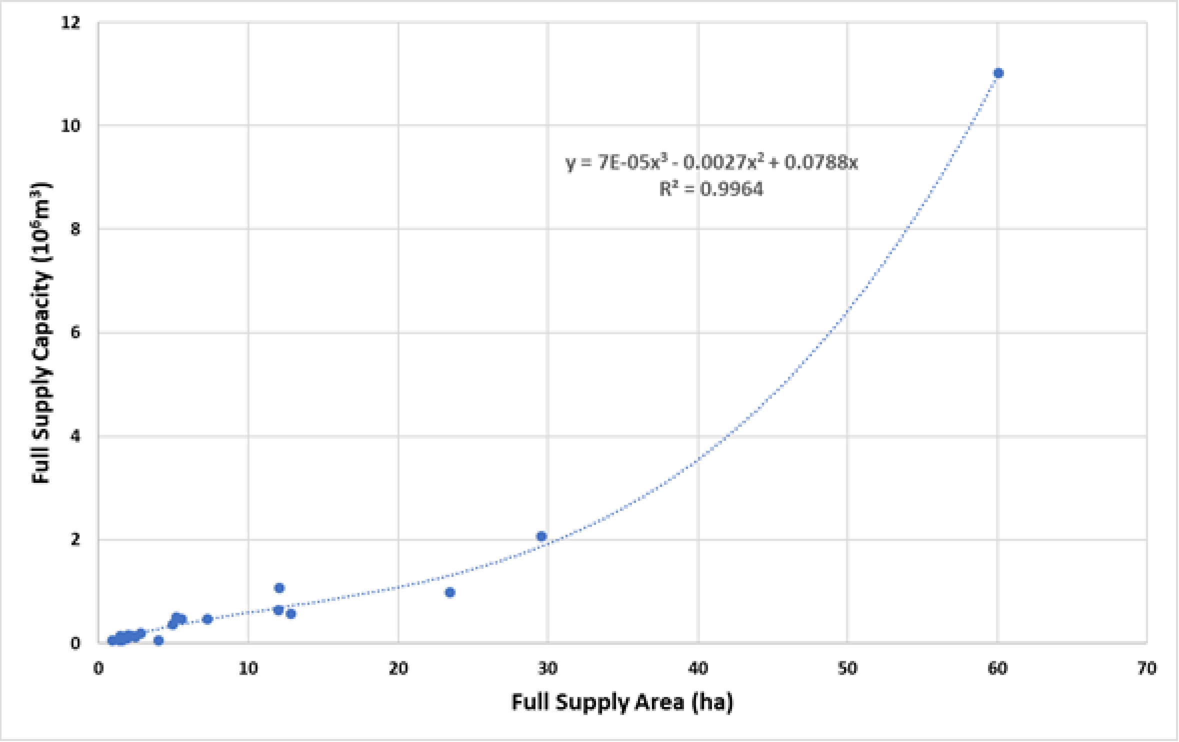


**Figure 10: Area-capacity relationship for registered farm dams in the Theewaterskloof Dam Catchment**

Additional farm dams that did not appear in the Dam Safety Database were identified on Google Earth and their surface area were digitised. The above relationship was then used to determine the additional farm dam capacities. The total farm dam and major dam full supply capacities and related areas for the Theewaterskloof Catchment are provided in Table 13.

It should be noted that due to the highest water demands occurring in the dry season, farmers tend to fill farm dams during the wet winter seasons. This behaviour was also incorporated into the model configuration to ensure that irrigation from farm dams have representative assurance of irrigational water supply.

The function used in the WRSM2000 to represents the relationship between the volume of water in a dam and the corresponding surface area is given by the equation:

$$\text{Area} = a * \text{Volume}^b$$

Where:

a = coefficient in the volume-surface area relationship (known as the A-value);

b = power in the volume-surface area relationship (known as the B-Value);

Volume = volume of water in the dam (million $m^3$);

Area = surface area of water in the dam, corresponding to Volume ($km^2$).

Detailed dam survey data is available for the Theewaterskloof and the Elandskloof Dams. The survey data was used to derive the required B-Values for each of the dams (the A-Value is derived by using the dam's full supply capacity and full supply area for any given B-value). When detailed survey data is not available (such as in the case of lumped farm dams), a default value of 0.6 is assumed.

**Table 13: Reservoir information for the Study Area**

| Reservoir Description | Full Supply Area (km$^2$) | Net Full Supply Capacity (10$^6$m$^3$) | B-Value applied |
|---|---|---|---|
| Theewaterskloof Dam | 51.2 | 479.3 | 0.68 |
| Elandskloof Dam | 0.6 | 11.0 | 0.68 |
| Farm dams in H60A (Scheme and Non-Scheme) | 0.4 | 2.7 | 0.60 |
| Farm dams in H60B (Scheme and Non-Scheme) | 0.2 | 1.5 | 0.60 |
| Farm dams in H60C | 0.4 | 2.9 | 0.60 |
| Total: |  | 497.4 |  |

## 3.5 Canals and pipelines

The Vyeboom Irrigation Board has a pipeline abstracting directly from the Theewaterskloof Dam. Water is provided under pressure to irrigators with assumed 5% transmission losses. Over the 24 years of monitored data the average supply was 8.4 million m$^3$/annum. Present Day (2009) development was calculated based on the average supply from 2005 – 2009 which was 9.1 million m$^3$/annum.

The Elandskloof Irrigation Board supplies irrigators downstream from the Elandskloof Dam as well as Villiersdorp with water via a system of ground canals that covers both the left and right bank of the river. The historical measured canal water supply was 10.7 million m$^3$/annum between 1988 to 2009, with Present Day (2009) water requirements assumed as 11.5 million m$^3$/annum according to the annual average between 2005 and 2009. Transmission losses were assumed to be 30% overall, although ground canals have losses in excess of 50%. This is to account for some of the losses returning to rivers and dams.

## 3.6 Land -and Water-use

### 3.6.1 Invasive Alien Plants (IAP) and Commercial Forestry

Commercial Forestry data from the WR2012 Study was used for this analysis. There was only one areas (H60C1) that had commercial forestry activity of 3.8 km$^2$ of Pine plantations which were verified on Google Earth historically. The total Present Day (2009) area under commercial forestry has however reduced to only 1.0 km$^2$.

IAP data was obtained from the publication “The impacts of different degrees of Invasive Alien Plant Invasion on yields from the Western Cape Water Supply System” (Görgens, 2016). The tables in the report as well as the map of distribution of plants in the catchment were used to disaggregate the rough spatial aggregation of condensed areas that is provided in the report. Table 14 provides an overview of the area of IAPs that was indicated per quinary. In the final model configuration only 4 of the 13 quinary catchments were simulated to have IAP’s, since Google Earth verification of the remainder of the areas showed that it is highly unlikely to have so much vegetation, let alone IAP’s in the given areas. The simulated reduction in runoff due to IAPs is also provided in Table 14.

**Table 14: Simulated reduction in run off due to invasive alien plants per quinary catchment.**

| Quinary Catchment | Condensed Area of IAPs (km$^2$) | % in Riparian Zone | Present Day (2009) water use (million m$^3$/annum)* |
|---|---|---|---|
| H60A1* | 6.28 | 0.00 | 7.9 |
| H60A2 | 1.9 | 0.36 | - |
| H60B1 | 3.12 | 0.36 | - |
| H60B2* | 11.10 | 0.00 | 7.3 |
| H60B3 | 2.46 | 0.36 | - |
| H60B4* | 9.65 | 0.36 | 7.2 |
| H60B8 | 2.33 | 0.36 | - |
| H60B9 | 1.23 | 0.36 | - |
| H60B10 | 0.67 | 0.36 | - |
| H60C1&2* | 8.02 | 0.59 | 5.7 |
| H60C3 | 5.22 | 0.36 | - |
| H60C4 | 1.05 | 0.36 | - |
| H60C5 | 5.68 | 0.36 | - |
| Total | 58.71 | | 28.0 |

* - Quinary catchments where possible IAPs could occur based on Google Earth assessment of total vegetation coverage for quinary.

### 3.6.2 Irrigation Water Use

Listed Irrigation Board irrigated areas and quotas for the Western Cape Water Supply System (WCWSS) were compared with the Western Cape Government Department of Agriculture's detailed crop survey from 2017. The Listed Irrigation Board and Government Water Scheme's irrigated areas were approved by the Minster of Water Affairs and Forestry in 1999 as being Existing Lawful Water Use in accordance to Article 33 of the National Water Act of 1998. Table 15 provides a comparison between the two sources of information's areas under irrigation for the Theewaterskloof Dam catchment.

**Table 15: Comparison between Verified Legal and Western Cape 2017 Crop Survey (km$^2$)**

| Source | Listed Legal | 2017 Survey |
|---|---|---|
| Vyeboom Irrigation Board | 18.63 | 18.73 |
| Elandskloof Irrigation Board | 19.09 | 18.32 |
| Direct from Theewaterskloof Dam | 15.64 | 11.51 |
| Local runoff | | 7.21 |
| Total | 53.36 | 55.77 |

Figure 11 shows the distributions of irrigated fields according to the 2017 Survey in the 5 irrigation sub-areas.

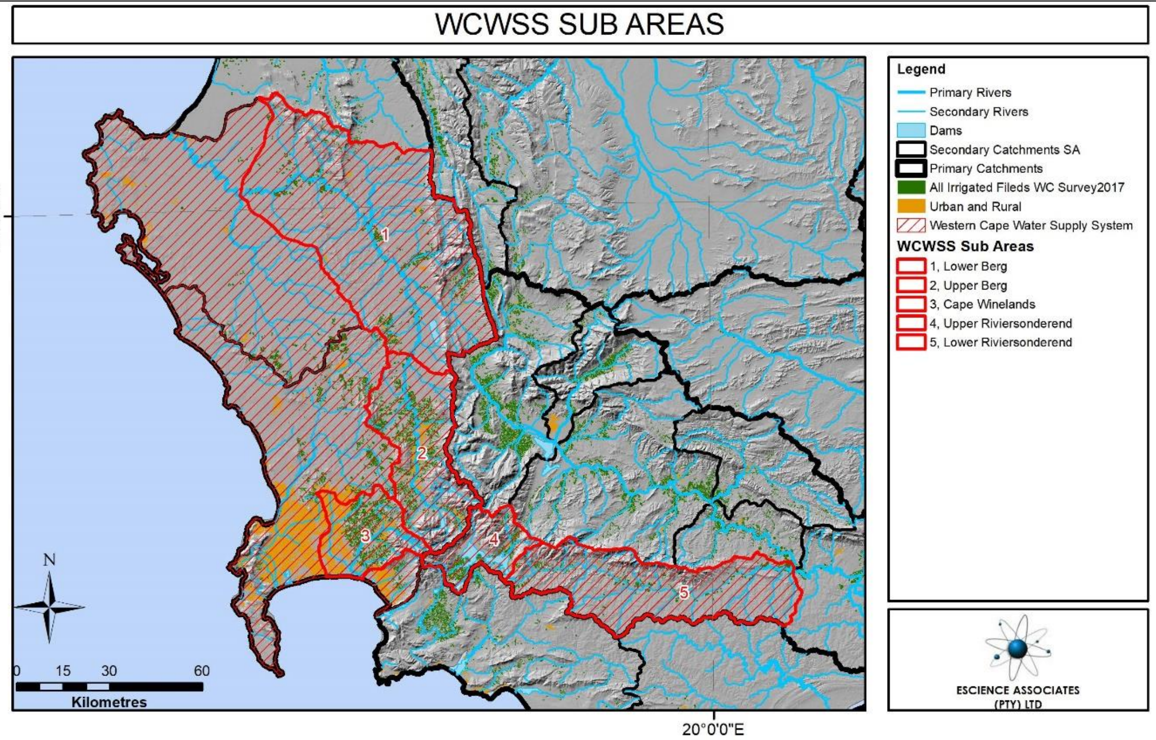


**Figure 11: Distribution of irrigated agriculture in the 3 main sub-areas of the WCWSS according to the 2017 survey (green = irrigated agriculture, red boundaries = WCWSS sub-areas.**

As can be seen the total areas under irrigation compare well, and the 2017 Crop Survey data was therefore accepted for use in the model as the 2009 development level irrigation distribution. The 2017 Survey shapefiles database was therefore used to determine irrigation areas, crops and irrigation methods for each of the affected quinary catchments. Personal communications with the Elandskloof and Vyeboom Irrigation boards also allowed for more detailed disaggregation of the irrigation demands and return flows, to ensure that only irrigation upstream or lateral from wetlands are included in return flow calculations.

SAPWAT was used in each quinary to determine crop-irrigation method requirements for each area and an area weighted representative crop was generated with an assumed efficiency. SAPWAT is a daily crop requirements simulation software package that calculates the crop requirements based on the crop type, the irrigation method and the hydro-climatic conditions of the crop. SAPWAT, developed by the Water Research Commission, is widely used throughout South Africa by agricultural engineers and water resource planners, amongst others (Van Heerdan & Walker, 2016). Return flows were assumed as 50% of the non-effective irrigation application efficiency (see Table 16).

Table 16 provides the breakdown of irrigated areas, quotas, Present Day (2009) long-term water requirements and supply for all quinary catchment areas. Table 16 shows that the irrigation in the Theewaterskloof Catchment has a long-term irrigation requirement far less than the quota (61% of quota). The low irrigation requirements are due to the relative high rainfall, low evaporation and due to the very high irrigation system efficiency. Furthermore, the irrigation requirements were met 99% of the time on over the 80-year monthly period. Most of the irrigation is provided either through a dedicated pipeline or canal system from a major reservoir or from farm dams which are filled during the wet winter months.

Through this detailed analysis the impact of irrigation water requirements and return flow on individual wetlands could be simulated. Return flows from irrigated areas were relatively small compared to runoff that feeds the wetlands, partly due to the high irrigation system efficiency of the irrigation schemes upstream from the wetlands.

### 3.6.3 Domestic water supply and return flows

Villiersdorp can abstract 0.694 million $m^3$/annum directly from the Elandskloof Government Water Scheme as well as from the Kommissieskraal River. Additionally, there are boreholes with an estimated yield of 0.2 million $m^3$/annum. The Water Treatment Works (WTW) has a maximum capacity of 1.081 million $m^3$/annum. The Wastewater Treatment Works (WWTW) has a capacity of 0.66 million $m^3$/annum of which 0.3 million $m^3$/annum is reused by the municipality for irrigating the parks and sports fields (Department of Water Affairs, 2011). The average annual measured outflow from the WWTW between October 2015 and September 2019 was 0.18 million $m^3$/annum, compared to the long term annual simulated inflow into the Elands River upstream from the Elandskloof Wetland of 44.5 million $m^3$/annum. In the dry, summer months the % of WWTW outflows are on average 8% of the total inflow to the wetland.

## 3.7 Measured flow data

Two DWS streamflow gauging weirs with historically measured flow data used during the calibration of the WRSM2000/Pitman model, are situated within the Theewaterskloof Dam catchment, one each upstream from the Du Toits and the Vyeboom wetlands. The two streamflow gauging weirs are H6H007 and H6H008 respectively. The two gauging weirs measured a significant amount of runoff into the Theewaterskloof Dam but were unfortunately closed in 1992, after 28 years of data recording.

**Table 16: Irrigated areas per quinary catchment.**

| Quinary Catchment | Source | Infrastructure | Present Day (2009) Irrigation | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Quota (million m$^3$/annum) | Area (km$^2$) | Requirement (million m$^3$/ annum) | Supply (million m$^3$/ annum) | Application Efficiency (%) | Return flow (%) |
| H60A3 | Vyeboom IB | TWK Pipeline & Dams | 6.57 | 9.26 | 2.97 | 2.97 | 95 | 2.6 |
| H60A3 | Local Runoff | Dams | 1.45 | 2.04 | 0.65 | 0.65 | 95 | 2.6 |
| H60B1 | Local Runoff | Run-of-river | - | 0.32 | 0.12 | 0.12 | 95 | 2.5 |
| H60B4 | Local Runoff | Run-of-river | - | 0.28 | 0.13 | 0.13 | 95 | 2.5 |
| H60B11 | Vyeboom IB | TWK Pipeline & Dams | 6.72 | 9.47 | 4.01 | 4.01 | 94 | 2.8 |
| H60B11 | Local Runoff/TWK Direct | Dams/TWK Dam | 6.47 | 9.62 | 3.86 | 3.86 | 94 | 2.8 |
| H60C2 | Local runoff | Dams | 3.14 | 4.57 | 1.98 | 1.91 | 95 | 2.5 |
| H60C6 | Elandskloof IB | Canals & dams | 12.57 | 18.32 | 8.94 | 8.92 | 95 | 2.6 |
| H60C8 | Local Runoff/TWK Direct | TWK Dam | 1.34 | 1.89 | 0.67 | 0.52 | 90 | 5.0 |
| Total | | | 38.26 | 55.77 | 23.34 | 23.10 | | |

Upstream from the Elandskloof wetland, the Elandskloof Dam and all its components are measured by DWS as H6R002. The components include the releases to the canal system, any spills or releases via the dam wall and the monthly volume of water stored by the dam. Rainfall and evaporation data from the Theewaterskloof Dam and all the different monitored components of the dam are used to calculate the daily and monthly inflow to the reservoir. This inflow record is then used to calibrate the model against for the area upstream of the dam. All historical releases from the dam is also incorporated into the model to contribute towards the Elandskloof Wetland inflow estimation.

So as for the Elandskloof Dam, DWS have a daily and monthly inflow calculation record for the Theewaterskloof Dam. This dam however has many more components in the inflow calculation than Elandskloof Dam, including five (5) pipeline and transfer tunnel meters. This calculated inflow record was used to calibrate the overall inflow from the three (3) quaternary catchment areas into the Theewaterskloof Dam. Table 17 provides a summary of the four (4) measure runoff sites used during the calibration process of the WRSM2000/Pitman Model.

**Table 17: Measured flow gauging sites in the Theewaterskloof Dam catchment.**

| Number: | H6H007 | H6H008 | H6R001 | H6R002 |
|---|---|---|---|---|
| Gauge name: | Du Toits River @ Purgatory Uitspan | Riviersonderend @ Swarte Water | Riviersonderend River @ Theewaterskloof Dam | Elands River @ Elandskloof Dam |
| Catchment Area (km$^2$): | 46 | 38 | 498 | 50 |
| Latitude: | -33.93869 | -34.0623 | -34.07741 | -33.95214 |
| Longitude: | 19.17077 | 19.07244 | 19.28993 | 19.28453 |
| Record Start: | 1964/03/14 | 1964/04/18 | 1979/06/18 | 1975/05/14 |
| Record End: | 1992/09/07 | 1992/09/07 | 2019/02/21 | 2018/10/24 |
| Raw MAR up to 2009 (million m$^3$/ annum): | 37.6 | 60.6 | 21.9 | 303.2 |
| Patched MAR up to 2009 (million m$^3$/ annum): | 37.8 | 68.3 | 22.6 | 303.2 |

## 3.8 Wetlands

This section will describe the wetland sub-module of the WRSM2000/Pitman model and is followed by the parameters used to simulate the water balance in each of the three (3) analysed wetlands.

### 3.8.1 Sub-Module description

The "Comprehensive" Wetland sub-module of the WRSM2000/Pitman Model is an improvement on the previous, more simplified version of the wetlands sub-module which initially modelled a wetland like a reservoir. The latest version represents a wetland more realistically as a defined channel that meanders through a wetland (either off-channel or in-channel), feeding it with water only when the river channel capacity is exceeded, and spilling back into the channel at different storage states. The flow of water between channel and wetland can be in the form of overbank spillage or via channels, or a combination of both. This wetland-module has successfully been applied in the Kafue River (Zambia) and the Pongolo River (RSA) (Bailey, 2015).

Figure 12 provides a diagram illustrating the flow balance through the wetland module in the WRSM2000/Pitman Model, with a subsequent discussion of the different components thereafter.

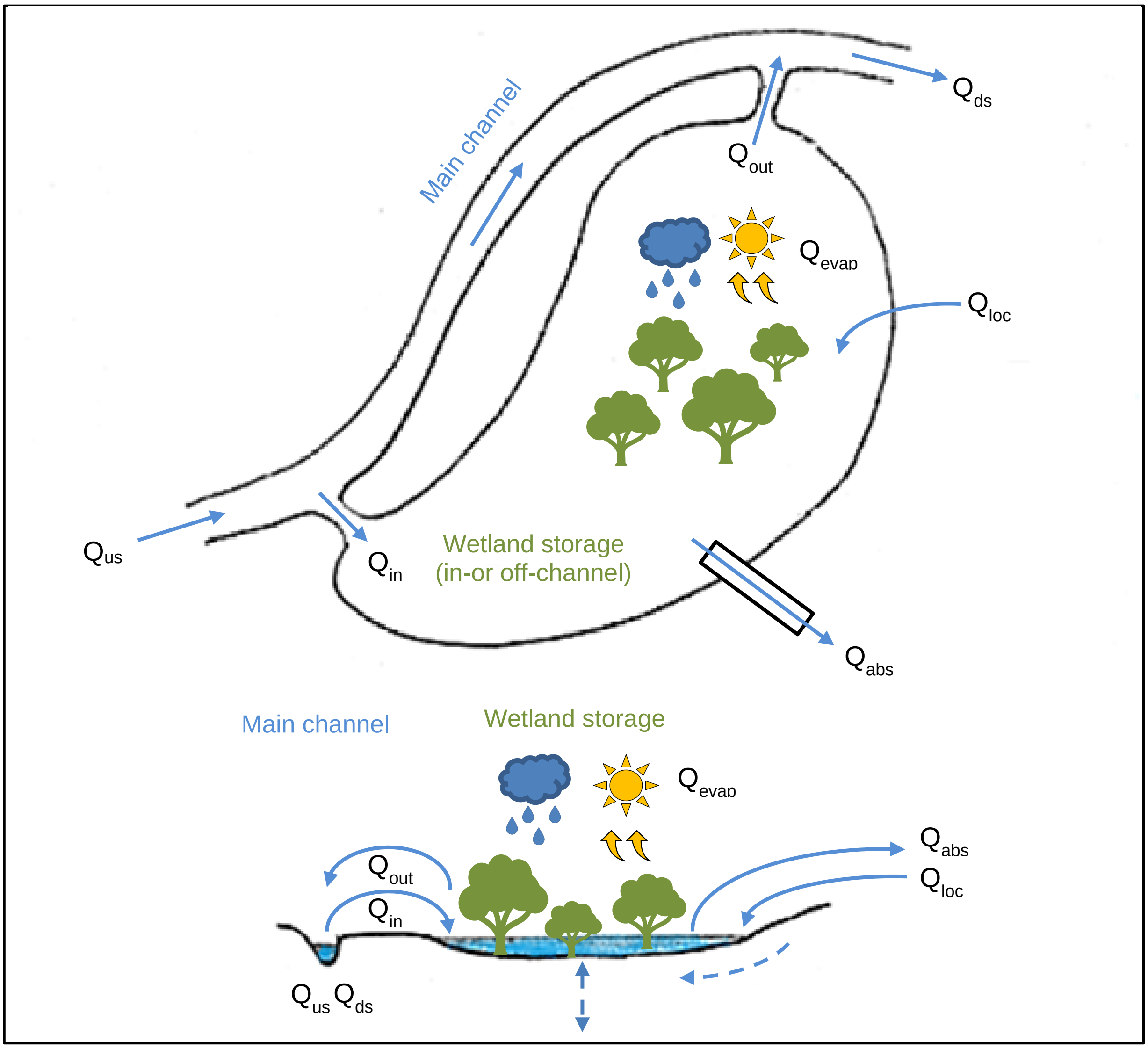


**Figure 12 : Flow balance diagram through the WRSM2000/Pitman wetland module (adapted from (Bailey, 2015)**

One of the main drivers for the wetland balance is the simulated upstream main channel inflow to the wetland ($Q_{us}$). The upstream inflow usually represents the flow from the total upstream catchment area which are continuously connected to the wetland storage areas or only under certain flow conditions. The latter conditions usually occur when there is a well-defined main channel such as in the case of strong perennial rivers, where an off-channel storage wetland often only fills under higher flow conditions. Other, more localised simulated runoff (usually lateral inflow) is also catered for in the module ($Q_{loc}$). The localised runoff has direct access to the wetland storage area and is not limited by flow conditions in the main channel. Another function also exists for wetland abstractions done directly from the wetland storage area ($Q_{abs}$).

A real wetland has many links, where water can flow from the main channel to the wetland storage area and back into the channel, depending on water levels. The flow from the main channel to the wetland storage area ($Q_{in}$) and from the storage area to the main channel ($Q_{out}$) are regulated by several module parameters. The monthly wetland water storage balance is calculated using $Q_{in}$, nominal monthly storage status of the wetland, net monthly evaporation ($Q_{evap}$ is the difference between the month's evaporation and rainfall) and $Q_{out}$ (Bailey, 2015). If known, the wetland's Evapotranspiration is used during the calculation of the $Q_{evap}$ value. The following wetland structural parameters are used to influence the monthly wetland balance:

Physical parameters:

$S_{nom}$ = Nominal wetland storage volume (million $m^3$)

$A_{nom}$ = Nominal wetland surface area ($km^2$)

B-Value = Constant in wetland area-capacity equation Area =A x Storage$^B$.

Where B = 0.1 is a bathtub shape and B = 0.9 is a V-shaped storage area

Flow into wetland storage area ($Q_{in}$):

$Q_{bf}$ = Channel capacity above which spillage into wetland occurs (million $m^3$ per month) – the "bf" refers to Baseflow, which is often used to estimate this parameter

$K_{in}$ = Proportion of $Q_{us}$ above $Q_{bf}$ flowing into wetland

Flow from the wetland storage ($Q_{out}$):

$K_{out}$ = Proportion of wetland storage above $S_{nom}$ returned to the main channel

$Q_{ds}$ = Flow in the river downstream from the wetland, as calculated for each month as: $Q_{ds} = Q_{us} – Q_{in} + Q_{out}$

Groundwater components such as interflow, baseflow and recharge are not explicitly modelled in the WRSM2000/Pitman wetland module. However, two runoff generating methods in the model, i.e. Sami- and Hughes- methods (Bailey, 2015)., provides estimations of surface-groundwater interactions. Recharge can be simulated outside of the wetland module and abstracted from the monthly wetland storage balance while interflow is usually included in the main channel and lateral inflow simulated runoff. However often the wetland storage has a relatively impermeable layer of organic material that hampers recharge and adds lateral contributions to baseflow directly to the wetland storage.

### 3.8.2 Evapotranspiration

The wetland specialist provided the estimation of the evapotranspiration for each of the three (3) wetlands by estimating the distribution of species in each wetland based on the field visit and from estimated water use for the different species from various sources. The annual evapotranspiration was then disaggregated into monthly values based on the A-Pan monthly evaporation pattern. Table 18 provides the estimated annual total evapotranspiration for each group of plants while Table 19 provides the approximate monthly distribution per wetland.

**Table 18: Estimated annual total evapo-transpiration for groups of wetland plants.**

| Plant Group | Annual total evapo-transpiration (mm/ annum) | Source of estimate |
|---|---|---|
| Palmiet | 1042 | Direct estimate from Rebelo (2012) |
| Tall mixed fynbos/ sedge/grass wetland | 1100 | Based on comparison with Dye and Jarmain (2004) |
| Short mixed fynbos/ sedge/grass wetland | 900 | Based on comparison with Dye and Jarmain (2004) |
| Black wattle | 1500 | Direct estimate Dye and Jarmain (2004) |
| Phragmites australis | 1174 | Dye et al. (2008) |

**Table 19: Approximate distribution of plant groups per wetland, and associated monthly evapotranspiration (pre alien clearing of Elandskloof)**

| Wetland | Vyeboom | Elandskloof | Du Toits Wetland #1 | Du Toits Wetland #2 | Du Toits Wetland #3 | Du Toits Wetland #4 |
|---|---|---|---|---|---|---|
| Palmiet | 35% | 0% | 5% | 0% | 40% | 5% |
| Tall mixed fynbos/ sedge/grass wetland | 20% | 10% | 35% | 15% | 20% | 30% |
| Short mixed fynbos/ sedge/grass wetland | 25% | 63% | 60% | 85% | 40% | 65% |

| | | | | | | |
|---|---|---|---|---|---|---|
| Black wattle | 20% | 25% | 0% | 0% | 0% | 0% |
| Phragmites australis | 0% | 2% | 0% | 0% | 0% | 0% |
| Annual Total (mm/annum) | 1110 | 1075 | 977 | 930 | 997 | 967 |
| Oct (mm) | 97 | 94 | 86 | 81 | 87 | 85 |
| Nov (mm) | 138 | 133 | 121 | 115 | 124 | 120 |
| Dec (mm) | 171 | 166 | 151 | 144 | 154 | 149 |
| Jan (mm) | 179 | 173 | 157 | 150 | 160 | 156 |
| Feb (mm) | 149 | 144 | 131 | 125 | 134 | 130 |
| Mar(mm) | 126 | 122 | 111 | 105 | 113 | 109 |
| Apr (mm) | 68 | 66 | 60 | 57 | 61 | 59 |
| May (mm) | 36 | 35 | 32 | 30 | 33 | 32 |
| Jun (mm) | 27 | 26 | 23 | 22 | 24 | 23 |
| Jul (mm) | 25 | 24 | 22 | 21 | 22 | 22 |
| Aug (mm) | 36 | 35 | 32 | 30 | 33 | 32 |
| Sep (mm) | 59 | 57 | 52 | 49 | 53 | 51 |

### 3.8.3 Parameter estimation

The two physical model parameters of a wetland, i.e. the nominal wetland storage volume ($S_{nom}$) and the nominal wetland surface area ($A_{nom}$) are usually the only parameters that can be measured. A survey is usually not available, however the surface areas of the wetlands can be digitised from Google Earth, as was done for this analysis. Assumptions regarding the wetland's average depth then provides the estimated capacity of the wetland. The B- Factor, indicating the area-capacity relationship or cross-section shape of the wetlands are usually deduced from Digital Terrain Models (DTMs) or field visits.

The effects of groundwater recharge and baseflow contribution can't currently be simulated directly by the Wetland sub-module. However, using the Sami-Runoff sub-module a small catchment that represents each wetland area could be configured and all surface and relevant groundwater flows could subsequently be routed into the wetland sub-module to calculate the wetland balances. This was however a cumbersome process and adjustment of the Sami parameters to account for the wetland area characteristics (especially due to the shallow impervious organic layer underneath the wetland) showed that recharge into deeper groundwater and contributions from groundwater.

In Section 3.9 the process of calibrating upstream and lateral inflows to the wetlands are discussed in more detail. Also included in this Section is a summary of the process undertaken to optimise the rest of the wetland sub-module parameters to allow for the best calibration fit between the simulated wetlands outflows and the overall Theewaterskloof Dam calculated dam balance inflow. The parameters used for the different wetlands are provided in Table 20.

**Table 20: Wetland parameters used during this simulation**

| Wetland | Vyeboom | Du Toits #3 | Elandskloof |
|---|---|---|---|
| Area (km$^2$) | 2.50 | 7.70 | 0.76 |
| Capacity (10$^6$m$^3$) | 1.83 | 5.62 | 0.55 |
| B-Value* | 0.60 | 0.60 | 0.60 |
| Bank-full flow (10$^6$m$^3$) | 1.94 | 1.04 | 0.89 |
| Contribution after bank-full (%) | 0.01 | 0.01 | 0.01 |
| Spill after full wetland (%) | 0.71 | 0.71 | 0.71 |
| MAP (mm/annum) | 976 | 907 | 613 |
| MAE (mm/annum) – See Table 19 | 1111 | 998 | 1075 |

Note: * - See Section 3.4 for a detailed description of the B-Value

## 3.9 Rainfall-runoff model setup and calibration

### 3.9.1 Purpose

The main drivers for all surface and groundwater resource availability are primarily precipitation (mainly rainfall in South Africa), evaporation and catchment characteristics. Surface and groundwater resources are scattered throughout South Africa due to the highly variable nature of rainfall, spatially and temporally. Most of the surface water resources in South Africa is generated on only 30% of the land surface, and the long-term variability is significant, running over decades, causing long lasting hydrological droughts (periods of below average rainfall) that occurs in different spatial locations often simultaneously throughout the country.

In order to confidently describe hydrological variability in any stream, river or reservoir, the longest possible measured streamflow record is required to ensure that as much as possible monthly and inter-annual variation in the streamflow can be observed and described. Table 21 provides an example of Midmar Dam's firm yield calculation different periods of observed or simulated data would have been used.

**Table 21: Example of historical yield analysis of Midmar Dam to illustrate the importance of long-term simulations of hydrological variability**

| Period of analysis | Number of years in analysis | Firm Yield (million $m^3$/annum) |
|---|---|---|
| 1930 – 1934 | 5 | 81 |
| 1930 – 1939 | 10 | 69 |
| 1930 - 1949 | 20 | 69 |
| 1930 – 1969 | 40 | 69 |
| 1930 - 1989 | 60 | 36 |

Table 21 illustrates that between 1969 and 1989 a severe drought influenced the inflow to Midmar Dam which dramatically reduced the analysed long-term yield capability of the resource compared to doing the same analysis using shorter observed/simulated hydrology.

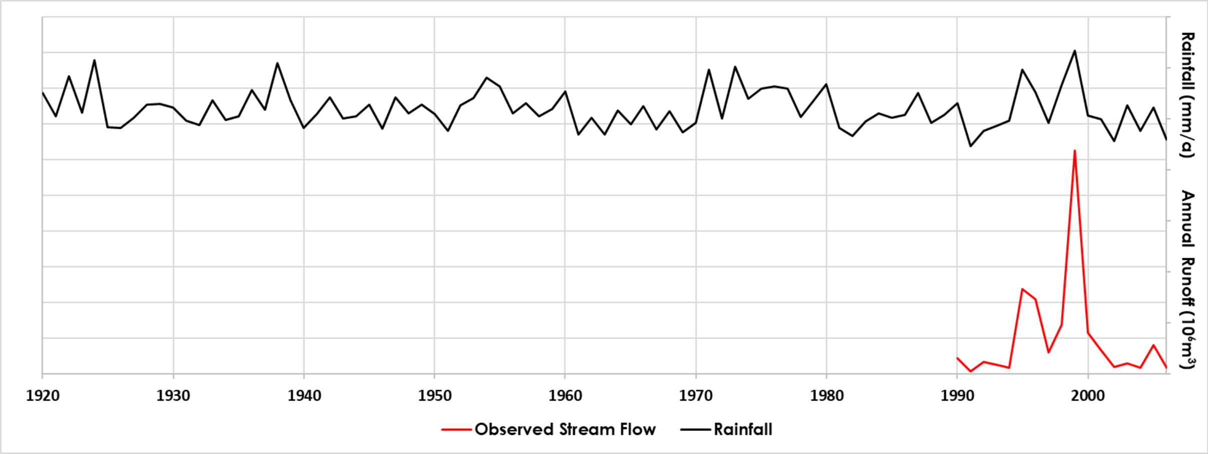
Unfortunately, streamflow gauging stations in South Africa only measure larger catchments and most of the gauges were only established after the 1970's which allows for only 40 to 50 years of observed streamflow gauging. Observed streamflow data also includes changing land- and water-use upstream from the site. In contrast to observed streamflow, there are a multitude of historic rainfall gauges across the country running from the late 1800's.

Due to rainfall being the primary driver behind runoff generation, a rainfall-runoff model (such as the WRSM2000/Pitman) can be used to simulate long-term streamflow based on long-term rainfall while considering historic changes in land- and water-use upstream from observed streamflow gauges. Figure 13 illustrates the purpose of rainfall-runoff modelling, model calibration and scenario based simulated hydrology. Plate (a) of Figure 13 shows the typical long-term observed (annual) rainfall and streamflow data available for a catchment area upstream from a flow gauging site.

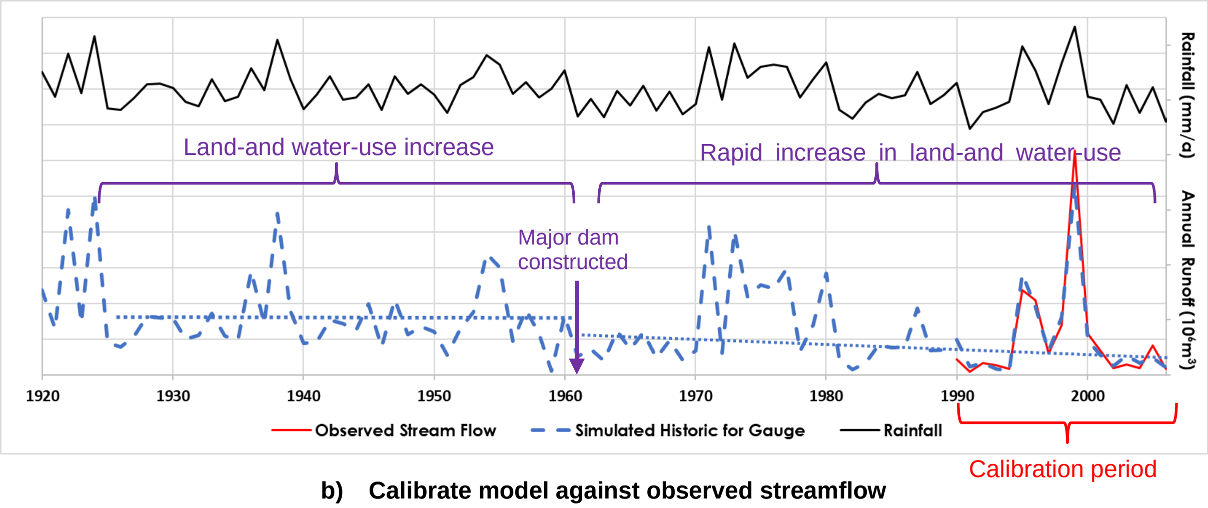
By setting up a rainfall-runoff model that includes the long-term rainfall, evaporation and growth in historic land- and water-use for the catchment, historic simulated streamflow at the streamflow gauging site can be generated, illustrated by the blue dashed line in Plate (b) of Figure 13. Plate (b) also shows how the streamflow reduced over time as land- and water-use increased, and a new major dam was constructed upstream from the site.

Importantly any rainfall-runoff model needs to represent reality accurately, and this is ensured by a process called calibration. Calibration involves comparing observed streamflow data against simulated streamflow at the same site over the calibration period and adjusting the model's simulated runoff generating parameters until an acceptable fit is achieved between the simulated and observed data. Plate (b) of Figure 13 shows the calibration period of the example and the relatively good fit that was achieved over that period of simulated and observed data.

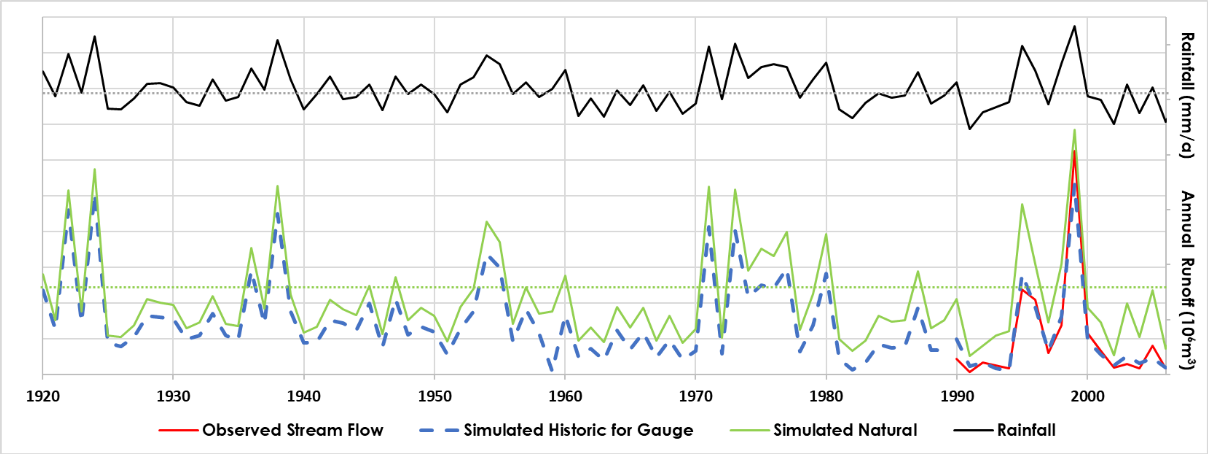
Once a reasonable calibration has been achieved the rainfall-runoff model can then be used for what-if scenarios to make long-term hydrological impact and water resource planning decisions. The main scenario is always to generate simulated natural hydrology, where all upstream land- and water-use are removed from the model to simulate what would the flow have been if there was no upstream development over the long-term (see Plate (c) of Figure 13). The scenario used in this analysis is referred to as Present Day Development scenario, where the model is configured to have all current infrastructure, land- and water-use development as it is for a specific date, but constant over the whole simulation period.



**a) Available Data**



**b) Calibrate model against observed streamflow**



**c) Simulate long-term scenarios, e.g. long-term simulated natural streamflow**

**Figure 13: An example to illustrate the purpose of rainfall-runoff modelling, model calibration and scenario based simulated hydrology.**

### 3.9.2 Model configuration

The catchment configuration upstream of Theewaterskloof Dam was defined by a WRSM2000/Pitman model network diagram, and the associated input datasets and the designed network was then configured in a calibration setup of the model. Figure 14 provides the network diagram for the Theewaterskloof Dam catchment area. All wetlands in the catchment were explicitly modelled (red circles) and the main channel and lateral inflow streams to each wetland were defined according to the observed catchment layout.

### 3.9.3 Model calibration and optimisation

The process of calibrating the model followed these steps:

- Calibrate H6H007 (main channel upstream from Du Toits #3 wetland)
- Calibrate H6H008 (main channel upstream from Vyeboom wetland)
- Calibrate H6R002 (inflow to Elandskloof Dam, upstream from Elandskloof wetland)
- Transfer runoff parameters from above calibrations to remaining catchments flowing directly into Theewaterskloof Dam and check against dam inflow calculation.
- Optimise wetland parameters using Evolutionary Optimisation tool in Excel.

The monthly simulated versus observed flow charts for the 4 calibration stations mentioned above are provided in Appendix C. In Appendix C, Table C-1 provides the Sami sub-module's calibration parameters used for the final calibration of the Theewaterskloof Dam catchment.

To determine the wetland parameters, the WRSM2000/Pitman wetland module was replicated in a spreadsheet. The spreadsheet replica was then configured to represent all the wetlands upstream from the Theewaterskloof Dam. Input provided to the spreadsheet replica included the simulated main channel and lateral inflows time-series, rainfall and evaporation time-series, and the $S_{nom}$, $A_{nom}$ and assumed B-Value for the combined wetlands (see Section 3.8 for explanation of parameters).

An Excel based Evolutionary Solver was then used to obtain the combined wetland parameters that provides the best sum of absolute differences fit between the simulated wetlands outflows and the portion of the Theewaterskloof Dam's calculated inflow record that is affected by the wetlands. Figure 15 provides the final integrated wetlands' simulated outflow versus observed Theewaterskloof Dam's calculated inflow data charts.

The optimised parameters were then disaggregated to individual wetlands sub-module replica spreadsheets with associated Present Day (2009) development level upstream and lateral inflows. The final parameters used for the different wetlands are provided in Table 22.

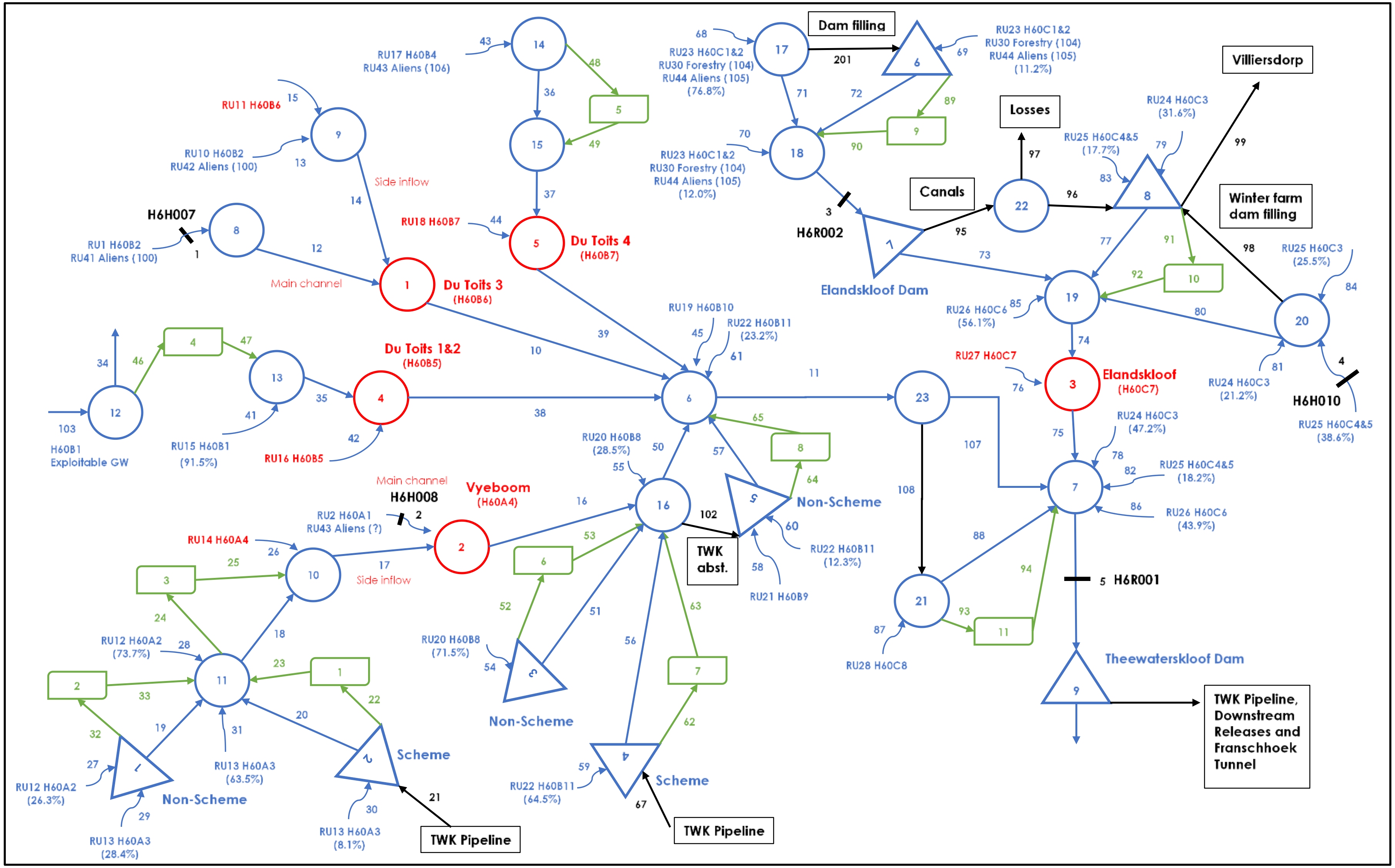
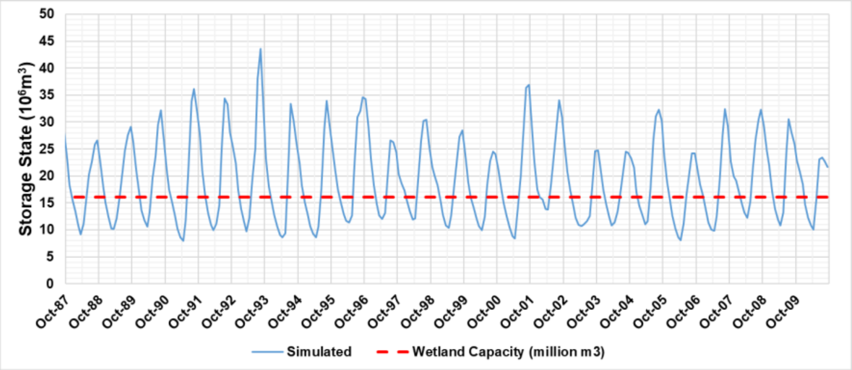
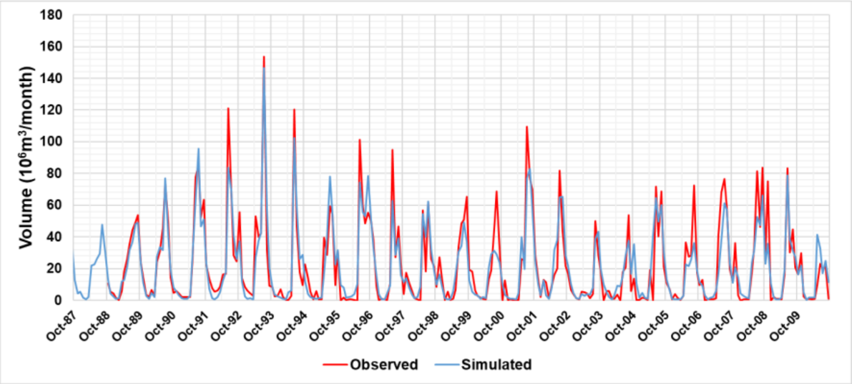


**Figure 14 : WRSM2000/Pitman rainfall runoff model network diagram.**

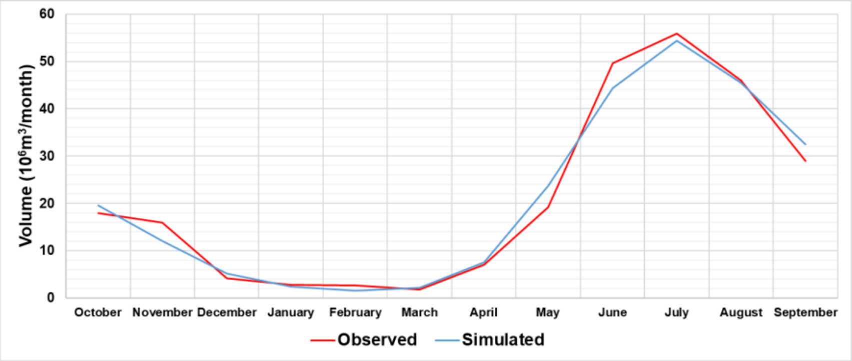
a) Simulated wetland monthly storage



b) Simulated: Total monthly wetlands outflows + other direct inflows. Observed: TWK Dam inflow



c) Simulated: Average monthly wetlands outflows + other direct inflows. Observed: TWK Dam inflow



d) Simulated: Annual wetlands outflows + other direct inflows. Observed: TWK Dam inflow

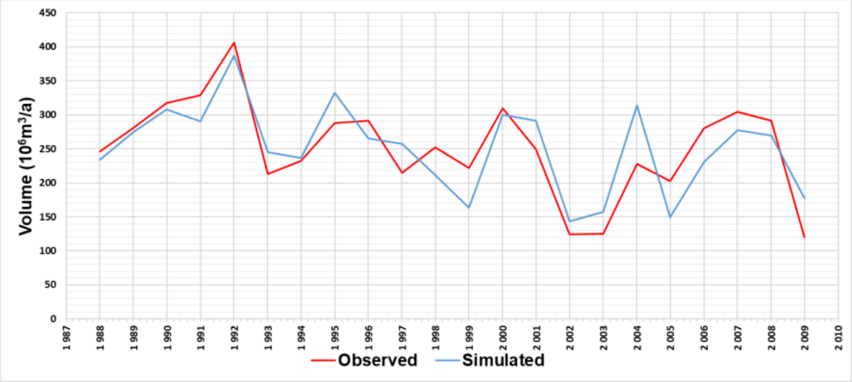


**Figure 15: Integrated wetlands parameter optimisation calibration results**

## 3.10 Wetland water balances

Table 22 below provides the long-term water balances for the Present Day Development Level Scenarios.

**Table 22: Water balances for the Present Day Development Level Scenario**

| Element | Sub-Element | Annual Average Flow ($10^6 m^3$/annum) | | |
|---|---|---|---|---|
| | | Vyeboom | Du Toits #3 | Elandskloof |
| | | Area: 2.5 $km^2$ | Area: 7.7 $km^2$ | Area: 0.7 $km^2$ |
| Inflow: | Main river channel | 72.58 | 37.34 | 44.52 |
| | Lateral Inflows to wetland store | 23.11 | 11.73 | 0.00 |
| | Total | *95.69* | *49.07* | *44.52* |
| Internal circulation: | River to wetland store | 0.54 | 0.28 | 0.37 |
| | Wetland store to river channel | 24.36 | 12.49 | 0.13 |
| Abstraction: | | 0.00 | 0.00 | 0.00 |
| Gains(+)/Losses(-): | | 0.71 | 0.49 | -0.24 |
| Total outflow | | *96.40* | *49.56*[!] | *44.28* |

Note: (1) – The total area of DuToits Wetlands #1 to #4 is 19.4 $km^2$, with a long-term average Present-Day outflow of 98.5 million $m^3$/annum.

From Table 22 it is seen that there are minimal losses or gains from the wetlands in terms of volumes of water per annum. This is due to the following reasons:

- Except for the Elandskloof Wetland, the MAP and MAE is very similar, meaning that even if the wetland is completely inundated most of the time that the net loss due to evapotranspiration is minimal.
- The total amount of inflow to the wetlands completely overshadows the actual wetland area and storage for Elandskloof and Vyeboom. Even in the case of Du Toits Wetland #3 which has the biggest area and capacity, the storage seldom goes under 75% of capacity)

To illustrate the monthly behaviour of each of the wetlands Figure 16 provides for each of the wetlands cumulative inflows (cumulative areas behind the stacked bar plots) and the cumulative outflows (stacked bar plots in front of the cumulative areas) for each month for the last 5 years of the 80-year simulation period. The balance does not reflect the part of the flow that by-passes the wetland completely due to very high volumes of flow, but only the portions of the flow that contributes towards the wetland storage. Figure 16 shows that for the Vyeboom and Du Toits #3 Wetlands there are outflow from the wetland for several months after the inflow to the wetlands has resided. Only a small portion of the main channel’s flow contribute towards the wetland storage but that most of the storage is filled by lateral flows. This is most probably due to the shape of the wetlands and the very high flows that pass through the wetlands into the Theewaterskloof Dam. The Vyeboom Wetland is nearly always fully inundated since it has the largest main and lateral inflow of all the wetlands. The Vyeboom Wetland area is relatively small compared to Du Toits’ #3 wetland, therefore the evapotranspiration from Vyeboom is less than Du Toits’ #3 wetland. Elandskloof Wetland is very small with higher evapotranspiration causing very little wetland outflows.

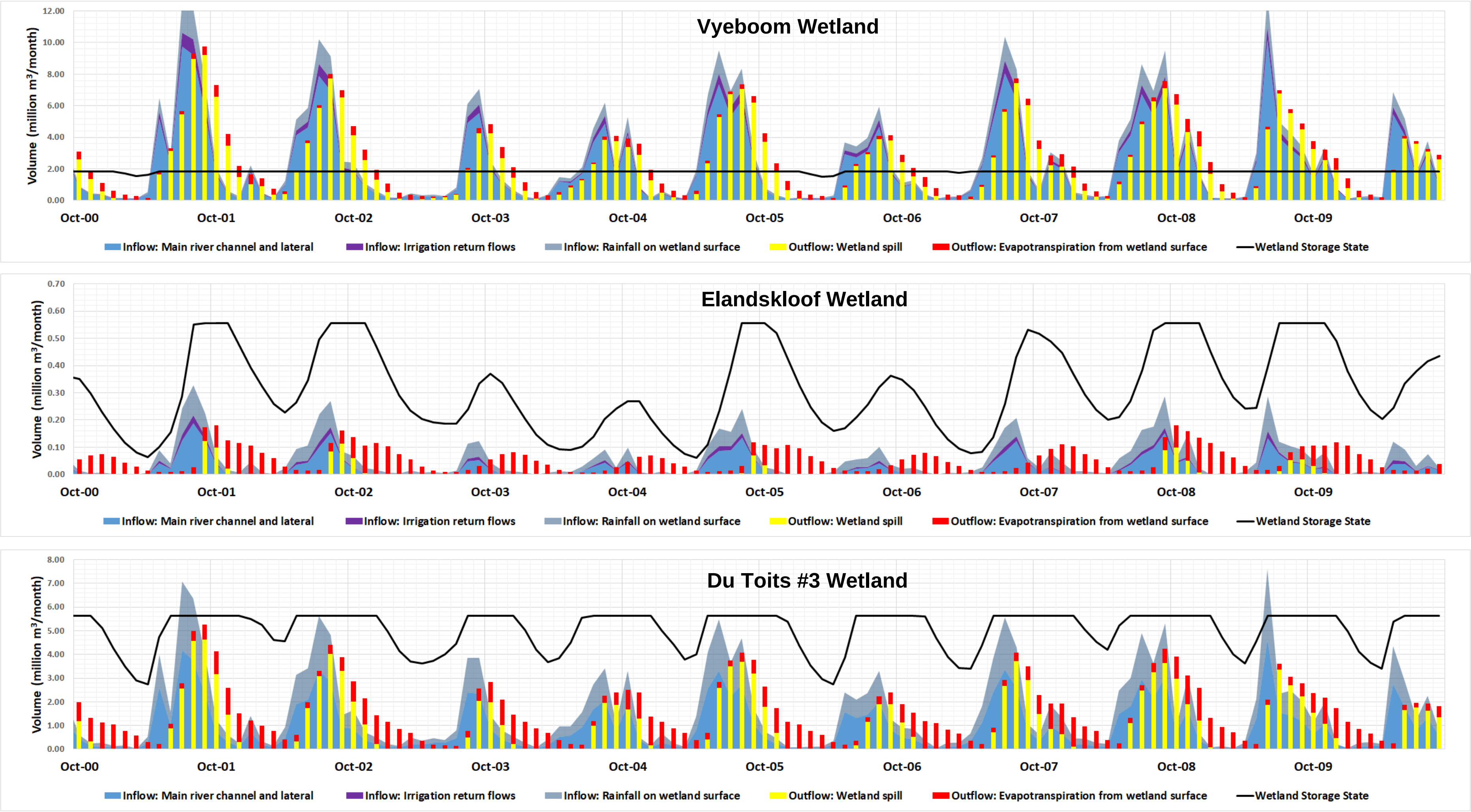


Figure 16: Part of the monthly water balance for 3 wetlands in the Theewaterskloof Catchment at Present Day development level. Cumulative areas at the back of the graphs show wetland inflows and cumulative bars in front of the areas are the total outflow from the wetland, showing the lag between inflow and outflows.

## 3.11 Conclusions and recommendations

This study has shown that a rainfall-runoff model which is adequately calibrated could provide relatively detailed water balances for a wetland without the flows in the wetland being monitored. The water inflows and evapotranspiration fluxes could assist in estimating nutrient removal capabilities of the wetland.

Although the wetland sub-module has several flow routing parameters, an Excel solver could potentially be used to estimate these parameters if most of the upstream wetland inflows are calibrated against observed data and there is another flow gauging station downstream from the wetland that could be used to calibrate the wetland outflows against. Several optimal answers could however be obtained and selecting the set of parameters that most likely describe the functioning of the wetland should be selected as the final solution.

In this analysis, the capacity of the wetland is far exceeded by the total wetland inflow for most months. As can be seen from Table 22, the lateral inflows contribute the most to the inflow to the wetland store since it flows directly into the wetland storage, which causes most of the main channel inflow bypassing or flooding the wetland storage.

The hydrological input to the economic evaluation is a long-term monthly simulation of outflows from the wetland storage (where plants have had access to the water) plus the associated monthly nett evapotranspiration losses (evapotranspiration minus the rainfall). The efficiency of the nutrient removal is associated with the area of plants that has direct access to the water. This efficiency fluctuates from month to month depending on the wetland storage level and therefore the area of plants that have direct access to the water. It is key to understand the capacity and area of the wetland plants to not to over-estimate the wetland’s nutrient removal capabilities. For example, if the total flow that enters the main channel plus the lateral inflows would have been used for the valuation, there would have been an overestimation of 3.7 times of the actual inflow to the wetland that would be available for nutrient removal.

The following recommendations are made

- Rainfall: Nine (9) rainfall stations were still open in 2012 within the Theewaterskloof Dam catchment (Agricultural Research Council, South African Weather Service and Department of Water and Sanitation stations combined). Only 2 of these stations’ data was usable in this analysis. With the alarming rate of rainfall station closures in South Africa and due to the importance of this catchment to the WCWSS it is suggested that new rainfall stations are opened and maintained to support future water resource and other analyses, especially closer to the or in the mountains.

- Flow gauging stations: Due to the large amount of flow that passes through flow gauges H6H007 (above Du Toits Wetland #3) and H6H008 (above Vyeboom Wetland), the current initiatives to reinstate these flow gauges is strongly supported. The gauges are crucial for future assessments of the water resources in this catchment. H6H010 (above Elandskloof Wetland) is still active today, however the quality of the measurement at this gauge is uncertain – comparison with simulated values show far lower runoff than what can be accounted for by the estimated reduction in MAP of this catchment. Dependable measurements at this relatively pristine catchment would be of great benefit.

# 4. WETLAND SERVICE ECONOMIC EVALUATION

## 4.1 Monetary valuation in perspective

The estimation of a return on investment (ROI) for a wetland rehabilitation initiative requires the determination of the benefits of restoration in both physical and monetary terms. There is usually a multitude of benefits to consider based on changes in ecosystem attributes. ROI is normally expressed as a monetary measure of performance indicating the balance between benefits and costs associated with the proposed intervention.

(Snaddon, et al., 2018) distinguish between provisioning, regulating and cultural services that can be used to classify the ecosystems generated by wetlands. The “direct use value” of harvested resources such as fish and reeds which can be consumed directly from provisioning services, while regulating services, also termed “indirect use values”, are normally associated with off-site benefits, e.g. water quality and sediment retention. Cultural services may include both direct use values and so-called “non-use values”. The cultural “direct use values” may be derived from non-consumptive actions such as the provision of recreational pleasure or the aesthetic enjoyment of a landscape. “Non-use values” reflect the intrinsic values that can be assigned to wetland ecosystems, over and above the values associated with usage. Ecosystems which may be of little or no use in the economic domain are often associated with a sense of a “loss” if they were to disappear.

Monetary values cannot be assigned to describe the full spectrum of values that encompass the total value of ecosystems (TSV). However, wherever data are available there exist various direct and indirect assessment approaches which can be followed to derive monetary values, e.g. market prices, replacement costs, avoided damages, revealed preference, stated preference and benefit transfer methods. In summary, the total economic values (TEV) of ecosystems such as wetlands do not provide the full system value, but only a portion of it. This notion is captured in the following diagram from (Snaddon, et al., 2018), based on presentations generated by (TEEB, 2011) and (Ten Brink 2011):

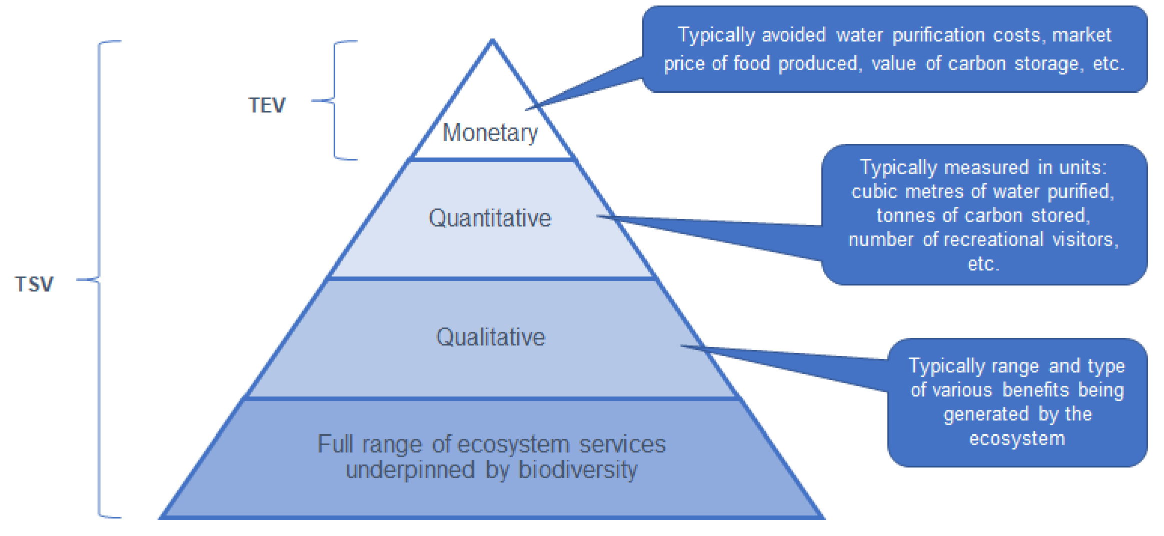


**Figure 17: The benefits pyramid illustrating the total economic value as part of the total system value**
**Source: Snaddon et al. (2018)**

## 4.2 Positioning the economic valuation model

The economic valuation of the conditions of the three wetlands and related rehabilitation proposals constitutes the monetary assessment in this assignment. It will focus on the quantitative aspects that are required to address the questions stated in the terms of reference to this assignment:

- How much are the wetlands worth in terms of both the intrinsic ecosystem and economic values that are provided by the ecosystem services?
- How do the three wetlands in different states of degradation or pristine condition in the Theewaterskloof compare and what would be the value, approach, and cost of rehabilitating the more degraded wetlands to the level of the more pristine wetland?

The economic valuation model acts as the culmination of the assessment of the wetland conditions in terms of hydrology, geomorphology, and vegetation. The goal is to understand the wetlands in both economic and intrinsic value as part of the role of water management within the broader hydrological systems, taking the flows of the systems and the rainfall of the region into account.

In order to achieve the above, the economic valuation model consists of five sections, i.e.

- a nutrient reduction (water quality enhancement) model,
- a sediment retention model,
- a carbon storage model,
- a tourism value model, and
- a cultural value model.

The quantified results are supplemented by a qualitative discussion on intrinsic values, for example intangible aspects that cannot be addressed by the economic valuation.

The discussion will commence with a view on the intrinsic value of the three wetlands, followed by a motivation for base assumptions and expected rehabilitation impacts on nutrient removal rates, carbon storage, and sediment retention. A brief discussion of the hydrology model output that would feed into the economic valuation model will follow before a more detailed outlook is provided on the nutrient reduction model, the sediment retention model, the carbon storage value model, and the tourism and cultural value models. The output from these models feeds the cost-benefit analysis model, from which the required inferences on the economic value of the wetlands and the viability of proposed rehabilitation/restoration initiatives may be derived.

## 4.3 Intrinsic value of the three wetlands and rehabilitation for biodiversity conservation

Most of the Du Toits Wetlands fall within a formally protected area managed by Cape Nature. The small portion of the Du Toits Wetland falling outside of the protected area and most of the Vyeboom Wetland have been classified as aquatic Critical Biodiversity Areas (CBAs) in the Western Cape Spatial Biodiversity Plan (Pool-Stanvliet, et al., 2017). The vegetation type covering both the Du Toits and Vyeboom Wetlands is Elgin Shale Fynbos, which has been identified as critically endangered owing to the irreversible loss of natural habitat (Pool-Stanvliet, et al., 2017). The fact that in addition to representing a critically endangered type, Du Toits is a very large wetland in good condition and with high connectivity to other natural areas makes it intrinsically extremely valuable from a biodiversity conservation perspective. Vyeboom also has a relatively high intrinsic value, but this is somewhat lower than Du Toits Wetland owing to its smaller size and lower ecological condition, as reported in the section on Present Ecological State (PES) of the wetlands.

The sub-catchment in which the Vyeboom Wetland lies has been identified as a Freshwater Ecosystem Protected Area (FEPA) catchment, and it not only supports a good condition river but also the endangered giant redfin, *Pseudobarbus skeltoni*, which is endemic to the Breede River (Snaddon, et al., 2018). It is possible that this is one of the three last remaining populations of this newly described species (Chakona and Swartz 2013; Snaddon et al., 2018). Smallmouth bass (*Micropterus dolomieu*), an alien fish species with a potentially devastating impact on indigenous fish populations, occurs in Theewaterskloof dam. However, it appears to be absent upstream of the Vyeboom Wetland where the giant redfin are located, and it seems that the weakly channelled sections of the Vyeboom, where water flows are spread amongst dense palmiet beds are serving as an important barrier to the upstream movement of small-mouth bass in the dam (Snaddon K, 2019. *Pers comm*. Cape Town). The active headcut erosion in the Vyeboom Wetland is causing the ingress into the weakly channelled palmiet beds of a much less obstructed channel. In the absence of rehabilitation, this ingress poses a considerable threat not only to vegetation habitat in the wetland, through its desiccation, but could indirectly threaten the giant redfin by allowing the smallmouth bass much less restricted access to the upper Riviersonderend stream. Therefore, it can be appreciated that in halting the headcut erosion, the rehabilitation will make a key contribution to sustaining the intrinsic biodiversity value of the wetland and its broader sub-catchment. Similarly, control of invasive alien plants, which pose a considerable long term threat to both the Du Toits and Vyeboom Wetlands, will make a key contribution to sustaining the intrinsic biodiversity value of these wetlands and their broader sub-catchments.

The intrinsic value of Elandskloof Wetland for biodiversity conservation is considerably lower than the Du Toits and Vyeboom. As reported for the Present Ecological State (PES) of the wetland, the vegetation is in a very poor condition and prior to clearing in 2018 was dominated by alien species and indigenous species which are generalists/pioneer. Therefore, although Elandskloof wetland occurs within Elgin Shale Fynbos, it is an extremely poor representation of wetland vegetation of this type. Nonetheless, it is important to emphasize that despite its low contribution in terms of floristic conservation, this wetland has value for the conservation of wetland habitat more generally. It also has recognized value for wetland-dependent fauna. For example, prior to alien clearing, the wetland supported the Cape clawless otter (*Aonyx capensis*) which are categorized as a near-threatened species, which although having a large distribution range, has a spatial area of occupied habitats which is much smaller and unknown, particularly due to the widespread habitat destruction and pollution problems (Jacques *et al.* 2015). It should be noted further that at a local level the Elandskloof Wetland is one of a very few remaining natural/semi-natural wetland areas in the landscape, and although not very well connected to other natural/semi-natural wetland areas, it makes an important contribution to improving the connectivity of this landscape. The proposed rehabilitation interventions at Elandskloof, in particular, the control of invasive alien trees, are anticipated to improve wetland and aquatic habitat provided by the wetlands, thereby enhancing the current intrinsic value for biodiversity conservation.

## 4.4 Motivation for economic model parameter assumptions

### 4.4.1 Contribution of wetland rehabilitation to nutrient reduction

Inferred removal of total N (Nitrogen) and total P (Phosphorus) by the study area wetlands under different scenarios is based primarily on the comprehensive and systematic survey of rigorous site-based studies examining the effectiveness of created or restored freshwater wetlands for N and P removal by Land *et al.* (2016) as well as referring to the results of Turpie *et al.* (2010) and Rebelo et al. (2018). Land *et al*. (2016) report that, on average, created or restored wetlands removed 1840 kg $ha^{-1}year^{-1}$ (fairly close to the results of Turpie *et al.* (2010)) of total N and 150 kg $ha^{-1}year^{-1}$ of total P. It was decided to apply these average values to intact wetland in the study area with moderate to high level of hydraulic contact (interaction) with flows through the wetland. This would apply to the currently intact portions of the Vyeboom Wetland, including the 25 ha area which is currently intact but is under severe and imminent threat of being severely degraded by the advancing erosion headcut. Degraded wetlands which have been deeply incised by erosion and wetlands which are naturally strongly channelled tend to have low levels of hydraulic contact with water flows through the wetland, and are therefore assumed to have much lower N and P removal capabilities, as elaborated on below.

Conservatively it can be assumed that for the Vyeboom Wetlands the assimilation of N and P is unlikely to be much above the average reported by Land *et al.* (2016) and for the following reasons it is assumed not to be very far below the average reported by Land *et al*. (2016): (1) the wetland is not subject to a winter dormant period, a key factor reported by Land *et al*. (2016) to limit the effectiveness of wetlands in assimilating nutrients under cold climates; (2) moderate hydraulic contact of the wetland given its weakly channelled character when not degraded; and (3) good vegetation growth through most of the intact wetland.

**Table 23: Assumed range in Total N and Total P assimilation for Vyeboom wetland under Intact and degraded scenarios**

| | Total N assimilation rate (kg $ha^{-1}year^{-1}$) | Total P assimilation rate (kg $ha^{-1}year^{-1}$) | Supporting references |
|---|---|---|---|
| Intact wetland | 920 – 2024 | 75 - 165 | (Land, et al., 2016) |
| Degraded wetland | (-50) - 368 | (-5) - 30 | Rebelo et al (2018). Note that the minor source of N and P at the "bottom" of the range results of what is likely to be a slow release of N and P as the desiccated organic soil in the wetland decomposes. |
| Difference between the Intact and degraded | 552 - 2075 | 45 - 170 | |

For the 25 ha of wetland affected this translates into 13 800 - 51 875 kg N per year and 1000 - 4000 kg P per year.

The possibilities of improving nutrient trapping through rehabilitation are much more limited in Elandskloof Wetland than in the Vyeboom Wetland and derive primarily from a 2 ha shift from strongly channelled in the "Without rehabilitation" scenario to areas of intermediately to diffusely spread flows in the "With rehabilitation" scenario in the Vyeboom Wetland.

**Table 24: Assumed range in Total N and Total P assimilation for Elandskloof Wetland under Intact and degraded scenarios**

| | Total N assimilation rate (kg $ha^{-1}year^{-1}$) | Total P assimilation rate (kg $ha^{-1}year^{-1}$) | Supporting references |
|---|---|---|---|
| Intact wetland | 920 - 2024 | 75 - 165 | (Land, et al., 2016) |
| Degraded wetland | 276 - 607 | 23 - 50 | Rebelo et al., (2018). Note that no organic soil is present to release nutrients in the degraded state. |
| Difference between the Intact and degraded | 313 - 1 748 | 25 - 142 | |

For 2 ha of wetland affected this translates into 626 - 3496 kg N per year and 50 - 284 kg P per year.

As indicated, no interventions are planned in the close-to-pristine Du Toits Wetland which are anticipated to contribute to improvements in N and P removal, and therefore in terms of N and P removal, no difference is anticipated between the "Without rehabilitation" and the "With rehabilitation" scenarios.

### 4.4.2 Contribution of wetland rehabilitation to carbon storage in the three wetlands

It is anticipated that the primary contribution of the proposed rehabilitation to carbon storage will be at Vyeboom. Organic soils cover an estimated 71 ha of the Vyeboom Wetland, with an average depth of 0.54 m, giving a total volume of organic soil of 383 153 $m^3$ (Kotze, 2015). The average organic matter content of the soil in Vyeboom wetland was estimated as 26% (Kotze, 2015). This translates to 15.1% C based on the Van Bemmelen Factor:

$$\%\ \text{Soil Organic Carbon} = \frac{\%\ \text{Soil Organic Matter}}{1.724} = \frac{26\%}{1.724} = 15.1\%$$

as recommended by Grundling et al., (2017). This further represents 30.2 kg C per $m^3$ of soil, based on the bulk density trend related to increasing percentage soil organic matter content reported by Grundling *et al.,* (2017), which for the Vyeboom organic soil was taken as 0.2 g $cm^{-3}$. Given the total volume of organic soil of 383 153 $m^3$, as estimated by Kotze (2015), the total stock of carbon in this material is 11 571 TC (Tonnes of Carbon).

Approximately 25 ha, constituting 35% (i.e. 4 050 TC) of the organic soil area in Vyeboom is under immediate threat from the currently active erosion head-cuts in the wetland. The potential depletion of soil carbon stocks in the wetland by this threat was estimated in consultation with Grundling P-L (2019, *pers comm,* Department of Environmental Affairs, Pretoria) and Pretorius L (2019, *pers comm.,* University of KwaZulu-Natal, Durban). A conservative estimate is that in the absence of rehabilitation interventions to halt this erosion, 30% of this carbon will be severely desiccated, decomposed and released into the atmosphere. However, given that the drying out of the organic soil greatly increases the risks of ground fires and the release of additional carbon into the atmosphere through combustion, a potentially much higher proportion of the overall carbon stock could be released into the atmosphere, and therefore 85% is taken as the upper end of the possible range. Thus, for the purposes of the economic assessment, the rehabilitation will contribute to preventing the loss to the atmosphere of 1 215 - 3 443 TC. This range can then be converted into Equivalent Total $CO_2$, using the global social cost of carbon (Nordhaus 2017, converted to 2019 Rands) and South Africa's share of this cost based on proportional GDP contribution and vulnerability index as described by Turpie *et al*. (2017).

The carbon stock of Du Toits wetland, estimated as 1 095 733 $m^3$ (Kotze, 2015) is not under any immediate observable threat for which rehabilitation interventions have been planned. In the long term, control of wattle trees in this wetland is likely to significantly reduce the threat to this organic material posed by their desiccating effect and destabilisation of channels in the wetland potentially posed by these trees in future decades if not controlled.

At the Elandskloof Wetland, no organic soils were encountered, but some of the soil conservation measures proposed are likely to encourage at least a slight increase in stocks of soil organic matter, probably taking decades to occur. However, owing to the very high uncertainties associated with any quantification of the positive effects of rehabilitation on carbon stocks at Du Toits and Elandskloof Wetlands, both of these wetlands were omitted from the carbon storage component of the economic assessment.

### 4.4.3 Contribution of wetland rehabilitation to sediment trapping in the three wetlands

When valuing the contribution of wetland rehabilitation to the sediment trapping service of a wetland, it is useful to draw the distinction between:

- The sediment already trapped in the wetland which will be directly released if erosion is not halted through rehabilitation interventions.
- Increased capacity (through the rehabilitation interventions) of the wetland to trap further sediment likely to be yielded from the catchment.

For already trapped sediment the projected volume likely to be lost was estimated based on the dimensions of the erosion gullies (and projected distances of gully advance) and the volume of recently deposited sediment which will be protected against wave action.

**Table 25: Projected sediment retention for Vyeboom and Elandskloof wetlands**

| | Width (m) | Depth (m) | Length, lower range (m) | Length, upper range (m) | Volume ($m^3$) of sediment prevented from entering Theewaterskloof dam | |
|---|---|---|---|---|---|---|
| Vyeboom | | | | | Lower range | Upper range |
| Prevention of main lower gully advance | 15 | 1,5 | 200 | 500 | 4 500 | 11 250 |
| Prevention of secondary lower gully advance | 7 | 1 | 50 | 150 | 350 | 1 050 |
| Prevention of upper gully advance | 8 | 1 | 100 | 700 | 800 | 5 600 |
| Enlargement of channel below road | 1 | 2 | 400 | 400 | 800 | 800 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total volume of sediment retention for Vyeboom ($m^3$): | | | | | 6450 | 18700 |
| Elandskloof | | | | | | |
| Prevention of localized channel incision | 6 | 0,5 | 50 | 200 | 150 | 600 |
| Trapping of sediment in the stream channel | 6 | 0,5 | 100 | 300 | 300 | 900 |
| | | Area ($m^2$) | Depth, lower range | Depth, upper range | Lower range | Upper range |
| Recent alluvial deposits stabilized with vegetation planting and wave energy dissipaters | | 70 000 | 0,2 | 1 | 14 000 | 70 000 |
| Remaining area below full supply level stabilized | | 420 000 | 0,005 | 0,5 | 2 100 | 210 000 |
| Total volume of sediment retention for Elandskloof ($m^3$): | | | | | 16550 | 281500 |

For the increased capacity of wetlands, a similar holding capacity estimate to that used by Snaddon *et al*. (2018) based on the area of wetland multiplied by depth could be used. However, a more refined means is required of identifying the effectiveness of this holding area which can be attributed specifically to rehabilitation. In this instance, it would be best to look to hydrology modelling, perhaps identifying the proportion of the wetland where channel dimensions are smaller (and therefore bank overspill occurs more readily) in the “With rehabilitation” scenario compared to the “Without rehabilitation” scenario. The most obvious of these is the 25 ha of Vyeboom which will remain weakly channelled “With rehabilitation” but become deeply incised without rehabilitation. At its most simplistic, one could simply exclude this 25 ha from the “holding area” in the “Without rehabilitation” scenario.

No interventions are planned in the Du Toits wetland in anticipation to contribute to improvements in sediment trapping.

## 4.5 Hydrological model output requirement

In order to calibrate water flow rates that are required for the economic valuation model, it is necessary to generate representative water balances for the three wetlands in question. These balances are derived from simulations based on long time series dataset that covers the period 1930 to 2009. Current water balances are assumed to be similar to that of 2009 observed and simulated values.

The time series profiles for gross inflow from catchment and sub-catchment areas, abstraction, additional inflows from agricultural rundowns, evaporation, transpiration, and rainfall are compared to the net outflows to the Theewaterskloof dam. The derived water balances incorporate surface water and groundwater flows.

The economic valuation model requires the total flow rate per wetland to inform the design of hypothetical waste water treatment works (WWTW) that could act as replacement facilities for the wetlands. The nutrient reduction performance of such hypothetical WWTWs is meant to match that of the wetlands while ensuring the same water throughput. The expected range of flow rates that such facilities should be able to provide, would be determined by inter-percentile ranges. It is often the case, where conclusive evidence for selecting a specific inter-percentile range cannot be sourced, to use the inter-quartile range as default position. Therefore, as a departure point for further analyses, it is suggested that the inter-quartile range be used for the simulated flows.

The connection between the hydrology and water quality model is based on an assumption of the principle that flow rates would correlate with nutrient removal rates. It is recognised that extremely high flow rates may spill over the usual flow profiles and will lead to unproductive removal of nutrients in the spill-over profile areas. The efficiency of nutrient removal is associated with the area of plants that has direct access to the water. In order to limit flow considerations to the domain where the assumed linear relationship between flow rate and removal rate applies, it is assumed in the economic model that flow rates will only vary in the interquartile range, i.e. 25%-75% (interquartile) of the probability distributions of flows that the hydrology model generates.

## 4.6 Nutrient reduction model

In order to derive the economic values of the nominated three wetlands areas feeding into the Theewaterskloof dam, the focus is on the indirect use value method, with special reference to the "minimisation of replacement costs" approach as propounded by (Grossman, 2012). This has been developed in terms of flood risk reduction and nutrient abatement constraints that need to be specified for the assessment.

The indirect use approach corroborates the arguments of (Grossman, 2012) that the public goods characteristic of many ecosystem services turns out to undervalue the contribution of floodplains and wetlands for public use. Thus, it is useful to generate a notion of the economic value that can be substantiated in quantification to supplement the intrinsic values that exist for the wetlands in question.

The main focus is on the nutrient abatement model which was constructed in MS Excel and is based on a minimisation of replacement cost problem statement as explained in (Grossman, 2012). It will subscribe to the fundamental conditions that:

- All alternative processes considered must be able to deliver similar services as the natural wetlands,
- The considered processes should not result in a shift in demand by society if such alternatives were to be implemented, and
- The optimal alternative choice should be the least cost option.

The (Grossman, 2012) approach would be valid if all constraints are linear. However, in practice, it is generally found to be more accurate when one considers the capital expenditure (capex) on infrastructure to be nonlinear, i.e. to allow for economies of scale in the required capex as a function of throughput, raised to a power factor which falls within the range of zero to one. In such a case the above formulation can only be solved by nonlinear techniques. The Lagrange multipliers (shadow prices) can still be generated from the calculations but the allowed ranges of stable accuracy disappear, i.e. the shadow prices are only applicable at the specific levels associated with the determined solution. However, this is not seen as a serious impediment as the models are specified in Excel and can quickly complete nonlinear solution runs. Lagrange multipliers are generally referred to as reduced gradients in nonlinear problems but provide the same interpretation as shadow prices. A layout of the optimisation problem configuration used in this study is expounded in Appendix B.

The nonlinear problem generally yields more accurate results than the linear programming (LP) problem, due to the fact that nonlinear formulations provide better descriptions of reality than linear approximations. The only downside to the nonlinear approach is that there is no guarantee that a global optimal value can be found – the optimal solutions are always of a local nature. However, by commencing the search for optimal solutions from different starting points, the probability of finding a global solution approaches unity.

The water balance outputs from the hydrological model provide for extensive time series of water flows, reflecting normal, as well as extreme conditions on a monthly basis. The time series exhibit extreme outliers that cannot always be considered representative of “normal” conditions. In order to be usable in the economic valuation model, the probability profiles of the observed phenomena are better described by inter-quartile ranges which can be estimated from the observed time-series data.

Besides the flow rate input, the nutrient reduction model also needs to be informed by nutrient assimilation statistics. The required statistical outlook is derived from the observations and opinions discussed in Section 4.4.1 above. A view on the expected average flow rates and nutrient reduction performance statistics for the wetlands in an intact condition can be summarised in the following table:

| **Wetland statistics** | | **Du Toits** | **Vyeboom** | **Elandskloof** |
|---|---|---:|---:|---:|
| Surface area | m2 | 7 669 716 | 2 424 025 | 749 855 |
| | ha | 767 | 242 | 75 |
| Volume | m3 | 5 598 892 | 1 769 539 | 547 394 |
| Flow rate | l/s | 1 537 | 2 980 | 1 327 |
| | m3/a | 48 484 323 | 93 981 137 | 41 843 677 |
| | Ml/d | 132.8 | 257.5 | 114.6 |
| Volume turnover rate | days | 42.15 | 6.87 | 4.77 |
| N-removal rate | mg/l | 23.29 | 3.80 | 2.64 |
| | kgN/a | 1 128 982 | 356 817 | 110 379 |
| | kgN/ha/a | 1 472 | 1 472 | 1 472 |
| P-removal rate | mg/l | 1.90 | 0.31 | 0.22 |
| | kgP/a | 92 037 | 29 088 | 8 998 |
| | kgP/ha/a | 120 | 120 | 120 |

**Table 26: Flow and nutrient removal rate statistics for the three wetlands in intact condition**

A similar view, reflecting the nutrient removal rates for the three wetlands in a degraded condition, is summarised in the following table:

| **Wetlands statistics** | | **Du Toits** | **Vyeboom** | **Elandskloof** |
|---|---|---:|---:|---:|
| N-removal rate | mg/l | 2.52 | 0.41 | 0.79 |
| | kgN/a | 121 948 | 38 542 | 33 106 |
| | kgN/ha/a | 159 | 159 | 442 |
| P-removal rate | mg/l | 0.20 | 0.03 | 0.07 |
| | kgP/a | 9 587 | 3 030 | 2 737 |
| | kgP/ha/a | 13 | 13 | 37 |

**Table 27: Nutrient removal rate statistics for the three wetlands in a degraded condition**

Expected averages are derived from the minima and maxima that are generated from the hydrological model output and the opinionated discussion in Section 4.4.1. The expected levels are based on an equally weighted distribution between the minima and maxima.

The nutrient reduction model generates indirect replacement values based on estimated capex and operating expenses (opex) of reference size WWTW designs. The capex and opex references are taken from (Cullis, et al., 2018) and (Snaddon, et al., 2018). The basic WWTW statistics applied in the nutrient reduction model can be summarised as follows:

| | | |
|---|---|---|
| Reference case WWTW throughput | Ml/d | 8.0 |
| | m3/a | 2 920 000 |
| Reference case WWTW installation costs | R/(Ml/d) | 7 000 000 |
| Plant depreciation period | yr | 15 |
| Reference case water collection/distribution cost | R/m3 | 0.50 |
| | R/a | 1 460 000 |
| Operating & maintenance cost per total annual cost | Ratio | 0.47 |
| Operating & maintenance cost per capex | Ratio | 0.118 |

**Table 28: Wastewater treatment works statistics**

Since the actual wetland flow rates are significantly larger than the reference rates listed in Table 28, it has to be scaled up to reflect the appropriate designs of the hypothetical replacement WWTW. The principle of scaling-up needs to reflect the economies of scale for the various throughput rates. This can be achieved by applying the following power factor relationship:

$$C_1 = \left(\frac{Q_1}{Q_0}\right)^p C_0$$

In this function the desired design throughput ($Q_1$) is divided by the reference throughput ($Q_0$) and the resulting ratio raised to the power $p$, with $p$ adopting a value between zero and one, to reflect economies of scale. The ratio-ed throughput is then multiplied by the reference cost ($C_0$, e.g. R7 million per Ml/d throughput for the 8.0 Ml/d reference case) to obtain the scaled cost ($C_1$). Following Cullis et al (2018), the power factor $p$ is assumed to be 0.75 in this study. This is considered a reasonable assumption as chemical plant facilities are typically costed with power factors varying between 0.5 and 1.0.

The operating cost of the hypothetical WWTW also includes a cost for collection of wetlands water inflows and distribution of treated water to the originally located outflows. This would be required if the water feed to the Theewaterskloof Dam needs to be diverted to WWTW facilities that are not located on-site.

The nutrient reduction model is configured to generate monetary values per wetland, subject to conditions of state (intact or degraded), as well as minimum, average or maximum flow rates and nutrient reduction rates. The estimated wetland values can then be applied in rehabilitation or restoration projects to determine the values of such initiatives.

The capability of the nutrient reduction model can be illustrated by evaluating the rehabilitation of a 25 ha area in the Vyeboom wetland, mentioned in section 4.4.1.The said 25 ha area is currently intact but is under severe and imminent threat of being severely degraded by the advancing erosion headcut. The original estimated cost for rehabilitation to prevent such degradation amounted to R2,2 million. By determining the differences in marginal value (shadow prices) of the wetlands in intact and degraded states, one can estimate the benefit value of the rehabilitation initiative. Such benefit values for average nutrient reduction have been estimated to be R37 832 ha$^{-1}$year$^{-1}$ for minimum flow rates, R36 673 ha$^{-1}$year$^{-1}$ for average flow, and R34 564 ha$^{-1}$year$^{-1}$ for maximum flow in the Vyeboom wetlands. The final results for the assessment of the financial viability of this rehabilitation initiative are concluded in the discussion of the cost-benefit analysis model (see section 4.10 below).

## 4.7 Sediment retention model

The sediment retention model follows the configuration specified by Snaddon *et al* (2018), based on earlier work by the DWAF (2010), as well as Schulze and Horan (2007). The configuration (Schulze and Horan (2007), DWAF (2010), Snaddon *et al* (2018)), provides for a determination of:

The volume of the wetlands under investigation;

The sediment storage capacity estimated at 20% (minimum) and 40% (maximum) of total volume;

The potential replacement value of sediment storage, based on an annualised capital replacement cost of R4,34/m$^3$ (2019 value) for the construction of dams of equivalent attenuation capacity.

The potential impact of an improvement in erosion control service is then determined on a pro-rata basis from the estimated replacement value of the sediment storage. For example, a specific view on the improvement of erosion control services might be taken to be 5%, whereby the incremental improvement of the sediment storage capability is estimated as 5% of the potential replacement value.

For this study, the views on potential improvement of the erosion control service are determined from the discussion in section 4.4.3 above. The following table illustrates the configuration of this model at minimum and maximum storage capacities, with the assumptions that there will be no improvement in erosion control service in the Du Toits and Elandskloof Wetlands, but a 2% improvement associated with the rehabilitation of the mentioned 25 ha of Vyeboom Wetland area:

| **Wetland** | | | **Du Toits** | **Elandskloof** | **Vyeboom** |
|---|---|---|---|---|---|
| Estimated Volume | | m$^3$ | 3 199 555 | 307 441 | 993 850 |
| Potential Storage Capacity | (min) | m$^3$ | 639 911 | 61 488 | 198 770 |
| | (max) | m$^3$ | 1 279 822 | 122 976 | 397 540 |
| Potential replacement value of storage | (min) | R/year | 2 775 166 | 266 662 | 862 026 |
| | (max) | R/year | 5 550 333 | 533 323 | 1 724 052 |
| Potential increase in erosion control service | | % | 0% | 0% | 2% |
| Potential increase in replacement value of storage | (min) | R/year | 0 | 0 | 17 241 |
| | (max) | R/year | 0 | 0 | 34 481 |

**Table 29: Configuration of sediment retention model**

## 4.8 Carbon storage value model

The carbon storage value model configuration (Kotze, 2015), (Grundling, et al., 2017), (Turpie, et al., 2017), (Mills & Hunter, 2018), also follows a configuration specified by (Snaddon, et al., 2018), based on earlier work by (Kotze, 2015), (Grundling, et al., 2017), (Turpie, et al., 2017), and (Mills & Hunter, 2018). The layout provides for a determination of:

- A conservative estimate of the potential organic carbon stocks (ton C), based on a carbon matter soil depth of 0.15m, carbon matter density of 0.1 (minimum) to 0.4 g/cm$^3$ (maximum), 15.1% carbon content of carbon matter;
- The economic costs avoided by sequestering or avoiding the loss of carbon to the atmosphere, which translates to a global social cost of R7,38/ton C (2019 value).

The potential impact of an improvement in carbon capture service is then determined on a pro-rata basis from the estimated economic avoided cost associated with carbon storage. For example, a specific view on the improvement of carbon storage services might be taken to be 5%, whereby the incremental improvement of the carbon storage capacity is estimated at 5% of the economic avoided cost.

For this study, the views on potential improvement of the carbon storage service are determined from the discussion in section 4.4.2 above. The following table illustrates the configuration of this model at minimum and maximum carbon matter density, with the assumptions that there will be no improvement in carbon storage service in the Du Toits and Elandskloof wetlands, but a 35% improvement associated with the rehabilitation of the mentioned 25 ha of Vyeboom wetland area:

| Wetland | | | **Du Toits** | **Elandskloof** | **Vyeboom** |
|---|---|---|---|---|---|
| Conservative estimate of potential organic carbon stocks | (min) | ton C | 16 525 | 0 | 11 572 |
| | (max) | ton C | 66 100 | 0 | 46 290 |
| Potential value of carbon to South Africa | (min) | R/yr | 126 901 | 0 | 88 869 |
| | (max) | R/yr | 507 605 | 0 | 355 475 |
| Potential increase in service | | % | 0% | 0% | 10% |
| Potential increase in value of carbon to South Africa | (min) | R/yr | 0 | 0 | 8 799 |
| | (max) | R/yr | 0 | 0 | 35 195 |

**Table 30: Configuration of carbon storage model**

## 4.9 Tourism and cultural value model

As in the case of the sediment retention and carbon storage models, the approach by the following authors (Snaddon, et al., 2018) acted as a guideline for the configuration of the tourism and cultural value models - (Turpie, 2003), The guidelines provided by Snaddon *et al.,* (2018) were informed by the work of (Turpie, 2003) and (Turpie, et al., 2017).

The recreation and tourism value of the wetlands is dependent on the surface area covered by the wetland, as well as the accessibility. Wetlands that are larger and accessible by major roads normally have a higher average value per ha than those in more remote locations. For this study, the tourism value is assumed to vary in the range of R45 - R203 per hectare per year (Turpie, et al., 2017), and (Snaddon, et al., 2018) values, updated to reflect 2019 prices.

The cultural value of the wetlands is also associated with its surface area and based on an estimated R9,26 per hectare per year (2019 value). This is an updated estimate, based on the findings of Snaddon et al, (2018) who derived their estimate from the contingent valuation study of (Turpie, 2003).

## 4.10 Cost-benefit analysis model

The culmination point of the economic valuation is configured in the cost-benefit analysis model. The final inferences can be derived from the net present values for potential benefits lost and costs of rehabilitation initiative budgets. The nutrient reduction, sediment retention, carbon storage, tourism, and cultural value models provide the potential benefits that would be lost if the wetlands were to be allowed to degrade.

The benefit estimations could be affected by the current state of degradation of the wetland, as well as views on the expected changes to erosion control services, carbon storage, tourism and cultural values that are associated with potential rehabilitation initiatives. Facilities are provided for these effects to be driven from the cost-benefit analysis model.

The capex and opex input to this model constitutes the cost requirements of specific rehabilitation initiatives. A once-off (capital) outlay is allowed in the first year of the assessment, supplemented by operating expenses in the same and subsequent years. This can also be used as a method to spread the rehabilitation initiative costs over a multi-year period.

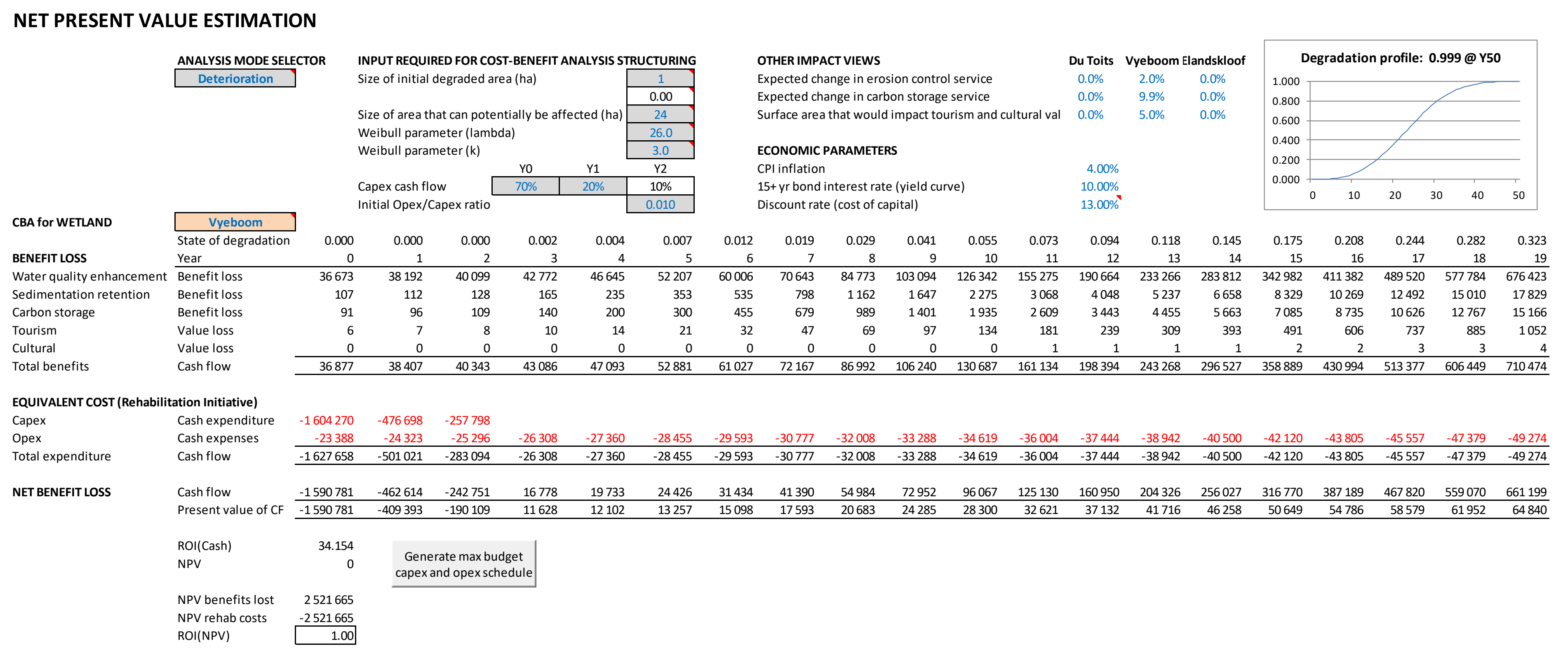
The net outcome is reported in terms of a net present value of differences between benefits and costs. In addition to that, a return on investment (ROI) is also determined for any specific rehabilitation initiative outlay.

In order to determine appropriate net present values, the nominal growth in benefits and costs are associated with the consumer price index (CPI). The appropriate discount rate (cost of capital) is assumed to be determined by the long-term bond rates derived from the South African yield curves for bonds with maturities longer than 15 years. Such bonds currently allow for yields of around 10% per annum. Investment in rehabilitation initiatives would not be without some form of investment, project implementation, and operational risks. A conservative estimate of ±3% risk premium is therefore advised, which brings the cost of capital to ±13%. The discount rate used in this study is thus 13%.

Although the cost-benefit analysis model allows for 80-year period estimates, the final year (year 80) numbers contain residuals to allow the cost-benefit assessment to cover an indefinite period.

It is recognised that benefits lost due to degradation would not necessarily manifest its full potential in the initial period. The cost-benefit analysis, therefore, allows for the impact to be ramped up over time in the form of a logistic curve, for the degradation profile, see Table 31. The desired deterioration profile can be achieved by means of a two-parameter Weibull function specification, which allows a multitude of profile variants to be specified by adjusting only two parameters. As an example, the financial viability of the rehabilitation of the Vyeboom wetland as discussed in section 4.6, of which 25 ha could potentially become degraded over time if left unattended, yielded the following outcome:

## Table 31: Rehabilitation initiative net present value estimation for the Vyeboom wetland



### NET PRESENT VALUE ESTIMATION

**ANALYSIS MODE SELECTOR**

Deterioration

**INPUT REQUIRED FOR COST-BENEFIT ANALYSIS STRUCTURING**

| | Y0 | Y1 | Y2 |
|---|---|---|---|
| Size of initial degraded area (ha) | | | 1 |
| | | | 0.00 |
| Size of area that can potentially be affected (ha) | | | 24 |
| Weibull parameter (lambda) | | | 26.0 |
| Weibull parameter (k) | | | 3.0 |
| Capex cash flow | 70% | 20% | 10% |
| Initial Opex/Capex ratio | | | 0.010 |

| **OTHER IMPACT VIEWS** | **Du Toits** | **Vyeboom** | **Elandskloof** |
|---|---|---|---|
| Expected change in erosion control service | 0.0% | 2.0% | 0.0% |
| Expected change in carbon storage service | 0.0% | 9.9% | 0.0% |
| Surface area that would impact tourism and cultural val | 0.0% | 5.0% | 0.0% |

| **ECONOMIC PARAMETERS** | |
|---|---|
| CPI inflation | 4.00% |
| 15+ yr bond interest rate (yield curve) | 10.00% |
| Discount rate (cost of capital) | 13.00% |

**Degradation profile: 0.999 @ Y50**

| **CBA for WETLAND** | Vyeboom | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | State of degradation | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.007 | 0.012 | 0.019 | 0.029 | 0.041 |
| **BENEFIT LOSS** | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Water quality enhancement | Benefit loss | 36 673 | 38 192 | 40 099 | 42 772 | 46 645 | 52 207 | 60 006 | 70 643 | 84 773 | 103 094 |
| Sedimentation retention | Benefit loss | 107 | 112 | 128 | 165 | 235 | 353 | 535 | 798 | 1 162 | 1 647 |
| Carbon storage | Benefit loss | 91 | 96 | 109 | 140 | 200 | 300 | 455 | 679 | 989 | 1 401 |
| Tourism | Value loss | 6 | 7 | 8 | 10 | 14 | 21 | 32 | 47 | 69 | 97 |
| Cultural | Value loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total benefits | Cash flow | 36 877 | 38 407 | 40 343 | 43 086 | 47 093 | 52 881 | 61 027 | 72 167 | 86 992 | 106 240 |
| **EQUIVALENT COST (Rehabilitation Initiative)** | | | | | | | | | | | |
| Capex | Cash expenditure | -1 604 270 | -476 698 | -257 798 | | | | | | | |
| Opex | Cash expenses | -23 388 | -24 323 | -25 296 | -26 308 | -27 360 | -28 455 | -29 593 | -30 777 | -32 008 | -33 288 |
| Total expenditure | Cash flow | -1 627 658 | -501 021 | -283 094 | -26 308 | -27 360 | -28 455 | -29 593 | -30 777 | -32 008 | -33 288 |
| **NET BENEFIT LOSS** | Cash flow | -1 590 781 | -462 614 | -242 751 | 16 778 | 19 733 | 24 426 | 31 434 | 41 390 | 54 984 | 72 952 |
| | Present value of CF | -1 590 781 | -409 393 | -190 109 | 11 628 | 12 102 | 13 257 | 15 098 | 17 593 | 20 683 | 24 285 |

| **CBA for WETLAND** | Vyeboom | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | State of degradation | 0.055 | 0.073 | 0.094 | 0.118 | 0.145 | 0.175 | 0.208 | 0.244 | 0.282 | 0.323 |
| **BENEFIT LOSS** | Year | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Water quality enhancement | Benefit loss | 126 342 | 155 275 | 190 664 | 233 266 | 283 812 | 342 982 | 411 382 | 489 520 | 577 784 | 676 423 |
| Sedimentation retention | Benefit loss | 2 275 | 3 068 | 4 048 | 5 237 | 6 658 | 8 329 | 10 269 | 12 492 | 15 010 | 17 829 |
| Carbon storage | Benefit loss | 1 935 | 2 609 | 3 443 | 4 455 | 5 663 | 7 085 | 8 735 | 10 626 | 12 767 | 15 166 |
| Tourism | Value loss | 134 | 181 | 239 | 309 | 393 | 491 | 606 | 737 | 885 | 1 052 |
| Cultural | Value loss | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 4 |
| Total benefits | Cash flow | 130 687 | 161 134 | 198 394 | 243 268 | 296 527 | 358 889 | 430 994 | 513 377 | 606 449 | 710 474 |
| **EQUIVALENT COST (Rehabilitation Initiative)** | | | | | | | | | | | |
| Capex | Cash expenditure | | | | | | | | | | |
| Opex | Cash expenses | -34 619 | -36 004 | -37 444 | -38 942 | -40 500 | -42 120 | -43 805 | -45 557 | -47 379 | -49 274 |
| Total expenditure | Cash flow | -34 619 | -36 004 | -37 444 | -38 942 | -40 500 | -42 120 | -43 805 | -45 557 | -47 379 | -49 274 |
| **NET BENEFIT LOSS** | Cash flow | 96 067 | 125 130 | 160 950 | 204 326 | 256 027 | 316 770 | 387 189 | 467 820 | 559 070 | 661 199 |
| | Present value of CF | 28 300 | 32 621 | 37 132 | 41 716 | 46 258 | 50 649 | 54 786 | 58 579 | 61 952 | 64 840 |

| | |
|---|---|
| ROI(Cash) | 34.154 |
| NPV | 0 |
| NPV benefits lost | 2 521 665 |
| NPV rehab costs | -2 521 665 |
| ROI(NPV) | 1.00 |

For this assessment, it was assumed that the initial state of the Vyeboom wetland is almost pristine (only 1 ha degraded), but that a further 24 ha would degrade over a period of 50 years, following a typical logistic evolution pattern. Furthermore, it is assumed that the wetland nutrient reduction performance and flow rates would remain on an average level for the future. By balancing the total investment to offset the potential loss in benefits, if the 25 ha should become degraded, it is evident that an amount of R1 627 658 can be afforded in the initial period (Year 0), followed by R501 021 and R283 094 in the two following years. It would be possible to allow further expenses on the upkeep of the wetland in the subsequent years, albeit by smaller amounts which may be CPI-inflated. The expenditure over the initial and first two years amounts to R2 411 773, which is slightly more than the estimated cost of the rehabilitation project (R2 210 717). This indicates that the proposed rehabilitation initiative would be financially viable under average conditions. The net present value of the total expenditure on the rehabilitation project equals the total estimated benefit loss, i.e. R2 521 665.

The rehabilitation project budget ceiling (R2 521 665) is based on an assumption of average water flow and nutrient removal capabilities of the Vyeboom wetland. Similar analyses for the minimum and maximum conditions of water flow and nutrient removal capability can be constructed to determine a range of budget values, which is indicative of the confidence level of the estimated average value. In this particular scenario, it was found that the estimated value could vary between R2,7 million to R2,4 million, depending on the assumptions for minimum and maximum conditions for water flow and nutrient removal. This results in a coefficient of variation of less than 10%, which means that the estimated average allowable expenditure of R2,52 million can be accepted as a valid estimate with an acceptable level of certainty.

In terms of benefits lost due to the degradation of the wetland, it would appear that the water quality impact dominates the valuation (>95% of the total value lost).

Besides estimating the potential maximum expenditure that could be allowed on rehabilitation projects, the model indicates that the marginal economic value of the Vyeboom wetland would fall from ~R896000 per ha per year (in 2019 Rand value) to ~R860000 per ha per year if the 25-ha area would be allowed to degrade over the expected 50 year period.

The analyst needs to be aware of the fact that the view on the progression of the potential degradation process, which is captured in the logistic evolution pattern, can contribute significantly to the present value of the total value lost over the 50-year period. It is advised to generate a range of values to quantify the potential impacts and then to select expected results in such a manner that the argument, which describes the degradation process, can be corroborated. If instead of a logistic profile, the wetland is assumed to be already in a state of accelerated deterioration, the rehabilitation project budget for Vyeboom Wetlands will increase. An updated view on the deterioration profile could justify the latest estimated cost for rehabilitation of the 25-ha area; the budget could increase to allow R4,4 million to be spent on the project. The budget may increase even further once the other intrinsic benefits described are considered in the analysis

## 4.11 Further rehabilitation scenario case studies

A potential degradation scenario for the Vyeboom wetland situation was addressed in sections 4.6 and 4.10 above. Similar potential degradation scenarios have been generated for the Du Toits and Elandskloof Wetlands. In the following discussion, these scenarios are stated and then put to the valuation model to determine the maximum allowed budgets for rehabilitation initiatives.

### 4.11.1 Potential degradation of the Du Toits Wetland

The Du Toits Wetland currently has a very low extent of invasive alien trees but does have a few scattered black wattle trees mainly along some of the drainage lines within the wetland. At the current very low level of infestation, these trees are having minimal impact on the ecological condition and ecosystem services provided by the wetland. However, if control measures were to cease then the extent of black wattle trees along the drainage lines of the wetland is likely to increase progressively over time, starting especially within the localized disturbed portions of the wetland.

Once a dense canopy of black wattle trees has developed along extensive sections of drainage line (likely within the next 20-30 years) this canopy is likely to out-compete most of the indigenous herbaceous vegetation. This, together with the relatively high incidence of black wattle trees falling over in riparian situations, will destabilize the drainage lines, thereby greatly increasing the risks of erosion.

The effect of the fluctuating dam level (described for the Vyeboom) is likely to further contribute to increased risk of erosion in the lowermost portions of the wetland. Therefore, although under much less imminent risk of degradation than the Vyeboom Wetland, in the absence of any invasive alien clearing, the Du Toits Wetland is likely to be subject to degradation in the long term. Considering the factors described above, a plausible future scenario is that in the absence of alien plant control, within the next 50 years, between 40 ha and 90 ha of the wetland is likely to become heavily infested with invasive alien plants and severely degraded.

The valuation model assumptions derived from this scenario are the following:

- Initial degraded area (current situation) is approximately 0.5 ha (insignificant in comparison to the total wetland surface area).
- Degradation will follow a logistic evolution pattern over a 50-year period
- The area which would be totally degraded in Year 50 is assumed to be 65 ha (say halfway between 40 and 90 ha). This magnitude of the potentially degraded area is selected purely for demonstration purposes – in practice, the analyst might prefer to generate outcomes for 40 ha and 90 ha cases in order to provide a range of outcomes.
- The wetland nutrient reduction performance and flow rates would remain on an average level for the future.

The valuation model layout for this assessment would then be as set out in Table 32:

## Table 32: Rehabilitation initiative net present value estimation for the Du Toits wetland

## NET PRESENT VALUE ESTIMATION

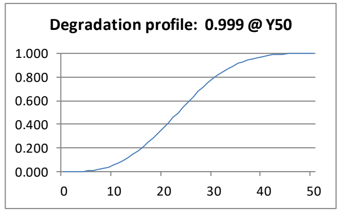
**ANALYSIS MODE SELECTOR**

Deterioration

| **INPUT REQUIRED FOR COST-BENEFIT ANALYSIS STRUCTURING** | | | |
|---|---|---|---|
| Size of initial degraded area (ha) | | | 0.5 |
| | | | 0.00 |
| Size of area that can potentially be affected (ha) | | | 64.5 |
| Weibull parameter (lambda) | | | 26.0 |
| Weibull parameter (k) | | | 3.0 |
| | Y0 | Y1 | Y2 |
| Capex cash flow | 70% | 20% | 10% |
| Initial Opex/Capex ratio | | | 0.010 |

| **OTHER IMPACT VIEWS** | **Du Toits** | **Vyeboom** | **Elandskloof** |
|---|---|---|---|
| Expected change in erosion control service | 0.5% | 0.0% | 0.0% |
| Expected change in carbon storage service | 8.0% | 0.0% | 0.0% |
| Surface area that would impact tourism and cultural val | 4.0% | 0.0% | 0.0% |

| **ECONOMIC PARAMETERS** | |
|---|---|
| CPI inflation | 4.00% |
| 15+ yr bond interest rate (yield curve) | 10.00% |
| Discount rate (cost of capital) | 13.00% |



| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CBA for WETLAND** | Du Toits | | | | | | | | | | | | | | | | | | | | |
| | State of degradation | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.007 | 0.012 | 0.019 | 0.029 | 0.041 | 0.055 | 0.073 | 0.094 | 0.118 | 0.145 | 0.175 | 0.208 | 0.244 | 0.282 | 0.323 |
| **BENEFIT LOSS** | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Water quality enhancement | Benefit loss | 3 493 | 3 660 | 4 000 | 4 708 | 6 003 | 8 135 | 11 385 | 16 057 | 22 487 | 31 031 | 42 063 | 55 973 | 73 150 | 93 983 | 118 845 | 148 081 | 182 000 | 220 861 | 264 861 | 314 126 |
| Sedimentation retention | Benefit loss | 18 | 21 | 34 | 71 | 145 | 274 | 474 | 766 | 1 172 | 1 714 | 2 417 | 3 305 | 4 405 | 5 741 | 7 338 | 9 217 | 11 400 | 13 901 | 16 735 | 19 910 |
| Carbon storage | Benefit loss | 25 | 29 | 47 | 98 | 202 | 381 | 659 | 1 065 | 1 629 | 2 383 | 3 360 | 4 595 | 6 124 | 7 982 | 10 202 | 12 815 | 15 849 | 19 327 | 23 267 | 27 680 |
| Tourism | Value loss | 4 | 4 | 7 | 15 | 32 | 60 | 104 | 168 | 256 | 375 | 528 | 723 | 963 | 1 255 | 1 604 | 2 015 | 2 492 | 3 039 | 3 659 | 4 353 |
| Cultural | Value loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| Total benefits | Cash flow | 3 540 | 3 713 | 4 089 | 4 892 | 6 382 | 8 850 | 12 621 | 18 056 | 25 544 | 35 502 | 48 368 | 64 596 | 84 643 | 108 963 | 137 990 | 172 130 | 211 743 | 257 131 | 308 525 | 366 071 |
| **EQUIVALENT COST (Rehabilitation Initiative)** | | | | | | | | | | | | | | | | | | | | | |
| Capex | Cash expenditure | -770 524 | -228 956 | -123 819 | | | | | | | | | | | | | | | | | |
| Opex | Cash expenses | -11 233 | -11 682 | -12 150 | -12 636 | -13 141 | -13 667 | -14 213 | -14 782 | -15 373 | -15 988 | -16 628 | -17 293 | -17 984 | -18 704 | -19 452 | -20 230 | -21 039 | -21 881 | -22 756 | -23 666 |
| Total expenditure | Cash flow | -781 756 | -240 638 | -135 969 | -12 636 | -13 141 | -13 667 | -14 213 | -14 782 | -15 373 | -15 988 | -16 628 | -17 293 | -17 984 | -18 704 | -19 452 | -20 230 | -21 039 | -21 881 | -22 756 | -23 666 |
| **NET BENEFIT LOSS** | Cash flow | -778 216 | -236 925 | -131 880 | -7 743 | -6 759 | -4 817 | -1 592 | 3 274 | 10 171 | 19 514 | 31 741 | 47 303 | 66 659 | 90 259 | 118 538 | 151 900 | 190 703 | 235 250 | 285 769 | 342 405 |
| | Present value of CF | -778 216 | -209 668 | -103 281 | -5 367 | -4 146 | -2 615 | -765 | 1 392 | 3 826 | 6 496 | 9 351 | 12 332 | 15 379 | 18 428 | 21 417 | 24 287 | 26 984 | 29 458 | 31 667 | 33 578 |

| | |
|---|---|
| ROI(Cash) | 39.099 |
| NPV | 0 |
| | |
| NPV benefits lost | 1 211 144 |
| NPV rehab costs | -1 211 144 |
| ROI(NPV) | 1.00 |

Generate max budget capex and opex schedule

By balancing the total investment to offset the potential loss in benefits, if the 65 ha should become degraded, it is evident that an amount of R1 211 144 can be afforded to be spent on the rehabilitation initiative described in the above scenario.

### 4.11.2 Potential further degradation of the Elandskloof Wetland

Much of Elandskloof Wetland is already degraded. However, the fact that a large proportion of the semi-natural area of the wetland lies below the full supply level of the Theewaterskloof Dam severely limits rehabilitation options in this wetland. Nonetheless, some possibilities exist for improving the ecological condition and functionality of this wetland. The following is a plausible rehabilitation scenario:

- 2 ha of wetland, which is currently degraded, will be rehabilitated by redistributing low flows into this area, thereby increasing by 2 ha the extent of wetland through which low flows are distributed diffusely amongst dense herbaceous vegetation. Although a relatively small area, this is anticipated to significantly increase the capacity of wetland for the assimilation of nutrients.
- 30 ha of wetland currently infested with invasive alien trees has been cleared. In the absence of clearing, within the next 50 years, the 30 ha would be likely to have expanded in extent to between 45 ha and 60 ha. The full 81 ha of the semi-natural area of the wetland is unlikely to become infested given the deep flooding that occurs periodically in the lowermost elevations of the wetland.
- 34 ha of wetland currently exposed to unmitigated wave-action erosion from the Theewaterskloof Dam will be protected, thereby facilitating improved vegetation cover and reduced erosion in this area.

This is a composite scenario consisting of three parts. The valuation model was employed to assess each of the sections independently, then to be aggregated to yield a view on the total expenditure that can be afforded on the proposed combination of rehabilitation initiatives.

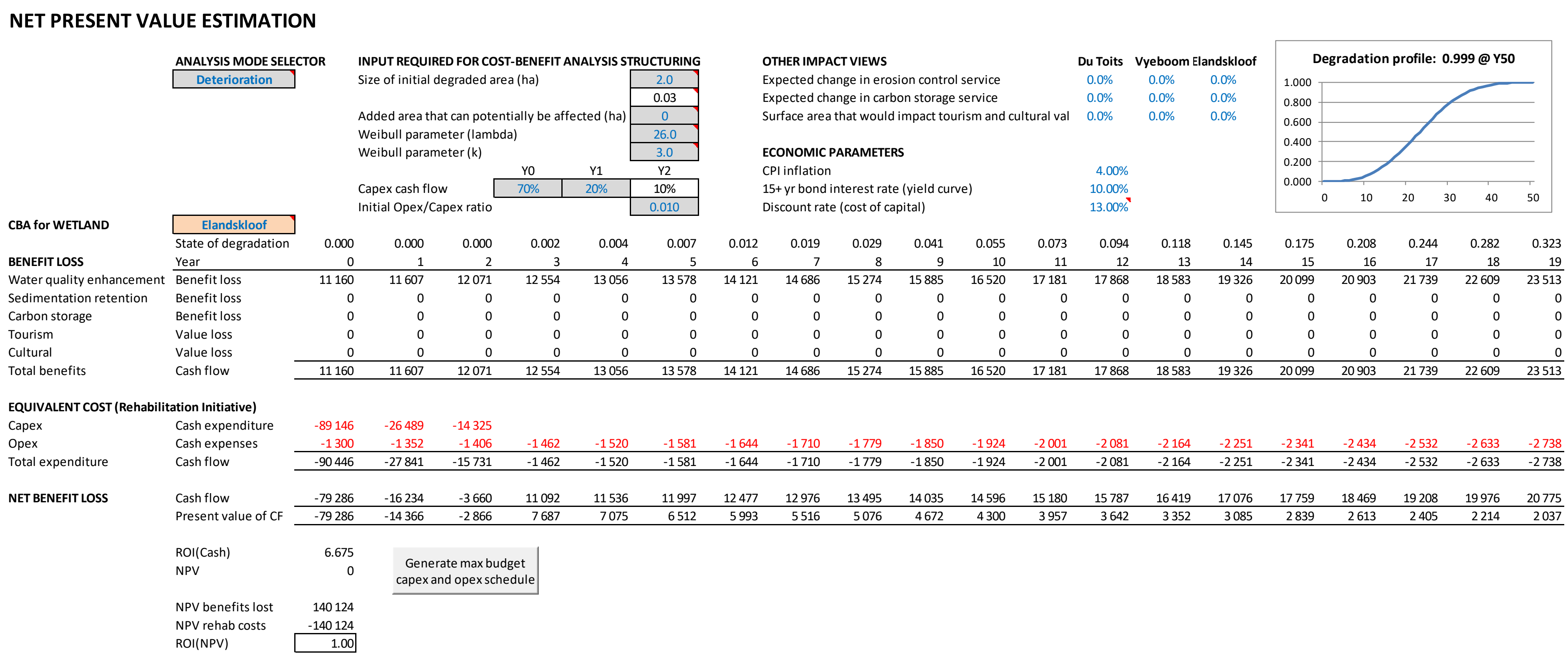
The first part addresses the rehabilitation of the specific 2 ha area. The valuation model assumptions derived from this part of the composite scenario are the following:

- Initial degraded area (current situation) is 2 ha.
- The affected area is not expected to increase in the future.
- The wetland nutrient reduction performance and flow rates would remain on an average level for the future.

The valuation model layout for this assessment is displayed in Table 33.

By balancing the total investment to offset the potential loss in benefits if the 2 ha should remain degraded, it is evident that an amount of R140 124 can be afforded to be spent on its rehabilitation.

**Table 33: Rehabilitation initiative net present value estimation for the Elandskloof wetland (part 1)**



## NET PRESENT VALUE ESTIMATION

**ANALYSIS MODE SELECTOR**

Deterioration

**INPUT REQUIRED FOR COST-BENEFIT ANALYSIS STRUCTURING**

| | | | |
|---|---|---|---|
| Size of initial degraded area (ha) | | | 2.0 |
| | | | 0.03 |
| Added area that can potentially be affected (ha) | | | 0 |
| Weibull parameter (lambda) | | | 26.0 |
| Weibull parameter (k) | | | 3.0 |
| | Y0 | Y1 | Y2 |
| Capex cash flow | 70% | 20% | 10% |
| Initial Opex/Capex ratio | | | 0.010 |

**OTHER IMPACT VIEWS**

| | Du Toits | Vyeboom | Elandskloof |
|---|---|---|---|
| Expected change in erosion control service | 0.0% | 0.0% | 0.0% |
| Expected change in carbon storage service | 0.0% | 0.0% | 0.0% |
| Surface area that would impact tourism and cultural val | 0.0% | 0.0% | 0.0% |

**ECONOMIC PARAMETERS**

| | |
|---|---|
| CPI inflation | 4.00% |
| 15+ yr bond interest rate (yield curve) | 10.00% |
| Discount rate (cost of capital) | 13.00% |

**CBA for WETLAND** Elandskloof

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | State of degradation | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.007 | 0.012 | 0.019 | 0.029 | 0.041 | 0.055 | 0.073 | 0.094 | 0.118 | 0.145 | 0.175 | 0.208 | 0.244 | 0.282 | 0.323 |
| **BENEFIT LOSS** | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Water quality enhancement | Benefit loss | 11 160 | 11 607 | 12 071 | 12 554 | 13 056 | 13 578 | 14 121 | 14 686 | 15 274 | 15 885 | 16 520 | 17 181 | 17 868 | 18 583 | 19 326 | 20 099 | 20 903 | 21 739 | 22 609 | 23 513 |
| Sedimentation retention | Benefit loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carbon storage | Benefit loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tourism | Value loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cultural | Value loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total benefits | Cash flow | 11 160 | 11 607 | 12 071 | 12 554 | 13 056 | 13 578 | 14 121 | 14 686 | 15 274 | 15 885 | 16 520 | 17 181 | 17 868 | 18 583 | 19 326 | 20 099 | 20 903 | 21 739 | 22 609 | 23 513 |
| **EQUIVALENT COST (Rehabilitation Initiative)** | | | | | | | | | | | | | | | | | | | | | |
| Capex | Cash expenditure | -89 146 | -26 489 | -14 325 | | | | | | | | | | | | | | | | | |
| Opex | Cash expenses | -1 300 | -1 352 | -1 406 | -1 462 | -1 520 | -1 581 | -1 644 | -1 710 | -1 779 | -1 850 | -1 924 | -2 001 | -2 081 | -2 164 | -2 251 | -2 341 | -2 434 | -2 532 | -2 633 | -2 738 |
| Total expenditure | Cash flow | -90 446 | -27 841 | -15 731 | -1 462 | -1 520 | -1 581 | -1 644 | -1 710 | -1 779 | -1 850 | -1 924 | -2 001 | -2 081 | -2 164 | -2 251 | -2 341 | -2 434 | -2 532 | -2 633 | -2 738 |
| **NET BENEFIT LOSS** | Cash flow | -79 286 | -16 234 | -3 660 | 11 092 | 11 536 | 11 997 | 12 477 | 12 976 | 13 495 | 14 035 | 14 596 | 15 180 | 15 787 | 16 419 | 17 076 | 17 759 | 18 469 | 19 208 | 19 976 | 20 775 |
| | Present value of CF | -79 286 | -14 366 | -2 866 | 7 687 | 7 075 | 6 512 | 5 993 | 5 516 | 5 076 | 4 672 | 4 300 | 3 957 | 3 642 | 3 352 | 3 085 | 2 839 | 2 613 | 2 405 | 2 214 | 2 037 |

| | |
|---|---|
| ROI(Cash) | 6.675 |
| NPV | 0 |
| NPV benefits lost | 140 124 |
| NPV rehab costs | -140 124 |
| ROI(NPV) | 1.00 |

The second part addresses the rehabilitation of the 30 ha of the Elandskloof Wetland previously infested with invasive alien trees. The valuation model assumptions derived from this part of the composite scenario are the following:

- Initial degraded area (current situation) is 30 ha.
- Degradation will follow a logarithmic evolution pattern over a 50-year period. Since the infestation is already substantial, the initial deterioration rate is expected to be substantial, and would not pick slowly as in the case of a logistic evolution pattern.
- The area which would be totally degraded in Year 50 is assumed to be 53 ha (say about halfway between 45 and 60 ha). This magnitude of the potentially degraded area is selected purely for demonstration purposes – in practice, the analyst might prefer to generate outcomes for 45 ha and 60 ha cases in order to provide a range of outcomes.
- The wetland nutrient reduction performance and flow rates would remain on an average level for the future.

The valuation model layout for this assessment is displayed in Table 34.

By balancing the total investment to offset the potential loss in benefits if the degraded area should increase from 30 ha to 53 ha, it is evident that an amount of R2 962 966 can be afforded to be spent on the rehabilitation of the currently infested 30 ha area.

## Table 34: Rehabilitation initiative net present value estimation for the Elandskloof Wetland (part 2)

## NET PRESENT VALUE ESTIMATION

**ANALYSIS MODE SELECTOR**

Deterioration

**INPUT REQUIRED FOR COST-BENEFIT ANALYSIS STRUCTURING**

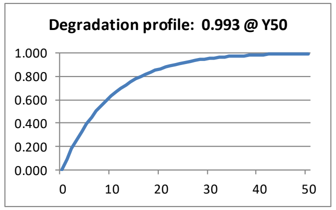
| | | | |
|---|---|---|---|
| Size of initial degraded area (ha) | | | 30.0 |
| | | | 0.40 |
| Added area that can potentially be affected (ha) | | | 23 |
| Weibull parameter (lambda) | | | 10.0 |
| Weibull parameter (k) | | | 1.0 |
| | Y0 | Y1 | Y2 |
| Capex cash flow | 70% | 20% | 10% |
| Initial Opex/Capex ratio | | | 0.010 |

**OTHER IMPACT VIEWS**

| | Du Toits | Vyeboom | Elandskloof |
|---|---|---|---|
| Expected change in erosion control service | 0.0% | 0.0% | 0.0% |
| Expected change in carbon storage service | 0.0% | 0.0% | 30.7% |
| Surface area that would impact tourism and cultural value | 0.0% | 0.0% | 15.3% |

**ECONOMIC PARAMETERS**

| | |
|---|---|
| CPI inflation | 4.00% |
| 15+ yr bond interest rate (yield curve) | 10.00% |
| Discount rate (cost of capital) | 13.00% |


Degradation profile: 0.993 @ Y50

**CBA for WETLAND** Elandskloof

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | State of degradation | 0.000 | 0.095 | 0.181 | 0.259 | 0.330 | 0.393 | 0.451 | 0.503 | 0.551 | 0.593 | 0.632 | 0.667 | 0.699 | 0.727 | 0.753 | 0.777 | 0.798 | 0.817 | 0.835 | 0.850 |
| **BENEFIT LOSS** | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Water quality enhancement | Benefit loss | 167 405 | 186 803 | 206 229 | 225 726 | 245 340 | 265 114 | 285 092 | 305 316 | 325 829 | 346 674 | 367 891 | 389 523 | 411 613 | 434 203 | 457 335 | 481 053 | 505 399 | 530 418 | 556 155 | 582 655 |
| Sedimentation retention | Benefit loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carbon storage | Benefit loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tourism | Value loss | 585 | 753 | 919 | 1 084 | 1 248 | 1 411 | 1 575 | 1 738 | 1 902 | 2 067 | 2 234 | 2 402 | 2 572 | 2 745 | 2 920 | 3 099 | 3 281 | 3 467 | 3 657 | 3 852 |
| Cultural | Value loss | 7 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 |
| Total benefits | Cash flow | 167 997 | 187 565 | 207 158 | 226 822 | 246 602 | 266 541 | 286 684 | 307 074 | 327 753 | 348 764 | 370 150 | 391 952 | 414 214 | 436 979 | 460 288 | 484 186 | 508 717 | 533 924 | 559 853 | 586 550 |
| **EQUIVALENT COST (Rehabilitation Initiative)** | | | | | | | | | | | | | | | | | | | | | |
| Capex | Cash expenditure | -1 885 024 | -560 121 | -302 914 | | | | | | | | | | | | | | | | | |
| Opex | Cash expenses | -27 481 | -28 580 | -29 723 | -30 912 | -32 148 | -33 434 | -34 772 | -36 163 | -37 609 | -39 113 | -40 678 | -42 305 | -43 997 | -45 757 | -47 587 | -49 491 | -51 471 | -53 529 | -55 671 | -57 897 |
| Total expenditure | Cash flow | -1 912 504 | -588 701 | -332 637 | -30 912 | -32 148 | -33 434 | -34 772 | -36 163 | -37 609 | -39 113 | -40 678 | -42 305 | -43 997 | -45 757 | -47 587 | -49 491 | -51 471 | -53 529 | -55 671 | -57 897 |
| **NET BENEFIT LOSS** | Cash flow | -1 744 508 | -401 136 | -125 479 | 195 910 | 214 453 | 233 107 | 251 913 | 270 911 | 290 144 | 309 651 | 329 472 | 349 647 | 370 217 | 391 221 | 412 701 | 434 695 | 457 246 | 480 395 | 504 182 | 528 652 |
| | Present value of CF | -1 744 508 | -354 988 | -98 268 | 135 776 | 131 528 | 126 521 | 120 998 | 115 154 | 109 140 | 103 078 | 97 058 | 91 152 | 85 411 | 79 874 | 74 565 | 69 504 | 64 699 | 60 154 | 55 870 | 51 842 |

| | |
|---|---|
| ROI(Cash) | 8.600 |
| NPV | 0 |

Generate max budget capex and opex schedule

| | |
|---|---|
| NPV benefits lost | 2 962 966 |
| NPV rehab costs | -2 962 966 |
| ROI(NPV) | 1.00 |

The third part addresses the rehabilitation of the 34 ha of the Elandskloof Wetland currently exposed to unmitigated wave-action erosion from the Theewaterskloof Dam. The valuation model assumptions derived from this part of the composite scenario are the following:

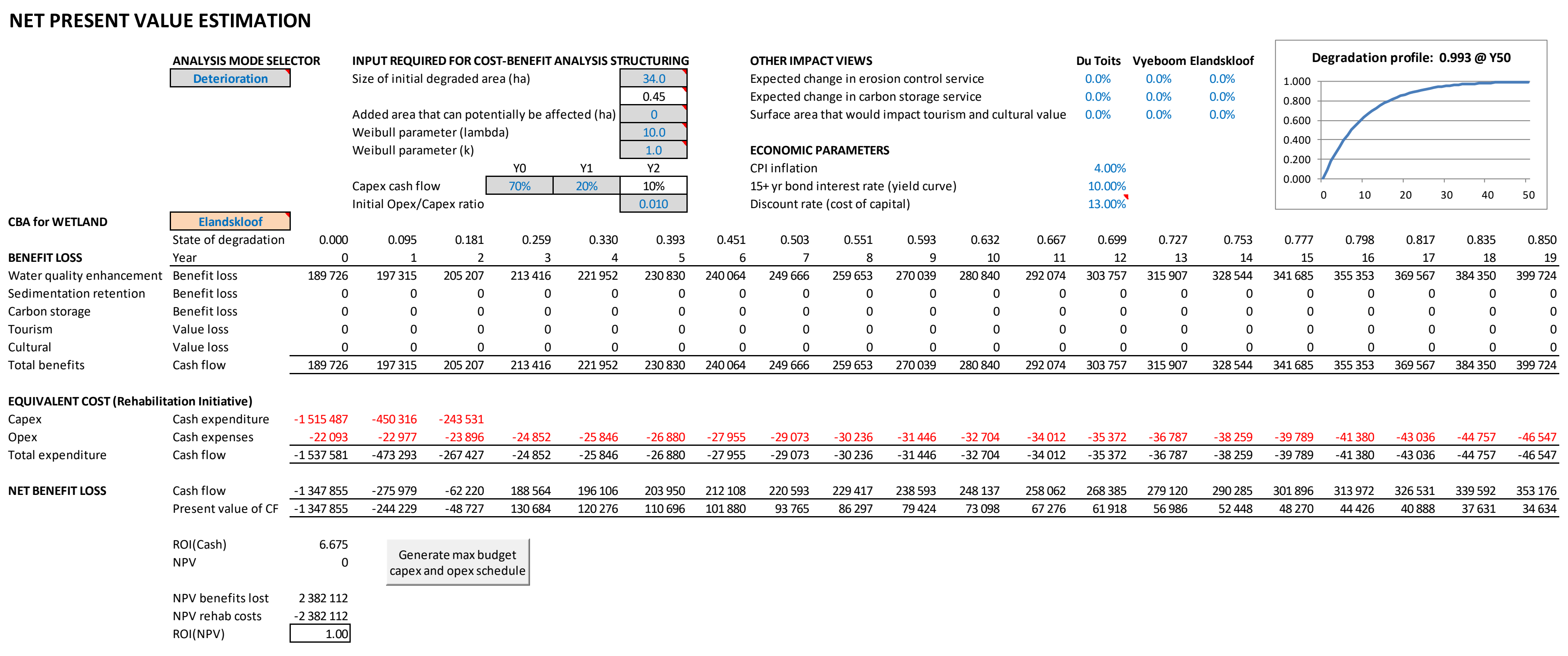
- Initial degraded area (current situation) is 34 ha.
- The affected area is not expected to increase in the future.
- The wetland nutrient reduction performance and flow rates would remain on an average level for the future.

The valuation model layout for this assessment is displayed in Table 35.

By balancing the total investment to offset the potential loss in benefits if the 34 ha should remain exposed to unmitigated wave-action erosion, it is evident that an amount of R2 382 112 can be afforded to be spent on the rehabilitation of the currently affected 34 ha area.

A combination of rehabilitation initiatives, with total cost amounting to R5,49 million can, therefore, be employed to address all the issues raised in the Elandskloof scenario description.

### Table 35: Rehabilitation initiative net present value estimation for the Elandskloof wetland (part 3)



## NET PRESENT VALUE ESTIMATION

| ANALYSIS MODE SELECTOR |
|---|
| Deterioration |

| INPUT REQUIRED FOR COST-BENEFIT ANALYSIS STRUCTURING | | | |
|---|---|---|---|
| Size of initial degraded area (ha) | | | 34.0 |
| | | | 0.45 |
| Added area that can potentially be affected (ha) | | | 0 |
| Weibull parameter (lambda) | | | 10.0 |
| Weibull parameter (k) | | | 1.0 |
| | Y0 | Y1 | Y2 |
| Capex cash flow | 70% | 20% | 10% |
| Initial Opex/Capex ratio | | | 0.010 |

| OTHER IMPACT VIEWS | Du Toits | Vyeboom | Elandskloof |
|---|---|---|---|
| Expected change in erosion control service | 0.0% | 0.0% | 0.0% |
| Expected change in carbon storage service | 0.0% | 0.0% | 0.0% |
| Surface area that would impact tourism and cultural value | 0.0% | 0.0% | 0.0% |

| ECONOMIC PARAMETERS | |
|---|---|
| CPI inflation | 4.00% |
| 15+ yr bond interest rate (yield curve) | 10.00% |
| Discount rate (cost of capital) | 13.00% |

| CBA for WETLAND | Elandskloof | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | State of degradation | 0.000 | 0.095 | 0.181 | 0.259 | 0.330 | 0.393 | 0.451 | 0.503 | 0.551 | 0.593 | 0.632 | 0.667 | 0.699 | 0.727 | 0.753 | 0.777 | 0.798 | 0.817 | 0.835 | 0.850 |
| **BENEFIT LOSS** | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Water quality enhancement | Benefit loss | 189 726 | 197 315 | 205 207 | 213 416 | 221 952 | 230 830 | 240 064 | 249 666 | 259 653 | 270 039 | 280 840 | 292 074 | 303 757 | 315 907 | 328 544 | 341 685 | 355 353 | 369 567 | 384 350 | 399 724 |
| Sedimentation retention | Benefit loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carbon storage | Benefit loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tourism | Value loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cultural | Value loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total benefits | Cash flow | 189 726 | 197 315 | 205 207 | 213 416 | 221 952 | 230 830 | 240 064 | 249 666 | 259 653 | 270 039 | 280 840 | 292 074 | 303 757 | 315 907 | 328 544 | 341 685 | 355 353 | 369 567 | 384 350 | 399 724 |
| **EQUIVALENT COST (Rehabilitation Initiative)** | | | | | | | | | | | | | | | | | | | | | |
| Capex | Cash expenditure | -1 515 487 | -450 316 | -243 531 | | | | | | | | | | | | | | | | | |
| Opex | Cash expenses | -22 093 | -22 977 | -23 896 | -24 852 | -25 846 | -26 880 | -27 955 | -29 073 | -30 236 | -31 446 | -32 704 | -34 012 | -35 372 | -36 787 | -38 259 | -39 789 | -41 380 | -43 036 | -44 757 | -46 547 |
| Total expenditure | Cash flow | -1 537 581 | -473 293 | -267 427 | -24 852 | -25 846 | -26 880 | -27 955 | -29 073 | -30 236 | -31 446 | -32 704 | -34 012 | -35 372 | -36 787 | -38 259 | -39 789 | -41 380 | -43 036 | -44 757 | -46 547 |
| **NET BENEFIT LOSS** | Cash flow | -1 347 855 | -275 979 | -62 220 | 188 564 | 196 106 | 203 950 | 212 108 | 220 593 | 229 417 | 238 593 | 248 137 | 258 062 | 268 385 | 279 120 | 290 285 | 301 896 | 313 972 | 326 531 | 339 592 | 353 176 |
| | Present value of CF | -1 347 855 | -244 229 | -48 727 | 130 684 | 120 276 | 110 696 | 101 880 | 93 765 | 86 297 | 79 424 | 73 098 | 67 276 | 61 918 | 56 986 | 52 448 | 48 270 | 44 426 | 40 888 | 37 631 | 34 634 |

| | |
|---|---|
| ROI(Cash) | 6.675 |
| NPV | 0 |
| NPV benefits lost | 2 382 112 |
| NPV rehab costs | -2 382 112 |
| ROI(NPV) | 1.00 |

# 5. CONCLUSIONS AND RECOMMENDATIONS

The Theewaterskloof Dam is an important source of water for the Western Cape, particularly Cape Town, and as such it is important to establish the value of the wetlands through which water drains into this dam. An economic valuation was done on three individual wetlands in the dam's catchment area, in order to establish the necessary perspective for the valuation of the wetlands a brief introduction of the catchment feeding into the wetland has been provided, highlighting the relation to the wetland and the surrounding geomorphic structures. This has been supplemented by a detailed description of the wetland functioning and performance in terms of the current status and expected future degradation or rehabilitation scenarios. Using the wetland description and catchment data, the hydrological functioning of the wetlands has been described in terms of the long-term internal water balances of the wetlands as simulated by a calibrated rainfall-runoff model. The economic valuation could then be determined from wetland scenario descriptions, water balances and basic assumptions on nutrient uptake rates.

In order to supplement a qualitative discussion of the intrinsic value of the wetlands in this study, a quantifiable economic valuation of a wetland was constructed by assembling a set of models which describe the functional values of the wetland in terms of water quality enhancement (nutrient removal), retention of sediment, storage of carbon, tourism potential and the manifestation of cultural values. The contribution from the nutrient removal model strongly dominates all other factor contributions.

The nutrient removal model is informed primarily by a simple water quality model which is based on the difference in nitrogen and phosphorous assimilation capacity of intact and degraded wetlands. It is also informed by the hydrological assessment of water flows that occur frequently in the particular wetland area. The determination of an economic valuation is primarily based on the indirect use value method, with a special focus on the "minimisation of replacement costs".

Besides the capability to determine marginal economic values for the wetland under various conditions, the economic model developed in this study can also provide a good indication of the maximum allowable expenditure that can be afforded on rehabilitation projects to curb or prevent various wetland degradation processes. Such an economic assessment assumes a long-term period (typically 50+ years) over which the somewhat degraded wetland would degrade even further. The monetary value difference between the current state and that expected if degradation would continue, provides useful justification for budgets associated with rehabilitation interventions. The assessed outcomes are generally found to be valid estimates with an acceptable level of certainty.

The economic models do, however, exclude potentially important ecosystem services and would likely result in rather conservative valuations of wetlands. Some potentially important ecosystem services that have not been included, are:

- The assimilation of toxicants, notably xenobiotic toxicants arising from the relatively high level of biocide application over extensive areas of the catchment,
- The assimilation of pathogens, notably E. *coli*, with direct implications in terms of the export of fruit, and
- Local storage of water (available for direct use by adjacent farmers).

It is recommended that these ecosystem services be included in future models if this information is available to enhance the value estimates. Valuations that include these factors may provide more detailed models, but based on the observations in this study, it will probably still be dominated by the nutrient removal contributions.

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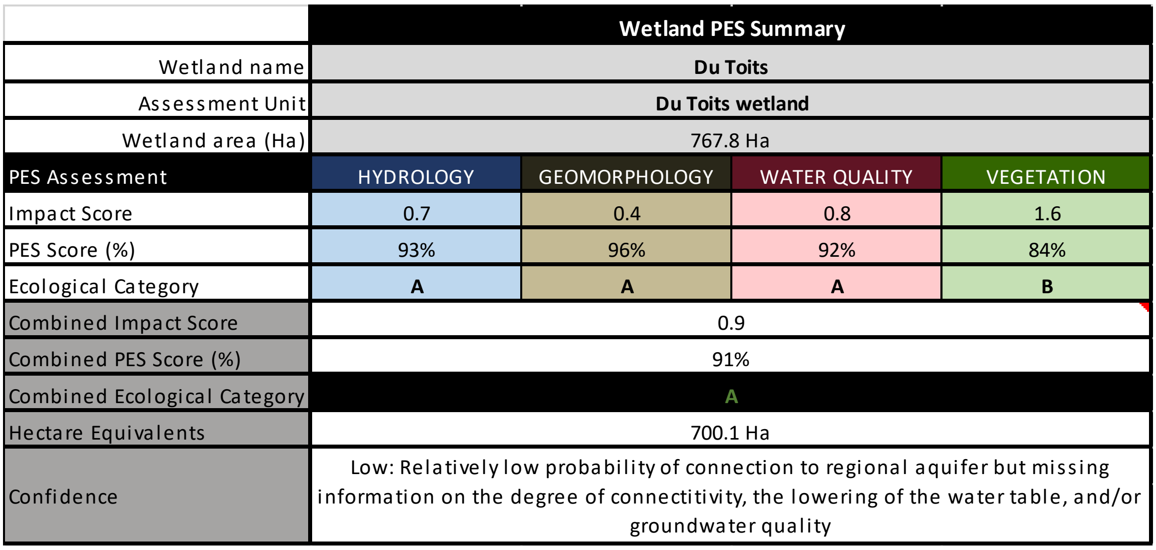
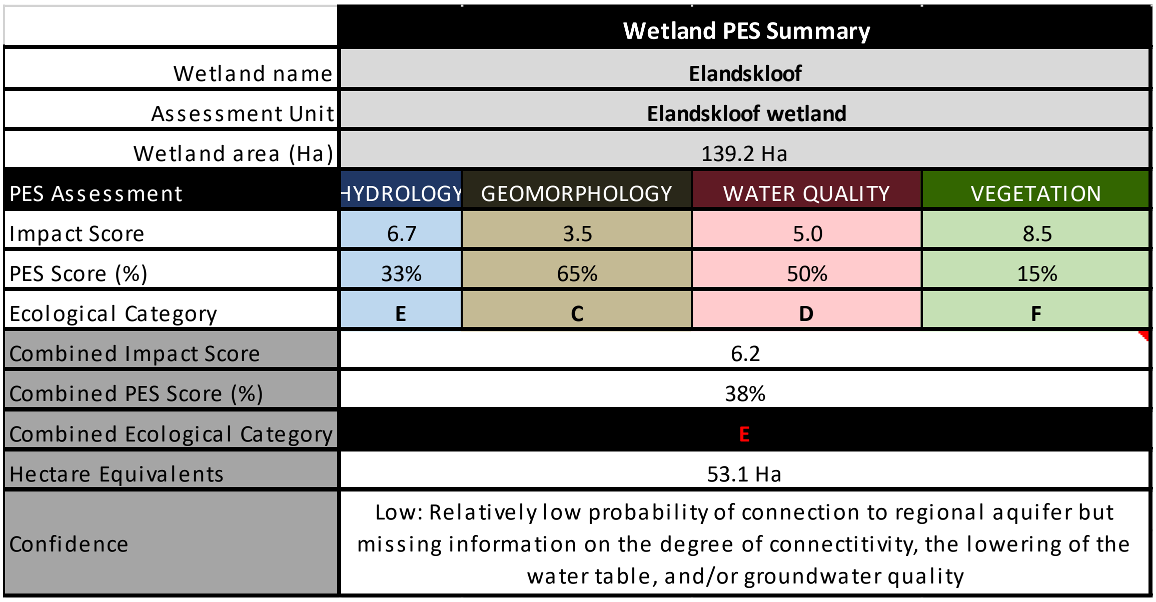
# APPENDIX A: WETLAND PRESENT ECOLOGICAL STATE SUMMARY

## Du Toits Kloof



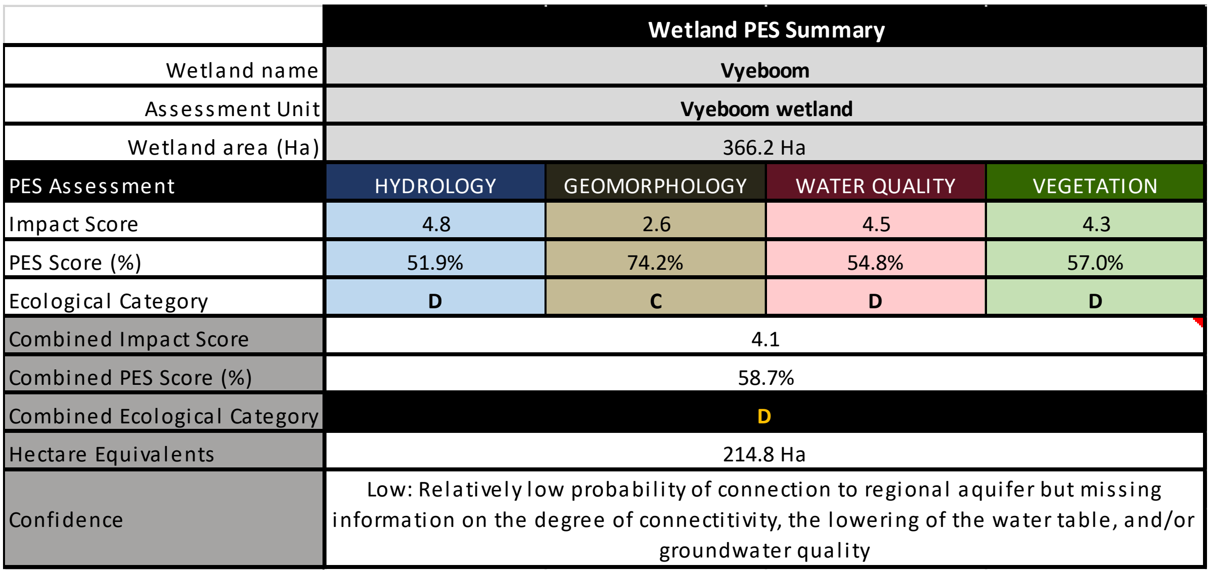
| | Wetland PES Summary | | | |
|---|---|---|---|---|
| Wetland name | **Du Toits** | | | |
| Assessment Unit | **Du Toits wetland** | | | |
| Wetland area (Ha) | 767.8 Ha | | | |
| PES Assessment | HYDROLOGY | GEOMORPHOLOGY | WATER QUALITY | VEGETATION |
| Impact Score | 0.7 | 0.4 | 0.8 | 1.6 |
| PES Score (%) | 93% | 96% | 92% | 84% |
| Ecological Category | **A** | **A** | **A** | **B** |
| Combined Impact Score | 0.9 | | | |
| Combined PES Score (%) | 91% | | | |
| Combined Ecological Category | A | | | |
| Hectare Equivalents | 700.1 Ha | | | |
| Confidence | Low: Relatively low probability of connection to regional aquifer but missing information on the degree of connectitivity, the lowering of the water table, and/or groundwater quality | | | |

## Elandskloof



| | Wetland PES Summary | | | |
|---|---|---|---|---|
| Wetland name | **Elandskloof** | | | |
| Assessment Unit | **Elandskloof wetland** | | | |
| Wetland area (Ha) | 139.2 Ha | | | |
| PES Assessment | HYDROLOGY | GEOMORPHOLOGY | WATER QUALITY | VEGETATION |
| Impact Score | 6.7 | 3.5 | 5.0 | 8.5 |
| PES Score (%) | 33% | 65% | 50% | 15% |
| Ecological Category | **E** | **C** | **D** | **F** |
| Combined Impact Score | 6.2 | | | |
| Combined PES Score (%) | 38% | | | |
| Combined Ecological Category | E | | | |
| Hectare Equivalents | 53.1 Ha | | | |
| Confidence | Low: Relatively low probability of connection to regional aquifer but missing information on the degree of connectitivity, the lowering of the water table, and/or groundwater quality | | | |

Vyeboom



|  | Wetland PES Summary |  |  |  |
|---|---|---|---|---|
| Wetland name | **Vyeboom** |  |  |  |
| Assessment Unit | **Vyeboom wetland** |  |  |  |
| Wetland area (Ha) | 366.2 Ha |  |  |  |
| PES Assessment | HYDROLOGY | GEOMORPHOLOGY | WATER QUALITY | VEGETATION |
| Impact Score | 4.8 | 2.6 | 4.5 | 4.3 |
| PES Score (%) | 51.9% | 74.2% | 54.8% | 57.0% |
| Ecological Category | **D** | **C** | **D** | **D** |
| Combined Impact Score | 4.1 |  |  |  |
| Combined PES Score (%) | 58.7% |  |  |  |
| Combined Ecological Category | **D** |  |  |  |
| Hectare Equivalents | 214.8 Ha |  |  |  |
| Confidence | Low: Relatively low probability of connection to regional aquifer but missing information on the degree of connectitivity, the lowering of the water table, and/or groundwater quality |  |  |  |

# APPENDIX B: ALGEBRAIC LAYOUT TO EXPLAIN THE GENERATION OF SHADOW VALUES FOR THE NUTRIENT REDUCTION MODEL

The Terms of Reference (TOR) for this project demands that shadow prices be used to determine the marginal value of the nutrient reduction capability of the wetlands under investigation. This is often used to indicate the value of restoration or rehabilitation projects.

The TOR is also clear in recommending the shadow price determination approach as expounded by (Grossman, 2012). Moreover, the TOR demands that the shadow prices be determined in MS Excel.

From the TOR discussion it is evident that the reader of the final report would have a satisfactory understanding of elementary optimisation theory which defines the concept of “shadow prices” as the marginal impact of unitary changes in the constraints postulated by linear or nonlinear optimisation problems.

It is also understood that the reader of the final report would be in a position to code and read formulations in MS Excel, for which a basic to intermediate skills-level is required.

The following layout explains the formulation of the optimisation problem to enable the generation of the shadow prices for the evaluated wetlands or the initiatives that might be implemented to restore/rehabilitate the said wetlands.

## B.1 The power law of costing

The configuration of the economic valuation model requires the introduction of the power law that is commonly used to scale the costs of chemical treatment plants, based on throughput. The principle of scaling needs to reflect the economies of scale for the various throughput rates. This can be achieved by applying the following power factor relationship:

$$Cost_{\mathrm{Scaled}} = \left(\frac{Throughput_{\mathrm{Scaled}}}{Throughput_{\mathrm{Ref}}}\right)^{p} Cost_{\mathrm{Ref}}$$

In this function the desired design throughput is divided by the reference throughput and the resulting ratio is raised to the power *p*, with *p* adopting a value between zero and one, to reflect economies of scale. The ratio-ed throughput is then multiplied by the reference cost to obtain the scaled cost. In this study the power factor *p* is assumed to be 0.75.

## B.2 The configuration of the optimisation problem

A variety of options can be defined to act as replacement process for the nutrient assimilation function of wetlands. Each of these processes has an associated cost of operation, which is composed of a capital expenditure and an operating expense component. The composite costs for the listed processes are scaled by the power law to reflect the throughput of the wetlands for which the valuation needs to be conducted.

Since the least cost options, or combination of options, need to be found in the optimisation estimation, the optimisation problem is set up as a minimisation of weighted costs that subscribes to the fundamental conditions that:

- All alternative processes considered must be able to deliver similar services as the natural wetlands,
- The considered processes should not result in a shift in demand by society if such alternatives were to be implemented, and

- The optimal alternative choice should be the least cost option.

The algebraic layout of the optimisation problem is therefore captured in the following expressions:

$$C = min \sum_{i} c_i (x_i)^p$$

subject to:

$$TR = \sum_{i} q(x_i)$$

$$0 \leq x_i \leq 1$$

where the indices and variables are denoted by:

i: process unit

p: power law factor

x: implementation level of a process based on the ratio of variable area to total wetland area

c: function describing the composite scaled cost of an alternative process

C: total cost of implementing a combination of optional processes

Q: nutrient removal capacity associated with the alternative process

TR: target nutrient load reduction

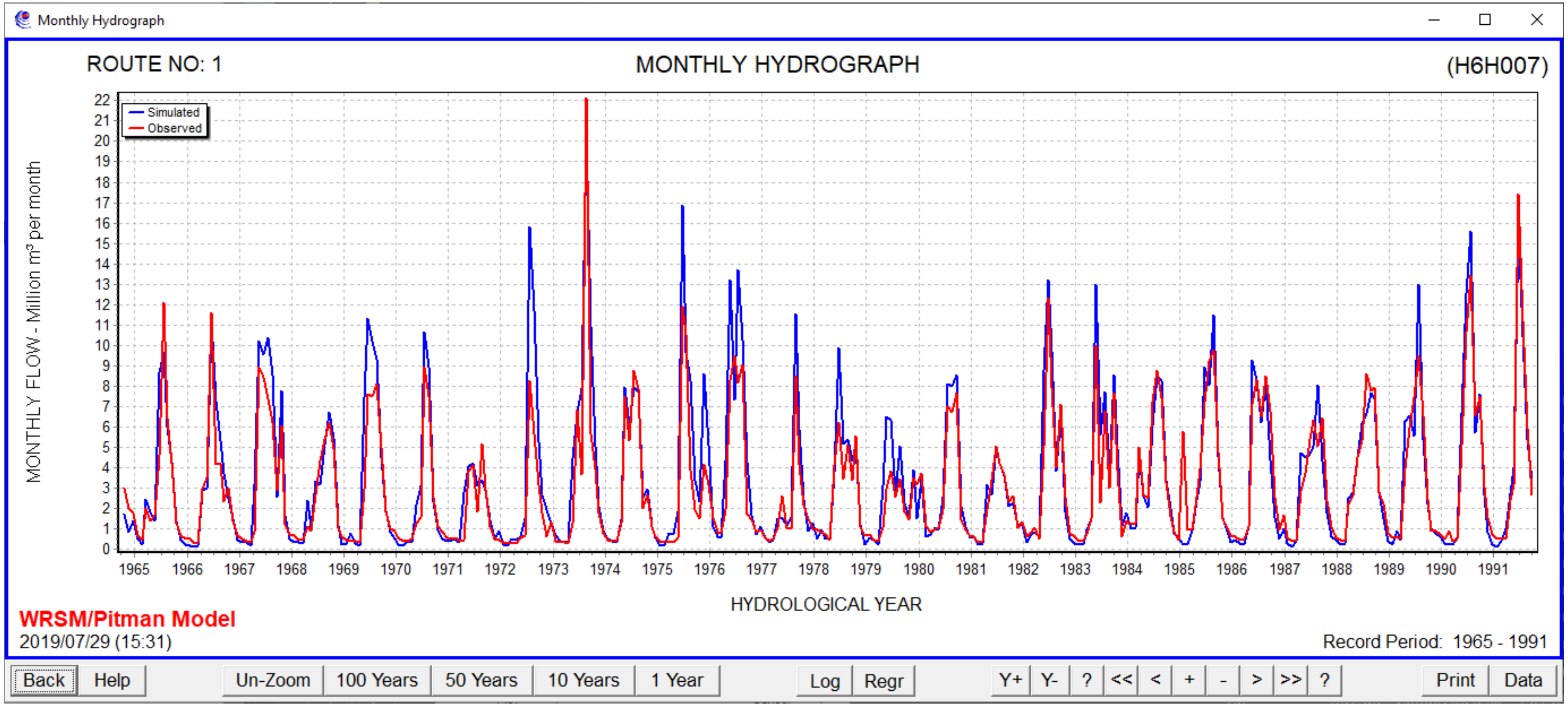
In order to solve the above optimisation model, mathematicians use Lagrange multipliers that are associated with each of the constraints. These multipliers are also referred to as “shadow prices” and indicate the marginal increase or decrease of the objective function (that for *C* above) value when the levels of constraint are individually adjusted by one unit. The incremental adjustment for constraint $x_i$ would relate to a 1 hectare partial adjustment in wetland surface area.

### B.3 MS Excel solutions to the optimisation problem

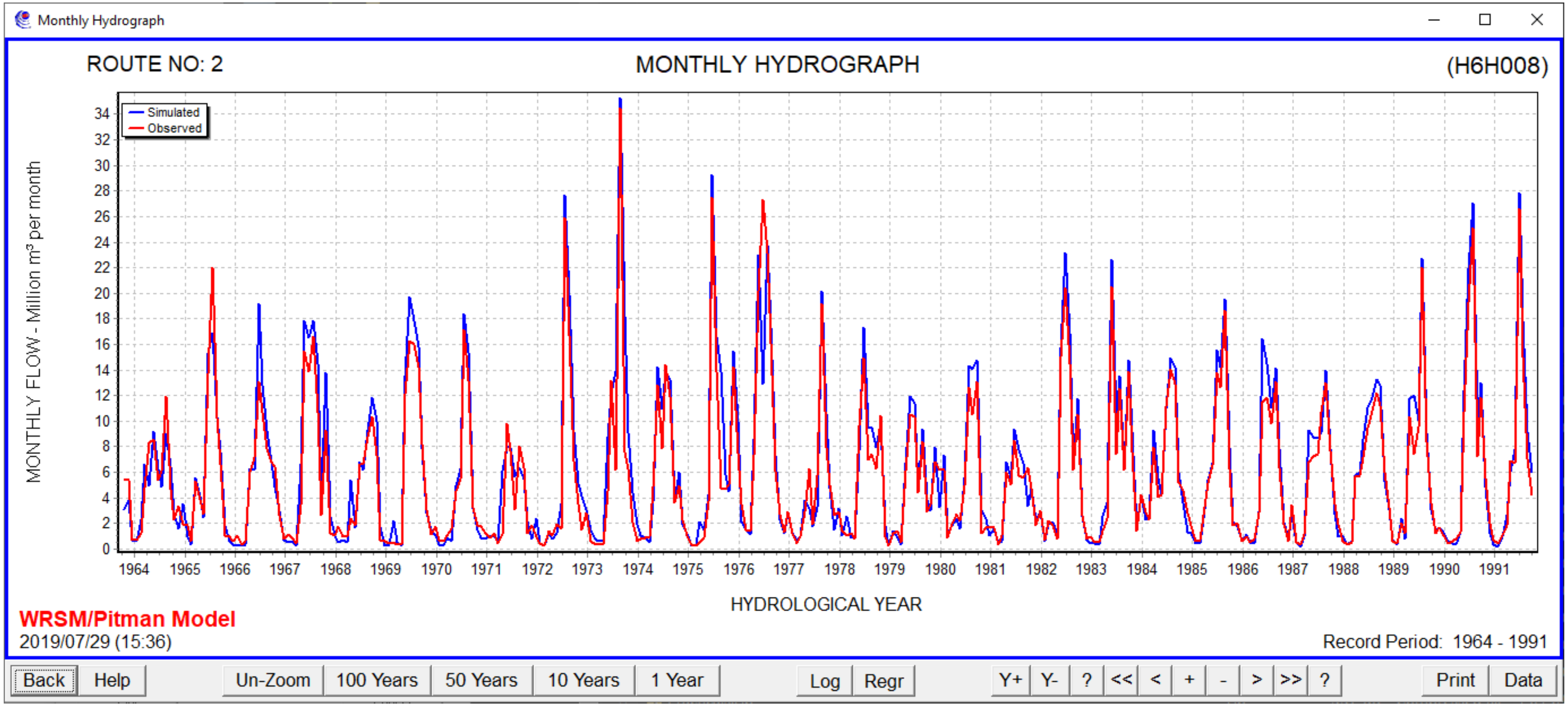
The standard version of MS Excel has a Solver add-in that does all the calculations to solve the above optimisation problem and which produces internally generated reports from which the shadow prices can be extracted.

The approach by (Grossman, 2012) is adopted in this study, whereby the restoration of the wetland is allowed as an optional “alternative” process, but for which the $x_i$- value must be forced to converge to zero. The reduced gradient value (Lagrange multiplier) for this option is then recorded as the shadow price associated with the wetland.

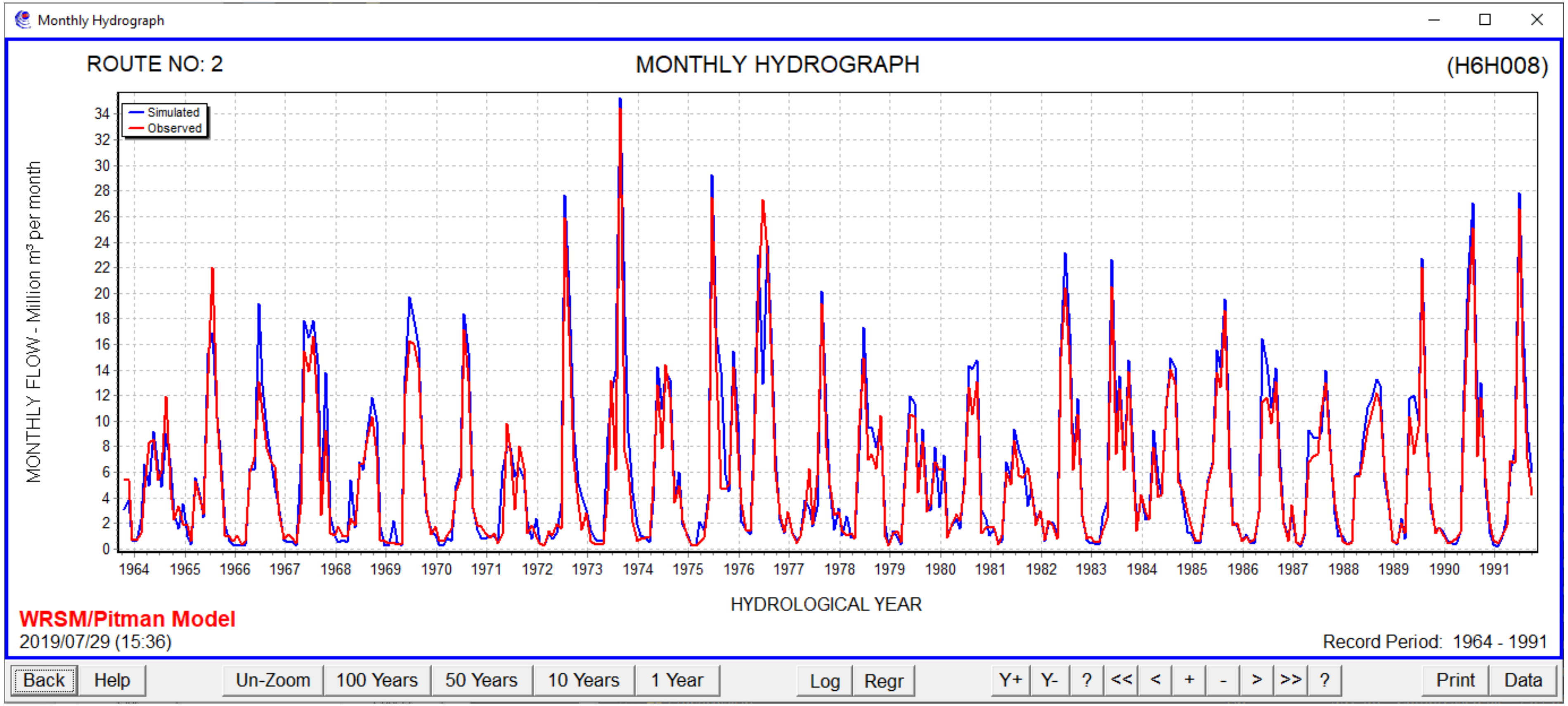
## H6H007: Main channel upstream Du Toits #3 Wetland



## H6H008: Main channel upstream Vyeboom Wetland



## H6R002: Elandskloof Dam Inflow, upstream of Elandskloof Wetland



## H6R001: Theewaterskloof Dam

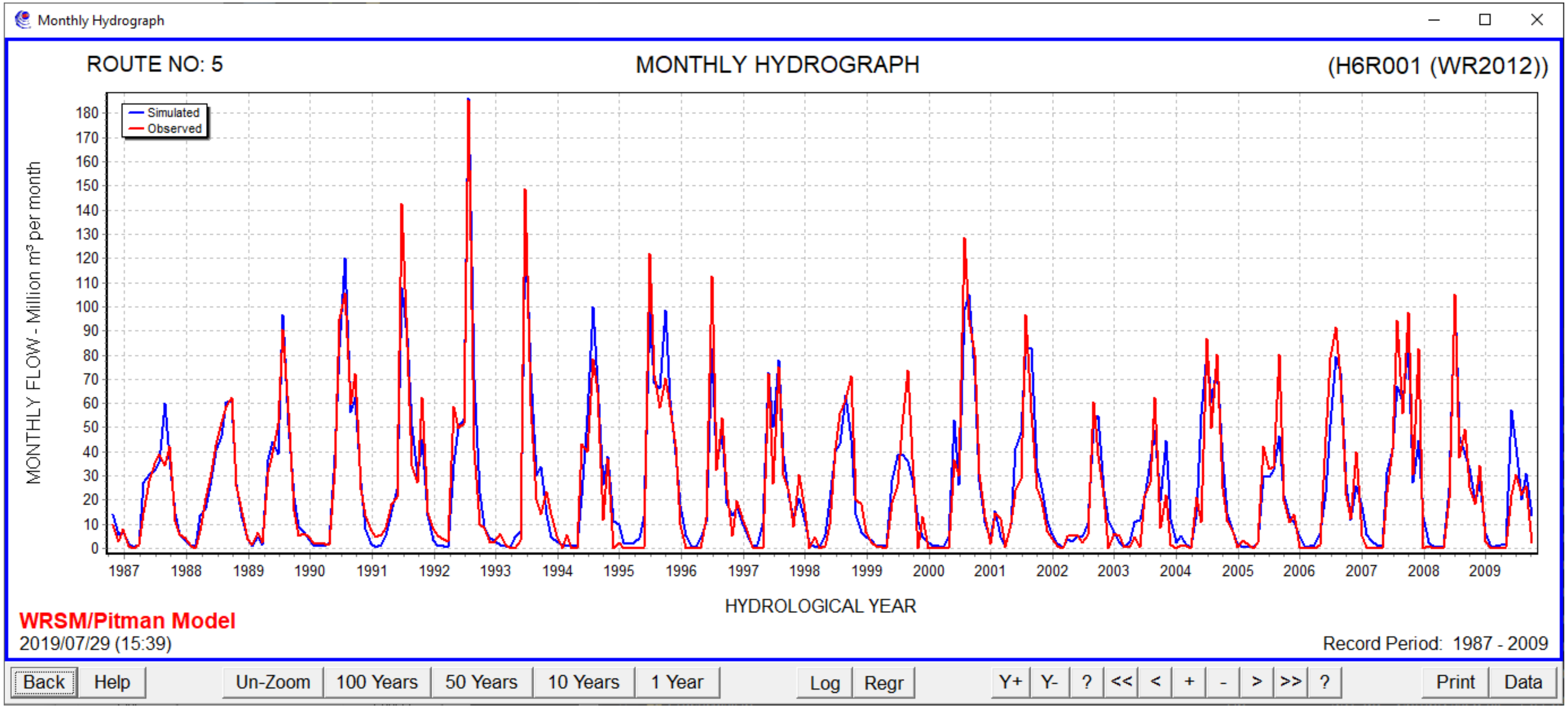


**Table C-1: WRSM2000/Pitman model calibration parameters**

| Quinary | RU | POW | GPOW | SL | HGSL | ST | FT | HGGW | ZMIN | ZAVE | ZMAX | PI | TL | R | Max Disch | %Evap | AreaEvap |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H60B1 | 15 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 15.75 |
| H60B2 | 1 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 13.74 |
| H60B3 | 10 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 12.59 |
| H60B4 | 17 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 13.80 |
| H60B8 | 20 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 2 | 5% | 11.72 |
| H60B9 | 21 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 2 | 5% | 12.26 |
| H60B10 | 19 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 11.36 |
| H60B11 | 22 | 2 | 2 | 0 | 0 | 150 | 0 | 7 | 0 |  | 200 | 1.5 | 2.5 | 0 | 5 | 5% | 0.47 |
| H60A1 | 2 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 20.70 |
| H60A2 | 12 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 |  | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 13.39 |
| H60A3 | 13 | 2 | 2 | 0 | 0 | 150 | 0 | 7 | 0 |  | 200 | 1.5 | 2.5 | 0 | 5 | 5% | 0.56 |
| H60C1&2 | 23 | 1 | 1 | 0 | 0 | 350 | 25 | 5 | 0 |  | 400 | 1.5 | 0.3 | 0 | 4 | 5% | 8.52 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H60C3 | 24 | 1 | 1 | 0 | 0 | 100 | 80 | 5 | 0 | | 250 | 1.5 | 0.1 | 0 | 4 | 5% | 13.79 |
| H60C4&5 | 25 | 1 | 1 | 0 | 0 | 350 | 25 | 5 | 0 | | 400 | 1.5 | 0.3 | 0 | 4 | 5% | 6.70 |
| H60C6 | 26 | 2 | 2 | 0 | 0 | 150 | 0 | 7 | 0 | | 200 | 1.5 | 2.5 | 0 | 5 | 5% | 0.57 |
| H60C8 | 28 | 2 | 2 | 0 | 0 | 150 | 0 | 7 | 0 | | 200 | 1.5 | 2.5 | 0 | 5 | 5% | 0.16 |