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EVALUATION OF ECOSYSTEM SERVICES OF THE PAPENKUILS WETLAND

2021

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DEA&DP 1159

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Prepared by:

SRK Consulting (South Africa) (Pty) Ltd

Authors:

Sue Reuther – Project Leader (SRK)
Simon Lorentz - Hydrology
Matthew Law – Economics
Liz Day – Ecology
Nick Helme – Botany
Roanne Sutcliffe - Hydrological modelling

Editors:

Christopher Dalgliesh - (SRK)
Annabel Marian Horn - Project Manager (DEA&DP)

Steering committee:

Wilna Kloppers – DEA&DP
Phil McLean – DEA&DP
Rudolph Roscher – DoA
Thembela Bushula – BGCMA
Elkerine Rossouw – BGCMA
Samantha Braid – SANBI

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Acronyms and Abbreviations

ACRU	Agricultural Catchments Research Unit
AQWATEC	Advanced Water Technology Centre
BID	Background Information Document
BOCMA	Breede Overberg Catchment Management Agency
BGCMA	Breede – Gouritz Catchment Management Agency
CAPEX	Capital Expenditure
CBA	Critical Biodiversity Area
CEO	Chief Eexcutive Officer
CO2	Carbon Dioxide
CPI	Consumer Price Index
CWRR	Centre for Water Resources Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA&DP	Department of Environmental Affairs and Development Planning
DHSWS	Department of Human Settlements, Water and Sanitation
DM	District Municipality
DO	Dissolved Oxygen
DUL	Drained upper limit
DWAF	(former) Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EIS	Ecological importance and sensitivity
EPA	Environmental Protection Agency
FEPA	Freshwater Ecosystem Priority Areas
GCFR	Greater Cape Floristic Region
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System

HGMU	Hydrogeomorphic Units
IFC	International Finance Corporation
ISBN	International Standard Book Number
IUCN	International Union for Conservation of Nature
LSU	Large Stock Unit
MEA	Millennium Ecosystem Assessment
ML	Mega Litre
MS	Microsoft
NFEPA	National Freshwater Ecosystem Priority Areas
NMMU	Nelson Mandela Metropolitan University
NO_3-N	Nitrate nitrogen
NPV	Net Present Value
NWA	National Water Act
OESA	Other Ecological Support Area
ORP	Oxidation Reduction Potential
PES	Present Ecological State
PNAS	Proceedings of the National Academy of Sciences of the United States of America
PVC	Polyvinyl Chloride
RQOs	Resource Quality Objecives
SoCC	Species of Conservation Concern
SA	South Africa
SABAP2	South African Bird Atlas Project 2
SANBI	South African National Biodiversity Institute
SANCOLD	South African National Committee on Large Dams
SDR	Social Discount Rate
SRP	Soluable Reactive Phosphorus
SRK	SRK Consulting (South Africa) (Pty) Ltd
SRTM	Shuttle Radar Topography Mission
tC	Tons of Carbon

TA	Transect A
TA-TC	Transect A – Transect C
TB	Transect B
TEV	Total Economic Value
ToR	Terms of Reference
UKZN	University of Kwazulu Natal
UN	United Nations
VSMOW	Vienna Standard Mean Ocean Water
WCBSP	Western Cape Biodiversity Spatial Plan
WET	Wetland
WCDA	Western Cape Department of Agriculture
WISA	Water Institute of Southern Africa
WMA	Water Management Area
WP	Water Pressure
WRC	Water Research Committee
WUA	Water Users Association
WWTW	Waste Water Treatment Works
ZAF	South Africa (ISO Country Code)

Glossary

Ameliorate	To improve (in this case, water quality).
Cumulative Impacts	Direct and indirect impacts that act together with current or future potential impacts of other activities or proposed activities in the area/region that affect the same resources and/or receptors.
Denitrification	Microbial process of reducing nitrate and nitrite to gaseous forms of nitrogen. A large range of microorganims can denitrify.
Direct Use Value	The direct consumptive value that people derive from the use of ecosystem goods and services.
Ecosystem Service	The benefits that people, including businesses, obtain from ecosystems.
Environment	The external circumstances, conditions and objects that affect the existence of an individual, organism or group. These circumstances include biophysical, social, economic, historical and cultural aspects.
Environmental Impact Assessment	A process of evaluating the environmental and socio-economic consequences of a proposed course of action or project.
Environmental Impact Assessment Report	The report produced to relay the information gathered and assessments undertaken during the Environmental Impact Assessment.
Impact	A change to the existing environment, either adverse or beneficial, that is directly or indirectly due to the development of the project and its associated activities.
Indirect Use Value	The value that people derive from ecosystem services provided through the regulation of ecosystem functions.
Large Stock Unit	The equivalent of an ox with a weight of 450kg.
Non-use Value	The *intrinsic* value that people derive from the mere knowledge that an environmental resource exists.
Perennial (flow)	Flow is maintained throughout the year.
Sedimentation	Process of materials suspended in water settling by gravity.
Stakeholders	All parties affected by and/or able to influence a project, often those in a position of authority and/or representing others.

1. Introduction

The Papenkuils Wetland is located north of the Brandvlei Dam and south-west of Worcester, downstream of the confluence of the Breede and Smalblaar Rivers which bypass the wetland to the north under normal flow conditions (Harding, 2003). The Holsloot River, whose flow is regulated by the Stettynskloof Dam, drains into the wetland, while a diversion canal also redirects water from this river and the Smalblaar River into the Brandvlei Dam.

The Papenkuils Wetland provides habitat to a variety of terrestrial and aquatic plant and animal species, including at least seven International Union for Conservation of Nature (IUCN) red-listed plant species, and the under-conserved and Endangered Breede Alluvium Fynbos vegetation type. The wetland is therefore considered to be of high conservation value.

1.1. Purpose and Objectives of the Study

The Papenkuils Wetland is an excellent example of a wetland that provides tangible ecosystems services. However, anthropogenic impacts affecting the wetland, such as damming, river diversion, in-stream abstraction, groundwater abstraction, internal draining, grazing, agriculture and invasion by alien flora, have reduced the Present Ecological State (PES) of the wetland, and therefore the ecosystem service value of the wetland. Furthermore, the raising of a diversion weir on the Holsloot River by 30 cm, which would increase the volume of water diverted from the Holsloot River into the Brandvlei Dam and away from the wetland during winter, is proposed (Basson & Vonkeman, 2018).

Any further reduction in surface water inflows are expected to exacerbate impacts on the system and lead to its further deterioration, with a concomitant decline in the value of service provision by the wetland (Harding, 2003). The Western Cape Department of Environmental Affairs and Development Planning (DEA&DP) therefore seek to estimate the environmental value of existing ecosystem goods and services provided by the wetland, as well as the potential change in wetland ecosystem goods and services value (the environmental economic impact) of raising the diversion weir on the Holsloot River. The outcomes of the study will inform ongoing management of the resource, and assist DEA&DP to estimate the environmental cost of water diverted from the wetland.

To inform policy and management of the Papenkuils Wetland, DEA&DP seek to:

- Identify and characterise the Papenkuils Wetland function / ecosystem goods and services provided by the wetland;
- Assign value to these ecosystem goods and services;
- Develop an environmental shadow price for water (which may be diverted from the wetland); and
- Assess impacts on the wetland of the proposed increased diversion of water from the Holsloot River to the Brandvlei Dam (changes in the value of ecosystem service provided by the wetland).

To achieve these objectives, this study undertook the following Scope of Work (SoW):

- Describe the wetland, in terms of its main ecosystem drivers (through literature review, dry season in situ monitoring and surveys):

  a. Hydrological dynamics of the wetland;

b. Water quality and impact of the wetlands on water quality;

c. Hydrogeological interactions;

d. Geomorphology (including slope and wetland size);

e. Physical and chemical soil characteristics, including moisture;

f. Flora and fauna; and

g. Human disturbance to the wetland;

- Identify wetland ecosystem goods and services;
- Characterise and quantify ecosystem service provision levels for different water flow rates through the wetland;
- Value ecosystem goods and services and develop a shadow price for water entering or diverted from the Papenkuils Wetland;
- Recommend management measures for different portions of the wetland, for consideration in subsequent engagement with the community and stakeholders; and
- Assess the potential impacts on ecosystem services of the raising of the diversion weir on the Holsloot River.
- Ecological inputs have drawn closely on the findings of the hydrological and hydraulic component of this study (refer to Sections 2 to 6). The ecological, hydrological and hydraulic components of the study in turn inform the identification and valuation of the ecosystem goods and services provided by the wetland (refer to Sections 7 to 10.4), as well as potential implications of the proposed diversion.

1.2. Modelled Abstraction Scenarios

Three abstraction (or diversion) scenarios are considered in this report:

- **Existing Abstraction Regime:** comprising diversions from the Smalblaar into the Holsloot and from the Holsloot into the Brandvlei Dam. Currently the main contributions to the wetland are via the Holsloot River, which splits into a northern and southern stream on entry into the wetland;
- **Modified Abstraction Regime 1: Future Raised Holsloot Weir:** comprising a proposed 0.3m increase in the height of the operable weir, effectively increasing future extractions from the Holsloot River to the Brandvlei Dam when Holsloot discharges (flow) exceed 30 m^3/s (2.592 Mm3/day). In this report this is sometimes referred to as the "Future 1" scenario; and
- **Modified Abstraction Regime 2: Proposed Future Scenario:** This scenario comprises increased flows into the Papenkuils Wetland to prevent a long-term trajectory of degradation. It entails a reduction in diverted flows to the Brandvlei Dam, to allow for higher flows into the wetland. These reductions entail the transfer of 85% of flows below 30 m^3/s to the wetland and a 30% reduction of abstraction of high flows, as well as breaks in the northern and southern Holsloot berms to allow for discharge into the currently dry zone in the western end of the wetland. In this report this is sometimes referred to as the "Future 2" scenario.

See Section 6.2 for detailed descriptions of, and rules governing, scenarios.

1.3. Assumptions and Limitations

The outputs of this study are also subject to certain assumptions and limitations, which should be borne in mind when considering information presented in this report. The following important assumptions and limitations apply:

- The 2018 Land Cover mapping was used as a proxy for current conditions owing that insufficient land use data (including total areas) for each catchment were available. Satellite imagery and high-level verification during site work was, however, used to ensure that no significant changes had recently occurred within the catchments, that would have significantly differed from the NLC2018.
- It is assumed that areas of wetland that have already been lost to farmland and other uses and no longer contribute wetland ecosystems services, other than those (e.g. flood attenuation) that might be attributed by any areas of low-lying open space. This is an important assumption, as it affects the total area of extant wetland reported on in this study, and differs from the approach taken in (Kotze D. , An Assessment of the wetlands of the Upper Breede Valley , 2014), where historical wetland extent was included in mapped areas.
- The extent of the wetland versus the scale and constraints of the study – the Papenkuils Wetland is vast and warrants detailed long-term monitoring and assessment to gain a full understanding of ecosystem processes, links, drivers and hydrological thresholds. The current project allowed for a short-term assessment only, not for rigorous and detailed assessment and monitoring;
- The wetland is also, in places, accessible only with difficulty (e.g. dense stands of Palmiet), and this limited the extent of wetland exploration, and practical locations for the establishment of regular (rather than ad hoc) monitoring positions;
- The wetland comprises a complex mosaic of pools, channels, depressions and wetland flats, and high quality georeferenced aerial photography would be required to map these areas with a degree of accuracy: constraints meant that this important informant was lacking;
- Although non geo-referenced, extensive drone photography of the wetland would have assisted in wetland mapping, the location of the wetland near to an airfield precluded drone footage. Video footage of a section of the wetland was however donated by the Cape Winelands Biodiversity Reserve (see Table 1);
- Existing data for the wetland appear to be largely limited to a few once-off water quality assessments and botanical surveys, and ad hoc observations;
- Timing and duration of the study – the study commenced at the end of the wet season, and although such timing was adequate for the botanical characterisation, it did not allow tracking of annual hydrological cycles through a full annual cycle. This would have been invaluable in identifying flow pathways and linkages through the system; informing more detailed understanding of hydroperiod and monitoring of wetland fauna such as frogs and aquatic invertebrates;
- The short duration of the study, with data collection between late October 2020 and early January 2021 and reporting by mid-March 2021, meant that not only were data limited, but also there was relatively little time for inter-disciplinary engagement and interpretation of monitoring results;
- The commencement of the study at the end of the wet season meant that site selection and sampling had to be initiated at pace, without time for full site familiarisation, which might have

led to adaptation of the original sampling strategy and (sampling) site placement. As a result, some sites were added or alternatively discarded during the course of the monitoring period, which means that the dataset presented in this report is not equal for all sites.

- Given the project's limited duration and late wet season timing, existing literature, data and other information sources were drawn on as far as possible, to inform this assessment.
- Given the short time frames and other constraints, detailed biophysical surveys of the wetland were not practicable;
- Water quality (including natural isotope), soil moisture and water level data were collected over a 2.5 month period from the central transect, while the other transects were assessed less intensively, with the collection of ad hoc samples from water bodies within these areas, and visual assessment of wetland condition and flow pathways; and
- The present study did not have scope for detailed faunal assessment. There is limited literature and observations of the faunal species inhabiting the Papenkuils Wetland. This highlights the need for a more detailed investigations into the fauna of this wetland, particularly those whose habitats and/or life cycles are potentially more likely to be affected by changes in flow regime into the wetland (e.g. frogs; fish).

1.4. Approach to the Study

This first phase of the assessment included an initial assessment task, where the critical wetland features, plant communities and wetland function were identified in order to characterise ecosystem goods and services and focus the fieldwork and monitoring. Dry season fieldwork and monitoring was then carried out to characterise critical elements of the wetland: those elements most sensitive and most likely to be affected by changes to flow rates were prioritised for fieldwork and monitoring.

Water, nutrient and sediment inflows were also determined to model flow within and through the wetland by undertaking topology surveys, dry season soil and vegetation community surveys, and using state-of-the-art surface and subsurface physics modelling. Findings were then verified against historic records and *in-situ* monitoring. The hydraulic and hydrology model was then used to estimate the impact on wetland functioning from changes to inflows (e.g. from raising the Holsloot diversion channel).

Based on the initial assessment of wetland function and literature review ecosystem goods and services provided by the wetland were identified and characterised. An economic model was developed to estimate the environmental value of a) existing and b) future service levels of the wetland based on the hydraulics and hydrology model for the wetland developed as part of this study.

1.5. Stakeholder Engagement for the Study

Engagement for this technical study focussed on key public representatives and selected stakeholders actively engaged in matters associated with the Papenkuils Wetland.

The aims of engagement were to:

- Source the most relevant data for inclusion in the project and encourage the sharing of information; and
- Workshop the findings of the valuation with key stakeholders to obtain input.

Stakeholder engagement included the following key activities:

- Identifying key stakeholders and establishing a stakeholder database;
- Disclosing a brief Background Information Document (BID) to identified stakeholders and inviting initial input into the valuation process;
- Engaging the key authorities, institutional stakeholders and landowners listed in Table 1 on an ad-hoc basis; and
- Presenting the Papenkuils Wetland Ecosystem Services Assessment and Valuation Report to stakeholders. A number of local landowners as well as members of organisations involved with various aspects of the Papenkuils Wetland or its catchment were consulted during the course of this project. They are listed in Table 1.

Table 1: Stakeholders consulted for input into the study

Name	Organisation	Topic of engagement
Mr Pierre van der Merwe	Landowner	Understanding local channeled inflows into the wetland; site history
Mr Schalk van der Merwe	Landowner	Understanding local channeled inflows into the wetland; site history
Mr Etienne Wydeman	Manager: Holsloot Water Users Association	Management and offtake system for the Brandvlei Canal
Mr Rudolph Roscher	Land Care Manager: Western Cape Department of Agriculture	General information around land ownership, access, wetland and river rehabilitation and general background
Mr Ryno Pienaar	Western Cape Department of Agriculture	Introductions to landowners; site selection; access
Mr Hugo Viljoen	Landowner	Understanding local channeled inflows into the wetland; site history
Dr Karl Reineke	Southern Waters Ecological Research and Consulting	Understanding the gazetted RQOs for the Breede Catchment, and the treatment of the Holsloot River in particular
Ms Nancy Job	SANBI	GIS data for previous wetland mapping; general discussions
Prof Graham Kerley	NMMU	Influence of large mammals on wetland habitat formation
Mr Leon Janse van Rensburg	DHSWS	Operating rules for Brandvlei Canal – Holsloot River and Smalblaar River offtakes
Mr Dean Ollis	Inland waters	Application of Wet-Health Ver 2 to Papenkuils Wetlands
Mr Mark Heistein	Cape Winelands Biodiversity Reserve	Drone video footage of Transect B
Peter Keuck	Elsenburg: WCDA	Water Resources of Breede
Bertrand van Zyl	DWS	Water Resources of Breede
Elkerine Rossouw	BGCMA	Water resources of Breede
Rudolph Röscher	Cape Winelands District	Water resources of Breede
Mike Shand	Aurecon	Management of Brandvlei dam
John Roberts	DHSWS	Management of Brandvlei dam. Mitchells Pass Diversion

Name	Organisation	Topic of engagement
Ashton van Niekerk	DHSWS	Groundwater
Kezia Smith	DHSWS	Groundwater
Louis Bruwer	CEO: Central Breede River WUA	Mitchells Pass Diversion. Operation of Stettynskloof Dam

2. Papenkuils Ecological and Hydrological Introduction

2.1. Purpose and Objectives of the Ecological and Hydrological Components of the Study

This section of the report serves to present the outcomes and conclusions drawn from the 2020 / 2021 assessment of the Papenkuils Wetland, from the perspective of aquatic ecosystem function, importance, condition and hydrologic, hydraulic, sediment, nutrient and soil organic carbon responses. Likely ecological response to changes in the main wetland ecosystem drivers, are identified through these combined ecological, hydrological and hydraulic assessments. This will contribute towards an overall understanding and quantification of ecosystem function. The report also provides (limited) water quality data for the Holsloot and Breede Rivers up- and downstream of the wetland, facilitating evaluation of some of the non flow-related impacts also affecting wetland condition and river water quality. These include inflows of treated and untreated sewage effluent and other waste associated with urban developments up- and downstream of the site.

2.2. Scope of Freshwater Ecosystems and Hydrology Components

The combined freshwater ecosystems and hydrology components had the following scope:

Describe the wetland, in terms of its main ecosystem drivers, condition, hydroperiod, wetland units and sensitivity to changes in flow – this would be based on a combination of literature review, monitoring and site surveys, including the following aspects:

- Water quality;
- Soil moisture;
- Flora and fauna;
- Assessment of human disturbance to the wetland; and
- Input from the hydrological and hydraulic component of this study,
- Update the wetland boundary map;
- Undertake a WET Health assessment;
- Contribute to a discussion of the ecological implications of raising of the Brandvlei Canal ;
- Recommend management measures for different portions of the wetland, for consideration in subsequent engagement with the community and stakeholders;
- Develop a hydrological model of the wetland, based on simulated catchment inputs, transfers into and extractions from contributing rivers and an understanding of the wetland conceptual flow regimes, developed together with the ecological specialist;
- Use the hydrological model to develop sediment, nutrient and organic carbon responses to changes in the flow regimes; and
- Consider the potential impacts of raising the Brandvlei Canal.

3. Papenkuils Ecological and Hydrology Methodology

This section provides an outline of the approach and methodology used in the study.

3.1. Broad Approach

Given the short time frames and limited budget, detailed biophysical surveys or models of the wetland were not practical and, instead, the approach taken was to assess the wetland along three transects, focusing the most detailed assessment and monitoring at the central transect. The location of two of the transects (including the central transect) corresponded approximately with those of the botanical assessment reported in DWAF (2004), and were both included in a botanical characterisation assessment, carried out by a botanical specialist with a history of botanical assessments in this area, i.e. Helme (2007).

Water quality (including natural isotope), soil moisture and water level data were collected over a 2.5 month period from the central transect, while the other transects were assessed less intensively, with the collection of ad hoc samples from water bodies within these areas, and visual assessment of wetland condition and flow pathways.

Given the project's limited duration and late wet season timing, existing literature, data and other information sources were drawn on as far as possible, to inform this assessment.

A more detailed description of the approach taken to, and rationale for, all of the above components is outlined in the following sections. Note that the data derived from these approaches was common to both the ecological and hydrological / hydraulic assessments, and the methodologies outlined thus apply to both components.

3.2. Contributing Specialists

In addition to the core team included in this project, additional specialists were contracted to provide input into specific aspects of wetland function. The following specialists provided such input:

- Mr. Nick Helme (botanical specialist);
- Dr Eduard Hoffman (University of Stellenbosch, soil scientist); and
- Ms. Roanne Sutcliffe (SRK Consulting; hydrological modelling)

3.3. Definition of the Extent of the Core Study Area

At the inception meeting it was agreed that the focus of the study would be the Papenkuils Wetland as bounded by the Holsloot River to the north and west; the Breede River to the north and east and the Durban Road / Nekkies Bridge crossing over the wetland, at its downstream extent. The reason for this defined extent is that downstream of the bridge, the Breede River is channelised and incised, with the result that the remaining wetland, although included in some maps as part of the Papenkuils Wetland, is severely degraded. It was agreed that the wetland downstream of the bridge would be described and its condition assessed, but that the main effort of the study would focus on the wetland upstream.

3.4. Literature Review and Gathering of Existing Information

A number of ecological studies have been carried out on the Papenkuils Wetland over the past ± 20 years. Those sourced that were considered most pertinent to the current assessment are outlined below, although a full list of literature referenced in this study is included in the Reference section:

- Papenkuils Wetland Intermediate (Ecological) Reserve Determination (DWAF, 2003)- this report includes (desktop) recommendations for the ecological water requirements for the Papenkuils Wetland, in order to maintain it in its desired state or condition. The report includes the results of a once-off botanical survey of two transects across the wetland as well as a brief geohydrological report, contextualising the wetland in terms of its geohydrological linkages;

- An Assessment of the wetlands of the Upper Breede Valley (Kotze D. , An Assessment of the wetlands of the Upper Breede Valley, 2014) – this report includes the Papenkuils Wetland among those assessed, which were mapped (including dysfunctional areas) and described in terms of wetland condition and importance. GIS files for the Papenkuils Wetland as mapped in this study were sourced from Ms Nancy Job (SANBI) (see Table 1);

- Case Study of the Papenkuils Wetland (Hay, Kotze, & Breen, 2014) – this report considers the Papenkuils Wetland in terms of both regulatory and provisioning ecosystem services, as well as users of these services, such as harvesting of water blommetjies by local communities. It also provides a brief description of changes in the historical grazing and burning regimes in the wetland, over time;

- Papenkuils Wetland (Malan, Day, Ramjukadh, & Olivier, 2014) – this report comprises a comparison of the present day condition (Present Ecological State (PES)) and water quality of a number of wetlands that were previously assessed in 1988. Included among these is the Papenkuils Wetland, and the report provides once-off water quality sample results and a brief description of wetland condition and dominant plant species observed;

- Overview of the Brandvlei Project (Western Cape Department of Agriculture, 2018) - this brief report summarises the findings of various specialist technical studies, undertaken to assess the design and feasibility of proposals to raise the height of the Brandvlei Canal, and permit additional abstraction from the Holsloot River upstream of the Papenkuils Wetland. The report concludes that no Environmental Impact Assessment (EIA) would be required for this activity and that, subject to approval from the (then) Department of Water and Sanitation (DWS) (now Department of Human Settlement, Water and Sanitation (DHSWS)), there should be no impediments to the implementation of this proposal;

- Environmental Resources Protection Plan for the Breede River Catchment in the Western Cape (DEA&DP 2017) – Included in the report are descriptions of some of the point source pollution inflows into the Breede River up- and downstream of the wetland, including in the Worcester area;

- Atlas and red data book of the frogs of South Africa, Lesotho and Swaziland (Minter, et al., 2004) – this document presents grid data for records of different frog species distributions, which was used as a coarse study informant; and

- Case Study: Testing the draft set of Wetland PES tools on the Papenkuils Wetland in the Breede Catchment (Kotze D. , 2018)– this document includes an assessment of WET Health in the Papenkuils Wetland, carried out during testing of (the current) Version 2 of the WET-Health assessment tool. Land cover data presented in this report was used in the current study, and the assessment provided a useful reference for the WET-Health assessment carried out in this report, which did however differ slightly in terms of mapped disturbance units and approaches to extant versus lost wetland habitat (see Section 1.3).

None of the above reports included faunal assessments, although qualitative reference is made to the presence of fish, frogs, birds and small mammals in the wetland as a whole.

3.5. Maps and Aerial Imagery

Mapping of present and historical wetland extent and river alignment was undertaken using digitized aerial imagery from 1948 onwards.

3.6. Fieldwork and Sampling

3.6.1. Rationale for Sampling and Site Assessment

The literature review highlighted that, while a number of isolated and localised botanical assessments have been carried out in the Papenkuils Wetland, there is a general paucity of data relating to wetland hydrology, hydroperiod, soils, water quality and wetland fauna, and no studies have tried to sample or assess the wetland in terms of its mosaic of different flow paths, habitats, or longitudinal and lateral internal linkages. Fieldwork in the present study attempted at least to initiate the collection of some of these data, to inform the WET Health and wetland ecosystem services assessments, as well as ultimately to allow more accurate prediction of the ecological (and other) implications of the proposed raising of the Brandvlei Canal, as considered in Section 6.2.3 of this report.

3.6.2. Site Selection

Sampling sites comprised a combination of *ad hoc*, usually once-off samples, collected early in the study when the wetland was at its wettest, and there were extensive areas of inundation, as well as fixed point sites, from where samples were collected / measurements taken on a regular basis throughout the project. For the most part, these were located variously on three fixed (roughly) north-south transects (TA-TC), set up across the wetland from its southern edge to the Breede River in the north, as illustrated in Table 1. Table 1 also shows the locations of numbered sites along the transects, as well as ad hoc sample points and sites located up- and downstream of the core wetland.

The three transects were situated as follows:

- Transect A (TA): In the upstream (western) section of the wetland, with water sampling sites on the southern and northern arms of the Holsloot River, and on the Breede River;
- Transect B (TB): In the central to western part of the wetland, in an area roughly corresponding to the most westerly of the botanical transects described in DWAF (2003). This transect formed the focus of routine monitoring, with access across large areas of dense Palmiet (Prionium serratum) vegetation being a significant factor in determining the locations of sites along the northern half of the transect; and
- Transect C (TC): In the downstream (eastern) portion of the wetland, again in an area roughly corresponding to the most easterly of the botanical transects indicated in DWAF (2003) - water sampling sites were largely confined to channeled flow along the southern arm of the Holsloot River, the Breede River and other significant channels through this area.

Sites along the transects were selected so as to include all of the main channels through the wetland, and - in the case of TB - to include a range of additional wetland habitats characteristic of the transect, ranging from shallow depressions to wetland flats and secondary flood channels.

In addition to sites along the three transects, sample points were also established as follows:

- At the upstream extent of the wetland, on the Holsloot River upstream of Transect A ("Holsloot Inflow");

- At the downstream extent of the wetland, on the Holsloot River, downstream of Transect C, and before the channel merges with the braided channels of the (northern) Holsloot and Breede River ("Holsloot outflow");
- Downstream of the wetland, at the main road bridge crossing, upstream and south of Avian Park (a high-density residential area on the outskirts of Worcester, with a high proportion of informal settlement) (D1); and
- Downstream of inflows from the Avian Park area, and just upstream of the Hex River confluence (D2).

Inter alia, the latter four sites provide information regarding water quality up- and downstream of the wetland, allowing some interpretation of non flow-related impacts that affect river and wetland condition, and the contribution of the wetland itself to ameliorating water quality impacts in particular.

Table 2 summarises information about sample sites, showing site codes, their locations on different transects, or elsewhere in the wetland or its vicinity, and the parameters measured at each.

The following sections provide brief information regarding sampling protocols and key variables assessed.

Table 2: Summary information regarding transects, site codes, sample parameters and sampling frequency. Table colour-coded to indicate frequency of parameter measurement / collection:

X – monthly; X two-weekly; X – once-off or *ad hoc*; X – continuous logging downloaded two-weekly

Transect	Site code	Frequency of site visit	Water level	Water quality		Soil moisture	Continuous EC	Botanical assessment
				In situ	Sample			
A	A-1	Monthly		X	X			
	A-2	Monthly		X	X			
	A-3	Monthly		X	X			
B	*B-1	Two-weekly	X	X	X	X		
	B-1A	Two-weekly		X	X			
	B-1B	Two-weekly		X	X			
	B-2A	Two-weekly	X	X	X			X
	B-2B	Two-weekly	X	X	X	X		X
	B-3	Two-weekly	X	X	X	X		X
	B-4	Two-weekly	X	X	X	X		X
	B-5	Two-weekly				X		X
	B-6	Two-weekly	X	X	X	X		X
	B-7	Two-weekly	X	X	X	X		X
	B-8	Two-weekly				X		X
	B-9	Two-weekly	X	X	X	X		X
	B-10	Two-weekly				X		X
	B-11	Two-weekly	X	X	X			X
	**B-12	Two-weekly				X		X
	#B-6/7	*Ad hoc*		X	X			
	#B-3/4	*Ad hoc*		X	X			
	#B-2/3	*Ad hoc*		X	X			
	#B-7/9	*Ad hoc*		X	X			
	#B-Eleoch	*Ad hoc*		X	X			
C	C-1 - south	Monthly		X	X			X
	C-2 - north	Monthly		X	X			X
	C-3	Monthly		X	X			X
Downstream sites	D1	Monthly		X	X			
	D2	Monthly		X	X			
EC sites	Holsloot Inflow	Two-weekly		X	X		X	
	Holsloot Outflow	Two-weekly		X	X		X	

***** Soil moisture sampling discontinued at this site from December 2020 – the site was located on a dry, disturbed mound, and contributed little to an understanding of wetland function.

** Soil sampling commenced at this site from December 2020 – this site was set up in place of site B-1, in order to provide some data regarding the soil moisture properties of droughted wetland areas with high levels of invasion by *Seriphium plumosum* (slangbos).
 # Ad hoc samples

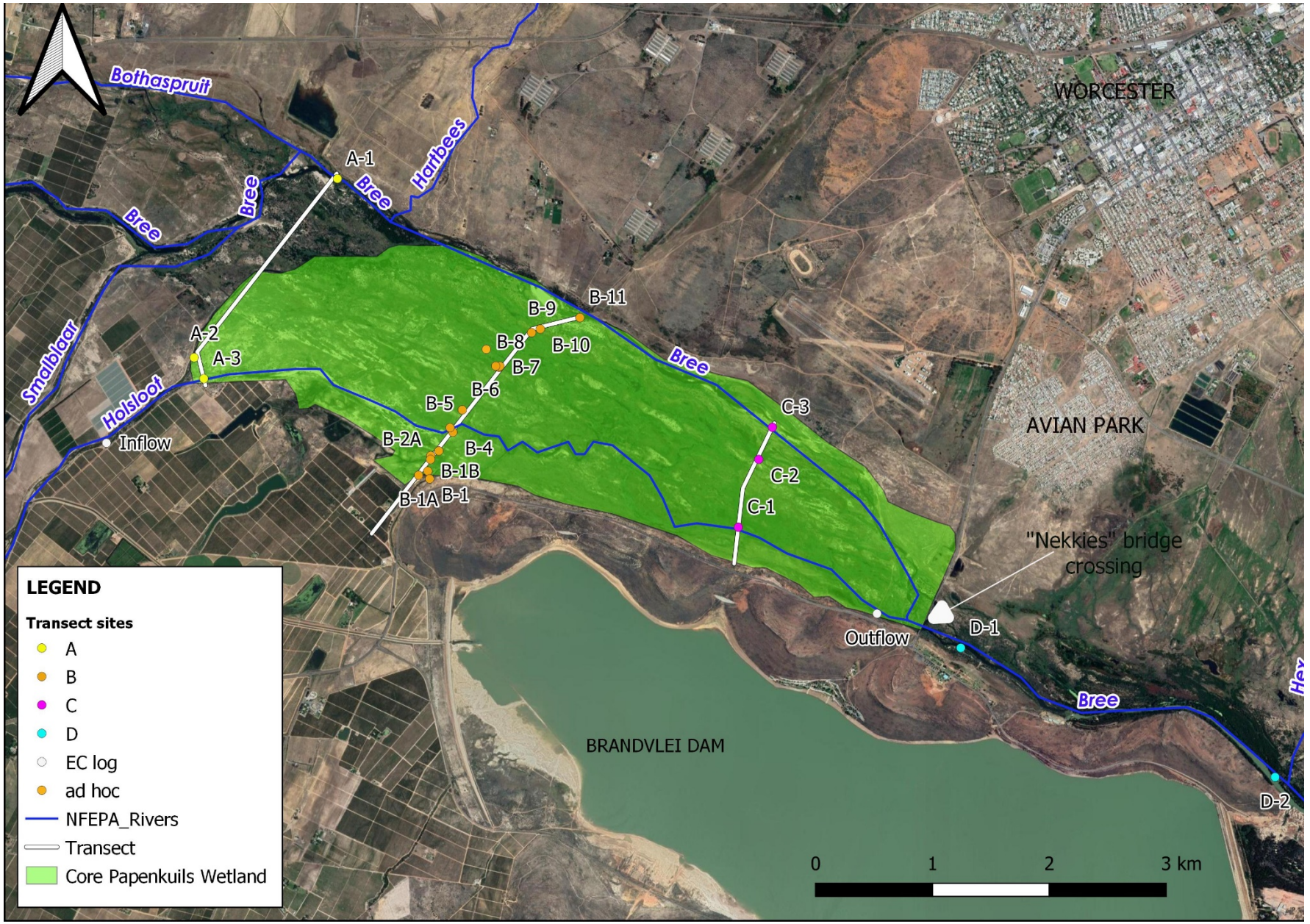

Figure 1: Map showing locations of transects A-C, and all routine sample sites, prefixed with the transect name where relevant.

3.6.3. Measurement of Water Level

Eight 55 mm piezometers[1] made up of slotted PVC piping were installed along Transect B at depths between 56 and 102 cm below surface level, depending on the depth of hole collapse. The piezometer tops were closed with PVC caps, to prevent contamination.

The depth of the water table was measured on a fortnightly basis in each piezometer.

3.6.4. Water Quality Sampling and Chemical Analyses

In *situ* measurements of pH[2], Electrical Conductivity (EC), temperature, dissolved oxygen (DO)[3] and Oxidation-Reduction Potential (ORP)[4] were taken during site visits, at routine and *ad hoc* sample sites, using calibrated meters.

Water samples for laboratory analysis were collected each month from sample sites, variously comprising:

- Selected open water channels and pools; and
- Piezometers established along Transect B (see Section 3.6.3).

Water samples were analysed as follows:

- Major nutrients:
- Nitrate nitrogen (NO_3-N) and soluble reactive phosphorus (SRP) (PO_4-P) concentrations were measured using a HACH DR900 Multi-Parameter Colorimeter[5];
- Stable isotopes[6]:
- Stable isotopes of oxygen (^{18}O and ^{16}O) and hydrogen (^{2}H and ^{1}H) are expressed as a ratio between the heavier isotope to the lighter isotope ($^{18}O/^{16}O$ and H^2/H^1), relative to the ratio of a standard (Vienna Standard Mean Ocean Water – VSMOW) and so are presented as the abundance of the heavier oxygen and hydrogen isotope relative to the standard, with the result expressed as parts per thousand ($\delta^{18}O$ (‰); and $\delta\,^{2}H$ (‰)). Differences in the relative abundance of the heavier stable isotopes between samples can provide useful information regarding surface and groundwater interactions, and the origins of different water sources, with typical sources such as rainwater, rivers and groundwater usually having discrete isotope signatures, as a result of their different histories of rainfall source, evaporation from open water bodies and enrichment or depletion during infiltration through the soil and rock. For instance, water subject to

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[1] Piezometers allow water sample collection as well as measurement of water table depth – sub-surface water enters the pipes through narrow slots cut at intervals of about 1.5cm in the lower third of the pipe. It equilibrates at the level of the water table. The depth to water table can be measured using a tape measure or dip meter.
[2] pH and EC meter: Hanna H19811-5.
[3] Temperature and DO meter: Hanna H19146.
[4] ORP meter: H198121.
[5] NO_3-N and PO_4-P concentrations were measured using programmes 353N Nitrate MR PP and 490P React PP respectively.
[6] Water samples for isotope analysis were shipped to University of KwaZulu-Natal, Pietermaritzburg (UKZN) and analysed by the Centre for Water Resources Research (CWRR), Soil and Water laboratory, using a Los Gatos DLT100 Liquid Water Isotope Laser Analyser.

significant evaporation usually have higher proportions of the heavier isotopes (^{18}O and ^{2}H) and fall along an evaporation line defined by the relationship between the delta values ($\delta^{18}O$ and $\delta^{2}H$).

3.6.5.Soil Profile Sampling and Analyses

Soil profiles were sampled at each fixed point monitoring site along Transect B, using a hand auger to excavate soil cores, until the point of hole collapsed under saturated conditions. Soils within the extracted cores were visually separated into different (measured) sections, based on soil colour, texture and degree of mottling.

Samples were subsequently analysed at the Soil and Water lab of the CWRR at UKZN for the following parameters, used to inform the hydraulic model:

- Particle size analysis;
- Water retention characteristics; and
- Saturated hydraulic conductivity.

3.6.6.Continuous Monitoring of Electrical Conductivity

Two probes, coded in this report as "EC Upstream" and "EC Downstream", measuring EC, Water Pressure (WP – converted to water depth in post processing) and Temperature (T), were bolted to two large rocks, and installed in the Holsloot River channel upstream of, and near the downstream extent of the Papenkuils Wetland, respectively. The probes, WW5000-TDCS[7], comprise epoxy sealed sensors. They were set to record EC, WP and T at 15 minute intervals. Data were downloaded from each site during routine sample collections, by BlueTooth connectivity to a hand-held Base Station located on the river bank during the connection period. Data were then sent to the cloud via cellular phone connectivity, once the base station accessed a cellular phone signal. Data was then be downloaded from the cloud.

3.6.7.Soil Moisture Monitoring

The piezometers described in Section 3.6.3 allow monitoring of free standing water, but do not provide information regarding longer-term relative moisture availability in the wetland, which might be of importance in determining habitat suitability for different plant communities.

As a result, ten, 52 mm (internal diameter) PVC access tubes, closed at the bottom with a PVC cap, were installed along Transect B, to monitor soil moisture. These tubes were installed close to the water level piezometers where practicable, so that water level and soil moisture data could be readily linked.

Access tube installation was carried out using a hand auger. Each tube was inserted to a depth of one metre, unless underlying soils precluded penetration to such a depth (e.g. Site TB-10). All the access tubes were closed at the top with a cap.

[7] Probes manufactured by Wireless Wildlife (Potchefstroom, South Africa).

Soil moisture readings were measured with a Sentek Diviner 2000 capacitance probe[8]. The instrument consists of a small data logger connected to a probe, which is inserted into the access tube and which takes measurements at 100 mm depth intervals, as the instrument is lowered into the access tube. Three replicate readings are taken at each access tube. Soil moisture readings were taken at approximately two weekly intervals.

The output of the Sensor is in volumetric water content (mm water per 100mm of soil), converted from a scaled frequency using a default calibration equation. Further accuracy is enabled by specific calibration of the instrument to each access tube, performed on site, after installation.

Volumetric water content was converted to an estimated soil saturation percentage, by dividing soil water content by the maximum soil water content recorded under known saturated conditions, i.e. submerged.

3.6.8. Botanical Assessment

Specialist botanical input into the project was provided in the form of a site characterisation report, focusing on Transects B and C[9]. This input was informed by a site visit on 27 October 2020, designed to meet the terms of reference, in order to:

- Identify dominant and characterizing plant species at each site along Transect B, and along a continuum for Transect C;
- Highlight rare or unusual species;
- Describe the botanical importance of the wetland; and
- Comment on likely ecological drivers of plant communities.

The full botanical assessment has been attached as Appendix A.

3.6.9. Sampling Frequency and Dates

As indicated in Table 2, samples were collected / different sampling parameters were measured at frequencies of approximately two to four weeks, depending on the variable in question.

[8] Sentek sensors are based on capacitance technology. Technical information derived from the Sentek Technical Information sheets describes the measurement process as based on a high frequency radio wave (1GHz), which is emitted by sensors in the probe, and which extends through the access tube into the surrounding soil. The sensors detect changes in dielectric constant or permittivity of the soil over time. At high frequency, the measurement is affected mainly by water molecules. The greater the amount of water, the smaller the frequency measured by the Sensor.

[9] Transect A is highly disturbed, mainly as a result of changes in hydrology, and was not considered a useful focus for the botanical assessment.

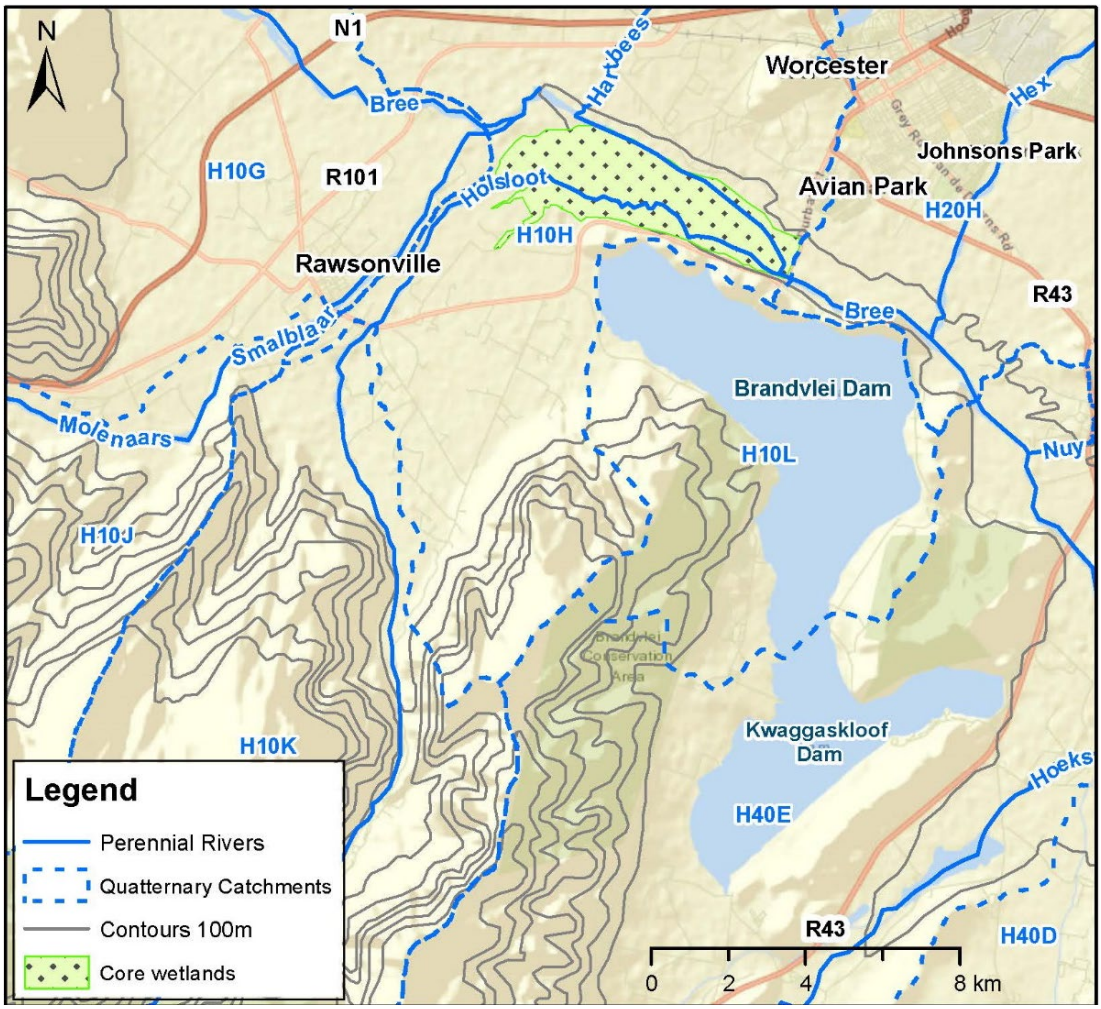

Figure 2: Map showing Papenkuils Wetland (green polygon) in quaternary catchment context. Map adapted from Cape Farm Mapper https://gis.elsenburg.com/apps/cfm/, produced by Sub-Directorate Spatial Information Management, DEA&DP, Western Cape Government.

4. Regional Ecological and Hydrological Context and Historical Perspective

4.1. Wetland Location

The Papenkuils Wetland (also referred to in various reports as Nekkies Wetland (Kotze D. , 2014) and the Bokkekraal Wetland (Malan, Day, Ramjukadh, & Olivier, 2014)) is located between the Western Cape towns of Worcester and Rawsonville, just north of the Brandvlei Dam. The wetland is large, with the extant portion considered in this study being some 6.6 km long (roughly west to east) and 1.6 km wide (north to south) (see Figure 2).

4.2. Catchment Context

The Papenkuils Wetland lies in the DHSWS' Breede-Gouritz Water Management Area (WMA), within quaternary catchment H10H (Figure 2). This quaternary includes runoff from the lower reaches of the Holsloot River, the Hartbees River and the Breede River upstream of the Worcester- Rawsonville road crossing over the lower reaches of the wetland (Durban Road), referred to as the Nekkies Bridge crossing (Figure 1). Note that the Breede River is also referenced in some maps and spatial datasets as the Bree River, while early literature refers to the Holsloot River as the Waterkloof River (Burman, 1970).

Surface waters feeding into the Papenkuils Wetland comprise primarily the Holsloot River, which drains the southern slopes of the Du Toitskloof Mountains and the northern slopes of the Stettynsberg Mountains to the south west. The upper reaches of the Holsloot River are impounded, forming the Stettynskloof Dam, which supplies both domestic and irrigation water to downstream water users. Water is also abstracted further downstream, in the river foothills, for additional irrigation scheme supply, with a new weir currently under construction. While the upper reaches of the Holsloot River are in relatively good condition (Day 2016 and Southern Waters 2008), the lower foothill reaches are highly degraded, with extensive channelisation, bulldozing of the river bed and loss of most indigenous riparian vegetation. These reaches flow through areas of intensive agriculture, comprising mainly vineyards. On the farm Pokkraal, which includes parts of the Papenkuils Wetland, the river splits into two major channels, the most southern of which passes immediately into the Papenkuils Wetland while the northern arm continues in a straight (channelised and bermed) northerly direction, before swinging north east and entering the Breede River along the north-western boundary of the Papenkuils Wetland. The Smalblaar River, comprising the combined flows of the Molenaars River and the Tierstel River, flows just west of the northern arm of the Holsloot River, and passes into the Breede River just upstream of the Papenkuils Wetland. The Breede River itself makes up the northern boundary of the wetland, and during flood conditions, overflows into the wetland to the south (Figure 2). Note that a diversion system on the Smalblaar River just downstream of Rawsonville diverts between 44 m^3/s and 48 m^3/s into the Holsloot River when the Holsloot River has capacity for these flows (e.g. when the Stettynskloof Dam is not releasing water into the Holsloot River). The Smalblaar-Holsloot diversion channel lies some 440m downstream of a waste water treatment works (WWTW), which discharges effluent into the Smalblaar River.

Flows from the seasonal Bothaspruit and Hartbees Rivers enter the Breede River from the north, just upstream of the wetland.

The Breede River in these reaches is known as the Middle Breede. Along with the Holsloot, Hartbees and Smalblaar Rivers, it is a so-called "working" river (Department of Water and Sanitation (DWS), 2020), flowing through predominantly agricultural areas, with high irrigation demands. Salinity, exacerbated by irrigation return-flows, limits the fitness for use of Breede River water for irrigation in the downstream river reaches (Department of Water Affairs and Forestry (DWAF), 2000).

4.3. Historical Perspective

4.3.1. Overview of Wetland Extent and Connectivity

Figure 3 shows the extent of the Papenkuils Wetland today, overlain with historical wetland extent, as determined by Kotze (2014) on the basis of mapping off the earliest available aerial photography of 1948. The figure shows extensive encroachment in to the wetland mainly by agriculture and associated land use (dams, roads, pastures etc.), but retention of the core wetland area.

The wetland under natural conditions was probably typical of many wetlands in the middle[10] Breede River Catchment, with its wide alluvial valleys that favoured the formation of alluvial fans in several of the rivers feeding into the Breede River in these reaches, including the Holsloot River (Kotze D. , An Assessment of the wetlands of the Upper Breede Valley, 2014).

The Papenkuils Wetland itself is likely to have formed largely from water backed up upstream of the narrowing of the Breede River Valley, as shown in the contours in Figure 2 - natural narrowing of the river valley would have promoted lateral spread of flood flows in the wide alluvial valley upstream, with the Holsloot and Smalblaar Rivers forming a broad alluvial fan, fed by flows from their steep mountain catchments.

This would have promoted the settlement of organic debris and fine sediments likely to promote the creation of conditions suitable for extensive wetland formation, coupled with shallow subsurface and groundwater flow linkages. Papini (2003) describes the role of surface and groundwater flows in wetland formation, noting that the naturally meandering Holsloot River in these alluvial reaches produces linear "shoestring" sand bodies that are aligned parallel with the direction of the river course and bounded below and on either side by fine sediments. The coarse sands provide preferential flow paths for groundwater while the fine sediments maintain surface water in the floodplains. These deposits may be underlain by clay sheets at depths of about 2m below the surface, which would account for rapid draw-down of the wetland after inundation and limit the rate of discharge from the alluvial channels into the floodplains (Papini, 2003).

[10] Note that Kotze (2014) refers to this section of the Breede River as the upper Breede; the later gazetted RQOs for the Breede -Gouritz Catchment (DWS 2020) show this section as the middle Breede, and it is referred to as such in this report

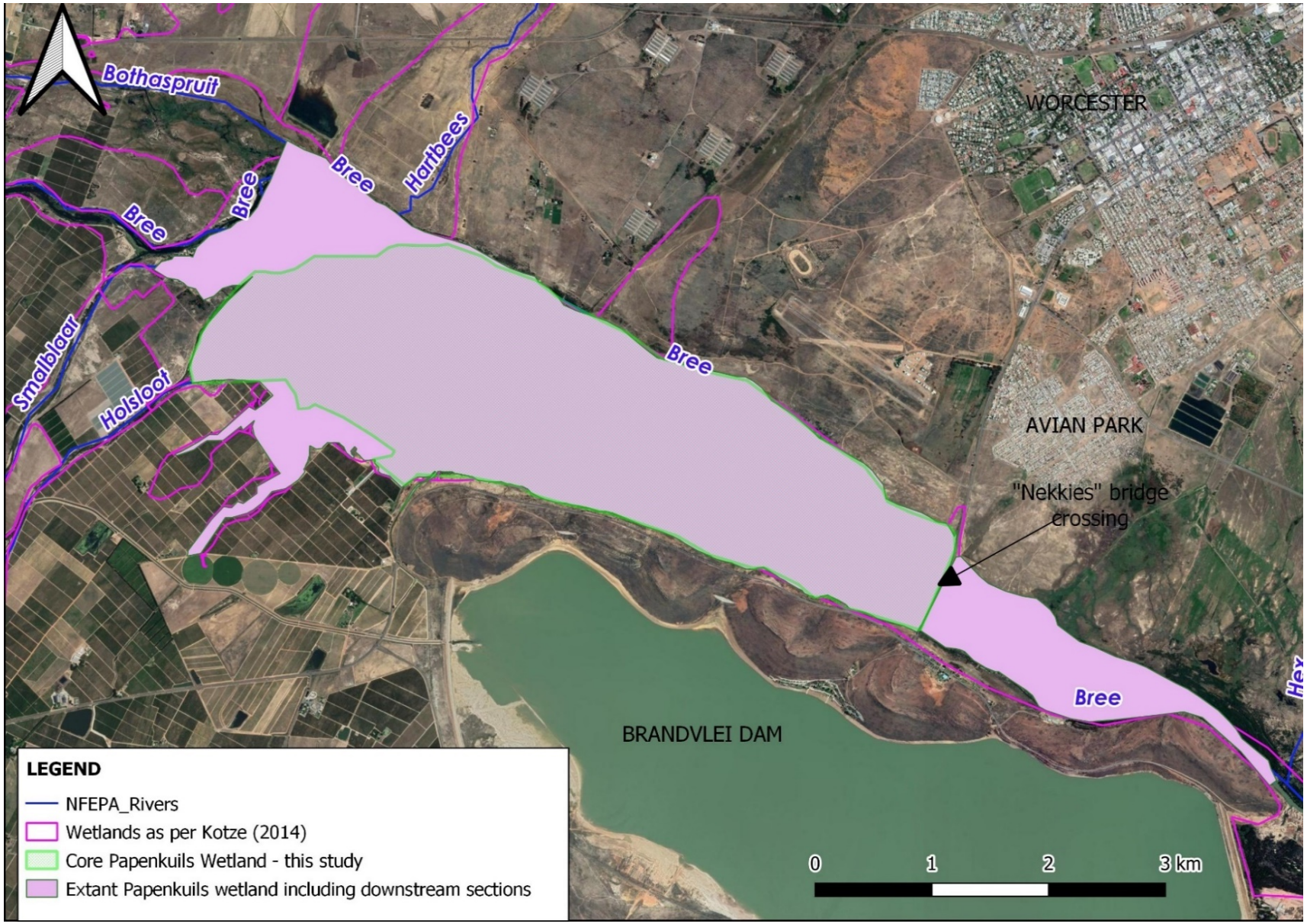

Figure 3: Map showing the Papenkuils Wetland as assessed in this study, in relation to mapping of original (broader) wetland extent shown in Kotze (2014) and including area of extant but degraded wetland outside of the core wetland assessed in this study.

4.3.2.Historical Wetland extent and Hydrology

Figure 3 also shows the extent of the Papenkuils Wetland as mapped during the present study, which focused on existing functional wetland extent, overlain with wetland extent as mapped in Kotze (2014)'s study, which included both extant wetland and the assumed natural extent of wetland in the area, much of which has now been subsumed by the encroachment of agriculture. The figure shows extensive loss of wetland along the Holsloot and Smalblaar River areas, as well as the main tributaries of the Breede in the vicinity of the study area.

In order to understand conditions in the wetland under more natural (i.e. "reference") conditions, Figure 4 shows the broader study area as depicted in a 1948 aerial photograph, this being the earliest aerial imagery available. Although there was already significant development in the area by then, the wetland itself was less disturbed than today and the figure can be used to illustrate the following key points about wetland hydrology:

- The Holsloot River comprised multiple channels that spread out in a wide alluvial fan, upslope of the Papenkuils Wetland;
- The northern and southern channels of the Holsloot River split upstream of the wetland, with the southern channel meandering as a well-defined narrow channel along the southern part of the wetland, while the northern channel meandered north, before turning east and braiding out into multiple wide vegetated channels and pools;
- The eastward swing of the northern Holsloot appears to be driven in part by inflows from the (also braided) Smalblaar River channels, which appear to link with the Holsloot and force flows east and roughly parallel with the Breede River;
- The Breede River flowed along the northern wetland boundary, and was associated with large expanses of sandy dunes and sand bars, which still characterise the river in these reaches today;
- The northern part of the wetland, comprising the Breede, Smalblaar and northern Holsloot Rivers is shown in the aerial photograph as densely vegetated with poorly defined channels and multiple wide areas, assumed to be the deep wide pools in the area today;
- The southern part of the wetland, between the northern Holsloot and the southern wetland boundary, and including the southern Holsloot, appears flatter and more homogeneous in the photograph, with broad flat floodplains;
- Parts of the flows in the southern Holsloot do break away from the main channel and spread out north, joining with flows from the northern Holsloot; and
- Although agriculture was already widespread in the area, the extensive wetlands along the Holsloot and Smalblaar alluvial fans and the Breede River confluence were still evident at this time.

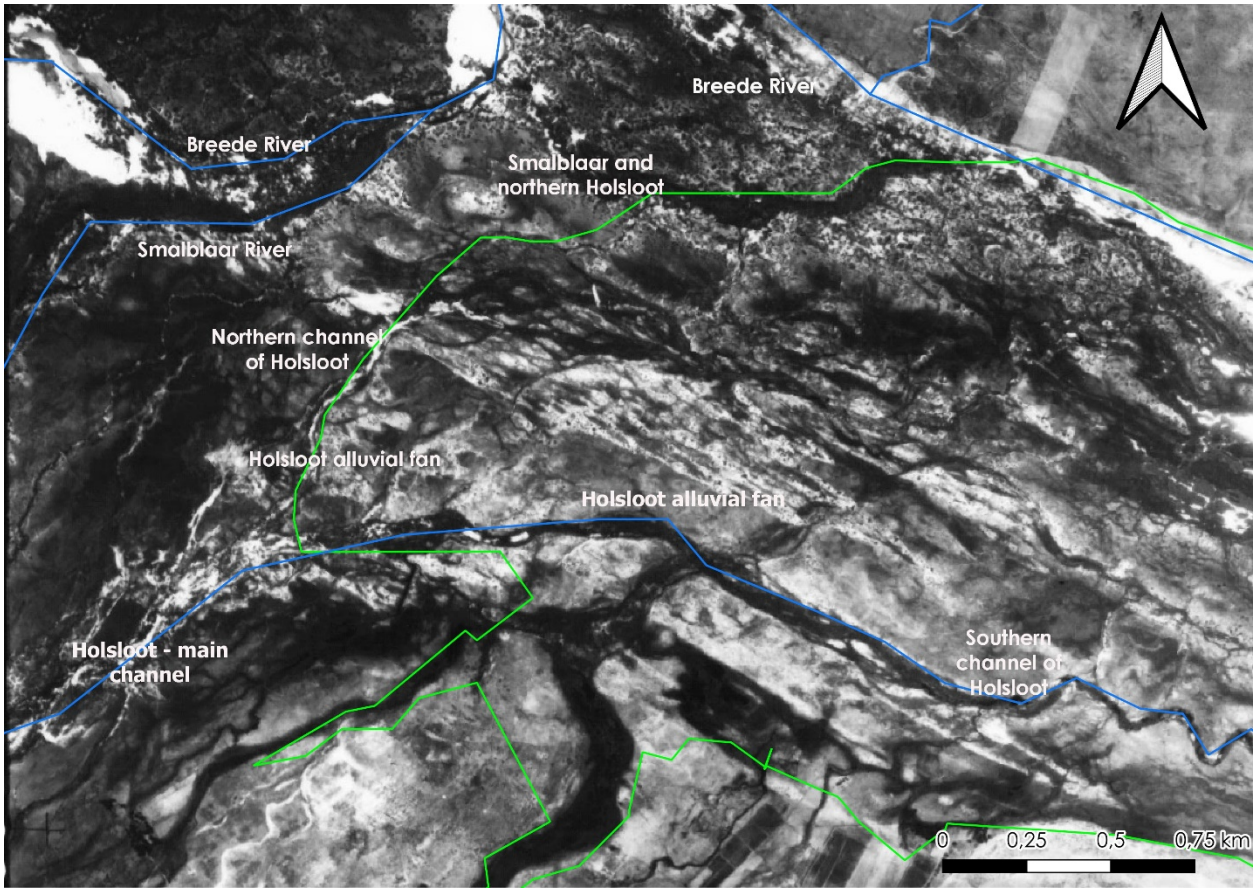

Figure 4: 1948 aerial photograph of the Papenkuils Wetland area.

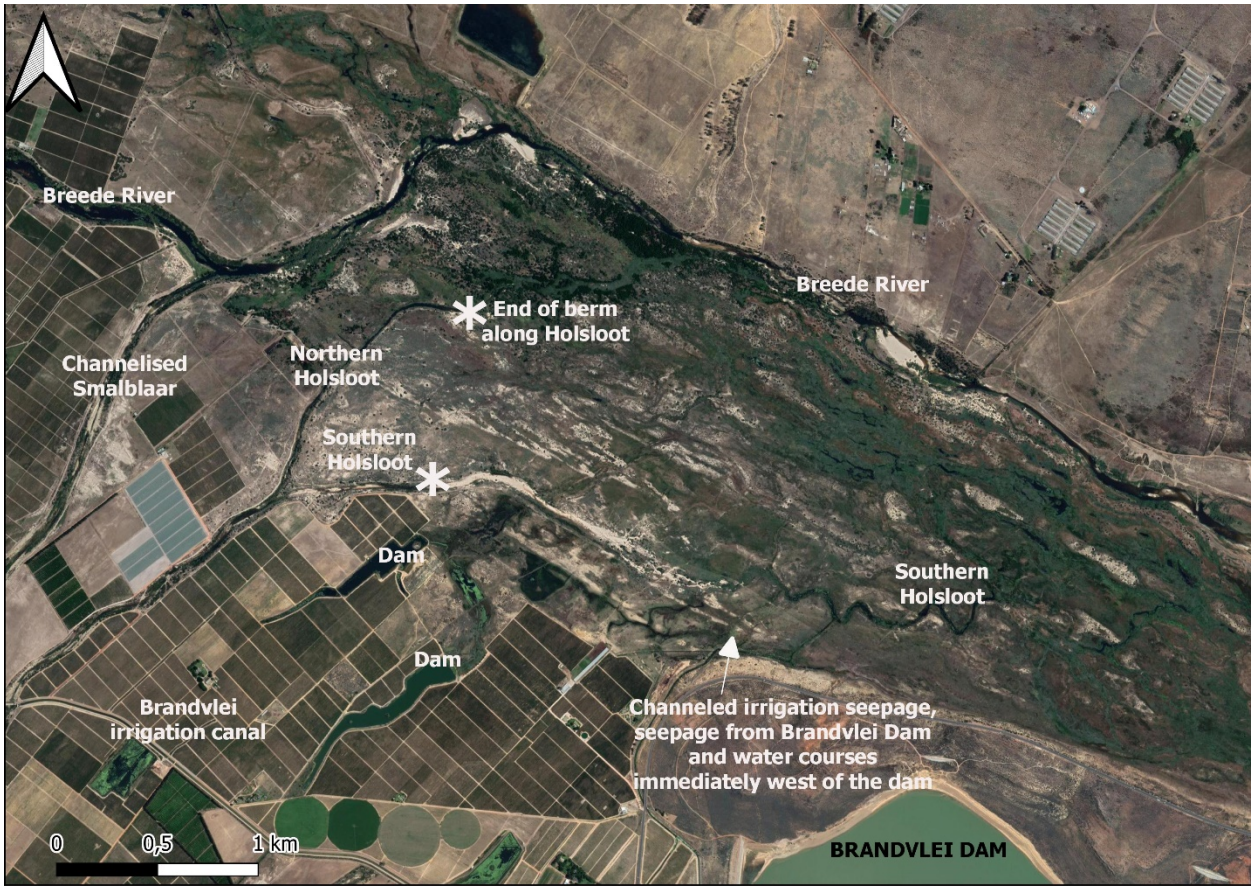

Figure 5: 2019 aerial photograph of the Papenkuils Wetland area.

Not evident in Figure 4 but already constructed at the time were the irrigation canals conveying flows from the Holsloot and Smalblaar Rivers upstream and south of the Papenkuils Wetland to the off-channel dam (then named) Lake Marais, which was enlarged in 1950 to form the Brandvlei Dam (Burman, 1970).

The flow regime in and through the wetland has changed considerably today, as described in subsequent sections, and evident in Figure 5.

4.3.3.Role of Large Mammals in Wetland Formation and Maintenance

Figure 6 and Figure 7 show an example of the large Palmiet (*Prionium serratum*) -dominated deep pools, separated by shallow channels in the north eastern section of the wetland. Given the flat braided nature of the wetland (Cape Farm Mapper (https://gis.elsenburg.com/apps/cfm/) indicates a 5m vertical drop over the 6.3 km length of the wetland between the northern channel and the Nekkies bridge, amounting to a gradient of some 0.07%, it is unlikely that these deep pools were created by scour under flood conditions. It is however more likely that they were created as wallows by large mammals, which are likely to have inhabited the wetland prior to the onset of intensive agriculture, hunting and associated densification of human settlement during the colonial era. Burman (1970) notes the presence of hippo in the Breede River in these reaches, in 1676, and it is likely that the extensive wetlands of the Papenkuils Wetland would also have supported these animals. Both hippo and elephant are known to be active habitat modifiers, and large enough to maintain large wallow pools in permanent wetland areas.

Since these large mammals have probably been absent from the wetland for at least 200 years, the question of long-term wetland habitat sustainability in the absence of disturbance by large mammals must arise.

Figure 6: Deep standing water pool in the Papenkuils Wetland – December 2020

Figure 7: Shallow channel linking to deep pool in Figure 6 – December 2020

4.3.4.Role of Fire in Wetland Maintenance

Today, the wetland is periodically burned, with fires sometimes thought to be accidentally started in the lower wetland, by local sellers of water blommetjies (*Aponogeton distachys*), the

buds of which are cooked as a traditional delicacy. Stacked piles of cleared alien vegetation[11] can also contribute to fuel loads and hotter fires. Although hotter and more frequent fires may reduce plant species diversity in the wetland and threaten peaty soils[12] potentially located within some sections of the Palmiet reedbeds, cool fires do play a role in preventing wetland senescence and the build-up of dead organic plant material in the wetland, which would ultimately change wetland function and form.

Prior to colonial settlement and the expansion of agriculture and dense human settlement in the area, the wetland would have been subject to periodic burning by lightning-triggered fires. In addition, it is likely that pre-colonial people living in the area also burnt the wetlands and surrounding areas fairly regularly (Hay, Kotze, & Breen, 2014). These authors note that hominids may in fact have been influencing the incidence of fire in the Breede Valley for over a million years, by burning to improve grazing and thus attract game for hunting; and later, to improve grazing for livestock

4.3.5. Role of Grazing in Wetland Maintenance

Boshoff and Kerley (2003) note that elephant, black rhinoceros, bushpig, red hartebeest, common duiker, grysbok, grey rhebok and eland were all likely to occur in the area included in the present study area (Boshoff & Kerley, 2001), and would have contributed to the maintenance of wetland areas by ongoing removal of vegetation. Hay et al. (2014) noted that grazing probably prevented the establishment of dense stands of fluijties ried (*Phragmites australis*) reedbeds in the wetland. These reeds, which form monospecific stands in many large, particularly disturbed wetlands in the Central Breede River Valley (and many other areas), are relatively patchy in the Papenkuils Wetlands, and appear to be out-completed by other wetland plants including Palmiet (*Prionium serratum*) and *Pennisetum macrourum*.

In pre-colonial times it is however also likely that indigenous hunters and herdsmen grazed their livestock through the wetlands and Hay et al (2014) note that it is likely that In the absence of indigenous grazers, grazing by cattle and horses could, to a reasonable extent, simulate their effect.

At the time of the present study, parts of the southern wetland were grazed, and displayed distinct differences in vegetation, between grazed and ungrazed/ less grazed areas (see Section 4.5). Distribution of alien propagules in livestock manure is also a possibility, and problem species such as bramble (*Rubus* spp.), are established in more disturbed parts of the wetland, prone to grazing and the movement of cattle.

4.4. Changes in Surface Flows into the Papenkuils Wetland

Figure 5 shows the Papenkuils Wetland as depicted in 2019 aerial imagery. Compared with Figure 4, the figure illustrates extensive changes in wetland hydrology, and expansion of vineyards / other agriculture along the Holsloot and Smalblaar Rivers, with the rivers themselves being straightened and bermed in places. The following are the main changes in the passage of surface flows into and past the Papenkuils Wetland:

[11] Discussions with Mr Schalk van der Merwe (Merwida Wines: Papenkuils landowner) indicate that cut wood is now chipped when possible, to reduce fuel loads.

[12] Note that no peaty soils were found in the current study and the extent of real peat soils is likely to be limited in this wetland dominated by riverine flows.

- Management of irrigation demand for agriculture in the Central Breede Valley by *inter alia* formalisation of the system of irrigation canals that convey water to the (now enlarged) Brandvlei Dam for summer irrigation – water is conveyed to the dam via the concrete Brandvlei Canal, which has an offtake system from the channelised Holsloot River, upstream of the north/south channel split. Water is abstracted from elevated winter flows, sometimes including the full run of river flows, until the canal and dam are full (note that in fact the Brandvlei Dam can only be filled by the canal to 73%, as a result of the level differential between the canal and the dam water level (Western Cape Department of Agriculture, 2018). Once the dam is as full as these levels allow, river flows continue along the Holsloot River. The northern channel has a slightly lower elevation than the southern channel and is maintained open by periodic excavation and vegetation clearing. As a result, summer flows continue along the northern channel longer than they do along the southern channel;

- The Holsloot River upstream of the Brandvlei Canal offtake receives 44 – 48 m^3/s flows from the Smalblaar River, when the former has capacity for these flows, without risking flood damage to the Brandvlei Canal or surrounding farming areas. Following late season storms in the catchment, the Brandvlei Canal may be opened for short periods to allow additional flows into the Brandvlei Dam. Alternatively, these flows from the Smalblaar River continue to the Breede River and, depending on flows in the Breede River at Le Chasseur Weir downstream of the site[13], might present an opportunity to be pumped into the Brandvlei Dam downstream of the site, at the Brandvlei Pump Station just downstream of Nekkies Bridge;

- Straightening and berming of the northern Holsloot channel, so that water no longer passes into the north-western portion of the wetland via braided minor channels from the natural alluvial fan, but remains in the Holsloot channel until just upstream, of the confluence with the Breede River;

- Berming and straightening of the upper reaches of the southern Holsloot, allowing expansion of agriculture on the southern side of the channel, but causing droughting (i.e. drying out) of the wetland downslope, to the east;

- Excavation and formalisation of impoundments formed where the water table is perennially high on the farm to the south of the wetland – these impoundments are used for irrigation;

- Channeling of water seeped from the Brandvlei Dam wall, from irrigation of agricultural areas south of Durban Road (the road between Rawsonville and Worcester, that crosses the wetland at Nekkies), and from parts of Pokkraal Farm, abutting the southern edge of the wetland – these channels converge on the southern boundary of the wetland, and the bulk of flows are conveyed via an extended unlined trench into the southern Holsloot River, while the rest dissipate with distance along the wetland margins;

[13] The Ecological Reserve for the Breede River requires however that minimum maintenance flows of 5 m^3/s must be allowed for in the Breede River, as measured at the Le Chasseur Weir downstream of the study area. When flows in the river at this site exceed 5 m^3/s, then additional water may be pumped from the Breede River, via pumps at the Brandvlei Pump Station, located just downstream of the Nekkies Bridge. Three pumps at this pump station, with a capacity of 2.3 m^3/s each, can pump water from the river. Thus late-season storm events that produce sustained elevated flow in the river may also be tapped into to add to water stored in Brandvlei Dam (notes from discussions with Mr Leon Janse Van Rensburg; DHSWS).

- The introduction of berms at the downstream end of the wetland upstream of the Nekkies Bridge; to force flood flows under the relatively narrow bridge; and
- Concentration of flows from the braided Holsloot and Breede Rivers at the bridge, to form a single incised channel, within which water now generally flows well below the level of the surrounding wetland, which has degraded as a result.

4.5. [14]Botanical Context

4.5.1. Regional Context

The study area is part of the Southwest Fynbos bioregion (Mucina & Rutherford, 2006) and is part of the Fynbos biome, located within what is now known as the Core Region of the Greater Cape Floristic Region (GCFR) (Manning & Goldblatt, 2012). The GCFR is one of only six Floristic Regions in the world, and is the only one largely confined to a single country (the Succulent Karoo component extends into southern Namibia). It is also by far the smallest floristic region, occupying only 0.2% of the world's land surface, and supporting about 11 500 plant species, over half of all the plant species in South Africa (on 12% of the land area). At least 70% of all the species in the Cape region do not occur elsewhere, and many have very small home ranges (these are known as narrow endemics). Many of the lowland habitats are under pressure from agriculture, urbanisation and alien plants, and thus many of the range restricted species are also under severe threat of extinction, as habitat is reduced to extremely small fragments. Data from the nationwide plant Red Listing project indicate that 67% of the *Threatened* plant species in the country occur only in the southwestern Cape, and these total over 1 800 species (Raimondo, et al., 2009). It should thus be clear that the southwestern Cape is a major national and global conservation priority, and is quite unlike anywhere else in the country in terms of the number of *Threatened* plant species.

The Southwest Fynbos bioregion is characterised by relatively high winter rainfall, strong rainfall gradients, poor, sandy soils, high topographic diversity, and large urban areas and high levels of alien invasive vegetation. Due to this combination of factors the loss of natural vegetation in this bioregion has been severe (>60% of original extent lost within the region), and the bioregion has a very high number of Threatened plant species (Raimondo, et al., 2009). The lowland regions have been particularly heavily impacted, particularly by cultivation, alien plant invasions and urbanisation.

4.5.2. Vegetation in the Study Area

According to the SA Vegetation Map the original natural vegetation in the study area is *Cape Lowland Freshwater Wetland* (Mucina & Rutherford, 2006), but this is a highly variable vegetation type covering numerous different habitats, and very little of the variation found in the study area is described by this broad category. In reality some of the elements on site are perhaps better treated as *Cape Lowland Alluvial Vegetation*, particularly those elements responding to the richer soils, probably derived from the underlying shales. The better drained acid sands are best treated as *Breede Sand Fynbos*, a threatened habitat restricted to the middle Breede River Valley.

[14] This section has been extracted from the specialist botanical report, included in full in **Appendix A**

4.5.3.Plants of Conservation Concern

There is significant habitat and plant diversity in the study area, with rapid plant community changes over very short distances. Most of these differences are driven by soil type and soil moisture. The latter can vary from year to year, depending on rainfall, meaning that species abundance may vary substantially even within the same area, from year to year. This would be most evident in the annuals and geophytes, which are remarkably common and fairly diverse in the area. The area would historically also have been subject to intense disturbance by large herbivores, which would not only have molded the landscape but also influenced plant diversity and distribution patterns.

A significant number of Species of Conservation Concern (SoCC) were recorded in the area, with some of the species occurring in very large numbers (notably *Aponogeton angustifolius* and *Lachenalia contaminata*). The most interesting record was of a fairly substantial population of the aquatic bulb *Geissorhiza geminata*, which was not previously known from further south than the Slanghoek valley. The area is clearly an important stronghold for most of the SoCC observed, further elevating its already high conservation value. The abundance of the very poorly known *Isolepis pusilla* was also a significant finding, as the species had only been collected once in the last 150 years (from the Paardeberg area near Wellington), until Doug Euston Brown found it in wetlands in the Slanghoek valley in 2013.

Some differences were noted between the more western and eastern portions of the wetland assessed in the botanical study (Transects B and C - see Appendix A). This is to be expected, as the wetland narrows and becomes more homogenous with distance east, in part also attributable to heavy grazing in the southern parts of Transect B.

The following SoCC were identified in the botanical study, and are described in more detail in Appendix A:

- ***Aponogeton angustifolius*** **-** This species is listed as *Near Threatened*, and is found only in lowland wetlands from Gouda to Worcester to Cape Town, and the results of this survey suggest that the Papenkuils system is by far the largest population of this species, possibly making up as much as 30% of the global population. It is a common element of seasonally flooded habitat throughout the study area, sometimes co-occurring with the larger waterblommetjie (*A. distachyos*), which tends to prefer deeper water (see Figure 8).

- ***Lampranthus debilis*** listed as *Endangered* with ranges throughout most of the seasonally wet lowlands from Mooreesburg to Cape Town and Agulhas

- ***Lachenalia contaminata*** listed as *Near Threatened*, with ranges throughout most of the seasonally wet lowlands from Mooreesburg to Cape Town and Agulhas (Figure 9). It has a particularly large population in the study area, again possibly comprising a significant percentage of the total remaining population (perhaps 10%).

- ***Aspalathus acanthoclada*** - endemic to the Breede River Valley, usually on sands;

- ***Caesia sabulosa***, mostly a west coast Sandveld species;

- ***Elegia recta;***

- ***Babiana nervosa;***

- ***Geissorhiza geminata*** – this is a significant find – this bulbous species was only known from Slanghoek valley, Tulbagh and the Leeurivier floodplain the Koue Bokkeveld, and this

extends the known range to the south, and may in fact be a previously unknown stronghold for this *Endangered* species (Figure 10);

- ***Isolepis pusilla*** - a poorly known sedge Red Listed as Data Deficient (collected only once in the last 150 years!), but is common in the area in ponds and channels where water depth ranges from 5-40 cm (Figure 11).

- ***Psoralea ensifolia*** – this rare species was found in only one patch in the vicinity of Transect C. This species is widespread but naturally rare, and cryptic (difficult to see / hidden) when not flowering.

Figure 8: *Aponogeton angustifolius* and the larger *Aponogeton distachyos* (flower at top right, and the 3 more robust stems) growing together in deeper water. The area supports probably the largest remaining population of the former, which is Redlisted as Near Threatened.

Figure 9: *Lachenalia contaminata* is common on site in seasonally inundated loamy or sandy soils, growing here with *Juncus cephalotes* (at right) and the alien herb *Lotus subbiflorus* (broad leaves).

Figure 10: The very rare aquatic bulb *Geissorhiza geminata* appears to have a previously unknown stronghold in the study area. It typically grows in sandy or loamy areas that have standing water of 5-20cm deep in spring and early summer.

Figure 11: *Isolepis pusilla* – this is a poorly known sedge Red Listed as Data Deficient.

4.5.4.Summary of Botanical Significance

The Papenkuils Wetland is the largest remaining relatively undisturbed wetland in the entire Breede River Valley (about 200km long), and one of the largest wetlands in the entire province.

Due to the alluvial nature of the sediments in the area there is a great variety of soils, ranging from pure acid sands (windblown and flood dispersed), to sandy or loamy soils embedded in sandstone cobbles, to underlying salt rich clays, and multiple combinations thereof. This diversity of soils, combined with subtle differences in topography and associated differences in hydroperiod (temporal and spatial spread of inundation) largely explains the high diversity of habitats and plant communities in the area.

The Papenkuils Wetland is thus not only very large and ecologically important but is clearly unique in terms of plant communities, and has extremely high conservation significance from a botanical perspective.

4.5.5. Invasion by Alien Plants

During the early 2000's, the Papenkuils Wetland as well as the Breede River corridor through this area were densely invaded in places by invasive alien vegetation, including *Acacia mearnsii* (Black wattle), *Sesbania punicea* (Sesbania), *Acacia cyclops* (rooikrantz); *Acacia saligna* (Port Jackson) and, particularly along the banks of the Breede River and in the north eastern portion of the lower wetland, by stands of Eucalyptus.

Extensive removal of alien vegetation has subsequently been undertaken, both by Working for Wetlands and Working for Water work groups, as well as by the Department of Agriculture and local landowners, who we understand ultimately will have responsibility for ongoing maintenance of cleared areas. The botanical specialist for this study (see Appendix A) commented specifically that "work undertaken by various parties to remove woody alien invasive species in the area has benefitted the area enormously, and is to be commended".

At the time of the study, the core wetland had only low levels of invasion by woody species. Moderate to high levels of remnant (or re-established) woody aliens were confined to sections of the Breede River itself (mainly *Eucalyptus* sp. stands and dense black wattle (*Acacia mearnsii)*; the north western corner of the wetland, along and south of the northern channel of the Holsloot River (mainly *Acacia mearnsii*); and the more disturbed north eastern part of the wetland, between the southern Holsloot River and the Breede River, where stands of young *Eucalyptus* sp. trees were resprouting and/or re-establishing as saplings.

Within the wetland channels / permanent open water pools of the wetland, a number of non-woody but nevertheless habitat-altering and undesirable invasive aliens were noted, including:

- Low levels of *Sesbania punicea*;
- Patchy stands of parrots feather weed (*Myriophyllum aquaticum)*;
- Bramble (*Rubus fruticosus*);
- Occasional Patterson's curse (*Echium plantagineum*) along the Breede River; and
- Occasional purple vetch (*Vicia benghalensis)* along grazed disturbed wetland margins.

4.6. Faunal Context

The study did not have scope for any detailed faunal assessment. It is however clear that, while the herds of large mammals that once would have occurred here have long gone (see Section 4.3), the extensive, largely undisturbed, complex mosaic of terrestrial and wetland habitats that still make up the Papenkuils Wetland today support a diversity of indigenous wetland, riverine and terrestrial fauna. This section attempts to list some of the species known to occur in the wetland, on the basis of (limited) literature and observations, and highlights the pressing need

for a more detailed investigation into the fauna of these wetlands, particularly those whose habitats and/or life cycles are potentially more likely to be affected by changes in flow regime into the wetland (e.g. frogs; fish).

4.6.1.Frogs

Consultation of the Frog Atlas Project (Animal Demography Unit, Department of Zoology, University of Cape Town, 2016) suggested that the following frog species could potentially occur in the Papenkuils Wetland:

- Sand toad (*Bufo angusticeps*);
- Arum Lily frog (*Hyperolius horstockii*);
- Cape caco (*Cacosternum capense*);
- African clawed frog (*Xenopus laevis*);
- Cape river frog (*Amietia fuscigula*); and
- Clicking stream frog (*Strongylopus grayii*).

Although no specialist frog assessment was carried out in the present study, frog calls by *Hyperolius horstockii; Cacosternum capense and Strongylopus grayii* were provisionally identified during site visits in spring 2020, and numerous (unidentified) tadpoles were observed in the shallowly inundated seasonal wetland pools – some of these pools dried out suddenly in early November 2020, due to diversion of flows from the Holsloot River into the Brandvlei Canal, with the result that tadpole mortalities in these areas were probably high.

Informal discussions with a faunal specialist (Mr Marius Burger) suggested that it is unlikely that any frog SoCC occur in the wetland.

4.6.2.Birds

The Papenkuils Wetland clearly provide an extensive mosaic of wetland habitats, interspersed by subtly elevated terrestrial areas on sandy dunes, and these are utilized by a diverse array of bird species.

DWAF (2003) describes the wetland as "moderately important" for waterfowl. During the present study, avian fauna identified on an *ad hoc* basis in the wetland included (nesting) African Snipe, Yellow Billed Duck, Marsh Harrier, Fish Eagle (along the Breede River), Grey Heron and Purple Heron – again, the study area is well-deserving of a detailed avifaunal assessment, with the shallowly inundated seasonal pans, densely vegetated with wetland sedges and grasses, providing specific and regionally rare habitat types.

4.6.3.Fish

During the site assessments of the present study, indigenous Mozambique Tilapia (*Oreochromis mossambicus*) and Cape Curper (*Sandelia capensis*) were tentatively identified in flowing wetland channels of the southern Hosloot River, and these species were also observed in the inundated floodplains during October and early November 2020.

Sculls of Sharp-toothed barbel (*Clarias gariepinus*) were observed in areas abutting permanent pools in the wetland, and these were assumed to have been preyed upon by birds and potentially otters.

4.6.4.Reptiles

The following species were observed in the wetland during the site visits:

- Cape cobra;
- Mole snake;
- Spotted Skaapsteker; and
- Cape terrapin.

4.6.5.Small Mammals

Signs of the following small mammals were noted during site visits:

- Cape clawless otter;
- Cape gerbil;
- Water mongoose;
- Bushpig; and
- Cape porcupine.

It is likely that the wetland as a whole still supports numerous small mammals including various other rodents, duiker and other small antelope.

4.6.6.Aquatic Invertebrates

The wetland habitats within the site support numerous aquatic invertebrates – these included several species of Gomphid dragonflies, as well as Coenagrionid damselflies, the adults of which were observed within the seasonally inundated wetland pools in early spring.

4.7. Conservation Planning Context

4.7.1. NFEPA Context

The National Freshwater Ecosystem Priority Area (NFEPA) rivers dataset (Driver, et al., 2011)includes all the country's larger rivers, as depicted at a 1:500 000 scale. The Holsloot, Tierstel, Molenaars, Smalblaar, Breede and Bothaspriuit Rivers are all thus included as NFEPA rivers. The Holsloot River sub quaternary has been classified within the NFEPA datasets as a "Phase 2 River FEPA" (see **Box 1**). This category was applied during the development of the NFEPA datasets to moderately modified rivers (PES Category C), where insufficient rivers in a better condition (Category B or A) were available to ensure conservation of rivers of that type (Driver, et al., 2011). In terms of the NFEPA management guidelines and priorities, Phase 2 FEPA rivers should not be degraded further, and may be considered for rehabilitation once the prioritized Category A and B rivers have been rehabilitated.

NFEPA data further identify the Holsloot River Catchment as a sub quaternary necessary for rehabilitation of threatened fish species.

NFEPA data show the Papenkuils Wetland itself as a FEPA wetland, of high conservation importance.

Box 1: What is a FEPA

FEPAs (Freshwater Ecosystem Priority Areas) are strategic priorities for conserving freshwater ecosystems and supporting the sustainable use of water resources (Driver et al 2011). They were developed as part of the National Freshwater Ecosystem Priority Areas (NFEPA) programme. FEPAs have been determined for different river and wetland types throughout South Africa, on the basis of a number of criteria that included ensuring that there is an adequate extent of conservation of different river and wetland ecosystem types, that they represent adequate habitats to support threatened fish species and their migration corridors; that free-flowing rivers (i.e. rivers without major dams) are prioritised as FEPAs, that water supply areas in high-water yielding sub-quaternary catchments are maintained and that ecological connectivity between systems is maintained as far as possible.

- FEPAs are often tributaries or rivers that support "hard working" rivers downstream (that is, rivers that are heavily utilised or impacted by agricultural, industrial or other human activities). They need to stay (or get into) good condition to manage and conserve freshwater ecosystems and to protect downstream water resources for human use.
- The extent of degradation of wetlands and rivers in South Africa means that even systems considered in the best relative condition for a particular ecosystem type may be highly degraded. Nevertheless, the recommended condition for all river and wetland FEPAs is an Ecological Category A or B, indicative of a system that is in an unmodified/natural to largely natural condition

4.7.2. The Western Cape Finescale Biodiversity Conservation Planning Context

Not surprisingly, given its size, relatively unimpacted condition and botanical importance, the 2017 Western Cape Biodiversity Spatial Plan (WCBSP) (Pool-Stanvliet, Duffel-Canham, Pence, & Smart, 2017) categorises the whole of the extant Papenkuils Wetland as a Critical Biodiversity Area (CBA)

The Holsloot River itself has been ranked as an "Other Ecological Support Area" (OESA) river, as have most of the other minor tributaries / seeps leading into the Holsloot River.

4.8. Context in the Breede River Reserve Determination Study

The Resource Quality Objectives (RQOs) for the Breede-Gouritz Water Management Area (WMA) were gazetted in September 2020, and include listings of water resource classes and RQOs for the rivers, estuaries and groundwater in this WMA (Government Notice 43726, 2020).

Wetland RQOs were not however included in the gazetted notice, and are still under development. Thus RQOs for the Papenkuils Wetland itself are not currently available. An Intermediate Reserve Determination was however carried out for the Papenkuils Wetland as part of the Breede River Basin Study (DWAF, 2003), and this study provided provisional recommendations for flows into the wetland. No monitoring of actual flows into the wetland has been carried out to date.

4.8.1.The Holsloot River

RQOs for the Holsloot River are based on the categorisation of this river as a "working system".

Of the river nodes included in the gazette, those relevant to the current study comprise Niv12, located on the Holsloot River at the weir at the Brandvlei Dam offtake canal, and Nv3, on the Breede River upstream of the Hex River, correlating roughly to site D1 referenced in the current study (see).

The gazette specifies a Target Ecological Category (TEC) of Category C for both of these nodes. The RQOs for working tributaries of the Breede River are specified as follows:

- Low and high flows sufficient to maintain the river in a condition equal to or better than a C category;
- Nutrient levels to be in a mesotrophic condition or better;
- Salt concentrations (as measured by Electrical Conductivity (EC) to be maintained at levels that do not adversely affect aquatic ecosystems (≤55 mS/m (95th percentile);
- pH between 6.5 and 8.5;
- Dissolved oxygen ≥8 mg/L;
- Vegetation: VEGRAI[15] scores to be within a D Category;
- Fish – FRAI[16] to be within a D category; and
- Invertebrates – within a C category as measured by SASS5.

4.8.2.The Papenkuils Wetland

DWAF (2003) defines the Intermediate Ecological (water quantity) Reserve for the Papenkuils Wetland as those conditions of flooding that result in the wetland being filled to a water surface level of about 199 m above mean sea level (mamsl), and the document prescribes that in any hydrological year all floods allowing this level of inundation should be allowed to enter the wetland. The study estimates that such conditions should generally occur on average with a frequency of three to five occasions per year, and the required flooding conditions are deemed to represent minimum flooding requirements for the wetland, in order to maintain it in its recommended Ecological Management Class (EMC) (or Target Ecological Category (TEC)) of Category B/C, representing a requirement for improvement of the wetland from its assessed current condition of Category C (moderately modified). More detailed inputs have been made in the current project regarding recommended inflows into the wetland, in order to prevent long-term degradation.

[15] Vegetation – Riparian Response Assessment Index
[16] Fish Response Assessment Index

5. Papenkuils Wetland Characteristics based on Fieldwork and Data Gathering

5.1. Results of Fieldwork and Data Gathering

The results of the wetland botanical assessment, water quality analyses and *in situ* water quality measurements, as well as of water table, soil moisture monitoring and the surveyed topographical profiles of the transects used to underpin data collection in this study are presented in Appendices A to F, as follows:

- Appendix A: Botanical report;
- Appendix B: Water quality data;
- Appendix C: Soil moisture and piesometer water level monitoring results;
- Appendix D: Wetland transect profiles;
- Appendix E: Soil Hydraulic Characteristics; and
- Appendix F: Sentinel Images and Analyses.

The appendices (in most cases) include brief notes as to the interpretation and/ or relevance of the data as illustrated in the graphs and tables used to portray these data. These have been incorporated into the following sections where relevant, and generally contribute to our understanding of the main drivers of wetland function and form.

5.2. Description of Key Wetland Habitats

5.2.1. Papenkuils Wetland Upstream of the Northern Holsloot east to Nekkies Bridge

On the basis of our understanding of surface and shallow subsurface flows through the wetland, and drawing on wetland habitat types as assessed and described in Section 5.1, the following deductions have been made about the current hydroperiod of key wetland habitats, bearing in mind the limitations of this brief study period:

Permanently inundated to saturated pools – these pools occur mostly in the area mapped in

- as the Northern Holsloot / Breede. They are characterised by deep pools with soft muddy substrate and obligate wetland vegetation typical of standing water habitat, including (alien) parrots feather *weed* (*Myriophyllum aquaticum*). They are edged by dense stands of Palmiet (*Prionium serratum*) which give way in some areas to (usually) stands of *Pennisetum macrourum*, *Cliffortia strobilifera* and occasionally to stands of *Phragmites australis*, all on slightly higher ground. Although water quality varied spatially and temporally throughout the site, the pools did appear to be slightly enriched to at least mesotrophic levels (DWAF 2008 and DWAF 1996) with regards to phosphate and nitrate nutrients.

Figure 12: Deep perennially inundated pools some 100m east of TB-8, dominated by Palmiet (Prionium serratum).

- **Southern Holsloot River channel** – the upper reaches of this river are highly degraded, being bermed on either side and in places possibly bulldozed at times. They nevertheless support a diversity of in-channel habitats, comprising sandy pools, occasional stands of Palmiet (*Prionium serratum*), stands of *Isolepis prolifer* and *Juncus cephalotes*. Fish were observed in these pools up until mid-summer (February 2021) by when they had largely dried out. Surface flows into the channel effectively ceased by early November 2020 however, with subsurface flows largely sustaining inundated areas.

  With distance downstream, the berms cease and the river starts to braid and split into multiple channels, that bleed north and east into the wetland, contributing flows under high flow conditions to feed the flats and pools described later. These sandy channels (in 2020) had a shorter period of inundation than the upstream reaches, with water levels dropping quickly in late spring, to well below bed level (see Section 5.1).

  In its reaches in the vicinity of Transect B, the river is characterised by a narrow but discrete band of Palmiet, marking the edge of the sandy channel (). Grazing of the Palmiet by cattle occurs in these reaches, which have also been moderately invaded by bramble. Further downstream, the coarse sands of the channel seem to give way to fine silts, promoting more sustained wetland conditions, with the vegetated pools being inundated until late December. These lower channels tended to be dominated by *Isolepis prolifer* and dense stands of *Pennisetum macrourum* on the slightly elevated channel margins (Figure 14). The most downstream reaches of the channel ("Outflow" site in) by contrast were patchily dominated by Palmiet, with open sections of the silty channel supporting dense *Aponogeton angustifolia* and *Aponogeton distachys* in the wet season.

Figure 13: Southern Holsloot channel in its reaches past Transect B (Site 4) (October 2020).

Figure 14: Southern Holsloot channel in its reaches past Transect C (November 2020).

- **Seasonally inundated wetland depressions and shallow pools** (Figure 15 and Figure 16) – these habitats occur primarily in the southern parts of the wetland, dominated by flows from the Southern Holsloot River (see Section 5.5). The shallow depressions are understood to be linked to groundwater inflows, as well as to the receipt of surface flows from the main

southern Holsloot, during high flow conditions. The wetlands appear to dry out by mid-summer (generally no standing water in early January 2021) but their (usual) links to direct high flow channels from the southern Holsloot means that they are flushed more frequently than the adjacent wetland flats and that these channels are more likely to play an active role in provision of wetland ecosystem services such as nutrient amelioration and sediment trapping, than are the less frequently inundated adjacent wetland flats. As habitat types, the wetlands provide localised inundated habitat for aquatic invertebrates including Coenagrionid damselflies and other taxa, and may be important breeding areas for frogs and other wetland fauna, particularly given their prolonged inundation, relative to other wetland habitats in the southern wetland area.

These habitats are generally edged by *Pennisetum macrourum*, with stands of *Watsonia* spp. and *Cotulla coronopifolia*. In-channel, they support patchy *Isolepis prolifer*, *Juncus cephalotes* and, during the wet season, aquatics such as *Aponogeton angustifolium and Aponogeton distachyos.*

Figure 15: Seasonally inundated wetland depressions and shallow pools at TB-6/7 (December 2020).

Figure 16: Seasonally inundated wetland depressions and shallow pools (October 2020) – Transect 2 site 2A.

- **Seasonally inundated wetland flats** (Figure 17) – these habitats characterise large parts of the southern and south-eastern wetland, where they are dominated by large stands of *Eleocharis limosa,* (in slightly depressed areas) and *Pennisetum macrourum* on slightly elevated areas, with a distinct vertical difference between the two habitat types, and the former remaining inundated for a few weeks longer than the latter. Only a few centimetres vertical height differentiates between these habitat types, and illustrates the subtle differences in wetland topography that affect wetland habitat suitability, and also illustrate the vulnerability of these habitats to even slight changes in water inflows.

  The botanical study noted that the *Ficinia indica, Isolepis hystrix, Juncus cephalotes, Aponogeton angustifolius* (SoCC), *Oxalis recticaulis, Drosera trinervia, Ornithogalum thyrsoides, Cyanella hyacinthoides, Hesperantha falcata, and* the alien herbs *Lotus subbiflorus* and *Erodium moschatum* were all also characteristic of, but not dominant in these habitats.

  When inundated, these habitats were observed to support numerous tadpoles, Cape terrapin, fish (assumed to be Mozambique tilapia (*Oreochromis mossambicus*) and Cape kurper (*Sandelia capensis*) and aquatic invertebrates including a seemingly high diversity of Coenagrionid damselflies (nymphs and adults observed).

Figure 17: Seasonally inundated shallow wetland flats (October 2020) (Transect B, site 6).

- **Seasonally saturated and occasionally shallowly inundated wetland flats** (Figure 18) - These wetland flats occur as a mosaic between the seasonally inundated channels, pools and flats described above, and although saturated for much of the early wet season, dry out rapidly and have a short (if any) period of inundation.

  Typical plant communities occurring in this habitat as described in the botanical assessment include *Cotula coronopifolia, Cynodon dactylon, Lampranthus debilis* (SoCC), *Sporobolus virginicus, Juncus krausii, Stipa capensis, Spergularia media, Hesperantha falcata, Lachenalia contaminate* (SoCC), *Ornithogalum thyrsoides, Arctotheca prostrata* and *Crassula strigosa*. Alien annual herbs found include *Lotus subbiflorus* and *Ornithopus pinnatus*. It is noted however that the above plant community is only indicative – there is a high diversity of plant species in the wetland as a whole, changing with distance eastward through the wetland and with subtle differences in soil, elevation and exposure to disturbance such as grazing, fire and flooding.

Figure 18: Seasonally saturated to occasionally shallowly inundated wetland flats immediately east of TB-3 (November 2020).

- **Drier, seasonally damp but not inundated wetland flats** – these habitats occur along the southern wetland margins and abutting low dunes / terrestrial areas, generally in the southern portion of the wetland (Figure 19). Along Transect C, they were characteristically found on silty sand areas with extensive *Leucadendron brunioides* spp *bruniodes, Elegia recta, Thesium sp* and the bulb *Ammocharis longifolia* (malgaslelie).

  The damp margins of Transect B were heavily grazed, and in places supported halophytes such as *Sarcocornia* sp. and *Cotula coronopifolia.*

Figure 19: Seasonally damp but not inundated wetland margins, Elegia recta in foreground, southern edge of TC (October 2020). Photo by Nick Helme.

- **Terrestrial mosaic and dune areas -** The wetland is interspersed with slightly elevated terrestrial areas, comprising low, usually sandy dunes and upland slopes. Sandy dunes tend to be more prominent in the west of the site, and more elevated along the southern bank of the Breede River. In combination with the surrounding wetlands, these contribute to overall habitat diversity in the system. Terrestrial areas have not however been mapped out as separate units.

- **Breede River channel -** The Breede River forms the northern boundary of the study area and is generally in these reaches a disturbed aquatic environment, the margins of which are dominated by alien vegetation (mainly eucalypts and black wattles (see Section 4.5.5). It does however retain secondary flood channels in these reaches, which are considered important habitat types, usually missing from the bulldozed and bermed channels of many rivers in this part of the catchment. These secondary channels are assumed to be important wet season refugia for fish and aquatic invertebrates, and support various wading and swimming waterfowl during periods of inundation. The northern side of the river channel is most disturbed, with the floodplain wetlands that would have characterised it under natural conditions being largely lost or degraded. The southern (right hand bank) is edged along much of the study area by dunes running parallel with the river (Figure 20), which confine surface flows in the river outside of major floods, although subsurface links to the deep northern Holsloot channels seem likely.

  The Breede River itself usually flows strongly during the wet season, with wet season flows from the northern Holsloot as well as the Smalblaar being diverted into the Breede River for salinity control purposes, and then abstracted downstream of the Nekkies Bridge, and pumped into Brandvlei Dam. During summer, irrigation releases are pumped from the Brandvlei Dam into the river at the same point.

By December 2020, flows in the Breede River at Transect B had however dropped to a shallow trickle, and by February there was no discernible flow, with isotope signals reflecting high rates of evaporation.

Figure 20: View south over Breede River at Transect B (December 2020).

- **Droughted channels and wetland flats -** Reference conditions for the area immediately east of the northern channel of the Holsloot, from its split from the southern channel, as far as the end of the berm marked in Figure 5, would be expected to be similar to those along the eastern portion of Transect B, albeit with perhaps more channels similar to the Southern Holsloot downstream of its bermed section, and with more seasonally inundated wetland depressions and shallow pools than extensive wetland flats.

  The berms along the southern and particularly the northern Holsloot River, which effectively cut off channels that formerly braided through this area, have resulted in significant loss of functional wetland in this area. Although channels are visible through the area, they are almost wholly now vegetated with slangbos (*Seriphium plumosum*) – a terrestrial plant species that occurs in Transects A and B only in well-drained areas – usually on low hillocks or dunes. This species is indicative of disturbed environments, and can indicate over-grazing of areas, as it is unpalatable to stock other than when plants are very small. In the western section of the Papenkuils, dominance of channels and depressions that clearly should have linked to the river upstream is assumed to be opportunistic invasion of now-dry areas. In places, remnant wetland species do still occur (e.g. *Juncus kraussii*) but these are now all in combination with presumably more recently established terrestrial species (e.g. *Searsia angustifolia*) (see and).

Figure 21: View north along northern Holsloot, showing raised berm and slangbos (Seriphium plumosum) - dominated former wetland to the east (December 2020).

Figure 22: Dominance of former floodplain flats and channels by dryland species – Watsonia and slangbos (Seriphium plumosum), with remnant Juncus kraussii in places, TB-12 (December 2020).

- **Artificial channels and drains** - A number of artificial drains and channels enter the wetland, mainly from the southern margins. These channels tend to be highly nutrient enriched, particularly with regard to nitrogen nutrients, which are assumed to enter the water course from surrounding agricultural areas, including runoff from feedlots and (in the vicinity of Transect B) a large manure stockpile / treatment area. They do convey additional water into the wetland, some of which would under natural conditions have entered the (now inundated and destroyed) Brandvlei Wetlands, within what is now the Brandvlei Dam basin. Because of their high levels of nutrient enrichment and passage through disturbed agricultural areas, the channels do serve as potential sources of weedy and alien plant propagules into the wetland, although this was not confirmed in this study. Disturbance associated with channelisation as well as elevated nutrients in the apparently permanently flowing or seeping channels provides ideal habitat for the indigenous but invasive *Typha capensis* bulrush, which forms dense stands along the channels. Such disturbed areas including some of the excavated dams are the only parts of the wetland dominated by this species.

  Summer irrigation in the adjacent farmland contributes an unquantified volume to perennial seepage into nearby wetlands – the wetlands mapped immediately north of the open farm dams shown in Figure 5 and highlighted in Figure 24 are clearly fed by seepage from these areas. These tend to be permanent systems, the surface waters of which are dominated by water lilies (e.g. *Nymphaea nouchali*) as well as *Aponogeton distachys* in the winter and spring.

- **Excavated dams and ponds –** In the south western part of the wetland, these tend to be permanently inundated systems, the surface waters of which are dominated by water lilies

(e.g. *Nymphaea nouchali*) as well as *Aponogeton distachys* in the winter and spring. They are likely to link directly to the shallow water table, and seep out into the adjacent wetlands.

In the lower reaches of the wetland, the ponds generally seem to dry out by mid-summer. Water blommetjies (bulbs of *Aponogeton distachys*) provide a seasonal source of income to local residents, who harvest and sell them along the roadside.

5.2.2. Papenkuils Wetlands and Breede River from Nekkies Bridge to the Heks River confluence

- **Incised channel with degraded wetlands –** This section of the wetland was not assessed in any detail in this study, but is illustrated in Figure 23. The combined flows of the Breede (plus Smalblaar) and north and south Holsloot Rivers pass under the Nekkies Bridge and into the downstream area. The bridge is however relatively narrow compared to the width of the floodplain and berms on the upstream floodplain force the river under the bridge and into the downstream area, where significant channel incision as a result of concentrated river flows has taken place. This means that the wetland in these reaches has negligible function, other than where fed by upland seepage flows. It is significantly invaded by alien vegetation (mainly eucalyptus (*Eucalyptus* sp. and black wattle (*Acacia mearnsii*) and the river outside of flood periods flows at the base of a steep sandy channel, edged on the right-hand bank by steep hillslopes.

  The river itself does support stands of Palmiet along its wetted channel, and these give way in less impacted sections of the river (e.g. at the Nekkies camp site) to narrow bands of *Pennisetum macrourum* dominated wetland, particularly where remnant secondary channels still occur.

Figure 23: Incised Breede River at D1, downstream of the narrow Nekkies Bridge (October 2020).

5.3. Wetland Classification

Section 5.2 provided a description of the Papenkuils Wetland from the northern Holsloot to the Heks River confluence with the Breede River. These wetlands as a whole have been classified as floodplain wetlands, using Level 4A of the Classification System for Wetlands and other

aquatic ecosystems in South Africa (Ollis, Snaddon, Job, & Mbona, 2013). This is the effective hydrogeomorphic unit (HGMU) for the system.

The mapped Papenkuils floodplain wetland upstream of the Nekkies Bridge has a total estimated area of some 982 ha. Within this HGMU, there are clearly multiple habitat types, classified variously at Level 4B of the above system as floodplain depressions and floodplain flats, through which the various river channels course. These have been described and illustrated in Section 5.4.

5.4. Wetland Disturbance Units

Drawing on the preceding sections, including the wetland assessment results presented in section 4.1 (and associated appendices), this section presents the Papenkuils Wetland in terms of **wetland disturbance units**, which lend themselves to broad descriptions and interpretation of current wetland function, and which are integral to the WET-Health assessment outlined in Section 5.9. It must however be noted that the disturbance units described have not been mapped to a high degree of accuracy, due to the wetland complexity and the absence of georeferenced high resolution aerial photography for the study area. Nevertheless, the disturbance units proposed here are considered to be relatively accurate within the constraints of the above.

Broad wetland disturbance units were differentiated as follows:

- The Breede River;
- The northern Holsloot (including the "interior" sites (see Section 5.1);
- The southern Holsloot and its mosaic wetlands;
- The bermed and droughted wetland east of the northern Holsloot;
- Artificial farm channels into the wetland;
- Farm dams and associated seepage areas into the wetland; and
- The Breede River and its remnant wetland fragments downstream of the Nekkies Bridge.

All of the above disturbance units are mapped in , and are driven strongly by the degree to which flows into and through the wetland have been impacted. Note that although the Smalblaar / Holsloot Wetlands are mapped in the figure, this wetland falls outside of the study area and was not assessed.

5.5. Water Quality

Table 3 summarises water quality assumed in this study to be associated with each of the disturbance units outlined above, drawing on data described and presented in Section 5.1 and Appendix B. The data are presented in terms of the core disturbance units described in Section 5.4, with site locations indicated in Figure 1.

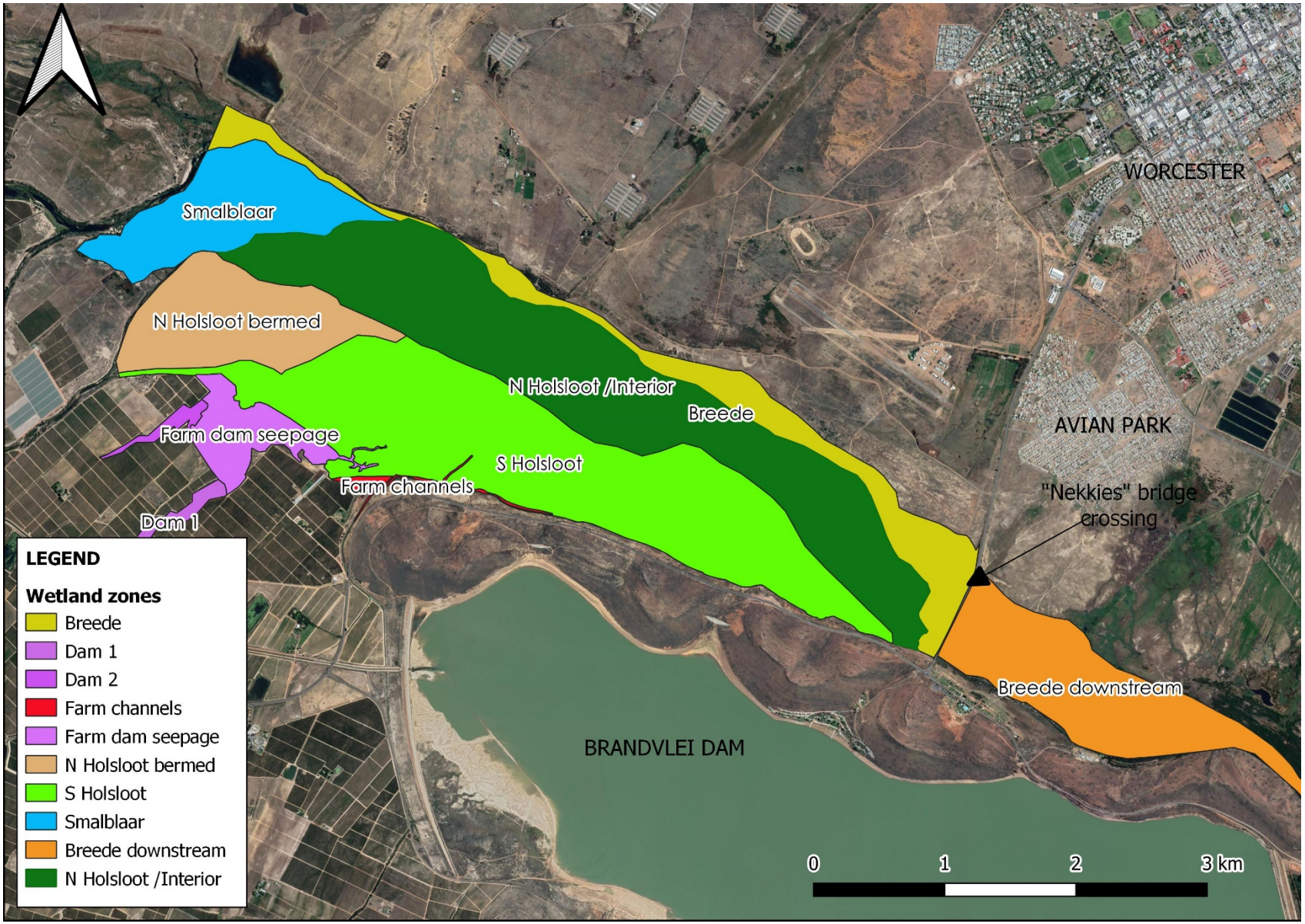

Figure 24: Disturbance units mapped over the Papenkuils Wetland – compare with Figure 9 indicating assumed changes in flows into and through the system.

Table 3: Summary of key water quality findings

Disturbance Unit	Isotope analysis	Nutrient characteristics	pH	Salinity (as measured by EC)
Breede River to Nekki bridge, with notes on water quality in downstream reaches too (Sites A-1; B-11; C-3; D 1; D-2)	Significant evaporation in Breede samples, in Jan and Feb indicates lack of significant groundwater refreshing. This is not evident in the Holsloot water. No association with adjacent Palmiet channels.	Nitrogen nutrients in the Breede River were low throughout the sampling period, and reflected measurements within the mesotrophic range for this nutrient, and thus well within the RQOs for this nutrient (see Section 4.5.1). Phosphate enrichment in the Breede River was generally low and below the hypertrophic thresholds of DWAF (2008 and 1996), barring elevated concentrations at B-11 in late November 2020. It was however generally above the mesotrophic levels implicit in the RQOs for the river in these reaches. Phosphate concentrations tended to be elevated at site D-2 compared D-1, presumably reflecting channeled inflows from the poorly serviced Avian Park area, which enter the Breede River between D-1 and D-2.	pH measured in Breede River water sites at all times fell within the RQOs for this system (see Section 4.8) – these pH levels do not however reflect runoff or seepage from areas with high fynbos components.	EC in the Breede River main ste ended to be lower EC than th n the wetlands, presumably eflecting faster flows with lowe evapoconcentration. EC increased into late summer when flows were very low.
Northern Holsloot including interior wetlands (Sites A-2; B-9; B-8; B-7; B-6)	Certain pool/slow moving water shows increasing evaporation through the sampling period (B6/7 and B3). However, nearer the Palmiet pools, there is little evidence of evaporation (B9), probably fed by Northern Holsloot.	Nitrogen nutrients in these systems were generally below eutrophic thresholds for rivers and wetlands, with the exception of the area represented by site B9, located in a secondary channel dominated by Palmiet, where nitrate concentrations were initially elevated (presumably as a result of inflows from the agriculture-dominated catchment in winter), and then reduced	pH levels in wetlands in these reaches generally fell below RQOs for the Holsloot River, indicating natural surface / groundwater interactions and the influence of humic acids in local fynbos	EC in natural wetlands and channels increased into the dry season, largely it is assumed as a result of evapoconcentration. The lowest EC levels occurred throughout the

Disturbance Unit	Isotope analysis	Nutrient characteristics	pH	Salinity (as measured by EC)
		over time. The dataset is however extremely limited in duration. Phosphate concentrations reflected increased nutrient inputs into the wetlands, downstream of the split of the southern and northern Holsloot River channels. Interestingly, while phosphate concentrations were relatively low in the upstream reaches of this wetland unit, as reflected by data from A-2, concentrations further downstream reflect significant phosphorus nutrient enrichment – particularly in the wetland channels at B-7 and B-9. In light of the fact that flood flows through these reaches have decreased as a result of upstream flow diversions, it is possible that the elevated phosphate concentrations at B-7 reflect relatively stagnant conditions with high levels of plant decomposition and low flushing rates. However, the wetlands may also be prone to nutrient build-up as a result of low flow inflows from the Rawsonville sewage works upstream of the Smalblaar-Holsloot channel	vegetation, leaching into shallow subsurface groundwater flows both on site and in upstream mountainous regions. Note that RQOs have not however been developed for wetlands in the Breede River Catchment to date.	wetland sites in early November – it is assumed that this reflected both a substantial rainfall event just before sampling as well as the fact that the Brandvlei Canal offtake was closed at the end of October, with the result that inflows into the wetland temporarily increased along the Southern and Northern Holsloot channels. Continuous logging of EC upstream of and towards the downstream end of the Papenkuils (see Appendix B) showed that although EC was generally low and indicative of a fresh water system, it increased with passage through the wetland. This would be explained at least in part by evapoconcentration of flows, as well as the (albeit small) contribution of inflows of polluted re-turn flows and runoff from livestock dominated landuse.
Southern Holsloot and its wetlands (Sites A-3; B-2A; B-2B; B-3; B-4; C-1)	The more southerly seepage streams are subject to evaporation late in the sampling season (B-2A), while the more interior or more continuously linked seepage	Nitrate-nitrogen concentrations in these sites were generally below DWAF (1996) qnd DWAF (2008) thresholds for eutrophic systems with regard to nitrogen nutrients, despite irrigation return flows and other contaminants in runoff via the farm	While the RQOs for the Holsloot River indicate pH should lie within the range of 6.5 and 8.5, in fact the Southern Holsloot Wetlands reflect	

Disturbance Unit	Isotope analysis	Nutrient characteristics	pH	Salinity (as measured by EC)
	streams progressively reflect groundwater signal (B-2B and B-4)	channels. Nutrients were generally higher in the wet season – presumably as a result of increased wash from adjacent agricultural areas. Phosphorus enrichment was an issue in most of the sites in the Southern Holsloot wetland unit (that is, usually above the eutrophic threshold for this nutrient), reflecting inputs from a highly agricultural upstream catchment. Phosphate concentrations did decrease with time into early to mid-summer, reflecting wetland nutrient uptake, reduced inflows and nutrient sedimentation processes – in the context of a system that was no longer receiving inputs from upstream Holsloot River flows, and by early summer was really only receiving inflows from the "farm channels" and groundwater subsurface flows .	wetlands with far lower pH levels, indicative of wetlands fed by groundwater that has seeped through soils affected by humic acids from fynbos dominated vegetation.	
Bermed and drying wetland east of Northern Holsloot	Channel draining close to the road, collecting return flows from irrigation below Brandvlei dam, has very little change in isotope response through the sampling period, and possibly groundwater fed. Streams draining the local farm dams show variable responses, possibly reflecting occasional releases of evaporated water and rainfall on 6 November 2020.			
Artificial farm channels (Sites B-1A; B-1B; B-1)	Channel draining close to the road, collecting return flows from irrigation below Brandvlei Dam, has very little change in isotope response through the sampling period, and possibly groundwater	Inflows into the wetland from farm channels, clearly reflecting agricultural return flows, show relatively high concentrations of nitrogen nutrients in flows into the Southern Holsloot Wetland. Nutrient loading is however likely to be relatively low, given the relatively low	pH measurements from these channels reflect water dominated by agricultural return flows. pH levels were significantly higher than those of natural systems	Electrical Conductivity (EC) was highest in runoff from farm channels into the southern Holsloot wetlands. Its net impact on downstream flows was however low, indicating

Disturbance Unit	Isotope analysis	Nutrient characteristics	pH	Salinity (as measured by EC)
	fed. Streams draining the local farm dams show variable responses, possibly reflecting occasional releases of evaporated water and rainfall on 6 November 2020.	discharge estimated17 from these channels (up to 0.5 m3/s). Elevated concentrations at B-1A in November 2020 assumed to reflect the (observed) discharges from a large manure heap established adjacent to this site. Irrigation return flows and runoff from other sources of nutrient enrichment in agricultural areas (e.g. manure stock piles) clearly contribute to nutrient enrichment into the southern Papenkuils Wetland. However, the discharge through these channels is relatively low (estimated as < 0.5 m3/s) and although occurring through summer too, would be at lower levels, as a result of evapoconcentration and infiltration Inflows from upstream sources (e.g. along B-1 comprise mainly seepage flows from the Brandvlei Dam, supplemented with irrigation return flows.	in this area, but not in the range (>8) likely to promote significant ammonia toxicity for aquatic organisms	relatively low loading compared to volume of inflows.

[17] Coarse estimates on the basis of catchment area and knowledge of the channels

5.6. Sources of Water into the Papenkuils Wetland

Mapping, isotope analyses and other water quality data collected in this study and described in Section 5.5 indicate that the Papenkuils Wetland derives its water variously, from the following sources:

- Direct precipitation – rainfall is mainly in winter and spring – May to September, although periodic rain events can occur throughout the year;
- Surface inflows from the Holsloot River, as well as the Breede River, which is fed in immediately upstream of the wetland by the Smalblaar, Bothaspruit and Hartbees Rivers;
- Channeled inflows from seepage from Brandvlei Dam wall, as well as from irrigation return flows and natural (but now channelised) watercourses draining through the area east of the Holsloot River's current (channelised) course;
- Inflows from the Smalblaar River diversion system, which feeds into the Holsloot River upstream of the Brandvlei Canal offtake – the Smalblaar diversion is located less than 500m downstream of inflows from the Rawsonville WWTW;
- Groundwater inflows, assumed to be from the Rawsonville aquifer;
- Subsurface inflows from the Breede River, during time of high flow;
- Seepage from irrigation dams excavated into the aquifer on the farm Pokkraal; and
- Runoff from irrigated areas on adjacent agricultural areas, some of which is channeled into the wetland along its southern edge.

The following section describes the movement of this water into and through the wetland.

5.7. Movement of Flows through the Wetland

Drawing on the results of soil and water level monitoring presented in Section 5.1, and with reference to soil hydraulic cross sections across the three transects assessed in this study in Appendix E, the following conclusions, implicit in the hydrological model presented in Section 6, can be drawn regarding flows into and through the Papenkuils Wetland:

- At present, early wet season high flows from the combined Holsloot / Smalblaar Rivers pass into the Papenkuils Wetland via the southern and northern Holsloot channels, with the northern channel feeding only into the northern and north-eastern parts of the wetland, and bypassing the western / north western section, outside of extreme flood events, when the berm along the channel edge may at times be overtopped;
- Most of the flows from the northern Holsloot River pass into the Breede River and overtop into the northern and north-eastern wetland only when the Breede River floods, although some small channels do braid into the northern / "interior" wetland, from the northern channel downstream of the end of the berm;
- The Breede River channel may, under conditions of high flow, feed shallow subsurface flows into the northern and north-eastern wetlands, where they sustain what are assumed, on the basis of their vegetation, to be permanent, deep pools that occur along the meandering channels of the northern Holsloot in its downstream reaches. Such subsurface flows are likely to occur in the wet season through to early summer only, where after water levels in the Breede River drop markedly;

- Surface flows through the southern Holsloot channel pass into the southern / south western and south-eastern wetlands at flows where the channel bed level of 232.20 mamsl is exceeded – the bed level of the channel along Transect A further east (downstream) (> 232.64 mamsl) must also be exceeded, for flows to actually pass along this channel. Under high flow conditions, water overtops the channels, and spreads out into the surrounding floodplain, where it gives rise to seasonally inundated pools and shallow depressions;

- Since the first ±1 340 m of the southern Holsloot channel is bermed, at least on the northern (left hand) bank, overtopping of the channel occurs only downstream of this point, whereafter the channel braids between low dunes, forming multiple discharge points into the surrounding wetlands;

- The main southern channel starts to meander sharply some 1.2km further downstream, but splits repeatedly and is joined by channels seemingly fed by flows from the northern Holsloot / Smalblaar / Breede Rivers, in the north eastern and eastern parts of the wetland;

- During the wet season, before flows are diverted into the Brandvlei Canal, water spreads across almost the whole of the south-eastern wetland, forming shallow pools and depressions, as well as the main flowing channels through the wetland;

- The southern Holsloot channels are shallower than those of the northern Holsloot and Breede River, and do not retain surface flows outside of significant flood events – subsurface flows do however flow preferentially through the coarse sands of these channels, into low-lying depressions within the channels. Such flows are assumed to support the dense stands of Palmiet that still characterise the southern Holsloot channel along sections, albeit at lower densities and sparser stands than along the northern Holsloot channels;

- Isotope data presented in Water Quality Data in Appendix B and Table 3 suggest that the southern Holsloot, and some of the deeper, north eastern channels within the wetland appear to be fed throughout the year by groundwater flows from the Rawsonville aquifer, which itself is recharged by runoff from the Holsloot and Smalblaar Rivers – naturally, the wide alluvial fan formed by these systems would have facilitated upstream aquifer recharge. The Rawsonville Aquifer is described as a large, alluvial aquifer, with a saturated thickness around Rawsonville estimated at 25 m (Rosewarne, 1981 in (Hay, Kotze, & Breen, 2014)) and is the aquifer into which the open farm dams on the farm Pokkraal have been excavated;

- The aquifer is likely to support the Papenkuils Wetland along the south-western margins;

- The inundated wetland flats of the southern and south western Papenkuils are reliant for their inundation on high flows from the southern Holsloot River – river flows must be high enough to pass into the Southern channel, and then overtop onto the silty wetland flats. However, early to late wet season diversion of flows into the Brandvlei Canal means that river flows are effectively capped, resulting in a shortened period of wetland inundation (i.e. a shorter hydroperiod) – this has implications for the life cycles of aquatic and wetland-associated fauna and flora reliant on these systems;

- Water that overtops onto the wetland flats remains perched in these areas, presumably trapped by fine silts and in places clays, and is lost mainly by evaporation. With high flows passing into the Brandvlei Canal, particularly towards the end of the wet season, recharge of these inundated wetland flats is probably infrequent; and

- By early summer, the shallow wetland flats are dry; by mid-summer (January 2021) the wetland depressions in the southern wetland were dry.

Figure 25: Indicative view of the braided spread of flows through the wetland, based on the above, showing channels currently deactivated by berms on the Northern and Southern Holsloot Rivers, as well as active seasonal braided channels further downstream. Asterisks mark approximate positions of the downstream ends of the berms. Marked channels have been mapped off GOOGLE imagery with low to medium accuracy only and are intended to represent main channels only. Areas between mapped channels comprise mosaic wetlands with islands of higher ground / dunes.

5.8. Wetland Plant Hydroperiod based on Soil Moisture and Water Level Monitoring

Soil moisture and piezometer water level monitoring data in Appendix C, indicated that the seasonally inundated to saturated wetlands of the Papenkuils dry out rapidly towards the end of the wet season, with water table and soil saturation levels dropping rapidly. In the 2020 monitoring period, from the end of October, water levels and soil moisture dropped by roughly an order of magnitude across all monitored wetlands, despite periodic rainfall[18] events in November, and the closing of the Brandvlei Canal outlet at the end of October, leading to observed increased flows along the southern (and presumably northern) Holsloot River channels.

This illustrates the importance of the passage of high flows along the Holsloot River downstream of the Brandvlei Canal offtake, such that they are able to flow into and penetrate the southern Holsloot, and from here, overtop the channel (downstream of the berm asterisked in) and inundate the southern wetland flats.

The wetland transect profiles illustrated in Figure 28 highlight the subtle differences in hydroperiod, and in patterns (frequency and duration) of inundation and saturation in particular, that can lead to significant differences in habitat type. For example, a 0.9m vertical difference across some 15 m horizontal distance distinguishes between seasonally moist habitat and the southern Holsloot channel along Transect C, while some 0.26 m vertical difference distinguishes between *Pennisetum macrourum* and *Eleocharis limosa* habitat, with the latter being inundated for (at least in 2020 /2021) an additional four to six weeks, compared with the *Pennisetum macrourum* habitat, which had little to no standing water by late December 2020. Such subtle differences may be important differentiators of habitat quality for taxa requiring extended inundation to support parts of their life cycles (such as tadpoles and invertebrates with aquatic egg, nymph or larval phases), as well as affecting habitat quality (such as access for terrestrial predators) for nesting wetland birds, and extent of foraging habitat for birds and other wetland-associated fauna.

5.9. Summary of Anthropogenic Impacts affecting Wetland Condition

The anthropogenic impacts which contribute to wetland condition in each of the disturbance units are illustrated in . These are used in the WET Health assessment presented in Section 5.10.

[18] No local rainfall data were available to inform this study

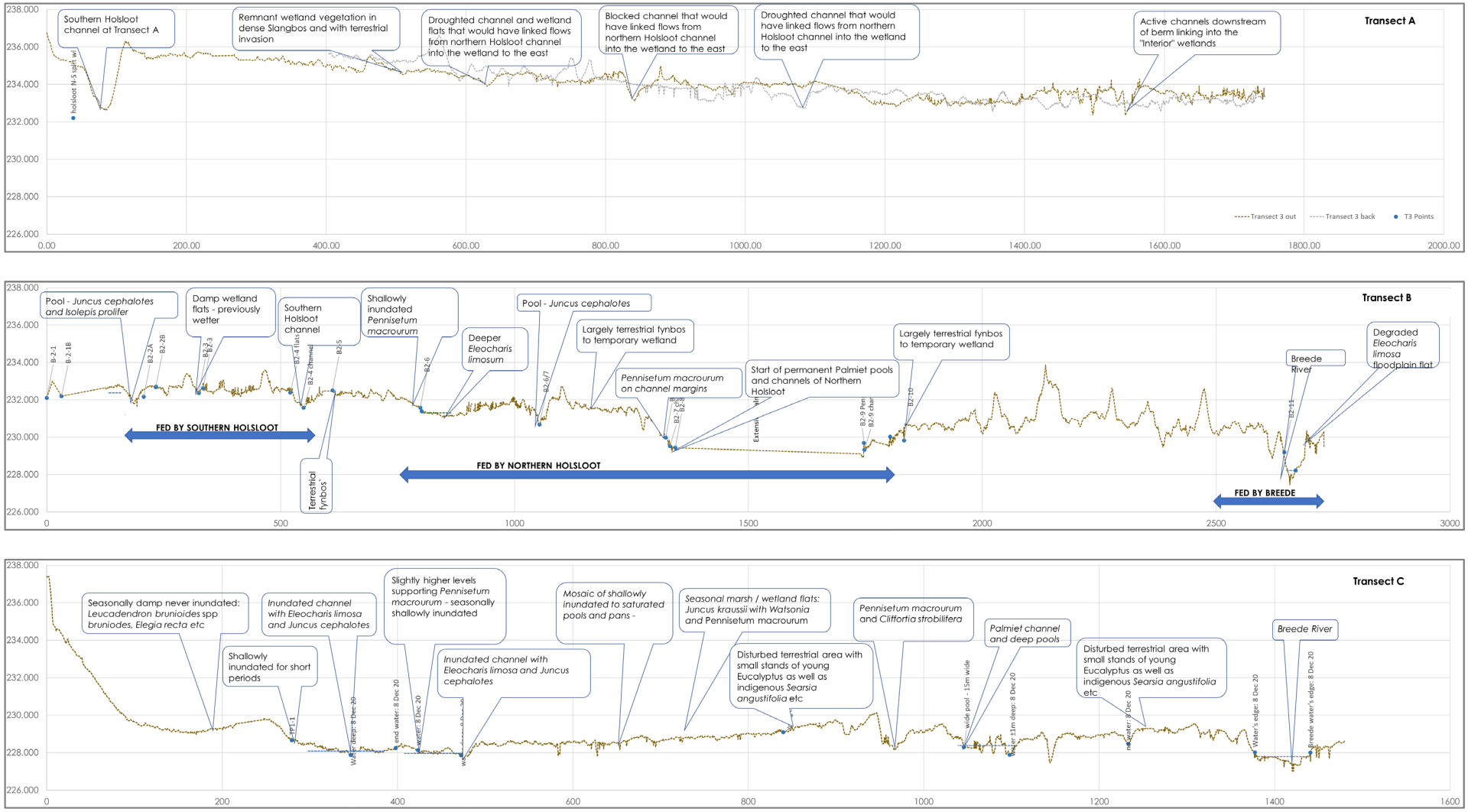

Figure 26: Elevations along the three fixed transects A to C, with annotations highlighting some key aspects of plant community zonation, relating to hydroperiod (noted water levels as surveyed on 8 December 2020).

Table 4: Anthropogenic impacts affecting wetland condition in Papenkuils Wetland disturbance units (see). All comments on "change" are relative to assumed reference conditions. Water quality data is limited, and water quality comments are based on results presented in Appendix B.

Disturbance Unit	Breede River	Southern Holsloot including wetlands	Northern Holsloot / interior wetland / Breede overflows	Bermed and droughted western wetland (east of Northern Holsloot)	Artificial farm channels / irrigation channels	Farm dams and associated seepage areas into the wetland	Breede River and remnant wetland fragments downstream of Nekkies Bridge
Area (ha)	121.559	358.118	351.954	114.951	6.079	61.568	149,432
Natural or artificial?	Natural	Natural	Natural	Natural	Artificial	Partly natural – excavated into water table but natural seepage areas likely	Natural
Changes in morphology and / or alignment	Straightened and bermed in places; northern edge encroached by agriculture and other	Western section of channel bermed and straightened; thereafter largely natural; includes some artificial farm channels	Largely natural downstream of berm	Western section of channel bermed and straightened; excavated and cleared at times	N/A	Significant changes – probably natural seeps into the Papenkuils; now excavated to expose groundwater and receive irrigation return flows from agricultural areas, possibly increasing seepage in summer	Significant – constriction of flows at Nekkies Bridge has re-aligned main channel downstream
Changes in hydroperiod	Category C (moderate) (Government Notice 43726, 2020)	Significant change due to diversions to Brandvlei and Breede	Significant change due to diversions to Brandvlei	Critical – wetland droughted and disconnected from upstream surface flows	N/A	Significant – now perennially inundated or at least saturated surface wetland	Category C (moderate) (Government Notice 43726, 2020)

Disturbance Unit	Breede River	Southern Holsloot including wetlands	Northern Holsloot / interior wetland / Breede overflows	Bermed and droughted western wetland (east of Northern Holsloot)	Artificial farm channels / irrigation channels	Farm dams and associated seepage areas into the wetland	Breede River and remnant wetland fragments downstream of Nekkies Bridge
Changes in timing of inflows	Significant – flows managed for salinity and irrigation	Wet season flow season significantly shortened by releases to Brandvlei Canal	Wet season flow season probably shortened by releases to Brandvlei Canal	No surface flows outside of major floods that breach berm	N/A	Significant – now permanently connected to water table	Significant – flows managed for salinity and irrigation – increased flows in summer released from Brandvlei
Changes in quantity of inflows	Reduced – upstream abstraction including diversion to Brandvlei Dam	Highly significant reduction (Brandvlei Dam and other irrigation schemes)	Significant reduction (Brandvlei Dam and other irrigation schemes) and knock-on effects of Holsloot berms	Complete loss of flows outside of major floods that breach berm	N/A	Increase – as connected to water table now and receive irrigation runoff	Reduced – upstream abstraction including Brandvlei Dam
Changes in duration of flows /inundation	Possibly increased as a result of irrigation releases, but still subject to heavy upstream abstraction	Significantly reduced as a result of high flow diversions to Brandvlei Dam	Reduced due to upstream catchment level abstraction and knock-on effects of Holsloot berms	Complete loss of flows outside of major floods that breach berm	Pass summer irrigation return flows into southern Holsloot wetlands at least into mid-summer	Increase – as connected to the water table and are now perennial	Possibly increased as a result of summer irrigation releases, but still subject to heavy upstream abstraction
Changes in water quality	Water quality often just in eutrophic range (PO_4-P) (does not meet RQOs); mesotrophic for NO_3-N; salinity a threat – but data	Phosphate enrichment in central reaches near agricultural areas – reduces with distance downstream and with time after	More enriched in PO_4-P than southern Holsloot wetlands (often hypertrophic);	No water remaining	High concentrations of PO_4-P and NO_3-N in hypertrophic and eutrophic ranges respectively; EC	No data but assumed to have elevated PO_4-P and NO_3-N	Limited data suggest PO_4-P mainly in eutrophic range, increasing downstream of Avian Park inflows) (does not meet

Disturbance Unit	Breede River	Southern Holsloot including wetlands	Northern Holsloot / interior wetland / Breede overflows	Bermed and droughted western wetland (east of Northern Holsloot)	Artificial farm channels / irrigation channels	Farm dams and associated seepage areas into the wetland	Breede River and remnant wetland fragments downstream of Nekkies Bridge
	show within RQOs for EC	inundation; NO_3-N oligotrophic; pH mildly acid (natural)			well in excess of natural systems;		RQOs); mesotrophic for NO_3-N; salinity a threat – but data show within RQOs for EC
Alien plant invasion	High – mainly black wattle and eucalypts	Low – small eucalypt stands *Eucalyptus* sp.); single specimens of Sesbania (*Sesbania punicea*); very low levels of bramble (*Rubus* sp.);	Moderate – mainly black wattle (*Acacia mearnsii*) and some eucalypts (*Eucalyptus* sp.; regrowth after clearing	Low to moderate – mainly confined to berm – wattles (*Acacia mearnsii*)	Moderate within agricultural areas; some aquatic invasives (e.g. Persicaria spp.; *Myriophyllum aquaticum*)	Low – some grasses and low levels of weeds such as bramble (*Rubus* sp.)	High – black wattle(*Acacia mearnsii*) and eucalypts (*Eucalyptus* sp); *Echium plantageum*; alien grasses;
Livestock grazing	Moderate	Low – but some areas more impacted	Low	Low	Low	Moderate to high outside of dams	Moderate to high in places
Burning				Burning periodically takes place in the wetlands, at varying frequencies – more often in the lower (eastern) wetland			
Erosion and incision	Moderate in places	None to low	None to low	None to low	Low	None to low	At least moderate
Changes in natural vegetation	Medium to high – loss of indigenous marginal and floodplain vegetation	Very low – important and diverse wetland mosaic	Low – important and diverse wetland mozaic	High – droughted out wetlands densely invaded by Slangbos	N/A	N/A	High – extensive loss of marginal vegetation, riparian vegetation and floodplain

Disturbance Unit	Breede River	Southern Holsloot including wetlands	Northern Holsloot / interior wetland / Breede overflows	Bermed and droughted western wetland (east of Northern Holsloot)	Artificial farm channels / irrigation channels	Farm dams and associated seepage areas into the wetland	Breede River and remnant wetland fragments downstream of Nekkies Bridge
							wetlands – mainly through incision

5.10. WET-Health Assessment

5.10.1. Background

Present Ecological State (PES) is a measure of the condition of a river or wetland, relative to its natural (or reference state) condition. The PES assessment protocol results in a score, reflecting the percentage similarity of the present state, to the assumed reference conditions. Depending on the score, one of six PES categories is assigned to each assessed wetland or part of a wetland.

The following categories are applicable in the present study (Macfarlane, Ollis, & Kotze, 2020):

- Ecological Category A: Natural (90-100%);
- Ecological Category B: Largely natural with few modifications (80-89%);
- Ecological Category C: Moderately modified (60-79%);
- Ecological Category D: Largely modified (40-59%);
- Ecological Category E: Seriously modified (20-39%); and
- Ecological Category F: Critically modified (0-19%).

There are several methodologies for determining wetland condition or PES. In this study, the WET-Health methodology was utilised, using the Version 2 Level 2 assessment protocols (Macfarlane, Ollis, & Kotze, 2020). This methodology allows the determination of wetland condition with regard to four key components, namely Hydrology, Geomorphology, Water quality and Vegetation. Together, the scores for these components yield a combined (overall) PES score and associated Ecological Category.

The assessment, the details of which can be obtained from the project team in electronic spreadsheet format, was based on the following broad assumptions and approaches:

- The Papenkuils Wetland as a whole is classified as a floodplain wetland, but includes numerous smaller habitat types within this overarching hydrogeomorphic (HGM) unit (see the sources of water entering the wetlands in Section 5.6);
- Although the mapped wetlands include small islands of terrestrial habitat, these have not been excluded from the overall areas – this is because of the complexity of achieving this and because their overall area is small in comparison to the overall size of the wetland;
- Separate WET-Health determinations were made for each of the following wetland disturbance units, within the Papenkuils Wetland:
- The northern Holsloot River Wetland (including the "interior" sites along the southern edge of the Breede River (see Section 5.4);
- The southern Holsloot and its mosaic wetlands;
- The bermed and droughted wetland east of the northern Holsloot;
- Separation of the above units and their treatment in the assessment as separate wetlands, meant that impacts to their flow regime deriving from the northern Holsloot berm and the Brandvlei Canal intake system were all assessed as catchment-based impacts affecting flows (to variously assessed degrees) within the wetland and not as diversions or berms within the wetlands.

The Breede River itself was not assessed using the WET-Health methodology.

Artificial wetlands and channels were also excluded, as PES assessment is relevant only to natural systems that can be compared against a reference condition.

5.10.2. Assessment Results

The results of the WET-Health assessments are presented in **Tables 5 - 7**. Data provided in this report were supplemented by catchment landuse data presented in (Kotze D. , 2018).

PES data for the assessed wetland units indicated that:

- Changes in hydrology, and in particular, in the hydroperiod, frequency, magnitude and duration of flood flows into the three wetlands is clearly the strongest driver of wetland overall condition and function. Hydrological change was rated as Category E in the northern and southern Holsloot wetland units, and Category F in the almost completely droughted bermed wetland, east of the northern Holsloot channel;
- Vegetation is still in a largely natural condition (Category B) in the southern and northern / interior Holsloot wetland units – this correlates with the specialist botanical findings presented in Appendix A;
- Geomorphology was also rated as largely natural in the Northern Holsloot system, where wetlands are exposed to slightly more natural hydrological processes (flooding) than the Southern Holsloot wetland unit;
- Although geomorphological form in all three wetland units is relatively unimpacted, the hydrological processes driving it have been wholly changed in the bermed wetland east of the northern Holsloot and to a lesser degree reduced in the Southern Holsloot. This drove the assignment of Category D and Category C to these units, respectively;
- Minor excavation and channelisation in both the southern and northern Holsloot units was however also considered;
- Water quality was rated as Category C in both the Southern and Northern Holsloot units, reflecting elevated nutrient discharges into the wetlands; and
- Water quality was not rated in the bermed wetland, where there is no longer any surface flow at all outside of extreme events.

Table 5: Present Ecological State of the Northern Holsloot Wetland (including interior wetlands) expressed as an Impact Score (%) and Ecological Category. Assessment as per methodology of Macfarlane et al (2020).

	Wetland PES Summary			
Wetland name	**Papenkuils**			
Assessment Unit	**Northern Holsloot and interior wetlands**			
HGM type	Floodplain wetland			
Areal extent (Ha)	344.0 Ha			
Final (adjusted) Scores				
PES Assessment	**Hydrology**	**Geomorphology**	**Water Quality**	**Vegetation**
Impact Score	6.5	2.0	2.3	1.5
PES Score (%)	35%	80%	77%	85%
Ecological Category	**E**	**B**	**C**	**B**
Trajectory of change				↓
Confidence (revised results)	Medium	Low	Medium	High
Combined Impact Score	4.2			
Combined PES Score (%)	58%			
Combined Ecological Category	**D**			
Hectare Equivalents	203.5 Ha			

Table 6: Present Ecological State of the Southern Holsloot Wetland expressed as an Impact Score (%) and Ecological Category. Assessment as per methodology of Macfarlane et al (2020).

	Wetland PES Summary			
Wetland name	**Papenkuils**			
Assessment Unit	**Southern Holsloot**			
HGM type	Floodplain wetland			
Areal extent (Ha)	358.1 Ha			
Final (adjusted) Scores				
PES Assessment	**Hydrology**	**Geomorphology**	**Water Quality**	**Vegetation**
Impact Score	6.5	2.4	3.5	1.5
PES Score (%)	35%	76%	65%	85%
Ecological Category	**E**	**C**	**C**	**B**
Trajectory of change				
Confidence (revised results)	Medium	Low	Medium	High
Combined Impact Score	4.5			
Combined PES Score (%)	55%			
Combined Ecological Category	**D**			
Hectare Equivalents	197.6 Ha			

Table 7: Present Ecological State of the bermed and droughted wetland east of the northern Holsloot channel, expressed as an Impact Score (%) and Ecological Category. Assessment as per methodology of Macfarlane et al (2020). Note no water quality assessment relevant in the absence of flows.

	Wetland PES Summary			
Wetland name	Papenkuils			
Assessment Unit	Bermed wetland east of Northern Holsloot			
HGM type	Floodplain wetland			
Areal extent (Ha)	115.0 Ha			
Final (adjusted) Scores				
PES Assessment	Hydrology	Geomorphology	Water Quality	Vegetation
Impact Score	9.6	4.4		8.0
PES Score (%)	4%	56%		20%
Ecological Category	F	D	N/A	F
Trajectory of change				
Confidence (revised results)	High	Low	Not rated	High
Combined Impact Score	7.5			
Combined PES Score (%)	25%			
Combined Ecological Category	E			
Hectare Equivalents	29.3 Ha			

5.10.3. Comparison of PES Assessment Data with Previous Study Outcomes

Previous WET-Health evaluations have been carried out on the Papenkuils Wetland (as per Kotze 2018), using the revised assessment methodology. The Kotze (2018) study) assessment yielded the following results, for the Papenkuils Wetland as a whole:

- Hydrology: PES Category D;
- Geomorphology: PES Category B;
- Water quality: PES Category C; and
- Vegetation: PES Category C.

Reasons for the differences in scores in the latter study, which reflects slightly better overall wetland condition than the current study, but vegetation in a worse condition, are based mainly on differences in the rating of the magnitude of impacts of loss of flows into the wetland, from the Holsloot River – in particular along the southern Holsloot Wetland, with the current study rating these impacts higher (i.e. worse) than Kotze (2018). The higher rating presented here is however supported by more detailed hydrological modelling in the present study, and also driven by the manner in which the current study has divided the wetland into separate assessment units, as opposed to assessing them as a whole, in the Kotze assessment. The purpose of assessment in the two studies was moreover also different, with the Kotze study using it as a test case for WET Health assessment of broad wetland condition, while the present study has used it as a tool to differentiate between the impacts of changes in key wetland drivers on specific parts of the wetland, and to predict future change in the event of further disruption in flows into different sections of the wetland, differentially affected by hydrological impacts.

Slightly higher geomorphological impact ratings in the present study are also associated with changes in hydrology, affecting sediment distribution regimes, particularly in the southern Holsloot Wetlands.

The lower (i.e. better) vegetation rating included in the present study for the northern and southern wetland units is based on the detailed recent botanical assessment informing this study, and the vegetation component was carried out with high confidence.

5.11. Recommendations for Improving Wetland Ecosystem Functioning

The Papenkuils Wetland is a diverse wetland system of extremely high importance from an ecological perspective, and particularly so from a botanical perspective, in part because of its importance as a stronghold for most of the SoCC that it includes. It includes up to 30% of the existing known global population of some of these species (see Section 4.5). The wetland falls under ownership of three private landowners only, with a portion of the eastern (downstream) wetland falling within municipal land. To date, alien clearing programmes carried out in various public-private partnerships with local landowners, in association with public programmes such as Working for Wetlands and Working for Water as well as DEA&DP, have improved wetland condition compared to that in the early 2000s. However, the long-term sustainability of the wetland, at least in its present extent, is threatened by a number of serious issues, with reduced water quantity and changes in hydroperiod probably being the most pressing. Given the ecological importance of the wetland, there would be great merit in pursuing measures that would actively address current impacts. Long-term threats to wetland sustainability, particularly in the context of ongoing climate change-associated threats to wetland resilience, thus warrant addressing.

It is recommended that the following issues should be considered:

- Measures to ensure that the remnant southern Holsloot Wetlands receive adequate flows to retain high levels of wetland function, and support their complex mosaic plant habitats:

- Since the northern Holsloot and (by implication therefore the interior and northern Holsloot Wetlands) receive preferential flow from the Holsloot River at the point of diversion from the southern Holsloot, meeting this requirement means that the Brandvlei Canal diversion rules should be adjusted to allow some of the larger flood flows to pass uncapped down the river, to the northern / southern Holsloot split. "Larger" flows would be defined as those that exceed the minimum threshold required to breach the southern Holsloot and allow its passage down the channel and beyond the end of the existing berm, from where flows can overtop the channel and spread out into the surrounding wetland flats;
- In terms of the Ecological Reserve for the wetlands as a whole (DWAF, 2003), such overtopping would need to:
  - result in the wetland being filled to a water surface level of about 199 m above mean sea level; and
  - occur at a frequency of three to five times per year;

- Measures to ensure that the perennial pools and channels of the interior and northern Holsloot Wetlands, fed mainly by the northern Holsloot, receive adequate flows to allow periodic flushing of pools and maintain saturated conditions – if the flooding requirements for the southern wetland were met, it is likely that these would be met in the norther part of the wetland too, as the northern Holsloot receives a larger proportion of upstream flows than the southern Holsloot (an 80:20 split ratio has been estimated in the hydrological model);

- Measures to re-introduce flows into the droughted western wetland, and rehabilitate this ±115 ha section of the wetland – such measures would:

- Improve the condition and biodiversity contribution of an important wetland system;
- Reduce fire threats as a result of dominance by terrestrial, weedy vegetation;
- Improve the grazing quality of this area, currently dominated by unpalatable slangbos shrubs; and
- Improve storage capacity in the wetland, potentially allowing a greater proportion of attenuated flood flows to be abstracted downstream of the Nekkies Bridge, and pumped back into Brandvlei Dam;

  Measures to consider could include:

- Breaching the berm along the northern berm at the points of infilled channels into the wetland to the east using pipes, to allow wet season low flows into the wetland; or
- Breaching the berms at selected points to allow high flows to recharge the wetlands;

- Attention to ongoing clearing of alien vegetation, particularly along the Breede River; along the northern Holsloot River, as far as its confluence with the Breede River; and in previously cleared areas (southern Holsloot and eastern end of interior wetlands) where regrowth of cleared aliens is occurring at low densities;

- Removal of nuisance species such as bramble (*Rubus* sp.) and Patterson's curse (*Echium plantagineum* before the plants spread further and become problematic;

- Management of livestock grazing so that some benefit from occasional intense grazing is derived, without allowing for loss of biodiversity through long-term low intensity selective grazing;

- Consideration of constructing cutoff drains that allow infiltration to groundwater of runoff / leachate from sources of high nutrients such as manure management areas and livestock feedlots, rather than conveying flows as concentrated runoff directly into the wetland.

Compilation of a detailed rehabilitation plan, informed by longer term water quality, flow and ecological monitoring, is however strongly recommended to inform the details of implementation of measures to address the above issues.

The above rehabilitation scenarios have been incorporated into the hydrological model presented in Section 6, as an alternative (Modified Abstraction Regime 2: Proposed Future Scenario) to the current proposal to raise the level of the Brandvlei Canal to increase storage capacity.

6. Ecological and Hydrological Impacts of Increasing Brandvlei Abstraction

6.1. Catchment Runoff Simulation

6.1.1. Background to the Agricultural Catchments Research Unit (ACRU) model

The ACRU model is a physical conceptual model that works at a daily time-step and allows for assessments on land use changes, and subsequent impacts on water resources, to be undertaken. The model has been used both at a local level in South Africa, as well as internationally, for multiple different purposes such as changes in land use, design hydrology and crop yield estimates. As such, it was deemed the best suited model for the purposes of the study.

The model uses a multi-layer soil water budgeting methodology (as shown in Figure 27) that considers distribution of soil water throughout the soil horizons. Following the partitioning of precipitation into vegetation interception or directly into streamflow, any water that is not partitioned enters the soil surface and fills up the topsoil horizon until its drained upper limit (DUL). Once this soil surface DUL (GeoTerraImage, 2019) is reached, water then percolates through to the subsoil horizon where it proceeds to fill to the subsoil's drained upper limit (Smithers & Schulze, 1995).

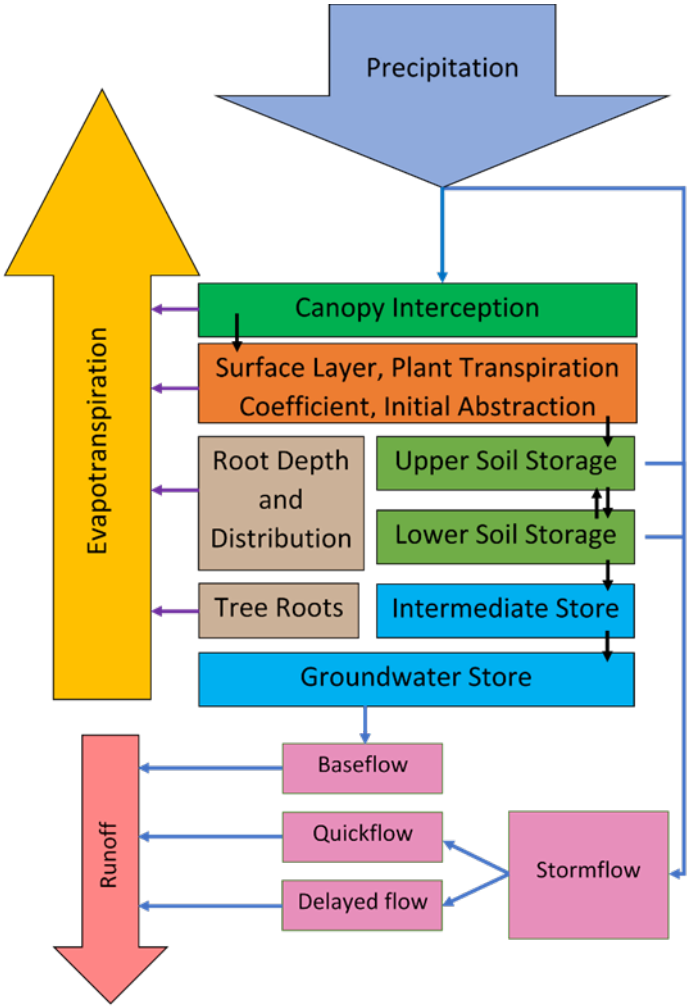

Figure 27: Multi-layer soil water budgeting methodology implicit in the ACRU model.

Runoff is generated within the model by firstly considering all initial abstractions (such as interception, depression storage and soil infiltration), and then producing runoff based on the amount of rainfall, its intensity, and the critical stormflow-generating soil depth. Whilst stormflow is generated on a daily basis, it does not all exit the catchment on the same day as the model allows for a lag to be created between stormflow being generated and it leaving the catchment.

Insofar as the vegetation and land cover of an area are concerned, the model needs to consider the above-ground, surface, and below-ground factors of the particular cover in order to best represent the soil water budget. As such, the model considers factors such as canopy interception, water use by the vegetation type, amount of litter on the surface, and rooting depth distributions, as root depth has an influence on transpiration and hence water yield. (Schulze, Angus, Lynch, & Smithers, 1995).

6.1.2. Inputs to the model

As part of the runoff determination undertaken, the following information was used to determine the input parameters and simulate the physical conditions of the drainage area:

- Daily rainfall records from the DWS' meteorological stations were used in the creation of the climate files used to drive the quaternary catchments and smaller outlet catchments;
- Daily A-pan evaporation records were used in the creation of the climate files used to drive the three main catchments from the DWS'meteorological stations were used in the creation of the climate files used to drive the quaternary catchments and smaller outlet catchments;
- Land use as per the South African National Land Cover 2018 (NLC2018) (GeoTerraImage, 2019) dataset created for the (former) Department of Environmental Affairs was extracted using zonal area calculations to provide the total land use type for each of the catchments used in the model;
- Soils data was obtained from the Land Type Survey Staff (developed by the Agricultural Research Council 's Institute for Soil, Climate and Water) (ARC-ISCW, 1972-2002) in order to determine the soil parameters to be input into the model (including soil texture and depth); and
- Topography and delineation of catchments was done using the quaternary catchment database available from DWS. Further to this, the Shutter Radar Topography Mission (SRTM) digital elevation model for the area[19] was used to verify the drainage of the area.

6.1.3. Catchments

In order for the ACRU model to be developed, the drainage area in which the wetland is located needed to be broken down into smaller sub-catchments for the determination of similar hydrologic response units (HRUs). These catchments were derived based on existing drainage areas, viz. the quaternary catchments, and then adjusted /delineated based on topography required outlet points (Figure 28).

It should be noted that, whilst all of the catchment areas were larger than the recommended < 30 km^2 for use in the ACRU model (Smithers & Schulze, 1995), these areas were shown to be representative of the drainage of the area and could not be further broken down.

[19] Available for download at: https://earthexplorer.usgs.gov/ [Accessed in June 2020]

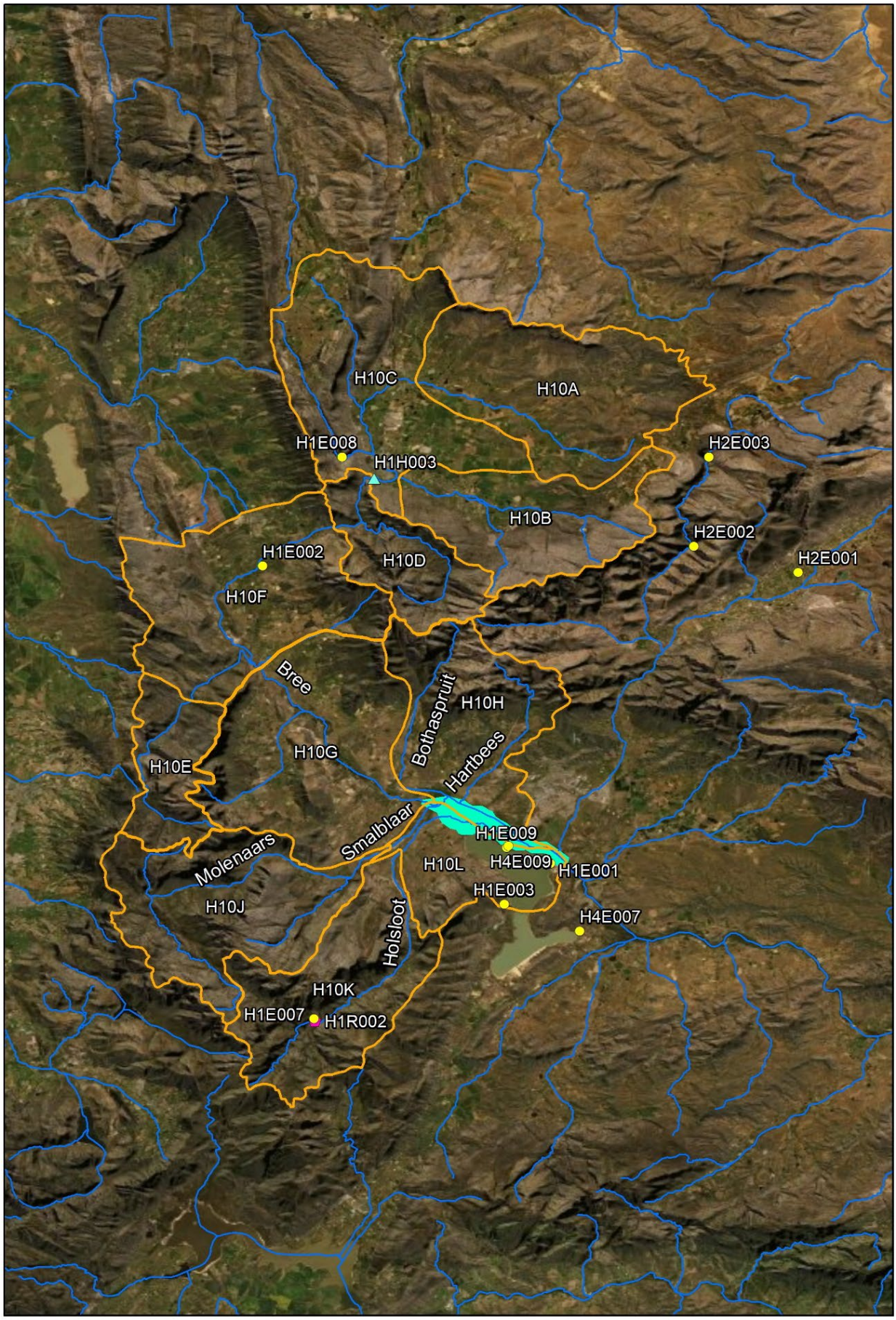

Figure 28: Quaternary catchments considered during the modelling of runoff in ACRU and selected meteorological stations (yellow markers).

In order to account for these larger catchments, the model was run as a unit model in order to derive an equivalent unit runoff (i.e. the depth in mm of runoff for each catchment) at a daily time step for each of the quaternary catchments used. The climate files used for these catchments included rainfall and evaporation derived from the selected driver stations used for each of the main catchments. Certain quaternary catchments were further sub-divided (Figure 29) to make allowance for simulation of:

- The Stettynskloof Dam;
- The Smalblaar diversion into the Holsloot River;
- The Holsloot diversion into the Branndvlei Dam; and
- Separate runoff inputs to the Breede from the Bothaspruit and Hartbees Rivers.

The unit runoff for each of these catchments was then converted to a volumetric runoff based on the area of the relevant catchment or sub-catchment. These subsequent volumes were then routed according to the natural drainage pattern (shown in Figure 30) to allow for further analysis of daily discharges into the Papenkuils Wetland, including operation of the diversions.

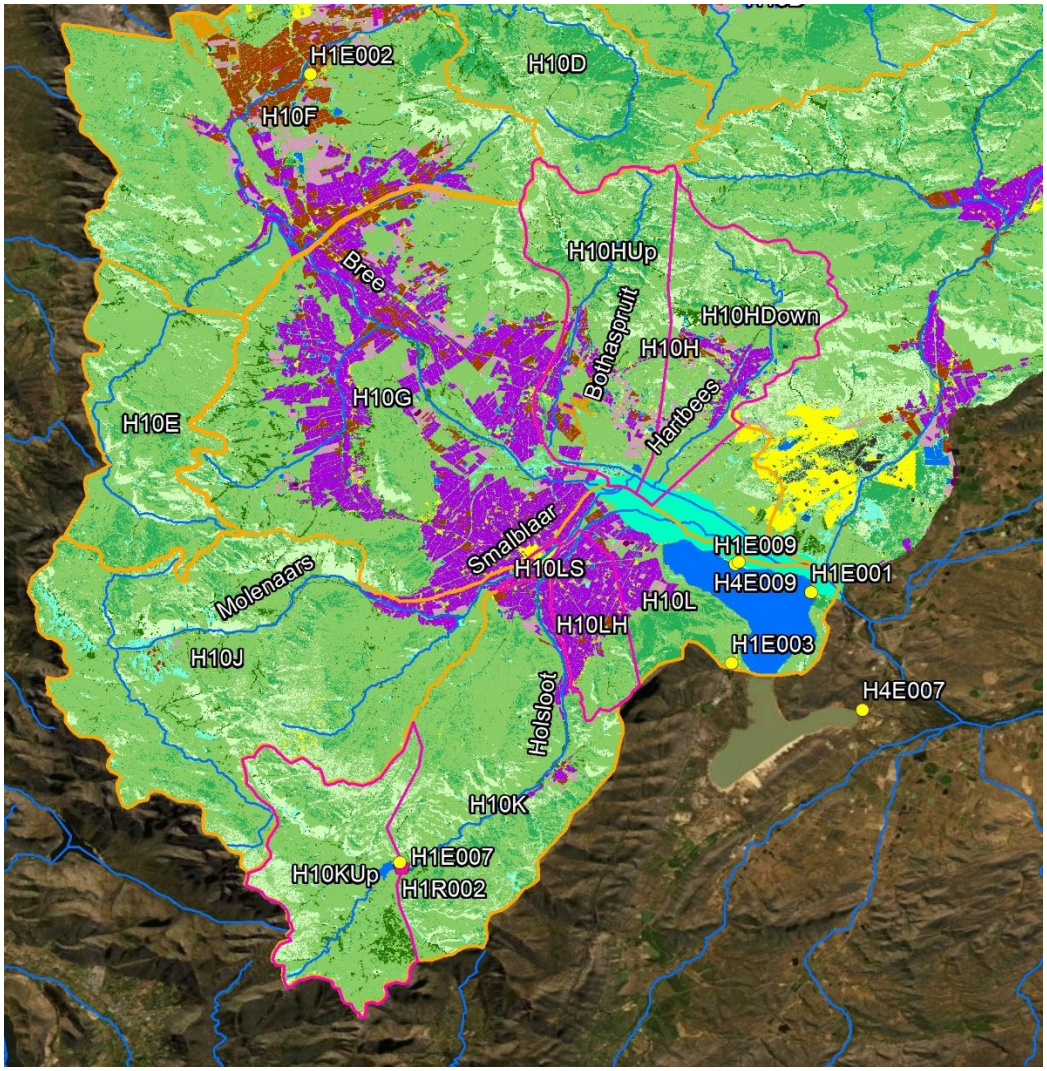

Figure 29: Sub-division of quaternary catchments to account for the Smalblaar and Holsloot diversions and for separate catchment contributions from the Stettynskloof Dam and Bothaspruit and Hartbees rivers.

6.1.4. Simulated Catchment Runoff

In order to verify the catchment simulations, two available observed flow gauging stations were used. These were the station H1H003 in the upper Breede River and station H1R002, which gauges the outflow to the Stettynskloof Dam. Further DWS gauging records were examined, but found to be outside of the simulated time frame or questionable records. Figure 31 shows the comparison of the monthly discharges simulated at the outlet of quaternary catchments H10A and H10C. The gauge lies slightly upstream of the outlet of these two quaternaries, but no adjustment was made to the record or the simulated values. The comparison is reasonable, with the simulated monthly flows clearly higher than the recorded flows, in the months where the gauged discharge is observed to have exceeded the weir rating curve. Otherwise, the simulations are reasonable, given a slightly larger area was simulated than the gauge represents. Figure 32 compares the cumulated observed flows at gauging weir H1R002, the outlet to Stettynskloof Dam, with cumulated simulated discharges from the dam. Simulation of the dam included the simulated catchment inflows, evaporation from the storage, changes in storage volume (max 15 Mm^3 ref), extraction of water supply to Worcester and Rawsonville (39 Ml/day) and baseflow releases (40 Ml/day – although these required reducing to 10 Ml/day for the period 1995 to 2005 to match the observed flows). Spills were determined as the excess flows, once the maximum storage capacity was reached. The accumulated discharges compare favourably and so the simulated record was accepted as input to the remainder of the Holsloot Catchment contributions.

The results of the simulated runoff from catchments contributing to the Papenkuils Wetland are illustrated in Figure 33 for the Breede River, including contributions from the Bothaspruit and Hartbees rivers, but excluding the Smalblaar and Holsloot contributions.

The simulated runoff in the Holsloot (including releases and spills from the Stettynskoof Dam) is presented in Figure 34, while the runoff in the Smalblaar is shown in Figure 35.

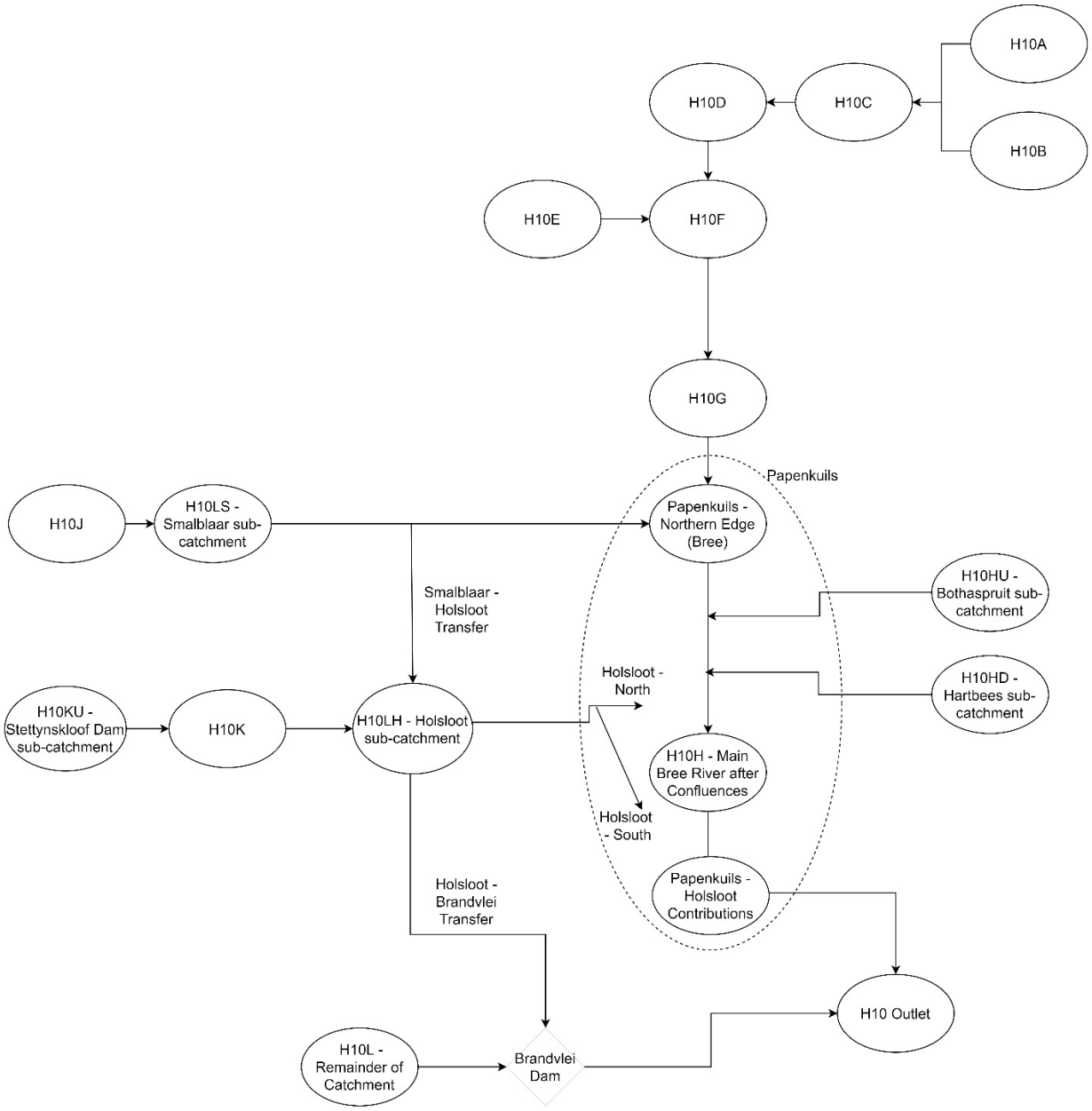

Figure 30: Flow routing throughout Quaternary catchment H10, including diversions.

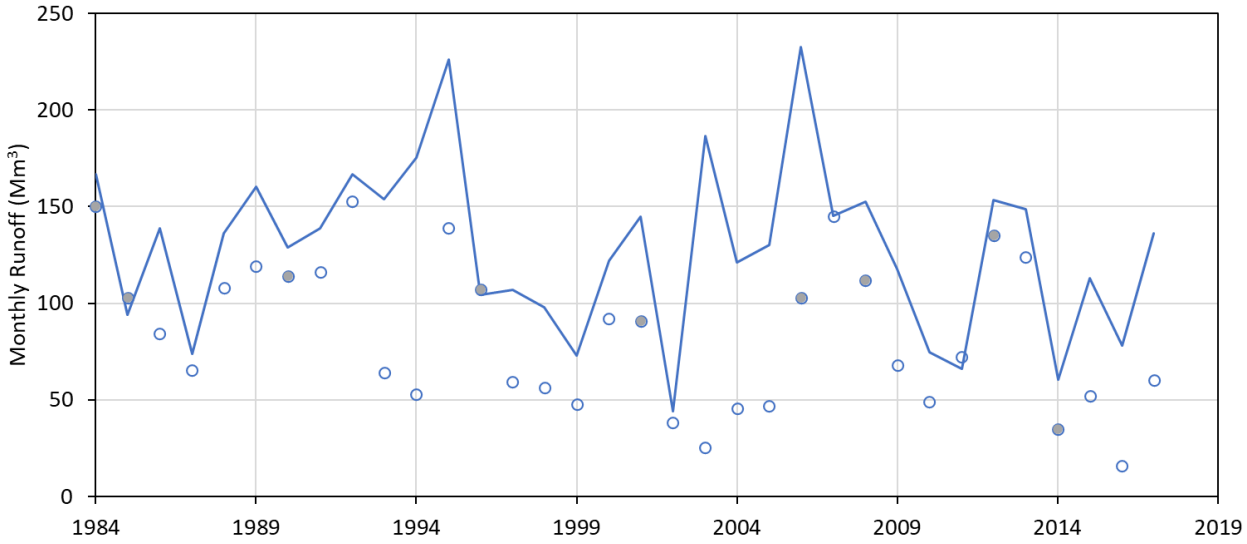

Figure 31: Simulated (blue line) flows at the outlet of quaternary H10C and the observations from H1R003 flow gauge (open circles – grey circles denote weir rating was exceeded).

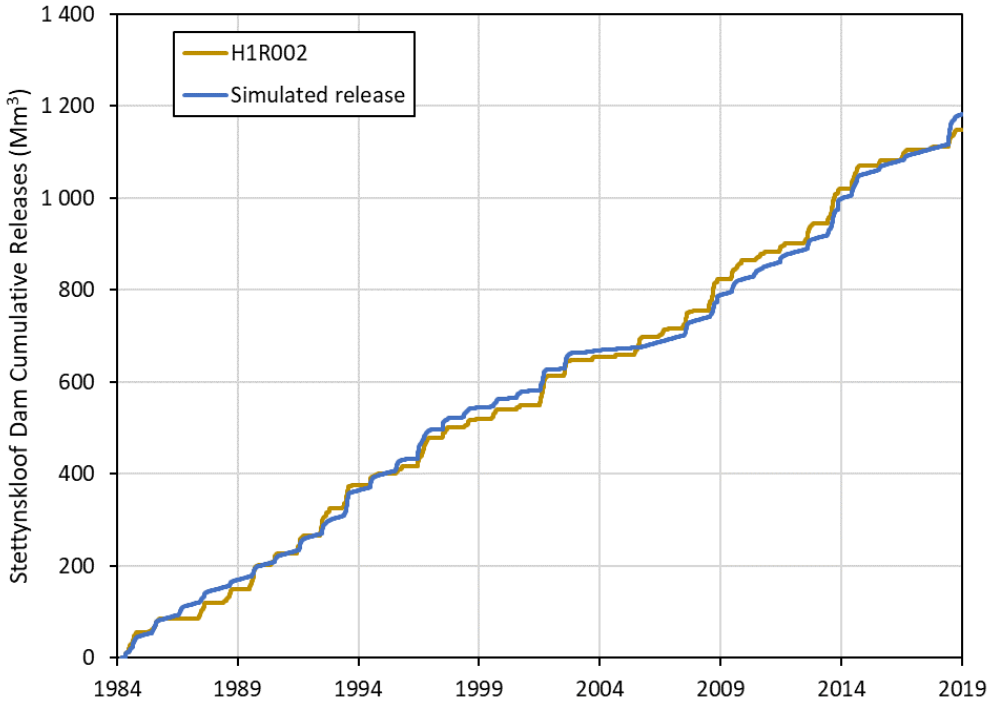

Figure 32: Comparison of simulated discharge from Stettynskloof Dam and observations at H1R002.

The discharge in the Breede River is clearly the largest entering the Papenkuils system, with peak flows reaching 23 Mm³/day. The Smalblaar (peak discharge of 20 Mm³/day) contributes slightly higher discharge than the Holsloot (peak discharge of 18 Mm³/day). The Stettynskloof Dam releases and spills were simulated by applying a water balance to the dam. A maximum storage was applied from published data, with inflows simulated for the contributing catchment upstream of the dam. Abstractions were included for water supply to Worcester and Rawsonville (39 Ml/day), downstream releases including irrigation water (40 Ml/day) and estimated evaporation (0.50 Ml/day).

Further analyses of the abstractions from the Smalblaar to the Holsloot and from the Holsloot to the Brandvlei Dam were determined in the wetland model (Section 6.2).

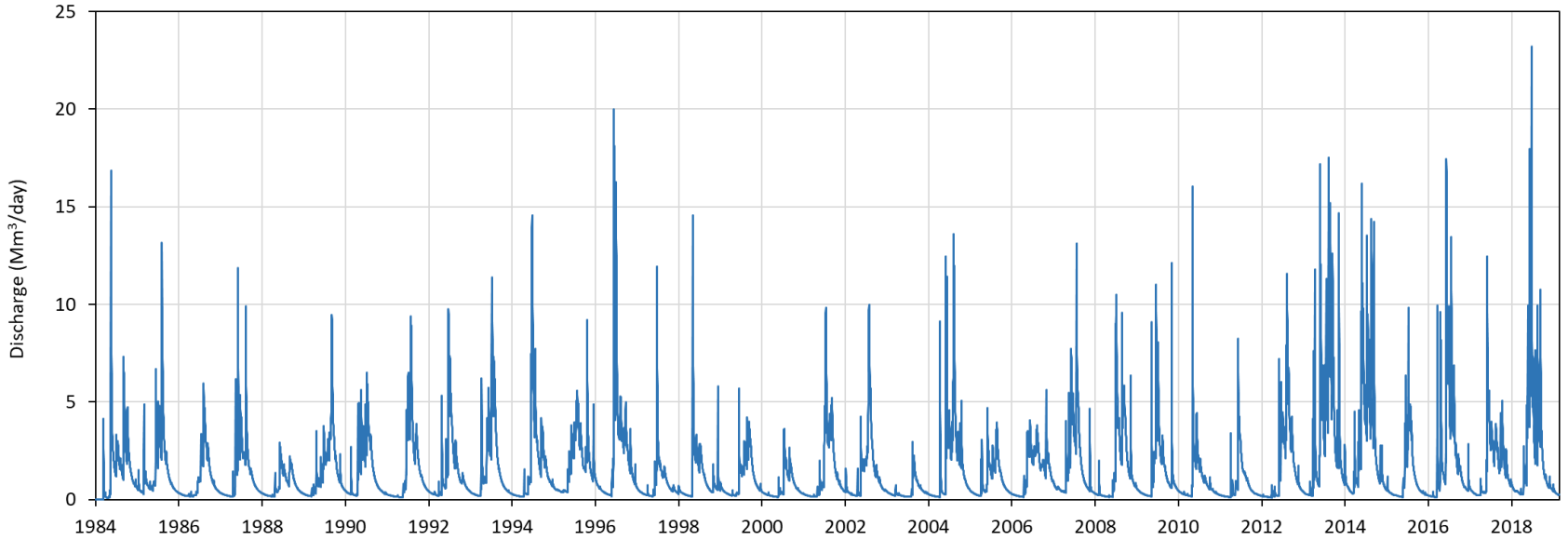

Figure 33: Simulated daily runoff in the Breede (including Bothaspruit and Hartbees rivers) contributing to the Papenkuils (1984-2019).

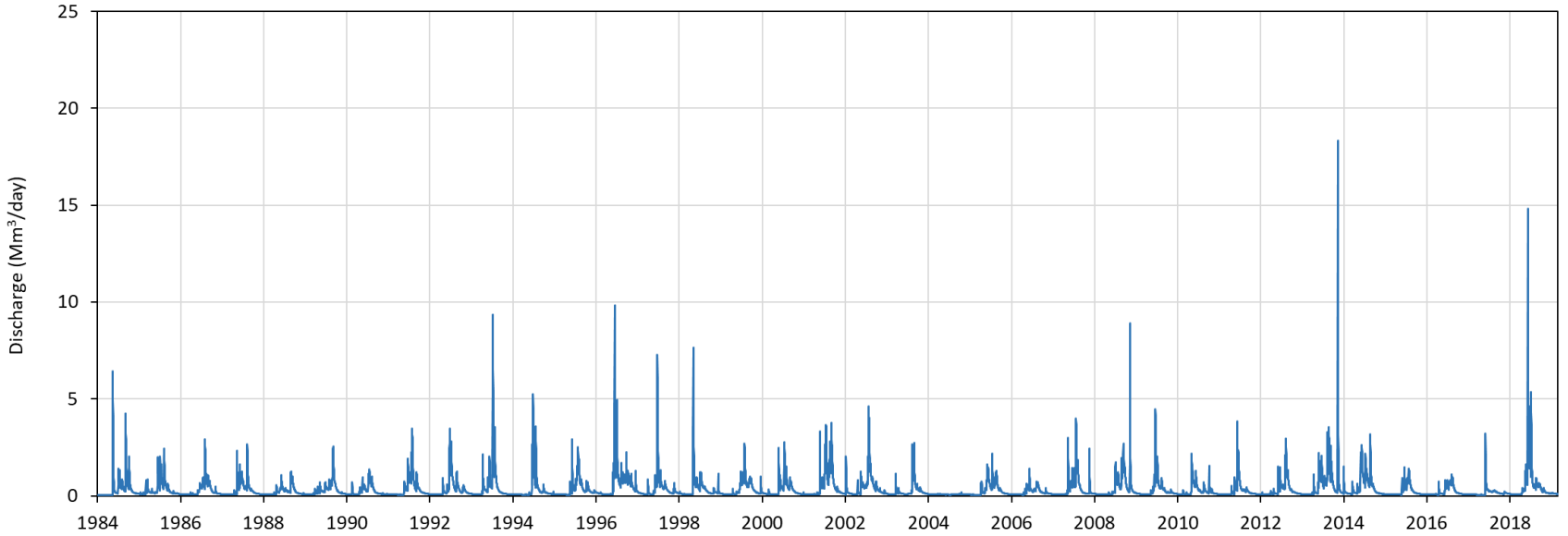

Figure 34: Simulated daily runoff in the Holsloot River (excluding transfers from the Smalblaar), (1984-2019).

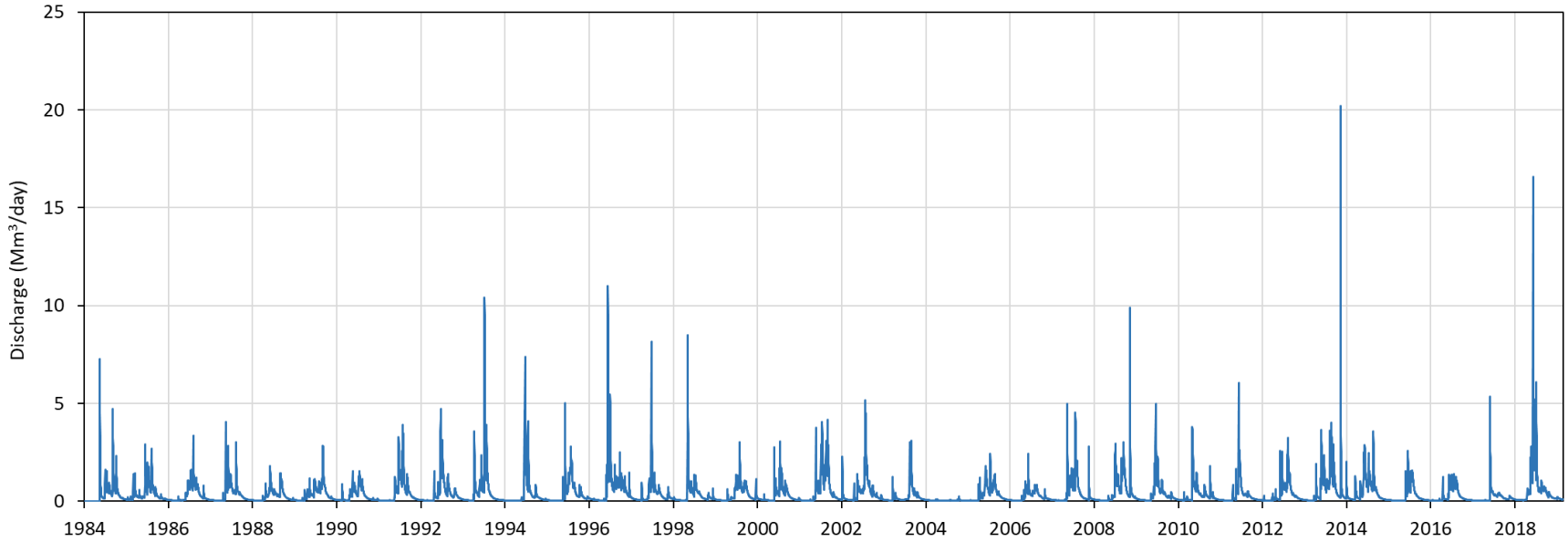

Figure 35: Simulated daily runoff in the Smalblaar river (excluding transfers to the Holsloot), (1984-2019).

6.2. Diversion Scenarios

The simulated streamflows were entered into a spreadsheet, in which the flows entering the Papenkuils Wetland were determined by applying the rules which determined the diversions from the Smalblaar into the Holsloot and from the Holsloot into the Brandvlei Dam. As determined during the field observations, surveys and satellite imagery, the main contributions to the wetland are via the Holsloot River, which splits into a northern and southern stream on entry into the wetland. The flow assessment is therefore focused on deriving the most reliable discharges in the Holsloot River and its two branches.

6.2.1. Current Diversion Rules Smalblaar to Holsloot

The releases from the Smalblaar into the Holsloot are determined as follows;

- The Holsloot must not be flowing full (Full flow in the Holsloot was taken as 2.5 Mm^3/day, This is the discharge where the raised weir in the Holsloot will extract higher volumes than the current weir,
- The maximum transfer from the Smalblaar into the Holsloot must not exceed 44 m^3/s (1.5 Mm^3/day); and
- Otherwise all flows enter the Holsloot from the Smalblaar.

Applying these rules resulted in a daily record of flows in the Holsloot at the point of extraction to the Brandvlei Dam.

6.2.2. Current Diversion Rules Holsloot to Papenkuils

Diversion of flows from the Holsloot to the Brandvlei Dam are determined as follows:

- The prevailing discharge in the Breede River at the Nekkies Weir must exceed 5 m^3/s (0.432 Mm^3/day),
- Abstractions from the Holsloot are restricted to the months between the beginning of June and the end of September,
- Abstractions from the Holsloot are controlled by the weir in the Holsloot and associated gates which release water into the channel, which discharges into the Brandvlei Dam. The relationship between the Holsloot discharge and the releases to the Brandvlei Dam is shown in Figure 36 for the current and proposed weir configurations; and
- The Holsloot discharge-Brandvlei diversion flow relationship implies that all flows in the Holsloot below 30 m3/s (2.592 Mm3/day) are diverted to the Brandvlei, if the remaining rules are satisfied. However, in practice the opening of the diversion gates are operated on a more ad-hoc observation sequence. Hence, a further factor is introduced to the diversion rules, allowing for a percentage of the Holsloot discharge to be diverted to the Brandvlei Dam, where Holsloot flows are lower than 30 m^3/s. This percentage is taken as 85% for the current operation.

All diversion rule parameters are set as adjustable variables in the discharge generation spreadsheet. These diversion rules are referred to as the "current" scenario.

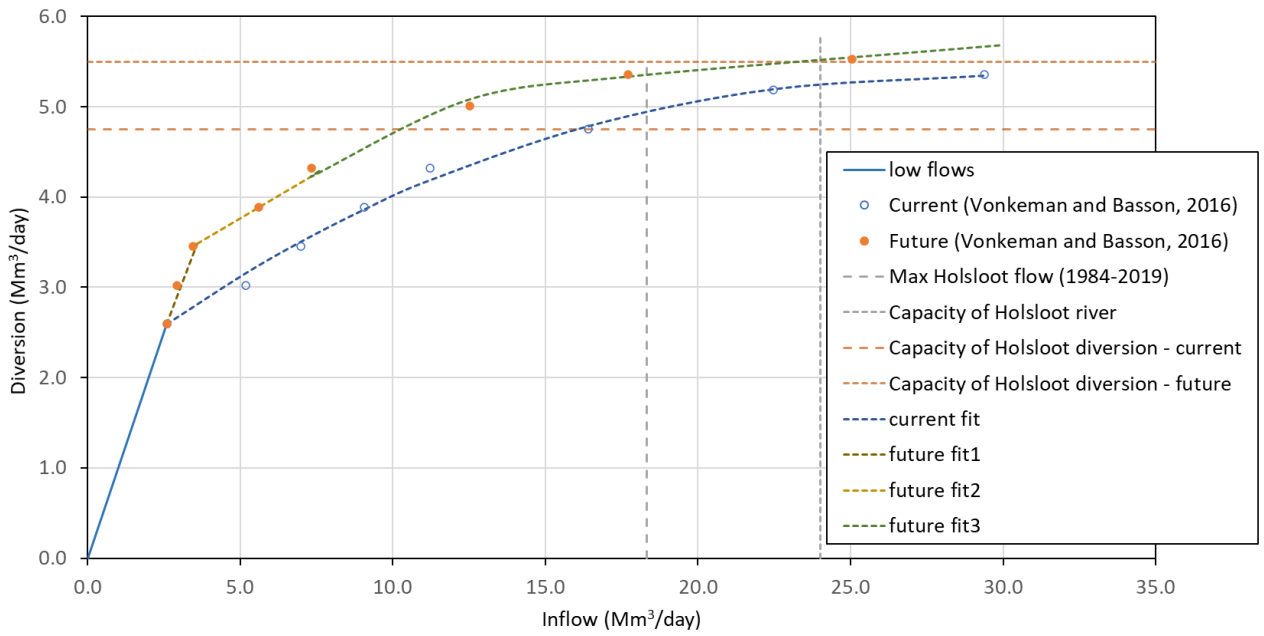

Figure 36: Relationship between the Holsloot discharge and the diversions to the Brandvlei Dam for current (blue) and future (green) scenarios.

6.2.3. Future Raised Holsloot Weir

In future it is proposed that the weir is operable with a 0.3 m increase in height (Department of Agriculture study - (Basson G. R., 2016)). This increases the future extractions from the Holsloot River to the Brandvlei Dam for Holsloot discharges exceeding 30 m^3/s (2.592 Mm^3/day), as illustrated in Figure 36.

In these operating rules, it is assumed that diversions of flow where the Holsloot discharge is less than 30 m^3/s, increases in efficiency to 95% of the prevailing Holsloot discharge. Again, all the parameters that control the diversion are set as user changeable variables in the spreadsheet.

These operating rules are referred to as the "future 1" scenario.

6.2.4. Proposed Future Scenario

This scenario was developed in response to the recommendations outlined in Section 4.11 regarding the urgent need to increase flows into the Papenkuils Wetland, and the southern wetland in particular, to prevent a long-term trajectory of degradation. In addition, rehabilitation of the critically droughted portion of the wetland (115 ha), currently affected by the berm along the northern Holsloot, is recommended.

In terms of this scenario then, which attempts a more sustainable approach to abstraction and the routing of flows into Brandvlei and the Breede River downstream of the wetland, the following is allowed for:

- A reduction in diverted flows to the Brandvlei, to allow for higher flows into the wetland, and therefore a regulated release back into the Breede prior to the extraction of Breede flows into the Brandvlei Dam. These reductions call for transfer of 85% of flows below 30 m3/s and a 30% reduction of abstraction of high flows,
- The provision of breaks in the northern and southern Holsloot berms to allow for discharge into the currently dry zone in the western end of the wetland, (referred to as North Holsloot Bermed in Figure 24, 115 ha).

The parameters in this option, referred to as "future 2" scenario, are set as user controlled variables in the flows spreadsheet.

6.3. Wetland Model

The wetland model has also been derived in a spreadsheet, which reads the output from the three flow scenarios. The model focuses on the fate of the flows, sediments, nutrients and soil organic carbon as a result of the three inflow options, via the Holsloot North and Holsloot South contributions to the wetland.

6.3.1. Wetland Flows

The discharges related to the Holsloot diversion are assessed in the flows section of the wetland model. The comparison of the volumes diverted to the Brandvlei Dam are illustrated in Figure 37. The future 1 scenario reduces the frequency of diversion rates below 1 Mm^3/day, but increases diversion greater than 1 Mm^3/day. Future 2 diversions are also greater than current, but include a significant increase in diversions of 3.2 M^3/day, whereas other high flow diversions are less than in future 1. Reasons for these flow differences are inherent in the rules governing each (Section 5).

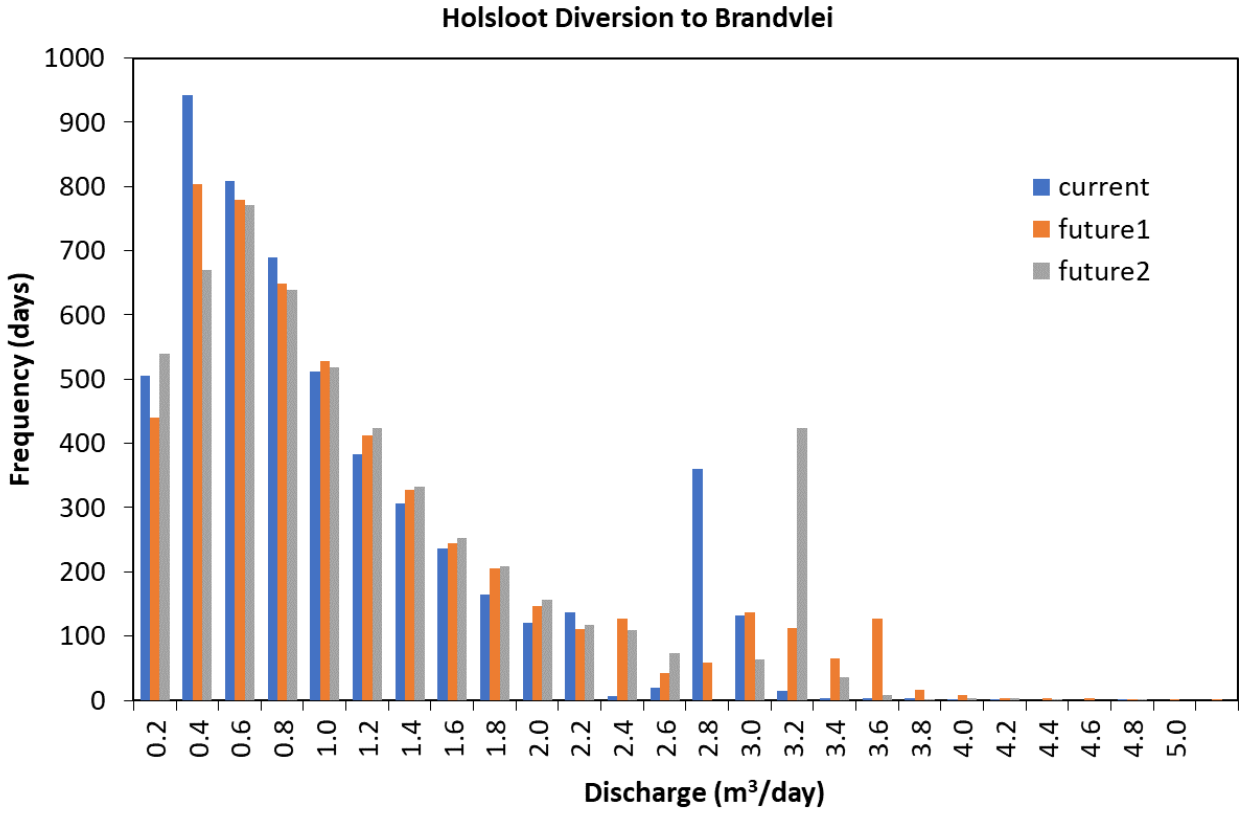

Figure 37: Frequency ranking of the Holsloot River diversion discharge to the Brandvlei Dam.

The remaining flows in the Holsloot, after extractions to the Brandvlei, are illustrated in Figure 38. It is clear that the low flows dominate, and these are therefore largely maintained within the bounded channels of the northern and southern Holsloot.

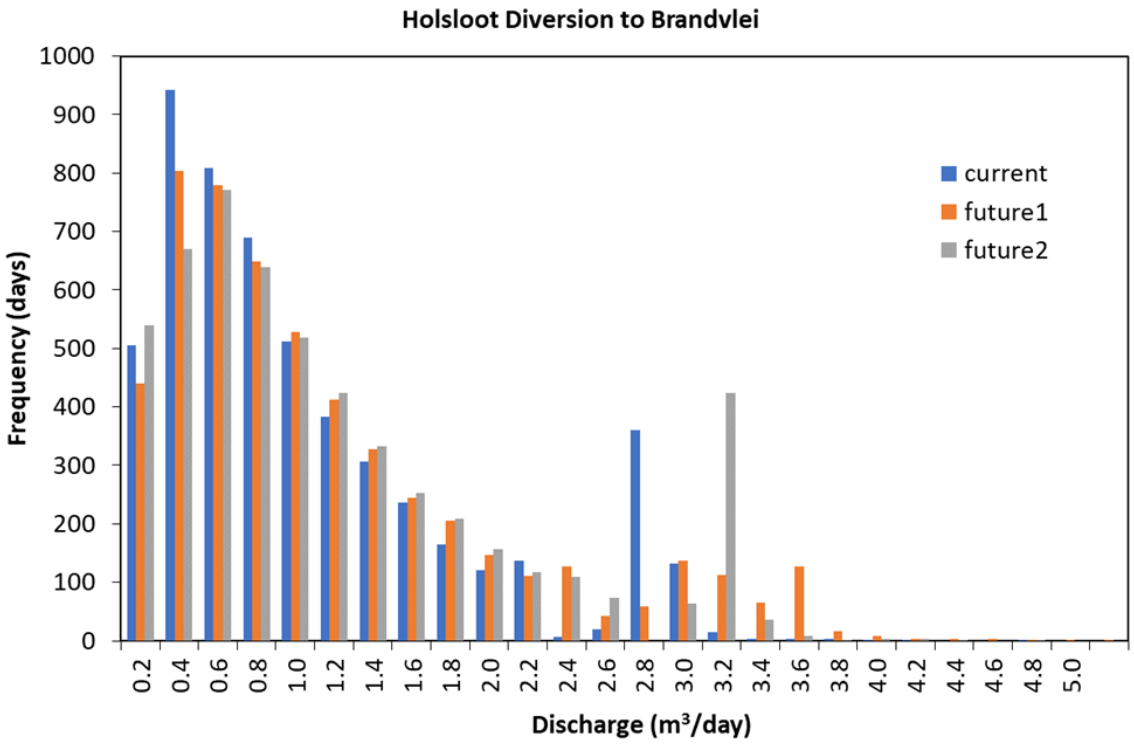

Figure 38: Frequency ranking of Holsloot discharge remaining after extractions to the Brandvlei dam.

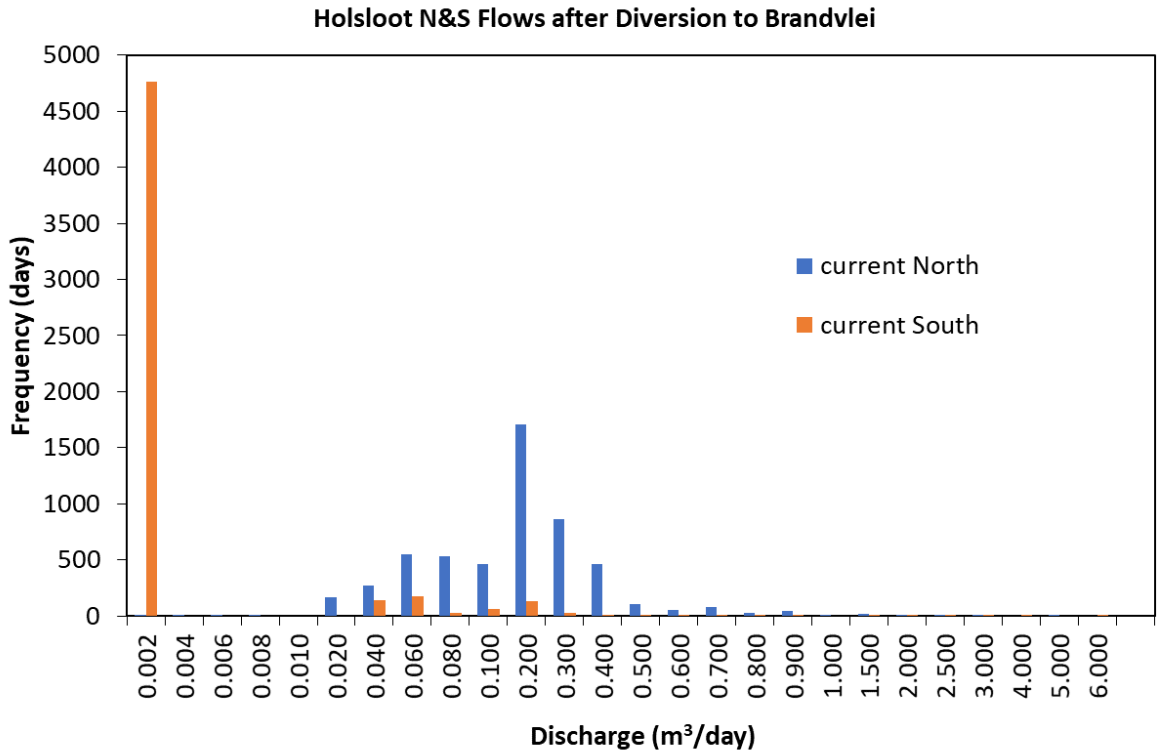

Figure 39: Frequency ranking of North and South Holsloot discharge after extraction to the Brandvlei dam.

During the differential GPS survey of the weltand, the elevations in the Holsloot northern and southern branch were measured. It was determined that the southern Holsloot branch is 0.4 m higher than the northern branch, were, or just beyond, the split in the main Holsloot stream. Discharge-flow depth relationships for both channels were determined using surveyed sections. Flows into the southern Holsloot were initiated when the main channel flow depth exceeded 0.4 m, resulting in the flow distribution shown in Figure 39.

6.3.2.Wetland Inundation

Key to the determination of the wetland value, is the frequency and extent of water inundation. In order to derive a history of inundation extent and frequency, images from the Sentinel satellite were subjected to a Water in Wetland Index algorithm to identify inundation locations. A typical dry and wet inundation sequence is shown in Figure 40.

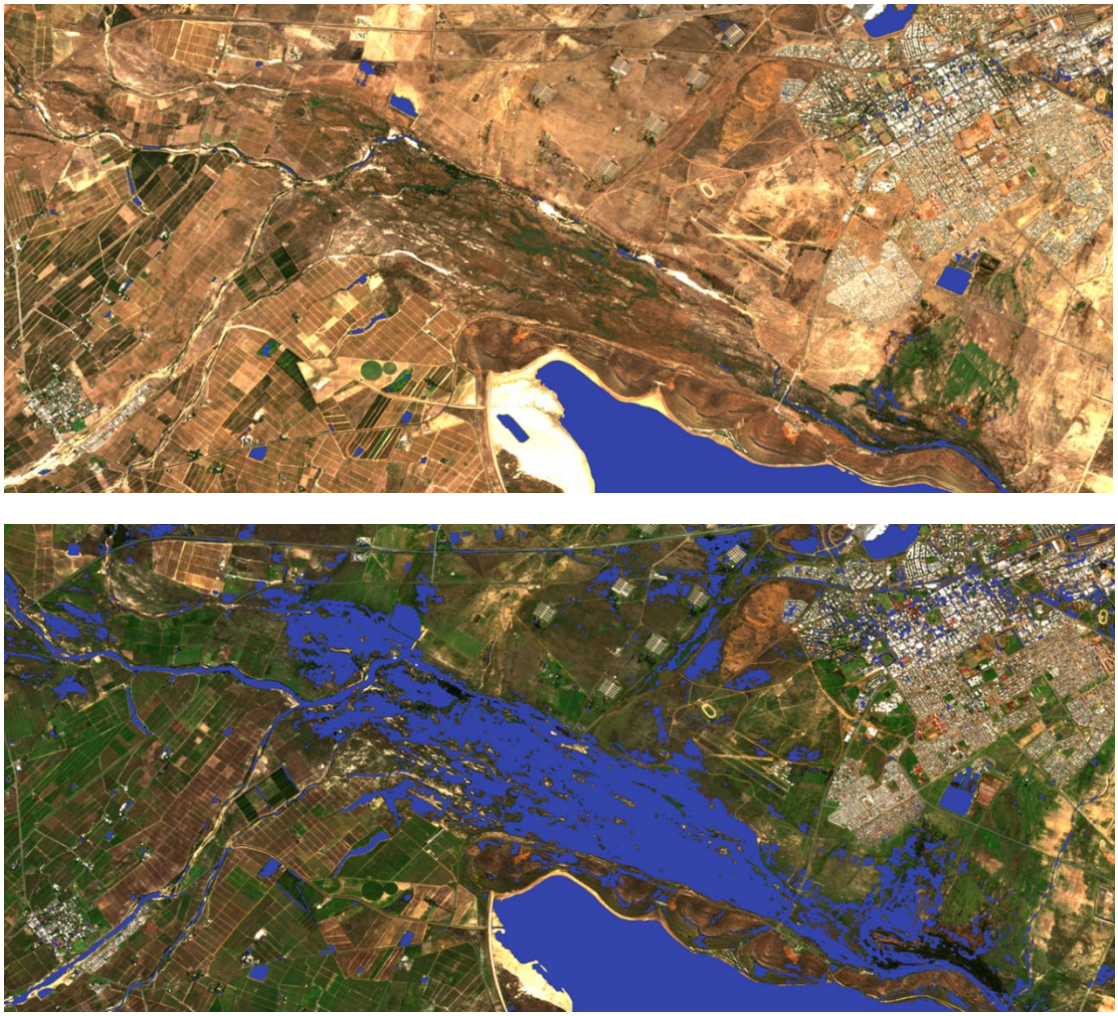

Figure 40: Papenkuils Wetland Sentinel satellite image, illustrating the Wetland Water Index for a dry (above) and wet (below) period.

The areas of inundation were digitized and extracted for a series of Sentinel images from 2016 to 2021. These were superimposed on the simulated daily discharge in the Holsloot, after diversion of flows to the Brandvlei Dam (Figure 41). It is interesting to note that the area of inundation peaked in July and subsequently began declining. This was checked and confirmed for each year of record for the Sentinel satellite (2016-2021) as well as with images from the LandSat 8 satellite (2013 -2016) as illustrated in Appendix F.

The peak inundation area and the associated accumulated winter discharges prior to the peak (April to July), were extracted. The relationship is shown in Figure 42. There appears to be a threshold cumulated winter discharge in the Holsloot (15 Mm^3), below which the inundated area decreases rapidly with decreasing flows (Figure 42). Cumulated flows higher than 15 Mm^3 per winter period, increase the inundated area marginally.

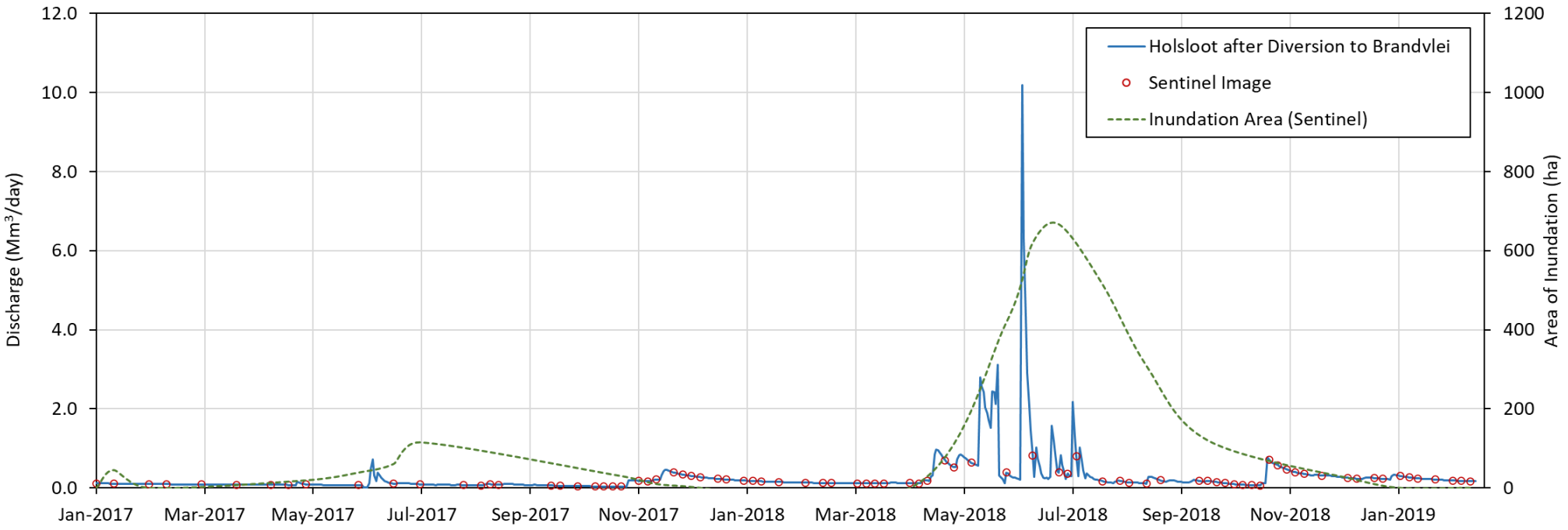

Figure 41: Flows in the Holsloot River (after diversion to the Brandvlei dam), showing instances of Sentinel images studied and the inundated area, measured from the Sentinel images.

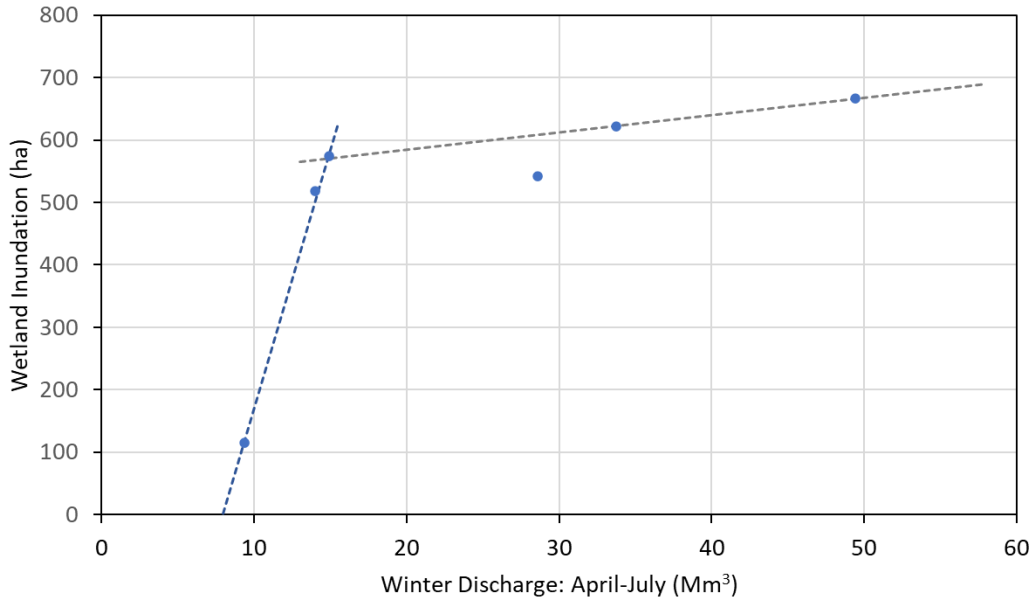

Figure 42: Relationship between winter discharge and Wetland Inundation Area.

A time series of annual peak inundation, based on annual cumulated winter flows (April – July) is shown in Figure 43. The inundation areas decrease, and therefore denuded areas increase in the future 1 scenario. Significant increases in inundation are realized in the future 2 scenario, since the currently bare area, cut off by the northern Holsloot berm, is likely to be inundated.

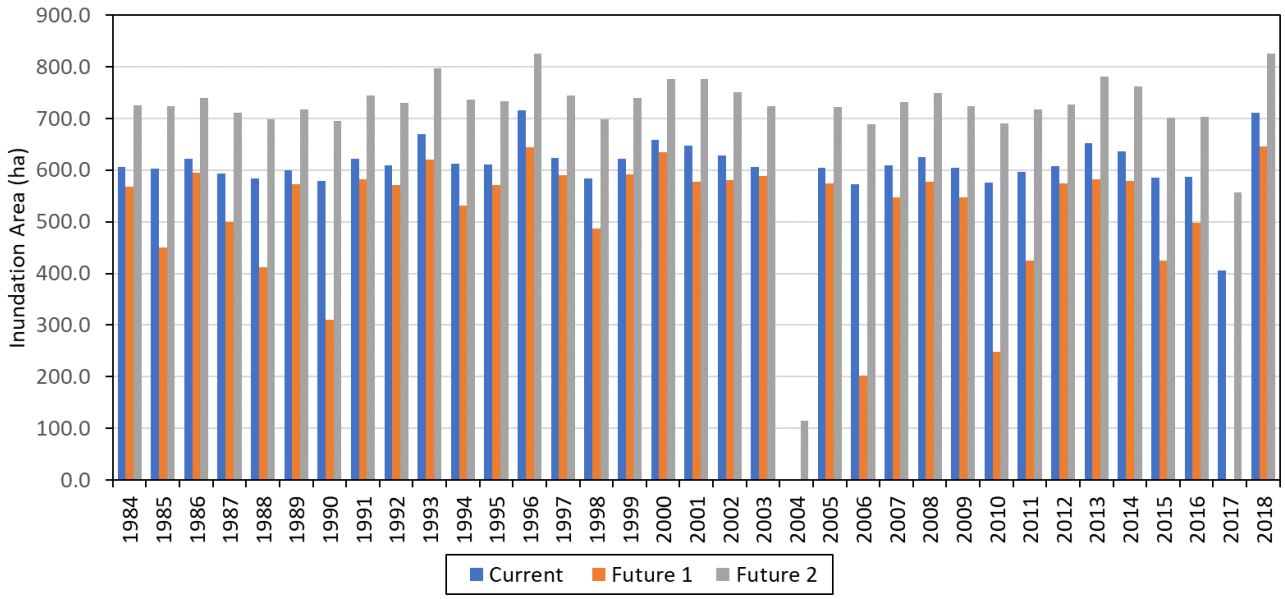

Figure 43: Time series of simulated annual areas of inundation.

6.3.3. Wetland Sediments

The annual sediment retention in the wetland is estimated by deriving a wetland storage volume, based on the inundated area (ref). The relationship considered appropriate for a flat wetland like the Papenksuils is: $V=aA^b$, where ***V*** is the storage volume and ***A*** is the inundated area. The constants ***a*** and ***b*** are set at 3.0 and 0.6, respectively, for the Papenkuils.

Sediment input was estimated at 200 t/km^2/annum from the Holsloot (Rooseboom, Verster, Zietsman, & Lotriet, 1992) and trapping efficiencies calculated from the area-volume relationship. The sediment trapped per annum is shown in Figure 44. Sediment inflows and discharges from the wetland are also calculated on an annual time step.

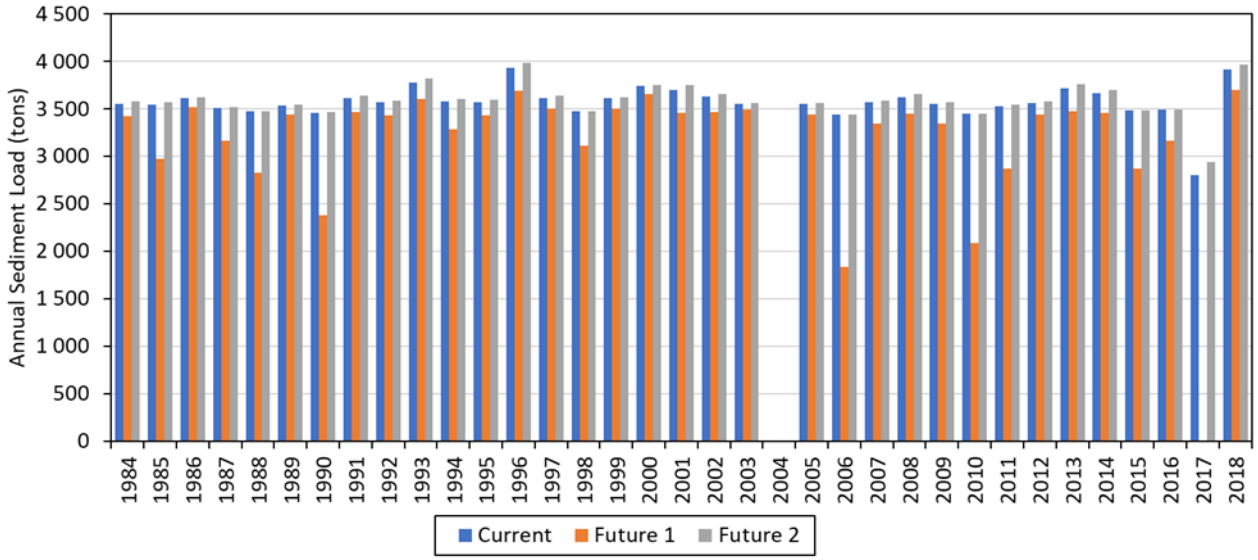

Figure 44: Time series of simulated annual sediment trapping in the wetland.

6.3.4.Wetland Nutrients

Nutrient inflow loads (kg nitrate), were estimated based on the observed concentrations and simulated flows, including the southern channels draining the farm dams. The nitrate assimilation rate was taken as 920 kg/ha/year, for a wetland with good assimilation capacity, where it is inundated. This rate was multiplied by the inundation area for each year to derive the net uptake/adsorption of nitrate. The annual uptakes are shown in Figure 45.

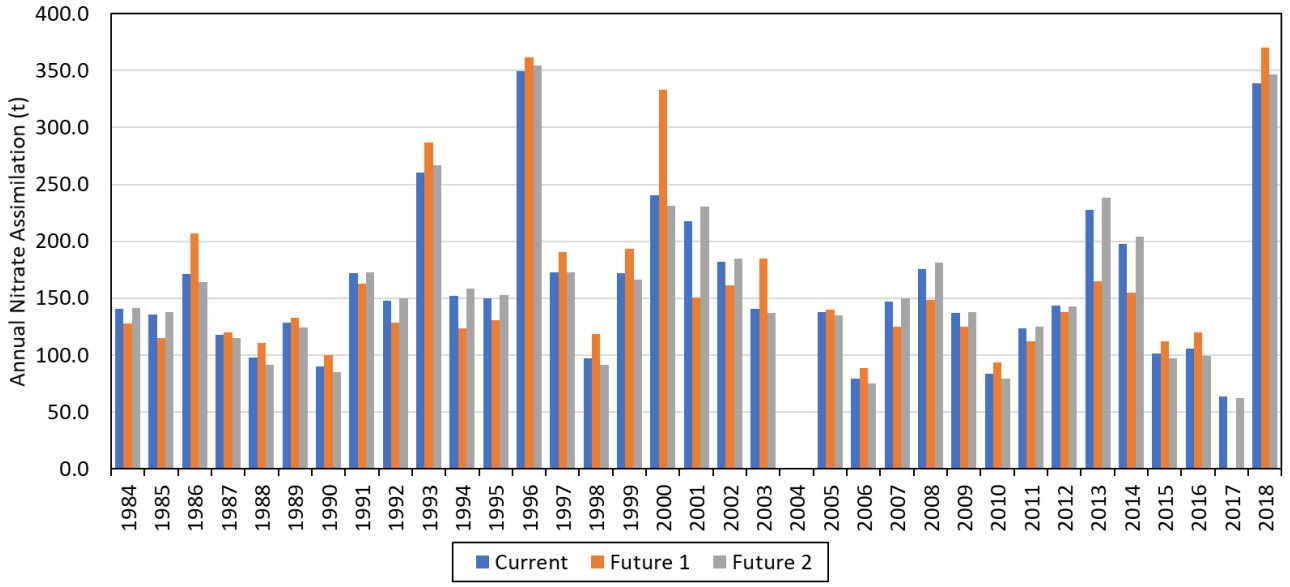

Figure 45: Time series of nutrient (NO3-N) uptake in the wetland.

6.3.5.Wetland Organic Carbon

The wetland organic carbon was determined as a viable mass, based on a volume of soil derived from the inundated area and an assumed depth of organic soils of 0.54m (ref). The volume was multiplied by the soil organic carbon content of 0.0302 kg per m^3 of soil. These were calculated for every scenario on annual basis, but because the soil organic carbon takes time to develop, the average annual soil organic carbon is listed in Table 8.

Table 8 Estimated Long Term Soil Organic Carbon Content for Diversion Scenarios

Potential Soil Organic Carbon		
Current	Future 1	Future 2
(t)	(t)	(t)
96 786	81 089	116 569

6.3.6. Wetland Model Conclusion

The wetland model was developed using these simple techniques described, rather than invoking complex deterministic models, for which there is very little data.

The flow, sediment, nutrient and soil organic carbon analysis results are subsequently lifted into the economics model.

6.4. Ecological Implications of Model Outputs

Impacts to the Papenkuils Wetland as a result of the proposed raising of the canal would be highly significant (and negative), resulting in the following ecological consequences, some of which would be mirrored in loss of ecosystem services:

- Change in hydroperiod - the hydrological model shows that ± 96.3 hectares of wetland that is currently seasonally to perennially inundated would no longer be inundated. This amounts to some 12% of the core wetland area considered in this assessment, excluding[20] highly impacted remnant wetland areas associated with dams and irrigation seepage in the south west of the site , and some 20% of the total area of wetland that is currently inundated on a regular basis. It must be stressed that current conditions in no way represent "natural" conditions, with 14% (114.951ha) of the "core" wetland having already lost all wetland function as a result of separation from upstream flows (see Table 4 – "Bermed and droughted western wetland";

- The modelled reduction in inundated areas across the wetland would translate into wetland shrinkage and degradation across all wetland habitat types, leading to a marked increase in terrestrial habitats, and a shift in wetland habitat type and quality across the wetland, reflected particularly in habitat change between habitat types that are separated by narrow hydroperiod thresholds – e.g. the difference between seasonally inundated *Eleocharis limosa* and *Pennisetum macrourum* wetland flats (see Appendix D) is at present only a difference some 20 – 30 cm vertical height, which allows persistence of extended inundation of the former habitat, well into summer, while the latter dries out in early summer. This has important knock-on effects for aquatic habitat quality, with *Pennisetum macrourum* habitat, as an example, not necessarily providing the length of inundation required for some aquatic fauna (frogs, aquatic invertebrates, some nesting birds) to complete their breeding cycles;

- The most resilient wetland habitats would probably be the deep-water pools, which would probably still be perennially saturated to inundated – however, reduction in (already

[20] A total "core" wetland area of 825.023 ha was considered in this regard – this excludes the artificial farm channels, dams and associated seepage areas, and Breede River wetlands, mapped up- and downstream of the Nekkies Bridge, Data are as per Table 4.

reduced) flushing frequency would reduce their habitat quality over time, leading to gradual encroachment of vegetation across open pools, and ultimately to their "natural" infilling;

- Shifts in wetland habitat type and quality would result in encroachment of terrestrial (usually weedy) species into drier, higher lying wetland margins – along Transects A and B, such species currently include marked dominance by the weedy and unpalatable Slangbos; and
- Increased invasion by alien plants into areas disturbed by drying would be anticipated, leading either to increased alien clearing costs or to reduced wetland condition and function, as a result of uncontrolled or uncontrollable alien invasion.
- By contrast, implementation of Future Scenario 2 could provide real opportunities to change the Papenkuils Wetland trajectory to a more resilient system, and potentially address wetland losses as a result of severe drying. The following benefits could be realized:
- Improved likelihood of meeting the (Intermediate) Ecological Reserve for the wetland, as determined in DWAF (2003), and thus meeting the requirement espoused in the National Water Act for ecologically sustainable management of water resources to underpin water allocations;
- Reduced likelihood of encroachment into the wetland as a whole by weedy, disturbance tolerant and often alien plant species; and
- Rehabilitation of ±115 ha section of the wetland, which would:
- Improve the condition and biodiversity contribution of an important wetland system;
- Reduce fire threats as a result of dominance by terrestrial, weedy vegetation;
- Improve the grazing quality of this area, currently dominated by unpalatable slangbos shrubs; and
- Improve storage capacity in the wetland, potentially allowing a greater proportion of attenuated flood flows to be abstracted downstream of the Nekkies Bridge, and pumped back into Brandvlei Dam.

6.5. Assumptions and Limitations

6.5.1. Inputs to the Model

The following assumptions and limitations are applicable to the study, based on information gaps or concurrent studies being undertaken that would result in duplication of scope:

- The 2018 Land Cover mapping was used as a proxy for current conditions owing that insufficient land use data (including total areas) for each catchment were available. Satellite imagery and high-level verification during site work was, however, used to ensure that no significant changes had occurred within the catchments in the last few years that would have resulted in differences with the National Land Coverage, NLC2018.

7. Papenkuils Wetland Ecosystems Economic Valuation Methodology

7.1. Introduction: Valuation of Wetland Ecosystems Services

Ecosystems, including wetlands, provide a number of ecosystem services. The effective operation and regulation of these systems underpin and support economic activities and livelihoods.

The International Finance Corporation (IFC) and the 2005 United Nations (UN) Millennium Ecosystem Assessment (MEA) define ecosystem services as "the benefits that people, including businesses, obtain from ecosystems". Although these ecological processes are present independently of human presence, they are only deemed to be 'services' if people benefit from those processes[21]. Ecosystem services thus link the functionality of ecosystems to human welfare (Grossman, 2012).

Impaired, dysfunctional ecosystems, as could be the fate of the Papenkuils Wetland, may have a reduced ability to provide resources and services that people enjoy or depend on[22], thereby affecting welfare and the value that people derive from ecosystem services – in this way a potential or realised impact on an ecosystem has an economic cost that can be calculated based on the change in ecosystem service value.

As ecology-based messages seldom find positive feedback from the broader community, resource economic valuation of environmental goods and services, or ecosystem services, provides a useful tool, or language, to evaluate the benefit derived by society from these goods and services (and therefore inform management decisions), and to quantify changes, or potential changes, in the value of ecosystem service provision – either positive or negative. If these costs and benefits are not fully understood, economic gains from, for example water abstraction for increased irrigation, will be selected over wetland management, and increasing human pressures aimed at intensive use of wetlands will influence decision-making and lead to a deterioration of wetland ecosystems (Grygoruk, Miroslaw-Świątek, Chrzanowska, & Ignar, 2013).

In order to avoid this consequence, a measure of the total value of ecosystem services is necessary and is referred to as Total Economic Value (TEV). The functions of TEV are classified as: direct use value, indirect use value, options value and non-use values. Provisioning, regulating and cultural services typically comprise the TEV of wetlands (Snaddon, Dietrich, Forsythe, & Turpie, 2018):

- Direct Use Value: The direct consumptive value that people derive from the use of ecosystem goods and services (i.e. provisioning services, such as harvesting waterblommetjies) and the non-consumptive value from direct use (i.e. cultural services such as recreation);
- Indirect Use Value: The value that people derive from ecosystem services provided through the regulation of ecosystem functions (i.e. regulating services, such as flood abatement, water quality amelioration and contribution to downstream perenniality);l and

[21] Beneficiaries can be at a local scale (using e.g. food [waterblommetjies] and water) and at a regional / global scale (e.g. benefitting from climate regulation).
[22] The wetland downstream of the road bridge could be considered as an example where ecosystem services have been reduced as a result of erosion, alien invasion and agriculture.

- Non Use Values: The *intrinsic* value that people derive from the mere knowledge that an environmental resource exists (for example people value the existence of certain environmental features, such as the Kruger National Park, even though they may never actually visit the park).

  Potential changes in these value functions depend on the current actual direct and indirect (or non-use) resource consumption. However, while certain ecosystem services are traded in the market (mostly provisioning services) and can relatively easily be quantified, other services are not traded in markets, and are unpriced. It is therefore necessary to assess the relative economic worth of these unpriced (goods and) services using non-market valuation techniques in order to determine TEV, and potential changes to TEV.

  Non-market valuation techniques include revealed preference methods (such as damage and replacement cost methods, and the benefit transfer method), and stated preference methods.

  Revealed preference methods are based on actual market behaviour of users of ecosystem goods and services. However, their applicability is limited to ecosystem goods and services for which surrogates are traded in markets, usually goods and services from which direct or indirect use value is derived.

  Stated preference methods can be applied to all types of ecosystem goods and services but are based on hypothetical situations and are therefore unreliable and are less defensible than revealed preference methods. Revealed preference methods are therefore preferred in studies that will be used to inform potentially controversial management decisions, and are, therefore, predominantly used for this study.

7.2. Approach

The following approach was taken to estimate the annual TEV of the Papenkuils Wetland, to determine the potential environmental cost of increased water abstraction from the system and estimate a shadow price for additional water diverted away from the system:

- Identify ecosystem goods and services provided by the wetland based on a literature review and site observations by the specialist team;
- Describe how ecosystem goods and services affect social wellbeing and generate economic value;
- Describe the existing service levels for the wetland (i.e. its baseline characteristics, based on a literature review and the outputs of the hydrology model and aquatic ecology assessment);
- Estimate the current demand for goods and services;
- Develop an economic model to estimate the TEV of goods and services provided by the wetland;
- Estimate the current annual TEV of the wetland for each of the identified goods and services, as well as total annual TEV (based on the outputs of the hydrology model);
- Estimate the change in annual TEV for wetland goods and services for an altered hydrological regime (i.e. a reduction of inflows, based on the outputs of the hydrology model);
- Determine the difference in the discounted Nett Present Value (NPV) of the benefit streams under the baseline and altered flow regime over a 50 year period (in 2020 prices); and

- Determine the shadow price / marginal environmental cost per Mega Litre (ML) abstracted.

7.3. Valuation Methodology

The main focus of this assessment is to value the direct and indirect use values, and non-use values, of the provisioning, regulating and cultural services provided by the Papenkuils Wetland, and the potential changes to that value based on changes to flows entering the wetland.

The approach followed includes the calculation of direct use values of consumptive uses and tourism, replacement, or damage avoidance, costs for indirect uses, and benefits transfer (from a previous contingent valuation exercise undertaken by Turpie, 2003) to calculate the current annual value of goods and services of the wetland, and to estimate how this value would change under different flow / abstraction scenarios[23].

An MS Excel model has been produced to estimate existing service values, as well as changes to this benefit stream based on differing flow rates entering the wetland – each service being valued as part of this study forms a component of the overall MS Excel costing model.

The methods used to value ecosystem goods and services provided by the wetland in this study are briefly described below.

7.3.1. Estimation of Direct Use Values

Certain ecosystem goods and services are used directly by economic agents and / or are traded in the conventional market (i.e. these goods and services have direct use value). Therefore, market prices or values for these goods and services exist or can be derived. In these circumstances it is possible to calculate environmental value by determining or deriving the supply, demand and market price of the good or service under consideration.

Direct uses can either be consumptive or non-consumptive. Consumptive direct uses of the Papenkuils Wetland included in this study are grazing and harvesting of waterblommetjies. The direct use value of these services is estimated by determining the market prices of these agricultural resources, the supply capacity of the wetland, and demand.

Tourism is an important non-consumptive direct use of freshwater resources. The tourism value of freshwater resources in the Cape Winelands District Municipality, as well as the Papenkuils Wetland, is estimated based on actual tourism data for the region.

The direct (damage) cost avoided by carbon stored in the wetland is also estimated in this study based on the Social Cost of Carbon.

7.3.2. Replacement Cost Method

The replacement cost (or substitute cost) method estimates values of ecosystem services based on the anticipated cost of replacing ecosystem services.

This revealed preference method is typically employed to estimate the value of regulating, or intermediate services, that represent only part of the value chain of final goods and services that are directly consumed (for example, the final product of nutrient assimilation is clean water). As such, replacement cost values do not constitute direct estimates of the benefit from

[23] Values were converted to 2020 values using the consumer price index (CPI), where necessary (StatsSA, 2020).

the ecosystem service to society (the value of clean water); they represent the value of having the ability to provide the benefit through an ecosystem service rather than through an alternative method (Grossman, 2012).

Therefore, this method does not provide a measure of final economic value, but rather assumes that replacement costs provide useful estimates of intermediate service value.

In this study the cost of impounding water (i.e. dam construction, operation and maintenance) is used to estimate the value of flood abatement, sediment retention and groundwater recharge services provided by the wetland, and the cost of water treatment (i.e. costs to install and operate a Water Treatment Works) as a surrogate for the nutrient assimilation function.

7.3.3. Benefit Transfer

The benefit transfer method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context. In order to estimate the intrinsic value of the Papenkuils Wetland, Turpie's (2003) contingent valuation of the Fynbos Biome is updated to reflect the current prices and the remaining extent of the biome.

7.4. Social Discount Rate

Social discount rates are used to estimate the present value of costs and benefits that will occur at a later date. The three main reasons for discounting future cost and benefit streams are 1) it is assumed that societies will become richer in real terms as economies develop and grow, and therefore a rand today is worth relatively more than a rand in the future, 2) the risk-free interest rate representing the cost, or opportunity cost, of money, and 3) because people prefer money now over receiving money in the future – i.e. the pure time preference of money (London School of Economics, 2018).

Discount rates are controversial, and some stakeholders argue that the time preference of money should not be included in environmental policy decision making, as sustainability requires that we conserve the environment for the benefit of current and future generations. Discounting for time preference implies that we value future generations lower than the present generation (London School of Economics, 2018), and therefore the higher the discount rate the lower we value future generations welfare.

In 2015, Drupp, Freeman, Groom, & Nesj (2015) surveyed 200 economists to disaggregate social discount rates into their component parts (i.e. pure rate of time preference, the wealth effect, and the real risk-free interest rate), and to determine the mean social discount rate (SDR) used by these experts. The survey found that the mean recommended SDR is 2.27%, and that over 90% of economists surveyed are comfortable with a social discount rate of between 1% and 3% (Drupp, Freeman, Groom, & Nesj, 2015). Based on this research a social discount rate of 2.27% is used for this economic valuation.

8. Papenkuils Wetland Ecosystems Services

8.1. Flood Abatement and Groundwater Recharge

Wetlands function like natural sponges, storing water and slowly releasing it (Ameli & Creed, 2018). As well as the ecosystem function of water storage itself, this process also has economic value by reducing flood intensity downstream (Turpie, Forsythe, Knowles, Blignaut, & Letley, 2017), facilitating groundwater recharge (Ameli & Creed, 2018) and contributing to base flow in surface water systems during dry periods, which has both ecological and economic benefits, including irrigation.

Water attenuation in wetlands also regulates surface flow velocities thereby reducing erosion (allowing wetlands to capture and store organic matter, sediment and nutrients – see Sections 8.2, 8.5 and 8.6 below) and downstream flooding. A loss in wetland extent decreases the storage capacity of wetlands, and therefore reduces the infiltration rate of groundwater resources from these groundwater sinks (Ameli & Creed, 2018) and the ability of the wetland to regulate flows / prevent floods. As well as a decline in regional groundwater supply, a reduction in wetland extent can also change the service levels of other ecosystem services (such as carbon sequestration, sediment capture, water purification, flood attenuation and biodiversity).

Other than for limited livestock watering, water stored on and in the wetland itself is not used directly; however, farmers who abstract from the Rawsonville alluvial aquifer benefit from groundwater recharge into this aquifer from the wetland.

By reducing flood intensities and magnitudes the Papenkuils Wetland helps to reduce damage and therefore the costs of repair to infrastructure, for example, the Le Chasseur diversion located ~5 km downstream of the wetland on the Breede River (Water Research Commission, 2014), and reduce the erosive capacity of floodwaters thereby slowing the loss of topsoil at farms downstream.

8.2. Sediment Retention

Increased human activity and associated land disturbances, including from agriculture, lead to erosion and sedimentation of rivers. Sedimentation leads to both direct downstream economic costs, such as from the siltation of irrigation infrastructure and dams, thereby reducing their capacity to store water and incurring maintenance costs and indirect economic costs from reduced functioning of, and therefore service levels from, downstream aquatic habitats.

By reducing water velocity or by regulating flow wetlands trap sediments that are suspended in river water thereby reducing downstream costs (Department of Water and Sanitation, 2017). Conversely, the loss of functional wetland area leads to the release of stored sediment.

In its current state and surface water flow regime, the hydrology model has calculated that the Papenkuils Wetland stores ~3 500 tons of sediment.

8.3. Agricultural Resource Provisioning

The value of agricultural production in South Africa was estimated to be R286.4 million in 2018 (DAFF, 2019). Agriculture is significant provider of employment, especially in the rural areas, and a major earner of foreign exchange in South Africa.

Three farmers who own portions of the Papenkuils Wetland use the wetland to graze cattle and to a lesser extent horses. Wetter areas of the wetland have a carrying capacity of ~1.5 hectares

per Large Stock Units (LSU[24]) while the dryer, temporary areas of the wetland have an even higher carrying capacity according to the WRC (2014) – in other words the wetland supplies sufficient fodder to sustain at least 0.66 LSU per hectare, and associated benefits from the economic activity this agricultural practice generates, through the production of agricultural products and employment.

The carrying capacity of the wetland is considerably higher than the average carrying capacity for the dryland region of ~40 ha per LSU reported by the Department of Agriculture Forestry and Fisheries (DAFF) (2018).

For the purposes of this valuation exercise, the lower carrying capacity of wetter wetland areas of 1.5 hectares per LSU reported by the farmers grazing the wetland is used.

8.4. Harvesting of Natural Resources

The trade of wild-harvested products in South Africa is believed to be considerable, and there is strong reliance on wild harvested products for household items, fuelwood, foods, and medicines (Petersen, Moll, Collins, & Hockings, 2012). As such harvested natural resources provide significant direct economic benefits to communities.

Waterblommetjies (*Aponogeton distachyos*) occur in depressions at the Papenkuils Wetland and are harvested informally by members of local community.

Waterblommetjies are an indigenous, herbaceous perennial plant occurring in waters usually 1 to 2 meters deep (Pemberton, 2000). Forked inflorescences bear small clusters of small flowers project just above the water surface. These flowers develop into groups of small green fruits. Waterblommetjies are collected and used as a vegetable both in the flower and fruit stages (Pemberton, 2000) at Papenkuils by between six and 12 members of the local community, daily for six months of the year (WRC (2014), Kotze (2020) and Van der Merwe (2020)).

8.5. Nutrient Reduction

The contamination of inland water resources from human activities leads to increased nutrient loads, sedimentation and contamination such as from pathogens, of river waters (Turpie, Forsythe, Knowles, Blignaut, & Letley, 2017). Reduced water quality leads to economic costs to downstream industries, manifesting as a decline in agricultural productivity[25] or the need to treat water for use in this or other industries or for domestic use. The success of the agricultural sector in the Breede River Catchment has led to a population influx into the region, thereby increasing anthropogenic stressors of water quality close to urban areas. In South Africa and in the Breede River Catchment this problem is exacerbated by inadequately maintained and upgraded wastewater treatment works (WWTWs) (Cullis, et al., 2018).

Through dilution and natural ecosystem processes, such as denitrification and sedimentation, nutrients are removed from river water. The removal of nutrients contributes to the provision of clean water that in turn has social and economic benefits, for example in terms of increased

[24] Roughly the number of hectare required to provide food for a year for one head of cattle weighing 450 kg (Western Cape Government: Agriculture, Undated).

[25] Reduced water quality for irrigation leads to soil degradation and directly affects agricultural production and therefore economic gains from the sector (Cullis, et al., 2018) – for example, a 5% decrease in production from irrigated crops would have led to a decline in the direct economic contribution of the sector of R200 million.

agricultural productivity (Grossman, 2012) or reduced or avoided water treatment costs. Wetlands and wetland vegetation in particular are very effective in removing these anthropogenic inputs, thus ameliorating water quality for the economic benefit of downstream users (Turpie, Forsythe, Knowles, Blignaut, & Letley, 2017). However, the degradation of freshwater ecosystems, including wetlands, reduces the ability of these ecosystems to perform this function.

In terms of water quality in the Breede River, phosphorus levels are well above South African water quality guidelines for irrigation and aquatic ecosystems for the entire length of the river, and nitrogen levels are also high, but concentrations appear to decrease downstream of Brandvlei Dam and the Papenkuils Wetland but rise again downstream at Robertson (Cullis, et al., 2018).

In its current state and surface water flow regime, the hydrology model of this study has calculated that the Papenkuils Wetland assimilates 154 tons of nutrients per annum.

Worcester's bulk water supply is sourced from the Stettynskloof Dam and the Fairy Glen Dam (Breede Valley Municipality, 2020), and therefore the residents of Worcester do not benefit directly from the nutrient reduction function of the wetland. However, agriculture is the largest water use sector in the catchment, accounting for ~90% of the average annual water demand, and is a dominant economic driver in the region: the direct value add from irrigated crops accounted for ~34% of regional production in 2016, or R3.94 billion (Cullis, et al., 2018 and Western Cape Government, 2018).

Salinity levels in the Breede River downstream of the Papenkuils Wetland are managed through dilution by water releases from the Brandvlei Dam. With increasing upstream urban and agricultural water demands the ability to release large volumes of water from the Dam may be constrained, leading to a decline in water quality and irrigation crop productivity downstream of the dam and the Papenkuils Wetland (Cullis, et al., 2018). This emphasises the economic value of the water polishing function of the wetland to downstream users.

Recreational water use downstream of the wetland and tourism has both use and non-use economic value and also benefits from improved water quality (WRC, 2014).

8.6. Carbon Sequestration

Carbon is stored in three major global reservoirs, namely the oceans (storing by far the most carbon), terrestrial biomass and atmosphere (storing the least carbon – see Table 9). Oceans and terrestrial biomass also regularly exchange carbon with the atmosphere. The level of atmospheric carbon plays a critical role in determining the global climate, as a higher level of carbon dioxide leads to global warming.

Table 9: Approximate carbon storage, sequestration and exchange rates

Reservoir	Carbon stored (Gt)	Carbon exchanged annually with the atmosphere (Gt)	Current net annual uptake of carbon* (Gt)
Ocean:	40 000	90	2.3
Terrestrial biomass:	2 200	60	0.7
Atmosphere:	760	n/a	3.3
Total:	**42 960**	**150**	**6.3**

Source: Wood, Sebastian, & Scherr (2001)

***Note**: uptake of additional carbon released through human activities per year

By taking up carbon during photosynthesis and burying undecomposed plant litter in anaerobic soils, freshwater wetlands generate organic soils with a high carbon content and sequester an average of ~40 times more carbon than terrestrial forests (Carnell, et al., 2018).

In its current state and surface water flow regime, the hydrology model in this study has calculated that the Papenkuils Wetland stores 96 786 tons of carbon (tC) in organic soil contained in the wetland, equating to 355 205 tons CO_2 equivalent.

It is widely accepted that there are direct and indirect economic benefits from less global warming. There are also economic costs associated with global warming. Therefore, the Net Present Value (NPV) of climate change damage differs to the NPV of the baseline climate pathway. This change in value is a function of the amount of carbon dioxide (CO_2) released into the atmosphere[26] and costs associated with climate damage. This change in value or cost to society is expressed as the *social cost of carbon*, per ton CO_2 (Ricke, Drouet, Caldeira, & Tavoni, 2018).

Economic costs of CO_2 release are estimated based on global damage caused by the total effects of emissions felt all around the world and / or domestic damage (e.g. those felt within South Africa). The United States Environmental Protection Agency (EPA) estimates that the *global* social cost of CO_2 is $12, $42 and $62 47 per tC emitted in 2015 for 5%, 3% and 2.5% discount rates respectively (CarbonBrief, 2017). The discount rate (based on our social time preference - the rate at which society discounts future benefits and costs from climate change) of future carbon costs / benefits greatly influences the estimated social cost of carbon – and is one of the most contentious and consequential aspects of social cost of carbon estimates. A more recent study by Nordhaus (2017) estimated the global social cost of carbon to be $31 per ton of CO_2.

8.7. Tourism, Recreation and Cultural Value

Tourism is an integral and significant part of the Western Cape economy, and the Breede River catchment hosts a number of domestic and international tourist attractions, many of which are either directly (for example, river rafting and river-side attractions) or indirectly (for example, wine farming, sustained through irrigation) reliant on freshwater environments (Department of Water and Sanitation, 2017). These attractions are reliant on the existence of freshwater systems, as well as the quality of water these systems provide. In this way freshwater resources and associated ecosystem services provide economic value by sustaining these tourism related businesses.

The ways in which changes to ecosystem service levels at the Papenkuils Wetland sustain, or impact tourism income generation downstream are as follows (Department of Water and Sanitation, 2017):

- Maintenance of flows suitable for river-based adventure tourism;
- Nutrient reduction for agricultural production;
- Habitat provision for avifaunal species facilitating avi-tourism; and

[26] Carbon has an atomic mass of 12 and oxygen has an atomic mass of 16. Therefore, CO_2 has an atomic mass of 44. This means that one ton of carbon will produce = 3.67 tons of CO_2.

- The provision of aesthetic landscapes for general nature-based tourism.

The indirect use value to the tourism industry of the downstream economic services provided by the Papenkuils Wetland and other ecological resources in the catchment manifests as real economic value generated by these businesses, as well as less tangible economic value to recreational users (bird watching, water sports, fishing and swimming, demonstrated by, for example, the expenditure of recreational users to access these amenities and by higher property prices closer to freshwater resources).

Although downstream indirect use value to business in the tourism sector and recreational users from regulating services provided by the wetland is probably significant, the wetland itself also has a very limited direct use value as a recreational and cultural amenity – i.e. the benefit to the few recreational and cultural users of the wetland from the use of this resource is low.

Although not a tourist attraction (but considered to be of tourism potential by the Breede Overberg Catchment Management Agency [BOCMA] – WRC, 2014), the following users are known to derive limited recreational and cultural value from the Papenkuils Wetland:

- Birdwatchers as demonstrated by the frequency of full cards completed on the South African Bird Atlas Project 2 [SABAP2] for the pentads over which the wetland extends; and
- Muslim worshipers, mostly from Cape Town, visiting kramats (shrines that honour holy people in the Islamic religion) that are located on the banks (Water Research Commission, 2014).

8.8. Intrinsic Value, Including Conservation

As well as the more tangible direct and indirect use values of ecosystem services, TEV includes (intangible) non-use, or intrinsic, value; such as the utility people gain from simply knowing an environmental resource exists and is conserved even if though it does not directly or indirectly benefit humans (Snaddon, Dietrich, Forsythe, & Turpie, 2018) so that future generations may be able to also experience these resources (Turpie J. , 2003). Therefore, even though the direct use of the wetland for tourism and recreation may be low, it is possible that the intrinsic value of the wetland is significant.

Although not traded in the market, habitat and species conservation are good indicators of society's recognition of the non-use value of biodiversity (Rea & Munns, 2018). In terms of conservation at the Papenkuils Wetland, the vegetation types at the wetland are Breede Alluvium Fynbos, an *Endangered* vegetation type and the Nekkies Silty Floodplain Fynbos, a *Critically Endangered* vegetation type of significant conservation importance (Water Research Commission, 2014). The entire wetland has been classified as a CBA and there is a proposed stewardship site covering most of the study area. Furthermore, the Papenkuils Wetland provides habitat to a variety of terrestrial and aquatic plant and animal species, including at least seven IUCN Red-Listed plant species.

Land transformation for agricultural production in the alluvial valley floor of the Breede River has led to the loss of wetlands along this watercourse, making the Papenkuils Wetland relatively rare and adding to its conservation-worthiness and importance as a regulatory service provider.

The Western Cape Department of Agriculture and local landowners provide support for the wetland, including an intensive 3-year alien plant clearing programme started in 2006, follow up alien vegetation clearing and other maintenance activities; and BOCMA also assists with alien invasive plant clearing, administration and awareness and capacity building (Water Research Commission, 2014).

The rareness of the Papenkuils Wetland and vegetation types located in the study area, the identification of the site as a CBA, and public initiatives to clear alien invasive species and maintain the wetland suggest that it has significant intrinsic value and that the *demand* for this service is high.

9. Papenkuils Wetland Valuation Model

9.1. Flood Abatement, Groundwater Recharge and Sediment Retention

In its current ecological condition and surface water flow regime, the hydrology model has calculated that the Papenkuils Wetland has a storage capacity or volume of 68 676 m^3 and retains 3 554 tons of sediment.

A dam would also provide similar flow regulation, sediment retention and groundwater recharge functions. Therefore, a practical way to value all three of these functions and avoid double counting is to calculate the *replacement cost* (see Section 7.3.2) of a dam with similar capacity or volume as the Papenkuils Wetland (Department of Water and Sanitation, 2017).

For this study the cost of a dam with a similar storage capacity is based on the annualised[27] replacement cost per m^3 for this infrastructure used in Snaddon, Dietrich, Forsythe, & Turpie (2018) corrected for 2020 prices[28], i.e. R4.51 / m^3 per annum[29].

The annual operational cost is assumed to be the lower range of the estimated operational and maintenance (O&M) costs for dams in Australia by Pertheram & McMahoon (2019): i.e. 0.14% of initial capital costs (at R20 / m^3).

The difference between the annualised replacement cost of these services, i.e. the construction of a dam, added to the discounted annual O&M costs of the dam (both factors of changes to wetland volume) under the baseline and abstraction scenarios are compared in Section 10. The difference in the annualised replacement cost provides an indication of the annual loss in service value of the wetland, or potential cost of increased water abstraction.

In order for regulating services to have value they must be demanded (Snaddon, Dietrich, Forsythe, & Turpie, 2018). Noting that the wetland contributes to groundwater recharge in an aquifer exploited for irrigation, that businesses and infrastructure downstream of the wetland are somewhat susceptible to potential flood damage, and that the agricultural sector would suffer direct costs from sedimentation of the river, it is assumed for this study that the flood abatement / flow regulation, groundwater recharge and sediment retention services provided by the Papenkuils Wetland are fully demanded.

Under the current flow regime, this study calculates that the Papenkuils Wetland has a storage volume of 68 676 m^3 which is estimated through the replacement cost method described above to be worth R311 609 per annum in 2020 prices in terms of its downstream flow regulation, groundwater recharge and sediment retention functions.

Should the Holsloot Weir be raised to divert more water away from the wetland, the average volume of the wetland is modelled to decrease by 6% to ~65 000 m^3. This would entail an

[27] The annualised cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component.
[28] The annualised dam replacement cost used by Snaddon *et al.* (2018) was R4.17/m^3. The CPI was 107.8 in 2018 and 115.9 in 2020, with 2016 as the base year (StatsSA, 2020).
[29] This is considered to be a conservative estimate as a recent study found that the average cost of dam construction in Australia was ~R20 / m^3 in 2018 when cost overruns are included (Pertheram & McMahoon, 2019).

environmental economic cost of ~R20 000 per annum in 2020 prices from a loss of this function value.

Under the recommended enhanced abstraction regime, the volume of the wetland is modelled to increase by ~6%, with a corresponding increase in annual service value of ~R20 000 in 2020 prices. This would offset the forgone opportunity of increased agriculture from increased water available for irrigation should the Holsloot Weir be raised (assuming water could not be used for agriculture after flowing through the wetland, in which case agricultural benefits could still be realised).

9.2. Agricultural Resource Provisioning

Following the method used by Turpie, Forsythe, Knowles, Blignaut, & Letley (2017), the value of fodder production by the Papenkuils Wetland is estimated as the minimum of the replacement cost of bought feed and value of livestock production.

9.2.1. Value of Agricultural Production

According to StatsSA (2020), 2 738 371 ha of land in the Western Cape (203 137 ha in the Cape Winelands District Municipality) was used for grazing, generating R20.85 billion in income in 2017 (R7.4 billion in the Cape Winelands District Municipality).

Livestock held under grazing In the Cape Winelands Municipality in 2017 was as follows (StatsSA, 2020):

Cattle:	40 809 (40 809 LSU[30])
Sheep:	51 736 (the equivalent of 5 174 LSU)
Goats:	2 416 (242 LSU)
Pigs:	50 225 (15 068 LSU)
Horses:	1 887 (1 510 LSU)
Donkeys:	42 (34 LSU)
Chicken broilers:	6 683 366 (46 784 LSU)
Chicken layers:	2 258 736 (31 622 LSU)
Ostriches:	5 775 (2 021 LSU)

In total, the equivalent of 143 262 LSU were held in the Western Cape in 2017, generating R7.4 billion in income, or R51 654 per LSU per annum (StatsSA, 2020). In 2017 expenditure excluding animal feed and supplements totalled ~77% of agricultural income in the Western Cape[31]. This

[30] European Union (2020)
[31] In 2017 all Western Cape Farmers received R64,3 billion in income and incurred R57.5 billion in expenses, including ~R8.3 billion in feed and animal supplements – i.e. net expenditure of R49.2 billion.

equates to a profit of R13 368 per LSU per annum in 2020 prices[32] in the Cape Winelands District Municipality, excluding feed expenses[33].

9.2.2. Replacement Cost of Feed

Based on the estimate used in Turpie, Forsythe, Knowles, Blignaut, & Letley (2017), it is assumed that livestock requires ~3% of body mass in feed per day. The average weight of an LSU is 450 kg (Western Cape Government: Agriculture, Undated). Therefore, each LSU would require 13.5 kg of feed per day, or 4 927.5 kg of feed per annum.

According to Nyhodo, Mbulah Mmbengwa, Balarane, & Ngetu (2015), the minimum cost possible for cattle feed with adequate nutrients was R4.17 per kg in 2015 (i.e. R5.17 per kg in 2020 prices)[34]. This equates to a cost of ~R25 475 for feed to sustain one LSU per annum in South Africa.

9.2.3. Conclusion

The profit generated per LSU per annum in the Cape Winelands District Municipality is selected to estimate the value of the agricultural resource provisioning function of the Papenkuils Wetland (per ha) as it is lower than the replacement cost of feed that would be required to sustain each LSU, and therefore, the more conservative estimate.

The agricultural resource provisioning function of the wetland is assumed to be only 50% demanded (i.e. sustaining ~200 LSU) based on observations by the specialist team. For the purposes of this study, the change in the functional extent of the wetland under different flow regimes, estimated based on the average annual maximum area of inundation over the 35 year period under consideration[35], as determined in the hydrology model, is used to determine the change in the value of this function per annum.

Under the current flow regime, the functional wetland area, or the average maximum area of inundation over the 35 year period under consideration, has an extent of 593 ha which is estimated to be worth a total ~R2.5 million per annum in 2020 prices in terms of agricultural (grazing) production value assuming 50% demand for this service.

Should the Holsloot Weir be raised to divert more water away from the wetland, the functional extent of the wetland (the average maximum area of inundation) is modelled to decrease by 8% to ~543 ha. This would entail an average environmental economic cost of ~R220 000 per annum in 2020 prices from a decline in grazing potential at the wetland.

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[32] It is assumed that profit per LSU equivalent is equal for all animals.
[33] The profit per LSU was calculated to be R5 165 in 2017. The CPI was 103.0 in 2017 and 115.9 in 2020, with 2016 as the base year (StatsSA, 2020).
[34] The CPI was 92 in 2015 and 115.9 in 2020, with 2016 as the base year (StatsSA, 2020).
[35] The hydrology model estimated the maximum annual extent of inundation under each of the three flow / abstraction scenarios. In order to estimate the annual loss (or gain) in the functional extent of the wetland the average maximum extent of inundation was determined for each scenario over the 35 year period, and a linear degradation (or improvement) profile was applied to determine the rate of decrease (or increase) in functional wetland extent from the average annual extent of inundation for the baseline scenario.

Under the recommended enhanced abstraction regime, the functional extent of the wetland is modelled to increase by ~11% to 652 ha, with a corresponding increase in annual service value of ~R265 000 in 2020 prices.

9.3. Harvesting of Natural Resources

Waterblommetjies are collected and used as a vegetable both in the flower and fruit stages (Pemberton, 2000) by between 6 and 12 members of the local community daily for six months of the year (WRC (2014), Kotze (2020) and Van der Merwe (2020)).

Harvesters at Papenkuils sell approximately 25 bags of waterblommetjies each a week during harvesting (estimate based on reported weekly earnings of ~R500 per person at R20 per bag in 2014 – WRC (2014)). The price of a bread bag of waterblommetjies was R40 in 2020[36]. It is therefore conservatively inferred that eight waterblommetjie harvesters earn ~R1 000 each per week (by selling 25 bags of waterblommetjies in this period) over a six month period each year from this practice.

Based on this data and the current extent of the wetland the economic model estimates the number of the waterblommetjie bags harvested per ha per year (i.e. the current supply level, which is considered to be fully demanded), as well as the current annual value of the harvest. The change in functional extent of the wetland under different flow regimes, based on the average maximum extent of inundation of the wetland under the different flow scenarios, is used to determine the change in the value of the harvesting function per annum.

Under the current flow regime, the wetland has a functional extent of 593 ha from which waterblommetjie harvesters are able to harvest ~5 200 bags of waterblommetjies per annum (i.e. 8.77 bags of waterblommetjies per ha per year) and generate an estimated revenue of ~R208 000 (at R40 per bag) in 2020 prices.

Should the Holsloot Weir be raised to divert more water away from the wetland, the functional extent of the wetland (the average maximum area of inundation) is modelled to decrease by 8% to ~543 ha. This would entail an average environmental economic cost of ~R17 000 per annum in 2020 prices from a decline in waterblommetjie harvesting potential at the wetland.

Under the recommended enhanced abstraction regime, the functional extent of the wetland is modelled to increase by ~11% to 652 ha, with a corresponding increase in annual service value of ~R21 000 in 2020 prices.

9.4. Nutrient Reduction

The annual value of the nutrient reduction function of the wetland is calculated as the replacement cost for construction and operation of a Waste Water Treatment Works (WWTW) that would provide a similar nutrient reduction capability as that of the wetland under the current flow regime.

As much of the area surrounding the wetland being under agricultural use, and the known anthropogenic impacts of such activities, the value of the wetland's nutrient removal capacity was quantified based on the amelioration of nutrients by the wetland vegetation and flow

[36] This higher-than-inflation increase in price of waterblommetjies between 2014 and 2020 is not surprising as the vegetable has cultural value to the people of Worcester and is consumed by all sectors of the local population (Water Research Commission, 2014).

dilution properties (primarily through denitrification and removal of excess phosphorous) and the maximum daily throughput of the wetland during the reporting period.

During a study conducted by Roux and Oelefse (2010), it was determined that the capital replacement cost in 2020 prices[37] of a number of different WWTWs ranged from R 9.5 million per megalitre (ML) per day capacity through to R 14.8 million per ML per day capacity. Similarly, the Municipal Infrastructure Guideline document for South Africa (Department of Cooperative Governance and Traditional Affairs, 2010) provides an maximum unit cost (in 2020 prices[38]) for a WWTW in the Western Cape of R 16.4 million per ML per day capacity, and an average unit cost of R 11.7 million per ML per day capacity for a package plant. However, capital costs of WWTWs, and other large infrastructure, are not linear: due to economies of scale the capital cost per ML per day capacity decreases the larger the facility contemplated (Cullis, et al., 2018), and the selection of the treatment methodology can have significant cost implications.

In order to estimate the capital (replacement) costs of a WWTW to emulate the nutrient reduction service of the wetland, an conservative, "at-least" cost for an Anion IX plant was costed[39] for this assessment in the economics model (from water quality, quantity, and recoverability user inputs as determined in the hydrology model), based on a Water Management Tool available from AQWATEC (2010) which includes economies of scale considerations for this infrastructure.

The following capital costs are excluded from the model:

- The purchase of land for the plant;
- Preparatory studies (such as geotechnical, hydrogeological and hydrology);
- Permitting costs; and
- Infrastructure required to transfer of water to the treatment plant.

Using a cost equation (Equation 1) derived from a Water Management Tool available from AQWATEC (2010) the "at least" CAPEX cost of a WWTW with a similar nutrient reduction capability as that of the wetland for the three abstraction regimes under consideration. Nutrient recoverability of 80% for the plant is assumed.

Equation 1:

$$\text{CAPEX (R million)} = cV^{a} \times V \times \text{Average CPI since 2010} \times \$/R \text{ Exchange Rate}$$

[37] The costs determined during the 2010 study by Roux and Oelefse ranged from R 6 million to R 9.3 million for a ML per day capacity. The CPIs applied were 74.2 (2011) and 115.9 (2020) , with 2016 as the base year (StatsSA, 2020).

[38] The costs determined in the CoGTA report range from R 7.127 million for a package plant to R 9.95 million for a ML per day capacity WWTW. The CPIs applied were 74.2 (2011) and 115.9 (2020), with 2016 as the base year (StatsSA, 2020).

[39] Two WWTW technologies were considered for this assessment brackish water reverse osmosis and Anion IX as these technologies are available in South Africa and have the technical capability to treat water similarly to the Papenkuils Wetland. Using the CBM Produced Water Management tool (2010), it was determined that in this context the Anion IX technology would be the most cost effective (cheapest) technology alternative, and as such the costs associated with this type of facility were used to calculate the replacement cost of the wetland nutrient assimilation function.

where: a = -0.21 (plant specific exponent determined by the AQWATEC model)

c = 0.652239683 (plant specific factor determined by the AQWATEC model)

V = Flows into wetland (megalitres per annum) / 3.785 (in order to align the inflow to the AQWATEC model gallons unit)

In order to distribute the CAPEX over the 35 year period under consideration, it was assumed that the full capital cost would be funded by a loan at an interest rate equal to South Africa's prime rate of interest, paid in annual instalments over the reporting period.

Albaladejoa, Trapote, & Simon (2014) determined the electricity usage of 90 WWTWs in the Murcia Region of Spain. This study concluded that electricity usage was lower for bigger plants (also owing to economies of scale) and found that the lowest electricity usage for any (large) WWTW was 0.3450 kWh per m^3 of water treated. This estimated rate of electrical consumption by large WWTWs in Spain, as well as the lowest cost of electricity to industrial users in South Africa in 2020 (JKNV Energy, 2020) was used in the economic model to estimate what the annual costs of electricity to power plants that would replace the wetland's nutrient assimilation function under the various flow regimes considered.

In its current state and surface water flow regime, the hydrology model in this study has calculated that the Papenkuils Wetland assimilates an average of 154 tons of nutrients per annum and has a maximum daily throughput of 473 ML. Based on the methodology described above, the average annual replacement cost (including an "at-least" CAPEX estimate for the plant and electricity usage) of the nutrient reduction function is estimated at ~R44 million.

Should the Holsloot Weir be raised to divert more water away from the wetland, the wetland is modelled to assimilate on average of 1.9 tons fewer nutrients. This is estimated to have an environmental cost to downstream users of R5 million per annum in 2020 prices from a decline in water quality, manifested by on-site water treatment costs, and a decline in agricultural production.

Under the recommended enhanced abstraction regime, the wetland is modelled to assimilate a similar mass of nutrients as is the case under the current flow regime.

9.5. Carbon Sequestration

Based on the estimate of the global social cost of carbon by Nordhaus (2017), Fischer, Haasbroek, Govender, & Kotze (2020) and Snaddon, Dietrich, Forsythe, & Turpie (2018) following Turpie, Forsythe, Knowles, Blignaut, & Letley (2017) estimated the South African social cost of carbon to be R7.65 in 2020 prices[40] taking South Africa's Gross Domestic Product (GDP) relevant to other countries GDPs and relative vulnerability to climate change impacts into account.

The annual value of the carbon sequestration function of the wetland is calculated as the avoidance (social) cost of the release of CO_2 from the wetland, and the change, or loss, in value from increased water abstraction is calculated by the domestic social cost of tons CO_2 released into the atmosphere per annum under this scenario.

[40] The South African local social cost of carbon was calculated to be R7.38 in 2019 prices by Fischer, Haasbroek, Govender, & Kotze (2020). The CPI was 112.2 in 2019 and 115.9 in 2020, with 2016 as the base year (StatsSA, 2020).

The hydrology model estimated the mass of organic carbon stored in the wetland each year under the 35 year period under consideration for the various different flow / abstraction regimes. In order to estimate the annual loss (or gain) in stored organic carbon in the wetland the average mass of organic carbon was determined for each scenario over the period, and a linear degradation (or improvement) profile was applied to determine the rate of decrease (or increase) in the mass of organic carbon stored from the average mass stored under the baseline scenario.

Under the current flow regime, the hydrology model has estimated that the wetland stores on average 96 786 tons of carbon in organic soils, equivalent to 355 205 tons CO_2. The annual domestic social cost avoidance of this store of CO_2, from preventing climate change impacts from its release, is estimated at R2 657 001.

Should the Holsloot Weir be raised to divert more water away from the wetland, the wetland is estimated to release ~8 000 tons of organic carbon over the 35 year period under consideration, with an average annual environmental cost of ~R225 000 in 2020 prices manifesting as costs associated with impacts from climate changes in South Africa.

Under the recommended enhanced abstraction regime, the mass of organic carbon stored in the wetland is modelled to increase by 11% to ~115 000 tons, with a NPV of R71 million over the 35 year period under consideration.

9.6. Tourism and Recreation

To estimate the direct tourism value of the Papenkuils Wetland[41] the spatial tourism valuation method followed by the Department of Water and Sanitation (2017) was adapted for this study: the total tourism spend in the Cape Winelands District Municipality, including the portion spent on nature based attractions (as opposed to spending that is not related to attractions – for example, conferences and medical treatments), is estimated based primarily on 2019 tourism expenditure data published by the Department of Tourism (2020). The total value of attractions associated with rivers and wetlands in the district municipality in 2019 is then estimated based on the density of photographs taken in the Cape Winelands District Municipality between 1 January 2017 and 31 January 2021 and uploaded to the www.flikr.com website[42] (georeferenced data downloaded from the www.flikr.com Application Programming Interface with permission). Based on this data, and the estimated demand for the service, the per ha annual tourism value of wetland and riverine resources in the municipality is estimated.

Total tourism expenditure in South Africa in 2019 was R112 billion in 2020 prices, including R84 billion by foreign tourists and R27 billion by domestic travellers (see Table 10). The majority of both inbound and domestic tourism in 2019 was for the purpose of visiting friends and relatives (VFR), while 23% and 28% of inbound and domestic tourists respectively travelled for the sole purpose of holiday.

The proportion of total tourism expenditure by purpose of visit is estimated, assuming that people that travel purely on holiday typically spend more than those travelling to visit friends and

[41] I.e. recreational and tourism activities directly attributable to the wetland itself, and not attractions downstream that benefit from the services that the wetland provides, which are accounted for elsewhere in the economic model.
[42] Flickr is a free international media hosting platform used by amateur and professional photographers to upload, organise, and sharing digital photos and videos.

relatives or do business, and that some tourists whose primary purpose of visiting is not for holiday purposes may also spend a smaller portion of their total expenditure on tourism attractions (Department of Water and Sanitation, 2017).

Based on estimated expenditure by purpose of visit, the proportion expenditure on attractions is estimated for each purpose of visit, informed by similar estimates made by the Department of Water and Sanitation (2017) (see Table 10).

It is conservatively estimated that in 2019, 27% of tourism expenditure was on attractions, including R21 billion by inbound tourists and R9 billion by domestic travellers (in 2020 prices)[43].

Table 10: Tourism expenditure in South Africa by purpose of visit in 2019 (corrected to 2020 prices)

Origin	Purpose of visit	% visits*	Estimated % spend**	Total spend (million)*	Estimated spend on attractions%**	Estimated spend on attractions (million)
Inbound	Holidays	21%	30%	R25 261	75%	R18 946
	Shopping	23%	30%	R25 261	5%	R1 263
	Business	6%	7%	R5 894	5%	R295
	VFR	41%	25%	R21 051	5%	R1 053
	Other	8%	8%	R6 736	2%	R135
	Subtotal	**100%**	**100%**	**R84 204**	**26%**	**R21 691**
Domestic	Holiday	28%	40%	R10 951	75%	R8 213
	Business	3%	5%	R1 369	5%	R68
	VFR	67%	45%	R12 320	5%	R616
	Other	2%	5%	R1 369	0%	R0
	Subtotal:	**100%**	**50%**	**R27 377**	**33%**	**R8 897**
Overall	**Total:**			**R111 581**	**27%[44]**	**R30 588**

Source: Updated from Department of Water and Sanitation (2017)

** Department of Tourism* (2020) *update to 2020 prices*[45]

** *Based on Department of Water and Sanitation* (2017)

In order to disaggregate national tourism expenditure on attractions to expenditure on attractions in the Western Cape, the proportion of estimated inbound and domestic tourism expenditure on attractions was multiplied by the percentage of inbound tourist arrivals and the

[43] Although partly accounted for by the dynamics of the tourism industry (there are fewer holiday travellers and more people visiting friends and families in 2019 than in 2015), this is considered a conservative estimate of total tourism spend on attractions as the Department of Water and Sanitation (2017) estimated that 64% of total tourism expenditure was on attractions in 2015.

[44] The Department of Water and Sanitation (2017) estimated that up to 64% of tourism expenditure was on attractions, therefore the 27% estimated in this study is considered a conservative estimate of total expenditure on attractions in 2019.

[45] Inbound and domestic direct tourism expenditure in 2019 was R81.2 billion and R26.4 billion respectively. The CPI was 112.2 in 2019 and 115.9 in 2020, with 2016 as the base year (StatsSA, 2020).

distribution of domestic tourism trips in 2019 respectively, as reported by the Department of Tourism (2020) (see Table 11). Based on this methodology, it is estimated that a total of ~R5.5 billion was spent in the Western Cape in 2019 by tourists on local attractions in 2020 prices[46].

Table 11: Estimated tourism expenditure on attractions Western Cape in 2019 (in 2020 prices)

Origin	Percentage of total expenditure	Estimated spend on attractions (million)
Inbound	19.6%*	R4 251
Domestic	13.5%**	R1 201
Overall	**17.8%**	**R5 453**

**Based on provincial of tourist arrivals in 2019 in Department of Tourism* (2020)

*** Based on provincial distribution of domestic tourism trips in 2019 in Department of Tourism* (2020)

In order to estimate the proportion of estimated total spend on attractions in the Western Cape in each of the municipal districts, the latest available Western Cape tourist bed-night data per region[47] was used as an indicator (Western Cape Government, 2003). From this data it is estimated that 14%, or R763 million in 2020 prices, of the tourism expenditure on attractions in the Western Cape was spent on attractions in the Cape Winelands District Municipality in 2019.

Table 12: Estimated tourism expenditure on attractions in Western Cape by District in 2019 (in 2020 prices)

District	Percentage bed nights*	Estimated spend on attractions (million)**
City of Cape Town	44%	R2 399
West Coast	13%	R709
Cape Winelands	14%	R763
Overberg	8%	R436
Central Karoo	2%	R109
Garden Route	19%	R1 036
Western Cape	**100%**	**R5 453**

**Adapted from Western Cape Government* (2003)

*** Based on tourist expenditure in 2019 in Department of Tourism* (2020)

The distribution of activities undertaken as a percentage of all activities undertaken by tourists surveyed by WESGRO (2017) is used as an indicator for the proportion of tourism expenditure on attractions allocated to nature based activities in the Cape Winelands District Municipality.

[46] This estimate is also considered to be a conservative estimate as tourists to the Western Cape are known to spend a greater proportion of their total trip expenditure on nature based tourism attractions as visitors to other regions in the country (Department of Water and Sanitation, 2017).

[47] The number of nights stayed by tourists in each of the municipal districts as a total of nights spend in the province in 2001.

From this data it is estimated that 31% of expenditure, or R237 million in 2020 prices, was spent on scenic drives, outdoor activities, national parks and nature reserves, and other activities, such as adventure based activities and angling, in the Cape Winelands Municipality in 2019 (Table 13).

Table 13: Estimated tourism expenditure on nature based attractions in Cape Winelands District Municipality in 2019 (converted to 2020 prices)

Attraction	Frequency as % of total*	Nature based: Yes / No	Estimated spend on attractions (million)**
Culture/heritage	23%	No	R0
Wine tasting	22%	No	R0
Cuisine	16%	No	R0
Scenic drives	11%	Yes	R86
Outdoor activities	11%	Yes	R85
Crafts and food	5%	No	R0
National parks / reserves	3%	Yes	R22
Shopping	2%	No	R0
Events	1%	No	R0
Other	6%	Yes	R44
Total	**100%**	**31%[48]**	**R237**

* *"Top activities undertaken" in WESGRO* (2017)

** *Based on tourist expenditure in 2019 in Department of Tourism* (2020)

In order to estimate the proportion of nature based attraction spend in the district municipality on attractions associated with rivers and wetlands, the proportion of photographs uploaded on the www.flickr.com website taken between 1 January 2017 and 31 January 2021 within 500m of wetlands and streams, buffered in terms of their order[49], of the total number of photographs taken and uploaded onto this website in the Cape Winelands District Municipality during the period was calculated.

The revealed preferences shown by analysis of photograph densities in the district revealed that ~40%[50] of photographs taken between 2017 and 2021 and uploaded onto www.flickr.com were taken at or close to freshwater resources (24% near true wetlands[51], and 15% near rivers – see Table 14). This suggests that that ~40% of tourism expenditure on attractions in the municipality (or ~R93 million annually) is generated at or near wetlands and rivers.

[48] The Department of Water and Sanitation (2017) estimated that 33.7% of tourism expenditure attractions in the Cape Winelands District Municipality was on nature based activities.
[49] I.e. within 100m of 1st order streams, 200 m of 2nd order streams, 300m of 3rd order streams, 400m of 4th order streams and 500m of 5th order streams.
[50] Using a similar methodology the Department of Water and Sanitation (2017) estimated that 55% of nature based tourism attraction value was generated in the upper and middle Breede River socio-economic zones was near rivers.
[51] Certain rivers are classified as wetlands, therefore, to determine the proportion of photographs taken near true wetlands the extent of river zones is subtracted from the combined extent of wetlands and rivers.

This tourism value / expenditure estimate is then divided by the approximate (unbuffered) extent of rivers and wetlands in the district (i.e. 41 020 ha) to estimate a tourism value per hectare per annum of these resources (i.e. R2 266 / ha / annum in 2020 prices). This value estimate, as well as perceived demand for the service, is used for the Papenkuils Wetland valuation model to estimate the current tourism value of the wetland based on the wetland's extent.

Table 14: Density of photographs uploaded to www.flickr.com and estimated river based attraction revealed preference tourism spend in 2019 converted to 2020 prices

Location	Area (ha)	Photos**	% of total pics 2017 – 2021	Estimated Attraction Spend in 2019***
Cape Winelands DM	2 228 894	4150	100%	R237 000 000
Wetlands – NFEPA* with 500m buffer	441 302	1192	29%	R68 000 000
Wetlands excluding rivers	392 868	992	24%	R57 000 000
River zones with buffers	119 259	633	15%	R36 000 000
Combined NFEPA Wetland and River Zones with buffers	512 127	1625	39%	R93 000 000
Papenkuils	593	0	0%	R0

**National Freshwater Ecosystem Priority Areas* (Water Research Commission, 2011)

** *www.flickr.com*

*** *Estimated from tourist expenditure in 2019 in Department of Tourism* (2020)

For the purposes of this study, the change in the functional extent of the wetland under different flow regimes (estimated based on the average annual maximum area of inundation over the 35 year period under consideration[52], as determined in the hydrology model) is used to determine the extent of the wetland under the various flow regimes. Under the current flow regime, the functional wetland area, or the average maximum area of inundation over the 35 year period under consideration, has an extent of 593 ha. In terms of the tourism model developed for this assessment, and assuming full demand, this equates to a tourism value of the wetland of ~R1.3 million per annum. However, as described in Section 8.7, the direct tourism, recreation and cultural use of the wetland is extremely low[53]. Therefore, the level of demand for this service is assumed to be only 10%. This assumption is supported by the fact that no photos in the vicinity of the wetland were uploaded to www.flickr.com between 2017 and 2021 – see Table 14. This equates to an annual wetland tourism, recreation, and culture value of the

[52] The hydrology model estimated the maximum annual extent of inundation under each of the three flow / abstraction scenarios. In order to estimate the annual loss (or gain) in the functional extent of the wetland the average maximum extent of inundation was determined for each scenario over the 35 year period, and a linear degradation (or improvement) profile was applied to determine the rate of decrease (or increase) in functional wetland extent from the average annual extent of inundation for the baseline scenario.

[53] Due to its diversity and rareness, it has been suggested that the Papenkuils Wetland has a high potential for investment as a regional tourism attraction. The tourism model developed for this study suggests an options value of up to R5 million per annum for the wetland for potential future development as a tourism resource. Because of the uncertainty of the realisation of this value it has been excluded from the current valuation of the Papenkuils Wetland and suitably captured in the estimated tourism value.

wetland of R131 403 in 2020 prices. The tourism value of the wetland could increase substantially if investments were made to increase the tourism potential of this area (e.g. by local landowners) and / or if the resource was promoted as a tourism resource.

Should the Holsloot Weir be raised to divert more water away from the wetland, the functional extent of the wetland (the average maximum area of inundation) is modelled to decrease by 8% to ~543 ha. This may reduce the tourism and recreation value of the wetland by ~R11 000 per annum under the current low level of demand for this service.

Under the recommended enhanced abstraction regime, the functional extent of the wetland is modelled to increase by ~11% to 652 ha, with a corresponding increase in annual service value of ~R13 500 in 2020 prices and at current demand levels.

9.7. Intrinsic Value

As intrinsic value is not traded in the market, the existence value society places on biophysical resources can only be elicited through stated preference valuation methods, such as contingent valuation. Turpie (2003) estimated that the value of the Fynbos Biome was US$3.3 million in 2003 through a contingent valuation survey (Willingness to Pay) of residents in the Western Cape, South Africa. This value equates to ~R60 million in 2020 Rands[54].

Noting that the remaining extent of the Fynbos Biome is estimated at ~5 500 000 ha (Skowno, Jewitt, & Slingsby, 2021), and assuming the value of fynbos is evenly distributed across the biome, the value estimate by Turpie (2003 and converted to 2020 prices) equates to a Willingness to Pay for fynbos of R10.88 per ha per annum. Noting the high conservation importance of the wetland, that the wetland is the largest remaining relatively undisturbed wetland in the entire Breede River Valley, and is one of the largest wetlands in the Western Cape, this valuation is considered to be very conservative and the service is considered to be fully demanded.

Based on this extrapolation it is conservatively estimated that the annual intrinsic value of conservation worthy Fynbos at the Papenkuils Wetland is R6 455 per annum.

Noting that floral diversity in the wetland is driven by soil type and soil moisture, changes in the intrinsic value of the wetland are considered to be highly susceptible to altered wetland flow patterns.

Due to its diversity and rareness of flora and fauna, it has been suggested that the Papenkuils Wetland has a high potential for investment as a regional tourism attraction in the future. In addition to the estimated intrinsic value for the wetland, the tourism model developed for this study suggests an option, or future value of up to R850 000 per annum for the wetland for potential future development as a tourism resource.

[54] Using an exchange rate of $1 = R7.58 in 2003 (Nedbank, 2020), Turpie (2003) estimated that the value of the fynbos biome was ~R25 million. The CPI was 48.5 in 2003 and 115.9 in 2020, with 2016 as the base year (StatsSA, 2020). Correcting for inflation, the 2003 estimate by Turpie therefore equates to ~R60 million in 2020 prices. The conversion of this Turpie (2003) estimate in Snaddon, Dietrich, Forsythe, & Turpie (2018) to R6.8 million in 2018 prices (and subsequently used in Fischer, Haasbroek, Govender, & Kotze, 2020) appears to be inaccurate.

10. Wetland Valuation

10.1. Existing Abstraction Regime

Under the current surface water abstraction regime, environmental services provided by the Papenkuils Wetland are estimated to generate an annual marginal environmental value of ~R50 million per year in 2020 prices (see Table 16), or ~R85 000 per ha annually.

Assuming a discount rate of 2.27% (see Section 7.4) the NPV of the environmental services provided by the wetland is estimated to be R1.2 billion (R1 200 million) over the 35 year period under consideration.

Approximately 90% of the environmental value generated by the wetland is accounted for by the nutrient reduction function.

Table 15: Baseline Existing Abstraction Regime environmental economic value

Ecosystem Service	Annual Average*	NPV:
Flood abatement, groundwater recharge and sediment retention:	R311 652	R10 886 603
Agricultural resource provisioning:	R2 671 047	R64 029 985
Harvesting of natural resources:	R208 000	R4 986 149
Nutrient reduction:	R44 239 108	R1 059 484 563
Carbon sequestration:	R2 717 315	R65 139 131
Tourism and recreation:	R134 386	R3 221 491
Intrinsic value:	R6 455	R154 727
Total in 2020 prices:	**R50 287 962**	**R1 207 902 650**

**Note: not discounted*

10.2. Modified Abstraction Regime 1: Future Raised Holsloot Weir

Under the first modified surface water abstraction regime under consideration, environmental services provided by the Papenkuils Wetland are estimated to generate an annual marginal environmental value of ~R44 million per year in 2020 prices (see Table 16), or ~R74 000 per ha of the original functional wetland extent annually.

Assuming a discount rate of 2.27% (see Section 7.4) the NPV of the environmental services provided by the wetland is estimated to be R1.06 billion over the 35 year period under consideration.

Table 16: Modified Abstraction Regime 1 environmental economic value

Ecosystem Service	Annual Average*	NPV:
Flood abatement, groundwater recharge and sediment retention:	R293 166	R10 239 675
Agricultural resource provisioning:	R2 448 065	R59 357 685
Harvesting of natural resources:	R190 636	R4 622 307
Nutrient reduction:	R38 755 795	R928 314 087
Carbon sequestration:	R2 490 669	R60 390 095

Ecosystem Service	Annual Average*	NPV:
Tourism and recreation:	R123 168	R2 986 417
Intrinsic value:	R5 916	R143 437
Total in 2020 prices:	**R44 307 414**	**R1 066 053 704**

**Note: not discounted*

The reduction of surface water inflows into the wetland under this flow regime are estimated to entail an average benefit-loss, or cost, of ~6 million per annum in 2020 prices, and a total benefit loss with a NPV of R142 million over the 35 year period under consideration (see Table 17).

Table 17: Environmental cost of Modified Abstraction Regime 1

Ecosystem Service	Annual Average*	NPV:
Flood abatement, groundwater recharge and sediment retention:	R18 486	R646 928
Agricultural resource provisioning:	R222 982	R4 672 300
Harvesting of natural resources:	R17 364	R363 842
Nutrient reduction:	R5 483 312	R131 170 476
Carbon sequestration:	R226 646	R4 749 036
Tourism and recreation:	R11 219	R235 074
Intrinsic value:	R539	R11 291
Total in 2020 prices:	**R5 980 548**	**R141 848 946**

The average annual and discounted total cost of the loss of wetland function is divided by the number of ML to be abstracted under this abstraction scenario to provide a conservative estimate a shadow price for the loss of wetland function per ML of additional water being diverted from the wetland.

Under the Modified Flow Regime 1 scenario, an average of 12 446 fewer ML of water would enter the wetland per annum, equating to an average environmental cost from the loss of ecosystem service value from the wetland of R481 per ML (see Table 18).

The environmental cost of water abstraction is estimated to have a NPV of R326 per ML over the full 35 year period under consideration.

Table 18: Environmental Cost of Modified Abstraction Regime 1 Per ML

Ecosystem Service	Annual Average*	NPV:
Additional water abstraction (ML):	12 446	435 597 (total)
Baseline environmental value:	R50 287 962	R1 207 902 650
Modified Abstraction Regime 1 environmental value:	R44 307 414	R1 066 053 704
Environmental cost of additional water abstracted:	R5 980 548	R141 848 946
Environmental cost of water abstraction per ML:	**R481**	**R326**

10.3. Modified Abstraction Regime 2: Proposed Future Scenario

Under the second modified surface water abstraction regime under consideration, environmental services provided by the Papenkuils Wetland are estimated to generate an annual marginal environmental value of ~R51 million per year in 2020 prices (see Table 19).

Assuming a discount rate of 2.27% (see Section 7.4) the NPV of the environmental services provided by the wetland is estimated to be R1.24 billion over the 35 year period under consideration.

Table 19: Modified Abstraction Regime 2 Environmental Economic Value

Ecosystem Service	Annual Average*	NPV:
Flood abatement, groundwater recharge and sediment retention:	R331 589	R11 584 350
Agricultural resource provisioning:	R2 937 139	R69 568 215
Harvesting of natural resources:	R228 721	R5 417 423
Nutrient reduction:	R45 240 849	R1 083 364 201
Carbon sequestration:	R3 002 960	R71 124 482
Tourism and recreation:	R147 774	R3 500 132
Intrinsic value:	R7 098	R168 110
Total in 2020 prices:	**R51 896 130**	**R1 244 726 912**

**Note: not discounted*

The increase of surface water inflows into the wetland under this reduced abstraction (enhanced flow) regime are estimated to entail an average benefit-gain of ~1.6 million per annum in 2020 prices, and a total benefit-gain with a NPV of R36 million over the 35 year period under consideration (see Table 20).

Table 20: Environmental Value Add from Modified Abstraction Regime 2

Ecosystem Service	Annual Average*	NPV:
Flood abatement, groundwater recharge and sediment retention:	R19 938	R697 747
Agricultural resource provisioning:	R266 092	R5 538 229
Harvesting of natural resources:	R20 721	R431 274
Nutrient reduction:	R1 001 742	R23 879 639
Carbon sequestration:	R285 645	R5 985 350
Tourism and recreation:	R13 388	R278 641
Intrinsic value:	R643	R13 383
Total in 2020 prices:	**R1 608 168**	**R36 824 262**

Under the Modified Abstraction Regime 2 scenario / reduced abstraction, an average of 1 931 more ML of water would enter the wetland per annum, equating to an average environmental benefit from the gain in ecosystem service levels from the wetland of R833 per ML (see Table 21).

The environmental benefit of this enhanced abstraction regime is estimated to have a NPV of R545 per ML over the full 35 year period under consideration.

Table 21: Environmental Value Add of Modified Abstraction Regime 2 Per ML

Ecosystem Service	Annual Average*	NPV:
Additional water entering wetland (ML):	1 931	67 588
Baseline environmental value:	R50 287 962	R1 207 902 650
Modified Abstraction Regime 2 environmental value:	R51 896 130	R1 244 726 912
Environmental value add from additional water entering wetland:	R1 608 168	R36 824 262
Environmental benefit of reduced water abstraction per ML:	**R833**	**R545**

10.4. Commentary on Wetland Service Value vis-a vis Agricultural Production

In 2013, BOCMA estimated the economic impact of water use by crop in the Breede Water Management Areas (WMAs) (BOCMA, 2013) – see Table 22. This data suggests that while the environmental value of water entering the wetland is similar to the production value of the least productive crops, the economic value of fruit cropping, per ML of water used, exceeds the estimated environmental cost of increased abstraction from the wetland.

Table 22: Economic value of water use by crop in the Breede WMAs

Crop	Value of production
Fodder:	R527 per ML
Apples:	R2 241 per ML
Wine grapes:	R2 637 per ML

Source: BOCMA (2013) converted to 2020 prices

At face value this suggest that the value of water use for grape production with current levels of nutrient assimilation and other ecological services in the Breede River Catchment (R2 637 per ML) would be approximately three times the value (cost) of forgone nutrient assimilation and other services from increased abstraction (R833 per ML). This is not atypical of resource economics studies which routinely find that economic production as traditionally measured frequently outweighs the quantified benefits of ecosystems services. However, if water was diverted away from the Papenkuils Wetland and therefore nutrients in this diverted water were not assimilated by the wetland, it is plausible that agricultural (e.g. grape) output (value of production) under irrigation with this diverted water may be in the order of 20% lower than baseline output levels due to a decline in water quality downstream of the wetland. This supports the finding that the total service value of the wetland is very significant.

Furthermore, it should be noted that the economic model is likely to underestimate the full conservation (intrinsic and scientific) value of the wetland, and that the wetland has untapped recreation and tourism potential that could significantly increase the annual service value of the wetland in the future.

11. Recommendations for long-term monitoring and assessment

Recommendations made in this report regarding flow management and wetland rehabilitation and management have been produced on the basis of a brief study with limited time and budget for data collection, analysis and modelling. It is strongly recommended that these findings should be solidified by a more detailed study, that extends the sampling and data analysis allowed for to date, through at least the rest of a full hydrological cycle,

12. Conclusions

This report reflects the outcomes of a brief study, intended to improve understanding of wetland function, form and key ecological drivers and responses in the Papenkuils Wetland, with a view to use this understanding to develop a high level hydrological model, that can be used to inform decision-making around flow allocations in the Holsloot system.

The study highlighted that:

- The Papenkuils Wetland is already significantly affected by changes in wetland hydrology, mostly resulting from the diversion of flows to the Brandvlei Dam via the Brandvlei canal; and the preferential channeling of residual flows along the northern arm of the Holsloot River and into the Breede River, at the expense of flows into the southern Holsloot and its wetlands, and wetlands iin the north west of the wetland, that would once have connected to the northern Holsloot;

- Some 115 ha of wetland mosaic have essentially been lost as a result of the above and the remaining (still extensive) wetlands also show signs in places of droughting (e.g. encroachment of terrestrial species into areas where remnant wetland vegetation suggests much wetter conditions);

- The wetland is extraordinarily important from a biodiversity perspective, as a result of inter alia its size, condition, rarity, number of plant species of conservation concern for which it provides a significant population stronghold; and role as the last remaining wetland of this size that reflects to some degree the lost biodiversity of the Central Breede Valley;

- Raising the Brandvlei Canal as proposed would significantly reduce the area of wetland (particularly in the southern wetland) that is inundated in a given rainfall exceeding the 1:30 year event, and by implication therefore, would potentially have knock-on effects across all of the wetland habitats identified in the system, with only the deepest Palmiet-dominated pools potentially remaining relatively unchanged. These impacts to wetland habitat quality and hydroperiod would also impact on the value of the wetland as a habitat for wetland fauna, with slight changes in depth of inundation translating into large changes in wetland extent, and potentially critical shrinkage of inundated areas, such that they can no longer provide support the life cycle requirements of breeding fauna;

- Modelling of the *Modified Abstraction Regime 2: Proposed Future Scenario* highlights the potential to achieve real (and necessary) wetland rehabilitation – and at least illustrates that the natural system has no capacity for further loss of flows;

- Raising of the Brandvlei Canal would trigger Section 21c and 21i water uses, as defined by the National Water Act 36 of 1998 (NWA) and require Water Use Authorisation, as well as Environmental Authorisation in terms of the National Environmental Management Act 107 of 1998;

- The NPV of the environmental services provided by the wetland for the *Existing Abstraction Regime* is estimated to be R1.2 billion (R1 200 million) over the 35 year period under consideration;
- The NPV of the environmental services provided by the wetland for the Modified Abstraction Regime 1: Future Raised Holsloot Weir is estimated to be R1.06 billion over the 35 year period under consideration;
- The NPV of the environmental services provided by the wetland for the Modified Abstraction Regime 2: Proposed Future Scenario is estimated to be R1.24 billion over the 35 year period under consideration; and
- Consideration could be given to the possibility of implementation of at least aspects of *Modified Abstraction Regime 2: Proposed Future Scenario*, in combination with increased abstraction into Brandvlei Dam from the Breede River downstream of the wetland, under conditions of attenuated flow enabled by passage of larger flood flows into the wetland. This would enhance the annual and potential environmental value generated by services from the Papenkuils Wetland.

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APPENDICES

APPENDIX A Botanical Report

APPENDIX B Water Quality Data

APPENDIX C Soil Moisture Monitoring Data

APPENDIX D Wetland Cross-Sections

APPENDIX E Soil Hydraulic Characteristics

APPENDIX F Sentinel Images and Analyses

APPENDIX G WET Health Assumptions

Chief Directorate: Environmental Quality
Directorate: Pollution and Chemicals Management
Western Cape Department of Environmental Affairs and Development Planning
Private Bag X9086
Cape Town, 8000
Tel: +27 21 483 4656
Website: www.westerncape.gov.za/eadp

Email: Wilna.kloppers@westerncape.gov.za or Annabel.Horn@westerncape.gov.za

Western Cape Government
Environmental Affairs and Development Planning