UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

EFFECT OF REHABILITATION ACTIVITIES ON ECOLOGICAL INTEGRITY AND FLOW REGULATION FUNCTION OF WETLANDS IN A GAUGED CATCHMENT

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PLAGIARISM DECLARATION

I declare that this Research Report is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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Bhuti Vincent Dlamini

07 day of JULY 20 21 at PRETORIA

ABSTRACT

Wetland ecosystems provide essential hydrological and ecological ecosystem services ranging from flow regulation, water quality improvement to biodiversity support. These systems face various pressures from surrounding land uses, and their ability to function optimally and provide ecosystem services is heavily dependent on the condition of the wetland. In a developing country like South Africa where land-use change is prevalent to support development agenda, wetlands and rivers are severely impacted. It is estimated that approximately 45% of wetlands are being heavily modified, which compromises the regulatory services that healthy wetlands can provide. This study seeks to respond to a perceived need for increased knowledge of the contribution that rehabilitation activities have made towards improving wetland health (ecological integrity) and flow regulation capacity in support of the country's investment made towards wetland rehabilitation. The study focuses on two wetland catchments which consist of two wetland systems, Kgaswane and Rietfontein wetland systems. Both wetland systems are located in the North West Province, and wetland rehabilitation work was completed in both systems. Additional criteria of selection included the presence of the streamflow gauge at the outlet of the rehabilitated wetland catchment for flow data analysis.

The study found that in general, the implementation of rehabilitation interventions on both wetlands (Kgaswane and Rietfontein) has shown improvement in ecological conditions. Kgaswane wetland system had shown a statistically insignificant improvement (i.e. little improvement) in the ecological conditions ranging from 3% to 8% with regard to rehabilitation activities. Rietfontein wetland system has shown a significant improvement in ecological conditions of 30%. The analysis of flow data at the outlet of the wetland catchments at streamflow gauges A2H038 (Kgaswane wetland) and A2H053 (Rietfontein wetland) shows an increase in the magnitude of high flows and a decrease in low flows as compared to our current knowledge that wetlands increase or maintain baseflows. The conclusion is that rehabilitation

efforts in both of Kgaswane and Rietfontein systems did not contribute positively to flow regulation, particularly with regards to improvement and maintenance of baseflows; the variability of flow between high and low flows increased following rehabilitation. All the wetland interventions are performing under the dry period for Rietfontein and an average rainfall period for Kgaswane. The cost-effectiveness of implementing rehabilitation activities for the Kgaswane wetland system is low and for Rietfontein wetland system is intermediate. The projects that yield high return on investments and are cost effective turned to be high priority in terms implementation. This is not the case for the two wetland systems assessed in this report. There are various limitations identified in all aspects (ecological integrity, flow regulation and cost-effectiveness) that can be addressed in future studies in similar projects. There is scope for future work to address issues raised on the limitations and to provide on-going improvements to the results on an assessment of this nature. The assessment is predominantly developmental to encourage versatile administration, reformist learning and persistent improvement of our understanding of the effects of rehabilitation activities. The purpose of the assessment is to provide some direction that can be developed and refined as adequate information becomes available.

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Above all, I give thanks to the Almighty, who has given me the wisdom and strength to accomplish this work.

DEDICATION

This Study is dedicated to my mother Gertrude Thandiwe Dlamini and my late father, Godfried Bethuel Dlamini**.** My parents did not only raise and nurture me but also taxed themselves dearly over the years for education and intellectual development. Both my parents have instilled in me the desire to do more in everything I do.

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LIST OF ABBREVIATIONS

BGIS	Biodiversity Geographical Information System
CVB	Channelled Valley Bottom
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
NFEPA	National Freshwater Ecosystems Priority Areas
NWI	National Wetland Inventory
PES	Present Ecological State
SANBI	South African National Biodiversity Institute
STATS SA	Statistics South Africa
UCVB	Unchannelled Valley Bottom
WfWet	Working for Wetlands
WRC	Water Research Commission
WR2005	Water Resources of South Africa 2005 Study
WR2012	Water Resources of South Africa 2012 Study

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1. CHAPTER 1: OVERVIEW

1.1 Introduction

Water is a limited resource in South Africa due to variability in climatic conditions, particularly rainfall patterns (Department of Environment Affairs and Tourism, 2012), and the high demand from a human population exceeding 57 million (Stats SA, 2018). The transformation of water resources as a result of changing land uses affecting the water resources themselves and in the supporting catchments has resulted in most of our inland aquatic ecosystems, particularly our wetlands and rivers, currently existing in a poor or rapidly deteriorating condition (Nel and Driver, 2012). Wetland ecosystems have value as a result of the hydrological and ecological ecosystem services that they provide, ranging from flow regulation and water quality improvement to biodiversity support. These systems face various pressures from surrounding land uses (Nel and Driver, 2012). The ability of a wetland ecosystem to function optimally and provide the maximum capacity of ecosystem services is heavily dependent on the condition of the wetland. Pristine or mostly natural wetlands are thought to have a higher ability to provide critical regulatory services, whereas heavily modified and impacted wetlands lose this capacity as their condition deteriorates. A term commonly used to express wetland condition is wetland ecological integrity (Macfarlane *et al.,* 2008). On-going changing land uses have impacted wetlands, resulting in approximately 45% of wetlands being heavily modified, which compromises the regulatory services that healthy wetlands can provide (Nel *et al.,* 2011). The present situation portrays a picture of the precarious state of our wetland assets. The climatic variability and the growing need for water resources in South Africa to support the agenda of a developing state impact heavily on the availability and reliability of usable water resources, including wetlands, in terms of water quantity and quality (DEA, 2012).

While it is crucial to understand the impacts of wetland rehabilitation on the ecosystem services provided by wetlands, at the onset it is essential to define various terms as well as the indicators used in monitoring wetland rehabilitation responses. Wetland rehabilitation is characterised as the way toward aiding the ecological recuperation of a wetland that has been degraded or in keeping up the health of a wetland that is currently deteriorating to improve the wetland's ability for providing services to society (Kotze *et al.,* 2008). Wetland rehabilitation has also been defined as the *"progression towards the attainment of former ecosystem structure, function and state (attainment of a state that is as near to the former as resources or local conditions allow) and the attainment of ecosystem structure, function and state that differs from the former (attainment of some desired state)"* (Grenfell *et al.*, 2007). Grenfell *et al.* (2007) further defined restoration as the *"Attainment of former (before anthropogenic disturbance) ecosystem structure, function and state"*. In essence, rehabilitation is returning a wetland towards its original state, i.e. closer to its un-impacted ecological state and thereby improving its provision of ecosystem services while restoration is the reinstatement of the original state of the ecosystem. The DEAs Working for Wetlands programme, a national government-funded programme initiated in 2000, has undertaken extensive wetland rehabilitation work through poverty-relief funding. The focus of the wetland rehabilitation programme is twofold: firstly, the improvement of the condition and functioning of wetland ecosystems, and secondly, job creation as part of poverty-relief projects. While the main focus is on ecosystem functionality improvement and job creation, part of the funding goes towards research and development that focuses on the production of supporting scientific materials that assist in strengthening the understanding of rehabilitation planning processes and monitoring of rehabilitation success. To this end, through the Working for Wetlands Programme, since 2004, an amount of R826.8 million has been invested in the rehabilitation of over 1000 wetland ecosystems (DEA, 2019).

Evaluation of wetland ecosystems post-rehabilitation has been limited in terms of responses to rehabilitation activities and the associated ecological outcomes, within the context and extent of the investments made in improving ecosystem services provision of these systems. Of the limited post-rehabilitation evaluations that have been undertaken, the focus has broadly been placed on wetland ecological integrity, rehabilitation interventions survival, vegetation and water quality responses post rehabilitation (Cowden *et al.,* 2013). Riddell *et al.* (2011; 2012) attempted to assess hydrodynamic behaviour of headwater wetlands post-rehabilitation in the Sand River in the Kruger National Park, Mpumalanga Province focusing on the shallow groundwater responses and headwater wetland hydrology, with emphasis on quantifying the contribution of technical rehabilitation activities to this behaviour. A common sentiment expressed in the above studies is that there has not been sufficient emphasis placed on the evaluation of post-rehabilitation responses of the wetland systems given the number of wetlands that have been rehabilitated and when one views this with the investment made through poverty-relief funding.

This study seeks to respond to a perceived need for increased knowledge of the contribution that rehabilitation activities have made towards improving wetland flow regulation capacity in support of the country's investment made towards wetland rehabilitation.

1.2 Problem statement

The South African Government, with a focus on the expanded public works programme, has invested a sizeable amount of money towards wetland rehabilitation projects. Therefore, it is essential to quantify and substantiate the return on investment, particularly with regard to the perceived ecosystem services gained associated with the rehabilitation activities. It is the intention of this research project to evaluate existing information, critically analyse all available data and assess changes in the ecological integrity of rehabilitated wetlands. The assessments will assist in determining whether the perceived ecosystem services gains within the restored wetland systems are achieved or not. Given the above, research questions asked are as follows:

- To what extent do wetland rehabilitation activities contribute to improvement in the ecological integrity of wetlands?

- Do wetland rehabilitation activities contribute to an improvement in the flow regulation function of wetlands?
- Can the investment made towards wetland rehabilitation projects be substantiated based on ecosystem service improvements realised?

1.3 Research Aims and Objectives

1.3.1 Aim

This study aims to assess the contribution of wetland rehabilitation activities towards the improvement of wetland ecological integrity and the flow regulation function of the rehabilitated wetlands.

1.3.2 Objectives

- To assess the ecological integrity responses of rehabilitated wetlands;
- To determine the impacts of rehabilitation activities on stream flow regulation function; and
- To compare and substantiate investments made based on achieved ecosystem services.

1.4 Overview of the Research Report

The report consists of six chapters. Chapter One presents the study and explanation of the research problem. It contains a brief introduction to the research, the context of the study, problem statement, research aims and objectives. Chapter Two presents the literature review of the assessment of the wetland responses as a result of rehabilitation activities. It considers the global perspective in terms of the understanding and the Level at which the responses are assessed and the scale at which this has been acknowledged globally. South Africa's context provides our understanding of the responses of wetlands to rehabilitation, some of the work that has been done and limitations as well as further work required to bridge our knowledge gap. Chapter Three focuses on the selection and description of the study site and the methodology adopted in meeting the aims and objectives of the study and

Chapter Four includes analysis of the data and interpretation of results, Chapter Five presents a discussion of the results while Chapter Six provides conclusions and limitations of the study.

2. CHAPTER 2: LITERATURE REVIEW

2.1 Global perspective

Wetlands provide a variety of ecological or ecosystem services. According to Kadykalo and Findlay (2016), wetland environmental functions are attributed to (amongst others) their ability to influence flow regime augmentation of low flows and attenuation of floods. Their findings concluded that, in general, wetlands do deliver positive flow regulation services, i.e. augmenting low flows and reducing streamflow and runoff. Analysis of observed and recorded streamflow and rainfall data for 51 years in Naoli Basin in China indicated that over the years the destruction and reduction of wetland areas have resulted in peak flow increases and declining streamflow regulation as the wetlands disappear (Yao *et al.,* 2014). A comprehensive review of 169 studies done between 1930 and 2002 by Bullock and Acreman (2003) concluded that there is some proof that wetlands have a positive effect on the hydrological cycle. The review that (1) floodplain wetlands dissipate the energy of large floods and limit environmental and infrastructural damage, (2) headwater wetlands increase floods, (3) wetlands lose water through excessive evapotranspiration, and (4) floodplain wetlands underlined by sandy soils are essential in recharging groundwater. In the researcher's assessment, it is clear that the functioning of wetlands depends on the regional climatic and environmental conditions, and the type and landscape setting in which the wetlands occur. It should therefore not be generalised that all wetlands perform flow a regulation function. The above studies show that globally, wetlands have an important and valuable role to play in regulating aspects of the hydrological cycle, and this contribution is in jeopardy due to on-going wetland habitat loss and deterioration.

2.2 South African context

There are various indicators used to evaluate success or response of wetlands to rehabilitation activities, and these are outlined in detail at different levels depending on the complexity of the assessment (Cowden and Kotze, 2008). There have, however, been budgetary constraints within the WfWet wetland rehabilitation budget to monitor and evaluate rehabilitated wetlands (Cowden *et al*., 2013). Where monitoring has taken place in the form of specific projects, the focus is on ecological integrity, ecosystem services, vegetation, rehabilitation interventions, and social and economic benefits (Cowden *et al.,* 2013; Kotze *et al.,* 2018). The existing monitoring indicators do not include monitoring of the flow regulation function (baseflow and flood attenuation) using qualitative assessment of streamflow data. Research conducted by Oberholster *et al.* (2016) to assess the effectiveness of rehabilitation activities and ecosystem responses has had a strong focus on water quality, bacteria consortium, freshwater algae, vegetation, toxicity and resource economics under pre- and post-rehabilitation conditions. The results indicated improvement in water quality post-rehabilitation in a short time with further recommendations to continue monitoring the system. Investments into protecting and rehabilitating ecological infrastructure, including wetlands, could create significant gains in water quantity (Mander *et al.,* 2017).

According to Browne *et al.* (2018) in an extensive literature review undertaken of the economic evaluation of wetland restoration globally, there is a lack of studies done in Africa and South America with regard to the evaluation of outcomes of wetland restoration projects; most particularly post-restoration evaluations. The conclusion is that our current understanding of value achieved through wetland restoration remains tentative and to bridge this gap, more work is required. Riddell *et al.* (2011; 2012) attempted to address the contribution to flow regulation function of headwater wetlands by considering hydrodynamics and hydrological responses of the wetland post-technical rehabilitation activities. The conclusion drawn from these studies was based on evaluating data from various measurements undertaken. Critical findings indicated that headwater wetlands do not contribute to flow augmentation and do not attenuate flows, particularly during summer seasons. Flow regulation findings contradict the perceived anticipated functions associated with wetlands. However, the study focused on the headwater rehabilitated wetlands; the results may have been different if this study considered valley bottom systems or different types of wetland systems.

Mander *et al.* (2017) found an improvement in water quantity (streamflow and baseflow (low flows – maintaining the watercourse system)) within two catchments where hydrological modelling was undertaken in the KwaZulu-Natal and the Eastern Cape provinces and the conclusion was that rehabilitating ecological infrastructure could result in improved water security. The findings of Mander *et al.* (2017) agree with current knowledge that wetlands increase or maintain baseflows, the increase in streamflow observed in this study is somewhat contradictory to the expectation that wetlands can attenuate flows and that this capacity would be improved following rehabilitation of ecological infrastructure. The expectation that wetlands contribute towards flood attenuation rather than increased streamflow (not to be confused with increased baseflow) is supported by Turpie *et al.* (2017) who described how vegetative cover within wetlands attenuates movement of water through the landscape and thus reduces flood peaks. Therefore, during high rainfall events and in the absence of wetland ecosystems, runoff volumes would be greater and would result in increased flood damage and an overall reduction in the yield of water supply systems. Given the currently limited extent of post-rehabilitation evaluations undertaken within the South African context and the apparent contradictions in findings regarding the role of wetlands in flow regulation, evaluation of rehabilitated wetlands must extend to an assessment of flow regulation function as this will provide a more complete picture of whether we are achieving anticipated ecosystem gains and also what needs to be done during the planning process to at least account for the investment made in wetland rehabilitation projects.

3. CHAPTER 3: STUDY SITE AND RESEARCH METHODOLOGY

3.1 Research Study Area

The study site proposed for the research project was selected based on the following criteria:

- There was a wetland present that has been rehabilitated.
- There was a streamflow gauges present at least downstream of the rehabilitated wetland.
- There was Present Ecological Status (PES) or similar condition information available for the situation before rehabilitation.
- The wetland was located should preferably be within relative proximity to Pretoria to facilitate easier access should fieldwork be required.

In order to use the above criteria in selecting a suitable study, a database of rehabilitation projects implemented before the 2012 period and indicating the structural interventions was obtained from the South African National Biodiversity Institute's Biodiversity Geographic Information Systems (SANBI BGIS). These data were superimposed with streamflow gauge location information received from the Water Resource of South Africa 2005 and 2012 datasets, using ArcGIS 10.2.2 software. Based on an analysis of these datasets and with the criteria stated above in mind, wetland sites located in the North West Province within the Kgaswane (Rustenburg) Nature Reserve and upper reaches of the quaternary catchment A21K were selected. The study sites are within the Department of Water and Sanitation (DWS) quaternary catchments A22H and A21K. The wetlands and gauging station catchments were delineated using 5 m contours using the gauge station as an outlet point. The delineations were conducted to enable assessments at the local level as well as the contributing catchment areas to the flow recorded at the gauge stations. The characteristics of the study sites as selected are summarised in Tables 1 and 2 and the location and extent of the study areas and focus wetlands are shown in Figure 1.

Table 1: Attributes of the Kgaswane Nature Reserve study site

	Rustenburg A22H Site
Catchment Area	16.6 km^2
Wetland Area	143.54 ha (desktop Level delineation)
Type of Wetland	Valley bottom
DWS Gauging Stations	A2H038 and A2H039
Streamflow Records	A2H038 (1971 – 2017), A2H039 (1971 – 2018)
Landuse	Nature reserve

Table 2: Attributes of the study site within the upper reaches of the quaternary catchment A21K

	Rustenburg A22H Site
Catchment Area	86 km^2
Wetland Area	200 ha (desktop Level delineation)
Type of Wetland	Valley bottom
DWS Gauging Stations	A2H053
Streamflow Records	A2H038 (1972 – 2018)
Landuse	Nature reserve and agriculture

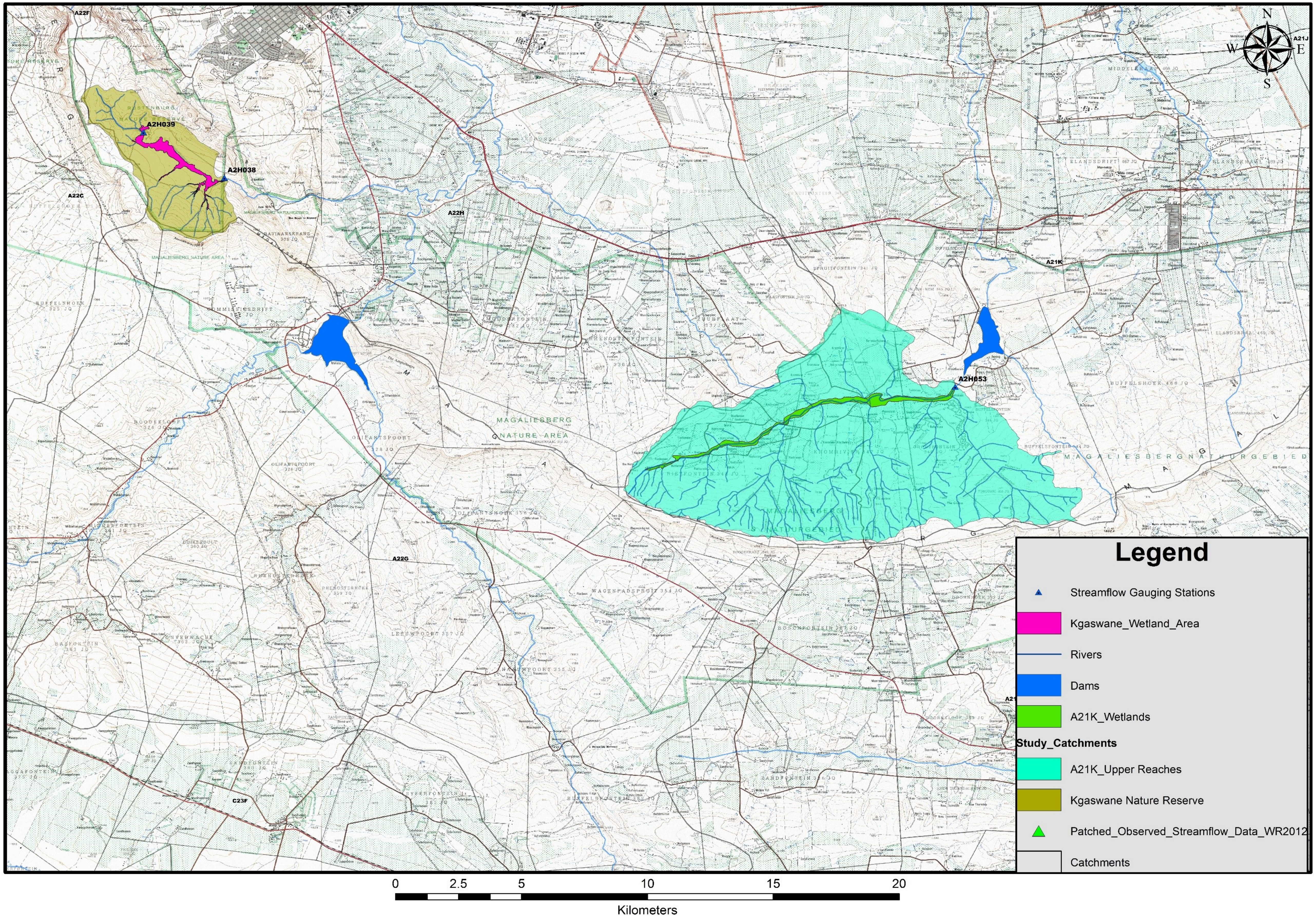


Figure 1: Location and extent of the study site within Kgaswane Nature Reserve and the upper reaches of the quaternary catchment A21K (1:50 000 Topographical Maps – 2527 CA, CB, CC and CD).

3.2 Wetland details

3.2.1 Wetland delineation

Wetland delineation was undertaken to provide an approximate extent of the wetland areas onsite. Existing wetland extent datasets from various sources including National Freshwater Ecosystem Priority Areas (NFEPA) and National Wetland Inventory datasets and existing wetland information from the BGIS were used and supplemented by desktop delineation to ensure that the full extent of wetland habitat within the study sites is represented. Desktop delineation followed the methodology as detailed by Thompson *et al.* (2002), which incorporates the use of ortho-rectified aerial imagery, Google Earth imagery, and any form of high-resolution aerial imagery available to identify the presence and extent of wetness signatures. The desktop delineation was digitised onto satellite imagery using ArcGIS 10.2.2 software to create digital base maps for the project. The following images (Figure 2 and 3) indicate the extent of wetland areas and their associated catchment areas. The extent of the wetland catchment areas was delineated from 5 m contours using the gauge station as an outlet point.

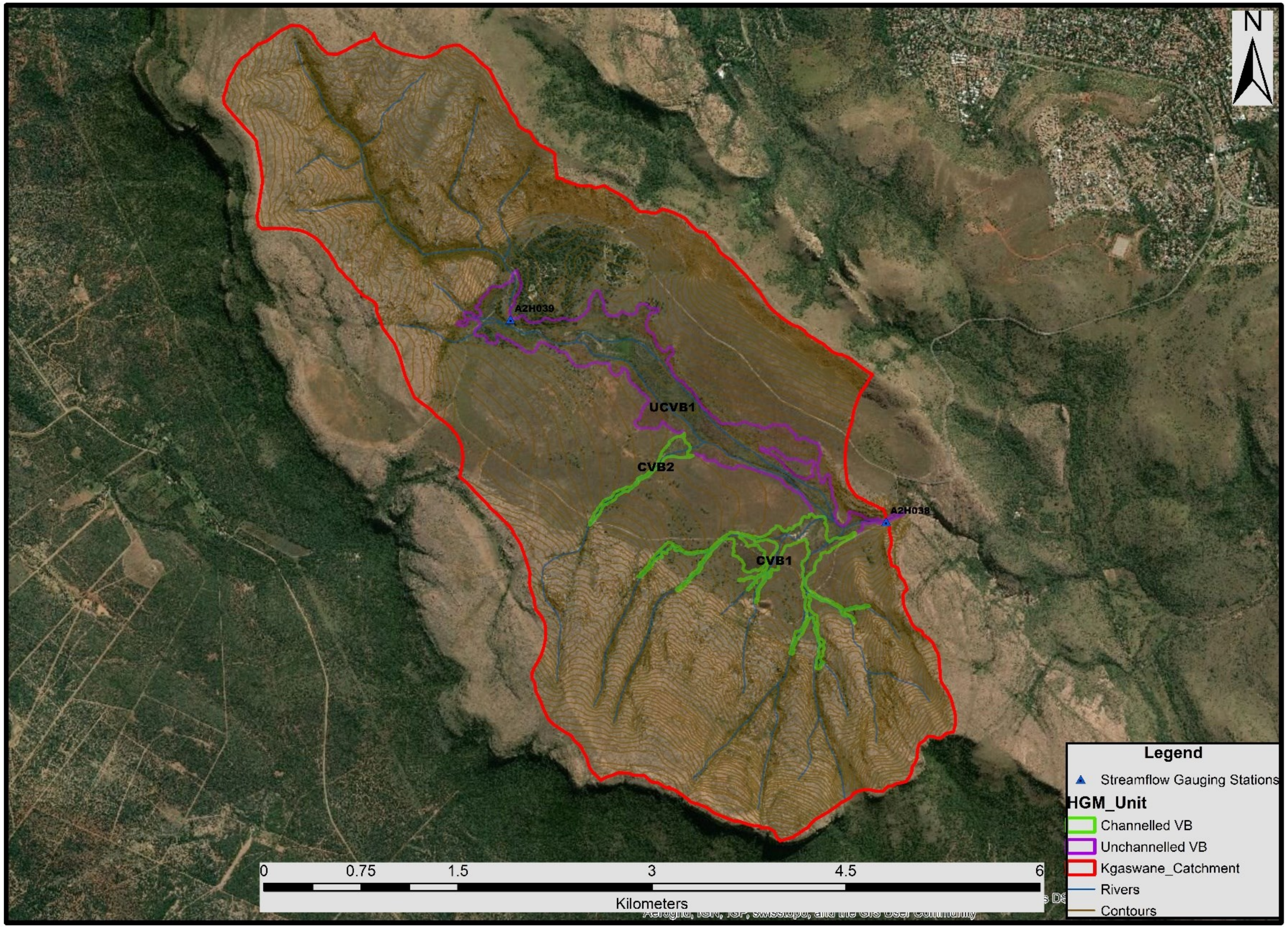


Figure 2: Extent of the Kgaswane wetland system and its catchments to be assessed as part of this project.

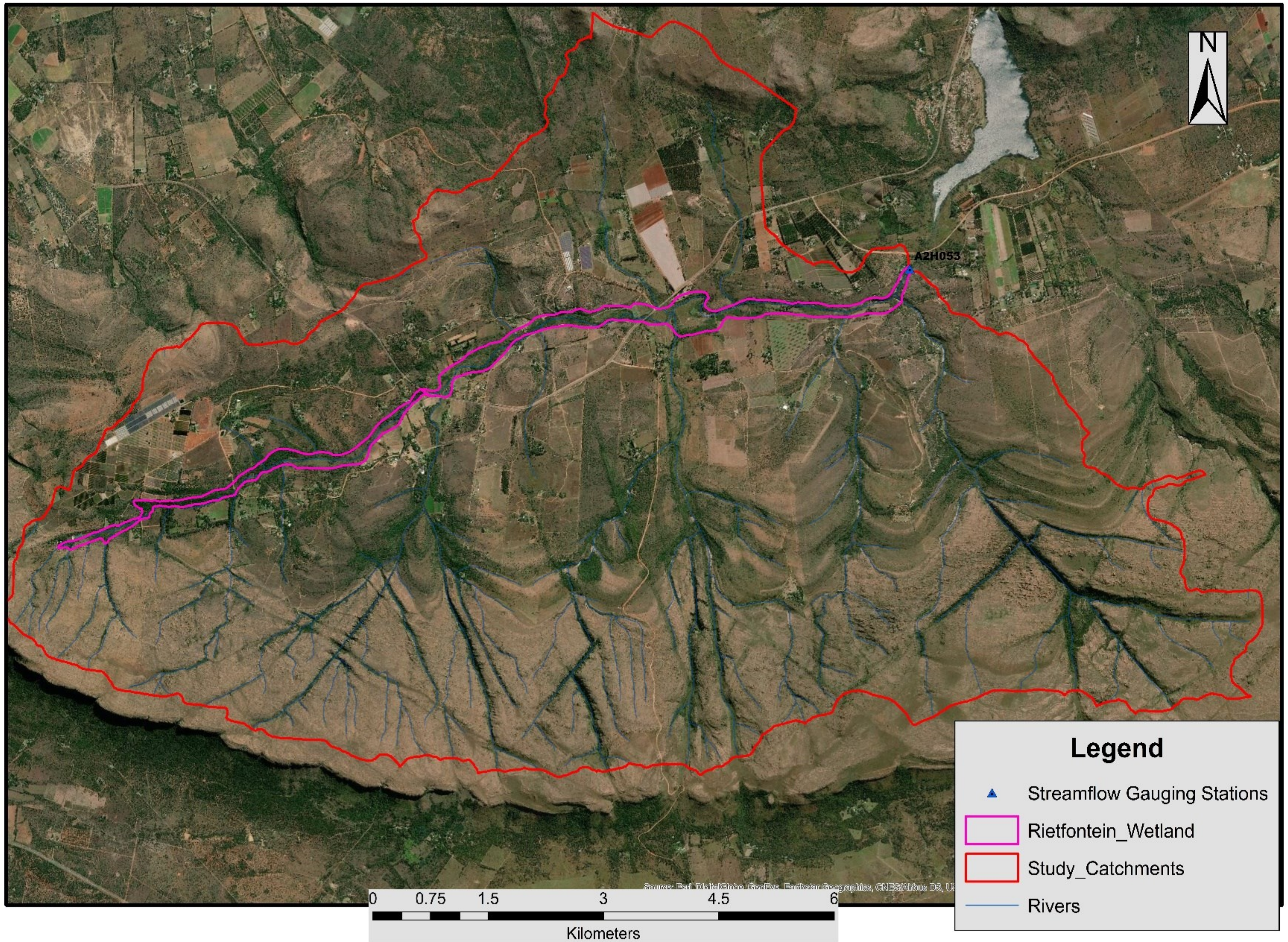


Figure 3: Extent of the Rietfontein wetland areas and its catchments to be assessed as part of this project.

3.2.2 Wetland description and classification

The wetlands within the study area consist of more than one hydro-geomorphic (HGM) unit. In particular, the Kgaswane wetland system is included in an Unchannelled Valley Bottom Wetland system (UCVB1) along the Waterkloofspruit, surrounded by Channelled Valley Bottom Systems (CVB1&2) from the side slopes south of the main unchannelled valley bottom system. Within the Rietfontein wetland catchment one HGM wetland unit is recorded on-site, i.e. main channelled valley bottom wetland system (CVB). The central channelled valley bottom wetland in the Rietfontein catchment forms part of the Sterkstroom River that drains the site and discharges to the Buffelspoort Dam downstream at the outlet of the catchment. Table 3 below describes the HGM wetland types recorded within the study areas.

Table 3: Wetland hydro-geomorphic type (HGM) units identified within the Kgaswane and Rietfontein wetland systems (modified from Brinson 1993; Kotze and Marneweck, 1999 and Marneweck and Batchelor, 2002).

Hydro-geomorphic Type	Description
Channelled Valley Bottom	*"Valley bottom areas with a well-defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterised by the net accumulation of alluvial deposits or may have steeper slopes and be characterised by the net loss of sediment. Water inputs from the main channel and adjacent slopes".*
Unchannelled Valley Bottom	*"Valley bottom areas with no clearly defined stream channel, usually gently sloped and characterised by alluvial sediment deposition, generally leading to a net accumulation of sediment. Water inputs mainly from channel entering the wetland and from adjacent slopes".*

The baseline conditions of the watercourses within the Kgaswane wetland system were assessed using the Landcover- based assessment tool (Level 1A, Wet Health assessment tool, (Kotze, 2016a & b)). The reason for this is no baseline assessment was undertaken before rehabilitation commenced on wetlands on site, and this tool was considered as a most appropriate tool for determining baseline conditions before rehabilitation on wetlands on site. The baseline ecological conditions for the Rietfontein wetland system were obtained from existing wetland rehabilitation plans that were compiled for the wetland area prior to implementation of the first interventions on wetlands onsite in 2009 and 2011, respectively.
After rehabilitation, the ecological assessment was undertaken, and Level 2 WET-Health assessment tool (Macfarlane *et al.,* 2008) was used. Site visits and evaluation of various HGM units for both Kgaswane and Rietfontein wetland system were undertaken. The information collected on wetland systems was used as an input on the tools to determine the current ecological state after rehabilitation had taken place on the respective wetlands. The HGM units assessed include UCVB1 and CVB1 wetland systems within the Kgaswane wetland system and the entire CVB within the Rietfontein wetland system. CVB2 within the Kgaswane wetland system was not evaluated; only baseline information was considered. The reason being there was no rehabilitation work undertaken on this wetland system.

3.2.3 Kgaswane wetland system

The Unchannelled Valley Bottom Wetland System is characterised by a large stand of *Phragmites australis* (Common Reed) along the majority of the wetland area with permanently wet conditions and seasonally wet areas mainly along its margins. It appears to have a weakly developed channel along the edges of the *Phragmites australis* marsh section just upstream of the streamflow gauge A2H038. In this section, a quartzite outcrop upstream of the streamflow gauge A2H038 functions as a suspected key point, which enables the formation of a wide upstream Unchannelled Valley Bottom Wetland area along the length of the Waterkloofspruit.

The limited extent of alien species was recorded within UCVB1 and included species such as *Verbena bonariensis.* No clear drains or furrows were recorded within UCVB1. An eroding trench located northeast of UCVB1 supplies additional sediment into the wetland. The trench is present on a steep slope in an area dominated by the fern *Pteridium aquilinum* and contains a rehabilitated area presumably a headcut feature and has various sediment nets to prevent erosion movements' downslope to the main UCVB1. The purpose of rehabilitating the trench and associated headcut was to protect the peat substrate and habitat for a plant species of conservation concern, *Gunnera perpensa*, which has a Declining IUCN conservation status category.

Eroding sediment from the steep slopes of the surrounding mountainous quartzite catchment are transported into the wetland via headwater channels and valley bottom wetland tributaries. The process of sediment movement is regarded as a largely natural process. The channels and valley bottom on the slope include CVB1 & CVB2. These CVB 1&2 wetland systems have experienced aggravated scour erosion due to the presence of a road crossing, which has resulted in flow concentration. Existing rehabilitation activities have attempted to halt erosion associated with road crossing impacts. Various crossing designs and supporting erosion control structures have been placed at different positions upstream and downstream of the road. CVB1 and CVB2 are riparian in nature dominated by soils that are young undeveloped soils with limited pedogenetic development and contain distinct layers of deposition (Nel, 2000) especially upstream of the road crossings, however, below the road where alluvial sediments washed down from the slopes upstream of the road deposits wetland soil, and plant features occur. A list of plant species recorded within the wetland system and supplemented from the research done by (Nel, 2000) are listed in Table 4:

Table 4: Recorded plant species within the Kgaswane wetland system based on-site observations during March 2019 (and supplemented by species recorded by Nel, 2000).

Trees and Shrubs	Grasses	Forbs, ferns and sedge
Cliffortia spp.	*Phragmites australis*	*Pteridium aquilinum*
Diospyros lycioides	*Miscanthus junceus*	*Cyperus* spp.
Faurea saligna	*Arundinella nepalensis*	*Hiliardiella hirsuta*
	Aristida junicformis	*Gunnera perpensa*
	Cynodon dactylon	*Persicaria attenuata*
	Eragrostis spp.	*Gomphocarpus fruticosa*
	Imperata cylindrica	*Persicaria* spp.
	Elionurus muticus	*Verbena bonariensis*
	Harpochloa falx	*Helichrysum* spp.
	Hyparrhenia hirta	*Rubus* spp.
	Melinus spp.	
	Paspalum dilatatum	
	Themeda triandra	

3.2.4 Rietfontein wetland system

The wetland is considered to be a channelled valley bottom wetland in terms of hydro-geomorphic classification and is driven primarily by the overtopping of water from the channel. The land use within the upper reaches of the wetland system (A21K-02) consists of Nature Reserve (Conservation). The channel within this reach is eroded with exposed soil profiles along the channel banks. The wetland area consists of riparian woody vegetation, such as *Buddleja salviifolia* along portions of the channel, and as well as obligated hydrophytes, such as *Gunnera perpensa*. The current impacts/uses of the wetland system include:

1. Water abstraction;
2. An extensive drainage link to gully incision that encourages draining of the wetland and;
3. Historical impacts such as infrastructure (roads and pipelines) that have also resulted in erosion upstream and downstream of these infrastructures and notable changes to the morphology of the wetland system.

Sections of the wetland are dominated by species of conservation concern, *Gunnera perpensa*. The current implemented rehabilitation interventions are aimed at addressing some of the results of these impacts.

The lower reach of the wetland system (A21K-01) is characterised by cultivation and water abstraction (water pumps and weirs recorded onsite). A large portion of the wetland area is infested by alien vegetation and characterised by reed bed succession. This has resulted in channel switching because of the resistance to flow offered by the reed bed. Water has switched from the original flow paths (patterns) and now flows through the low resistance areas adjacent to the reed bed, consisting mostly of sandy soils derived from the weathering of quartzite. The soils in these areas are highly mobile, and an incised eroding channel has thus formed. The current rehabilitation interventions are likely to stabilise sediments that threaten to silt up the

Buffelspoort Dam downstream (at the outlet of the catchment study site). The overall A21K-02 wetland area is exposed to sediment loss and channel incision and extensive alien vegetation invasion resulting in the uneven distribution of water across the wetland (areas previously permanently wet are now only marginally wet). The morphology and structural diversity within the wetland area have changed as a result of the impacts recorded within the wetlands. The following problems have been identified as posing a risk to the integrity of the wetland:

- Wetland habitat desiccation caused by incised channels, which is in part a natural process, have worsened by road construction and pipe laying within portions of the wetland;
- Active headcut erosion, which includes small in-channel headcuts to large in-channel and proximal headcuts. Headcut erosion is expected within this headwater wetland setting, but the same anthropogenic impacts listed in the above have worsened headcut advancement and development; and
- Alien vegetation encroachment to within the lower reaches of the wetland system and cultivation within and around the wetland area.

The implemented wetland rehabilitation interventions are aimed at addressing some of the impacts recorded on-site particularly erosion- and sedimentation-related impacts, and there are, however, no interventions that have been implemented on-site to deal with alien vegetation invasion most particularly *Eucalyptus* spp. and *Populus* spp.

3.3 Research design

3.3.1 Sources and collection of spatial data

The following data sources and datasets will be consulted to form the baseline data for assessments:

- Location and naming of streamflow gauges - Water Resources of South Africa 2005 and 2012 (WR2005 and WR2012) datasets from Water Research Commission (WRC) – (Bailey and Pitman, 2009 : 2015);
- Catchments and rivers - WR2005 datasets from WRC (Bailey and Pitman, 2009; 2015);
- Wetland coverage shapefiles - National Wetland Inventory (NWI) and National Freshwater Ecosystem Priority Areas (NFEPA) wetland datasets (BGIS.SANBI.ORG. (2021);
- Landcover and conservation plans shapefiles - BGIS.SANBI.ORG. (2021),
- Verified streamflow records - DWS Hydrological website – Department of Water and Sanitation, (2011)
- Wetland interventions location shapefiles – Department of Environmental Affairs' Working for Wetlands (DEAs WfWet) - (BGIS.SANBI.ORG. (2021); and
- Rainfall data – South African Weather Bureau (SAWB) and satellite downloads of rainfall time-series datasets - Matsapola, (2019).

3.3.2 Hydrological data preparation

Over the years, the streamflow gauges have not been well maintained in South Africa due to limited resources and technical expertise within the DWS (Basson *et al.,* 1994). A fair amount of work is required to extend flow records, and possibly repair and clean records. Currently, in some cases, records are short, patchy and prone to errors. A review of some of the streamflow datasets used in WR2012 as part of the Pitman model by Bailey and Pitman (2015) indicate that some gauges were cleaned and patched to analyse data for this project. The specific gauges required as part of this proposed research project did not form part of the Pitman model project in term of data analysis, and therefore, the gauges necessary may require additional preparation. Affected streamflow data will be reviewed, cleaned and patched to prepare it for assessments essential for this project.

3.3.3 Wetland ecological integrity data

Existing implemented wetland rehabilitation plans and associated specialist reports have been reviewed to establish the most appropriate post-rehabilitation ecological integrity assessment to be used in evaluating and quantifying any changes or improvements in wetland condition.

3.3.4 Data analysis

3.3.4.1 Ecological integrity assessment

3.3.4.1.1 Pre-rehabilitation ecological integrity assessment

Baseline ecological integrity assessment was collated from the existing rehabilitation plans. The information on the rehabilitation plans consists of the PES scores of the wetlands before rehabilitation activities onsite. In cases where baseline information is not available, which is likely to be the case for the older rehabilitation plans as it was not mandatory to form part of the old rehabilitation plans, the following was undertaken to set the baseline conditions. Level 1A wetland evaluation tools was used to assess wetland conditions dependent on land cover type before rehabilitation (Kotze, 2016a & b). This technique uses computations within the wetland and encompassing wetland land-uses as an intermediary to decide wetland impacts, and subsequently wetland ecological state. High-resolution aerial imagery will be used to supplement land-use cover type particularly when identifying the morphological impacts on wetlands; these include the extent of erosion, deposition, dams, and impoundments and alien vegetation invasion. The mapped land use areas are area-weighted as a percentage of cover; the tool provides the various intensities of land use/ land cover for areas within the wetlands and those surrounding the wetlands. The impact score of each land use is the percentage area of extent multiplied by the intensity of such activity as provided by the tool. The overall PES is calculated as a combination of impact scores using the combined PES equation of (Macfarlane *et al.,* 2008). The Land-Cover dataset used for pre-rehabilitation ecological conditions for the wetland was the South African National Land-Cover (SANLC) 1990 dataset obtained from the Department of Environmental Affairs Open Access (DEA, 2021). The SANLC 1990 is the only dataset available before rehabilitation work undertaken on site. The results of the assessment of Land-Cover datasets and aerial imagery of the site are indicated in the following sections.

3.3.4.1.2 Post-rehabilitation ecological integrity assessment

Present Ecological State (PES) assessments was undertaken for wetland areas delineated and rehabilitated onsite. PES assessments were done to establish the current state of the wetlands' post-rehabilitation activities. A Level 2 wetland assessment tool was used to determine the PES of the wetland system onsite. An evaluation technique of this tool is based on readily described field indicators that critically examine the three components of wetland ecological integrity, namely:

- Hydrology;
- Geomorphology; and
- Vegetation.

A Level 2 wetland evaluation tool (WET-Health) is customised explicitly for South African conditions and has a wide application, as a feature of Ecological Reserve Determination and for environmental impact assessments. There are two levels of intricacy accessible in the WET-Health tool. Level 1 is utilised for rapid appraisals on a more extensive scale, and Level 2 gives more noteworthy detail to individual wetlands dependent on a more extensive field evaluation of indicators of degradation. As indicated above for this project, a Level 2 assessment was conducted for each wetland unit. The categories used to define wetland health are shown in Table 5 below.

The PES categories indicate the changes in the system to its reference state, the reference state being a pristine un-impacted natural system. The PES category of a pristine natural system is "A", the scale of modification cascade from A to F, with F representation being a system that is completely modified with no natural habitat remaining.

Table 5: Present Ecological State (PES) categories used to define the health of wetlands (Macfarlane *et al.,* 2008).

Description	Combined impact score	PES Category
Unmodified, natural.	0-0.9	A
Largely natural with few modifications. A slight change in ecosystem processes is discernible, and a small loss of natural habitats and biota may have taken place.	1-1.9	B
Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place, but the natural habitat remains predominantly intact	2-3.9	C
Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred.	4-5.9	D
The change in ecosystem processes and loss of natural habitat and biota is great, but some remaining natural habitat features are still recognisable.	6-7.9	E
Modifications have reached a critical level, and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8 - 10	F

Combined PES scores will be obtained by combining the three module scores using the following formula (Macfarlane *et al.,* 2008) as follows:

$$\mathbf{PES} = \frac{\mathbf{(Hydrology\ score \times 3) + (Geomorphology\ score \times 2) + (Vegetation\ score \times 2)}}{\mathbf{7}}$$

Hydrology refers to the movement of both surface and sub-surface water into, through and out of a wetland. Hydrology is the characterising highlight of wetlands and therefore, forms a vital segment of the appraisal of wetland health. The hydrological conditions in a wetland influence numerous significant processes, including the advancement of anaerobic conditions for the soil (waterlogging), accessibility of nutrients, different solutes and sediment fluxes. These variables unequivocally impact which fauna and flora will occupy a wetland, and this has an input impact on hydrological conditions (Mitsch and Gosselink, 1997). The outcomes of altering the hydrological conditions in a wetland may be enormous to wetland structure and the biophysical processes taking place in a wetland and thus this component is weighted more than other components of the integrity assessment. The results will be compared to the baseline PES assessed before rehabilitation as per information indicated on the existing rehabilitation plans and from the results of the Level 1A assessment tool where required. The results of the overall PES will provide a combined impact score, which will determine the PES Category of the wetland system (Table 5). The assessment will be used to determine if there has been any improvement or deterioration due to the rehabilitation activities on the wetlands by comparing before and after rehabilitation PES scores.

3.3.4.1.3 Wetland functional hectare equivalents

A hectare equivalent (ha-eq) is a quantitative articulation of the ecological integrity of a wetland hydro-geomorphic (HGM) unit under a given land-use. It represents the common currency that empowers the functional wetland area restored to the landscape by restoration, rehabilitation and artificial creation to be compared to that removed from the landscape by a development or any other activities (SANBI and DWS, 2016)**.** Most authorities advocate a no net loss of resources approach, be it to biodiversity or wetland functioning, and the hectare equivalents give the reasonable methods for deciding whether these recovery objectives have been fulfilled. For the purpose of this project, the calculation of the potential wetland hectare equivalent gains as a result of the rehabilitation activities on site will be determined.

'Hectare equivalent' is a measure of functional wetland area obtained through a conversion of the wetland health (PES) rating and the wetland aerial extent (hectares)' (Macfarlane *et al.,*

2008; Cowden and Kotze, 2008). The following bullets indicate how wetland functional hectare equivalent is calculated:

- Change from natural state (Impact score) = 10 – PES Score, where 10 represents intact natural state and PES score is the calculated state of the wetland under current conditions
- % PES score = (Change from natural state/10)*100
- Hectare equivalent = % PES score X wetland Area

As an example, a 15 ha wetland with a PES score of 4.95 (category D – moderately modified) would be equal to:

- Change from natural state (Impact score) = (10 – 4.95) = 5.05
- % PES score = (5.05/10) * 100 = 50.5%
- Hectare equivalent = 50.5% X 15 ha = 7.6 ha-eq

The functional area of the 15 hectares of wetland extent with a PES category D (largely modified) is 7.6 ha-eq, this means this wetland is only expected to be performing at 76% of the function that the wetland would be performing under pristine conditions. This will be done by converting the PES impact scores into health scores for both before and after rehabilitation. The difference between pre-rehabilitation functional hectare equivalent and the post-rehabilitation hectare equivalent will indicate the hectare equivalent gains by any interventions that took place in a wetland on site.

3.3.4.2 Hydrological data analysis

Streamflow data was analysed to produce different flow duration curves (FDC) and a discharge time series of hydrographs. The results focused on before and after rehabilitation data analysis. Statistical analyses were used to quantify streamflow and base flows and their responses to the rehabilitation and consequent change in wetland condition. The distribution of flows from high flows to low flows was calculated. This was done by calculating the probability of exceedance of certain ranked flow events. The following exceedance probability equation called Weibull's formula (frequency of occurrence) was used for the before and after rehabilitation streamflow events:

F = 100* R/(N+1) ………………..(Kannan and Jeong, 2011)

Where,

- F is the frequency of occurrence (expressed as % of the time a particular flow value is equalled or exceeded)
- R is Rank of observed records
- N is Number of observations

The exceedance probability was plotted against mean flows to create flow duration curves. The FDC graphs provided a display in graph format of the distribution of flow within the wetland. This exercise was done for before and after rehabilitation activities; the record of the event between before and after rehabilitation was kept the same to present similar length of streamflow records in both situations. It is expected that with the improvement or otherwise of the streamflow regulation functions the changes must be seen on the distribution of high flows versus low flows with a hypothesis that a wetland attenuates high flows and improves base flows.

3.3.4.3 Statistical analysis

A T-test analysis before and after rehabilitation, was undertaken on the FDC data. FDC provides for paired, two samples of exceedance against pre- and post-rehabilitation flows. Where T test was found to be unsuitable U test was conducted to further analyse the datasets. The analysis was done using Microsoft Excel and other available free statistical programs; the idea was be to compare two means and variances to see how significant the differences are.

The smaller score of the U and T-test indicates that there is more similarity between the sampled groups and vice versa. Other attributes such as p-value were considered; a p-value is a probability that the results from your sample data occurred by chance. A threshold of a p-value of 5% (0.05) was used to discuss analysis results. Significance Levels: ns – non-significant, $**p < 0.05$, $***p < 0.01$. This analysis hypothesised that rehabilitation activities have a significant effect on the before and after rehabilitation flows. A coefficient of variance (Cv) between before and after rehabilitation flows were calculated using standard deviation divided by the mean of the flow record data as a percentage (x100) for both before and after rehabilitation flow records. As it is expected that base flows increase and high flows become attenuated as a result of rehabilitation activities, Cv value was expected to respond if the hypothesis is true and that is, it is likely to decrease and that indicated a more stable flows exiting the systems.

To evaluate the effects of different rainfall periods (dry and wet), rainfall data of nearby rain gauges was analysed for dry and wet periods. The evaluation was done by plotting rainfall time series data and identifying the distribution of wet and dry periods. The idea is to ensure that there are enough wet and dry periods within the rainfall period to conclude that the streamflow consists of a representative record that accounts for different rainfall periods.

In addition, accumulative plotting of rainfall before and after rehabilitation was analysed. Any significant anthropogenic catchment disturbances can alter the relationship between rainfall and runoff. Analysis of the plotting included clear identification of different trends in streamflow data by studying slope gradients of cumulative flow vs cumulative precipitation, any changes on the slope gradients before and after rehabilitation marked a change in streamflow. Should rainfall plotting show no change in the gradient before and after rehabilitation, then the changes in the FDC were the result of the activities that have taken place in the catchment in this case rehabilitation activities independent of rainfall patterns and periods.

3.3.4.4 Cost-effectiveness of rehabilitation activities

The wetland functional gains (represented as hectare equivalent gains) calculated from the differences between before and after rehabilitation activities on wetlands, as per the above sections, were utilised to determine the cost-effectiveness of the proposed rehabilitation activities. The common currency (hectare equivalents) was utilised to ensure that evaluation of the returns on investment compares the cost and benefit in the same currencies. The question in this regard is *"Did interventions in the project work to produce the desired outcome and were they cost-effective."* In order to assess the entire rehabilitation process, the information was recorded; this information considered improvements in wetland integrity and the cost of interventions implemented to achieve the gains in the functioning wetland area. The following Table 6 indicates categories of defining cost-effectiveness of the rehabilitation projects (Cowden and Kotze, 2008).

Table 6: Cost of rehabilitation interventions per hectare equivalent gained and likely cost-effectiveness.

Costs of rehabilitation interventions per functional hectare of reinstated/ secured intact wetland	Likely cost-effectiveness
<R50 000 per ha-eq	High
R50 000 - R150 000 per ha-eq	Intermediate to high.
R150 001 - R300 000 per ha-eq	Moderate: Can be justified if return in terms of ecosystem system delivery is moderate to high.
R300 001 – R500 000 per ha-eq	Low to intermediate: Can be justified if the benefit is high. Therefore, benefits would need to be well-justified.
>R500 000 per ha-eq	Low: Such a project would need to be extremely well-motivated such that it could only be justified if benefits are exceptionally high.

4. CHAPTER 4: RESULTS

4.1 Ecological data analysis – Present Ecological State (PES)

Present Ecological State (PES) assessments were undertaken for both before and after rehabilitation scenarios. The purpose of this was to evaluate and quantify any changes or improvement in wetland conditions as a result of rehabilitation interventions.

Existing ecological information was used where possible and supplemented by assessments where data was not available for baseline ecological integrity assessment. The post-rehabilitation scenarios were assessed using WET-Health assessment tools under current conditions on-site. The categories used to define wetland health are discussed in Section 3, Table 5.

4.1.1 PES for Kgaswane wetland system - Before rehabilitation

The first rehabilitation work was completed in the 2005/6 financial year following wetland rehabilitation planning that was done within the 2003/4 financial year. Additional rehabilitation work was completed in 2007/2008 and 2016/2017 financial years, respectively, from the rehabilitation plans that were done in 2006 and 2015. The pre-rehabilitation ecological conditions, therefore, considered the state of the wetland before 2004. Additional work completed after that was regarded as being part of the overall post-rehabilitation ecological integrity assessment, which was undertaken as part of this project. A Level 1A wetland assessment tool was used to determine the ecological conditions of the wetlands before rehabilitation.

4.1.2 Unchannelled Valley Bottom Wetland (UCVB1)

Natural grasslands and open waters dominate the wetland area. There were minor impacts within the wetland that include erosion and road crossings at various points. The wetland itself was generally in good condition; the impacts recorded only accounted for approximately 3%

of the wetland area. It is, however, essential to note that the extent of impacts increased as you moved outside of the wetland to the buffer and then the broader wetland catchment. This was due to the construction of various infrastructures, such as roads and houses outside the wetland but within its catchment. There were also additional activities recorded within the buffer zone and the catchment, including mining (quarry) and excavations. The change in land-use within the wetland and its catchment affected the overall ecological state of the wetland. These changes affected hydrology, geomorphology and vegetation components of the wetlands with regard to flow impediments, infilling, excavation and hardening of surfaces, which generally affected the flow and sediment deposition and resulted in erosion and channelling. Observations on site indicate that removal of vegetation where infrastructure was erected and where excavation and infilling took place affected vegetation composition and promoted bush and alien vegetation encroachment in grasslands areas. The distribution of various land-use types within the Kgaswane UCVB1 wetland, 200 m buffer of the wetland, and the broader wetland's catchment are illustrated in Tables 7, 8 and 9, respectively. Appendix 2 provides maps that indicate the extent and coverage of different land-uses assessed as part of this assessment. Improvement to ecological integrity needs to focus on responses as a result of changes in land-uses, these include erosion, sedimentation, bush encroachment, alien vegetation invasion and possibly complemented by on-going implementation of various ecological management plans within the Reserve.

Table 7: Coverage of land-uses within the Kgaswane UCVB1 wetland based on Land-Cover datasets before rehabilitation work.

Land-use	Classification	Coverage (ha)	Coverage (%)
Grasslands	Natural	48.47	42.56
Thicket/ dense bush	Natural	12.51	10.99
Wetland	Natural	47.81	41.98
Woodland open bush	Natural	1.87	1.64
Erosion	Eroded areas	1.85	1.63
Roads	Infilling/ informal urban	1.36	1.19
	TOTAL	**113.87**	**100.00**

Table 8: Land-use coverage of the Kgaswane UCVB1 wetland based on Land-Cover datasets within the 200 m buffer area before rehabilitation work.

Land use	Classification	Coverage (ha)	Coverage (%)
Erosion	Eroded areas	1.46	0.71
Grasslands	Natural	97.64	47.30
Roads	Urban informal	6.77	3.28
Thicket/ dense bush	Natural	10.55	5.11
Woodlands/ open bush	Semi-natural	74.51	36.10
Houses	Urban	1.19	0.58
Low shrublands	Semi-natural	14.29	6.92
	TOTAL	**206.41**	**100.00**

Table 9: Land-use coverage of the Kgaswane UCVB1 wetland catchment area based on Land-Cover datasets before rehabilitation work.

Land use	Classification	Coverage (ha)	Coverage (%)
Grasslands	Natural	487.98	29.38
Grasslands	Semi-natural	157.40	9.48
Low shrublands	Natural	530.20	31.92
Thicket/dense bush	Natural	75.55	4.55
Woodland/ open bush	Semi-natural	322.77	19.43
Bare ground/ excavation	Eroded areas	23.66	1.42
Erosion	Eroded areas	14.17	0.85
Houses	Urban	2.17	0.13
Roads	Urban informal	46.77	2.82
Mining	Low-risk mining	0.26	0.02
	TOTAL	**1660.92**	**100.00**

4.1.3 Channelled Valley Bottom Wetland 1 (CVB1)

Kgaswane CVB1 is dominated by natural grasslands, while natural grasslands dominate the wetland, a sizeable portion of it is impacted upon by erosion, excavation and road construction. These impacts cover approximately 25% of the wetland area. The extent of impacts within the wetland is higher compared to activities and impacts within the buffer and its catchment, with an impact coverage combined at approximately 6%. The change in land-use within the wetland and its catchments affected the overall ecological state of the wetland. The drivers of change relate to erosion, excavation, construction of linear infrastructure within the wetland and its catchment area. The distribution of various land-use types within the Kgaswane CVB1 wetland, 200 m buffer of the wetland, and the broader wetland's catchment are illustrated in Tables 10, 11 and 12, respectively. Appendix 2 provides maps indicating the extent and coverage of different land-uses assessed as part of this assessment. The focus of rehabilitation will be to improve the ecological conditions of the wetland by addressing the number of impacts recorded in the wetland.

Table 10: Land-use coverage of the Kgaswane CVB1 wetland based on Land-Cover datasets before rehabilitation work.

Land-Cover	Classification	Coverage (ha)	Coverage (%)
Grasslands	Natural	16.31	65.91
Thicket/ dense bush	Natural	0.48	1.96
Low shrublands	Natural	0.02	0.06
Wetlands	Natural	0.09	0.38
Woodlands/ open bush	Natural	1.72	6.94
Erosion	Eroded areas	5.07	20.50
Bare ground/ excavation	Eroded areas	0.04	0.18
Roads	Informal Urban (infilling)	1.01	4.08
	TOTAL	**24.75**	**100.00**

Table 11: Land-use coverage of the Kgaswane CVB1 wetland based on Land-Cover datasets within the 200 m buffer area before rehabilitation work.

Land use	Classification	Coverage (ha)	Coverage (%)
Erosion	Eroded areas	1.89	1.24
Excavation	Eroded areas	3.59	2.37
Grasslands	Natural	73.39	48.46
Low shrublands	Natural	16.92	11.17
Mines	Low risk mining	0.26	0.17
Roads	Urban informal	4.15	2.74
Thicket/ dense bush	Natural	3.00	1.98
Wetlands	Natural	0.08	0.05
Woodland/ open bush	Natural	48.16	31.80
	TOTAL	**151.43**	**100.00**

Table 12: Land-use coverage of the Kgaswane CVB1 wetland based on Land-Cover datasets within the wetland catchment area before rehabilitation work.

Land use	Classification	Coverage (Ha)	Coverage (%)
Grasslands	Natural	218.02	40.51
Low shrublands	Natural	144.75	26.89
Thicket/ dense bush	Natural	14.69	2.73
Wetlands	Natural	0.08	0.01
Woodland/ open bush	Natural	129.87	24.13
Bare ground/ excavation	Eroded areas	17.13	3.18
Erosion	Eroded areas	6.97	1.29
Roads	Informal urban (infilling)	6.45	1.20
Mining	Low-risk mining	0.26	0.05
TOTAL		**538.20**	**100.00%**

4.1.4 Channelled Valley Bottom Wetland 2 (CVB2)

Kgaswane CVB2 wetland was dominated by natural grasslands and the wetland had experienced several impacts ranging from erosion and erected infrastructure within the wetland, including road traversing wetland in different areas. These activities impacted on 27% of the wetland area resulting in a wetland that was moderately modified. Similar to Kgaswane CVB1, the extent of impacts within the wetland were higher than the impacts within the buffer and its catchment. The drivers of change relate to erosion, excavation, and construction of infrastructure within the wetland and its catchment area. The distribution of various land-use types within the Kgaswane CVB2 wetland, 200 m buffer of the wetland, and the broader wetland's catchment are summarised in Tables 13, 14 and 15, respectively. Appendix 2 provides maps indicating the extent and coverage of different land-uses assessed as part of this assessment and as summarised in the Tables mentioned above. The change in land-use within the wetland and its catchments affected the overall ecological state of the wetland, and the focus of rehabilitation is to improve the ecological state of the wetland by targeting the listed impacts on the wetland as indicated.

Table 13: Land-use coverage of the Kgaswane CVB2 wetland based on Land-Cover datasets before rehabilitation work.

Land use	Classification	Coverage (ha)	Coverage (%)
Grasslands	Natural	3.33	72.38
Woodlands/Open bush	Natural	0.01	0.20
Erosion	Eroded areas	1.23	26.65
Roads	Informal urban (infilling)	0.04	0.76
	TOTAL	**4.60**	**100.00**

Table 14: Land-use coverage of the Kgaswane CVB2 wetland based on Land-Cover datasets within the 200 m buffer area before rehabilitation work.

Land use	Classification	Coverage (ha)	Coverage (%)
Erosion	Eroded areas	0.20	0.52
Grasslands	Natural	24.12	62.68
Low shrublands	Natural	1.74	4.52
Roads	Urban Informal	0.85	2.21
Thicket/ dense bush	Natural	0.53	1.39
Woodland/ open bush	Natural	11.03	28.68
	TOTAL	**38.48**	**100.00**

Table 15: Land-use coverage of the Kgaswane CVB2 wetland based on Land-Cover datasets within the wetland catchment area before rehabilitation work.

Land use	Classification	Coverage (ha)	Coverage (%)
Grasslands	Natural	53.16	38.52
Low shrublands	Natural	37.07	26.86
Thicket/ dense bush	Natural	1.08	0.78
Woodlands open bush	Natural	39.41	28.56
Erosion	Eroded areas	1.43	1.03
Roads	Informal urban (infilling)	5.85	4.24
	TOTAL	**138.00**	**100.00**

This is based on the area-weighted impacts and associated intensities as provided by the LEVEL 1A assessment tool, using tabulated input land-use datasets as indicated in the above Tables (also refer to Appendix 1 for LEVEL 1A impact assessment Tables). An assessment of the impacts on the Kgaswane wetland system (UCVB1, CVB1 and CVB2) before rehabilitation activities took place indicated that:

1. UCVB1 wetland system was generally in good condition with recorded impacts only accounting for approximately 3% of the wetland area. These impacts, however, increased within the buffer and the catchment of the wetland.
2. CVB1 and CVB2 both experienced several impacts ranging from erosion and erected infrastructure within the wetlands, including one or more roads traversing the wetlands in different areas. These activities impacted on 25% to 27% of the wetland areas in Kgaswane CVB1 and CVB2, respectively, resulting in wetlands that were not pristine but moderately modified.

The changes in land-use within the wetlands and their catchments affected the overall ecological state of the wetlands. These changes affected hydrology, geomorphology and vegetation components of the wetlands with regard to flow impediments, infilling, excavation and hardening of the surfaces, which generally affected the flow and sediment deposition, and led to erosion and channelling. Removal of vegetation where infrastructure was erected and where excavation and infilling took place affected vegetation composition and promoted bush and alien vegetation encroachment in grassland areas. Table 16 below provides summaries of the results of the area-weighted impacts on the wetlands, buffers and catchment areas.

Table 16: Summary of results of the assessment of the land-use impacts before rehabilitation activities using a level 1A assessment tool for the Kgaswane wetland system.

Wetland ID	Wetland Type	Wetland areas (Ha)	Impact Scores		
			Hydrology	Geomorphology	Vegetation
UCVB1	Unchannelled Valley Bottom	114.00	1.13	0.85	1.23
CVB1	Channelled Valley Bottom	25.00	2.02	2.17	2.98
CVB2	Channelled Valley Bottom	5.00	2.14	2.33	3.20

The Present Ecological State (PES) of the wetland systems were calculated from the impact scores, as indicated in Table 16, and the results of the overall PES scores and categories are indicated in Table 17.

The baseline ecological condition of the wetlands within the Kgaswane Nature Reserve indicates that Kgaswane UCVB1 wetland was largely natural with a PES category of B. This wetland system consisted of an extensive reed bed and was generally in good condition with only 6% of the anthropogenic activities directly impacting the wetland. The baseline ecological conditions of the CVB1 and CVB2 wetland systems indicated that these systems were moderately modified with PES categories of C for both. The direct impacts on the CVB1 and CVB2 wetlands had coverage of approximately 25% to 27%, respectively, with a gradual reduction in the extent of impacts within the buffers and respective catchments.

Figure 4 indicates PES categories of various wetland systems assessed as part of this project.

The objective of rehabilitation in this instance was to improve the ecological state of the wetland systems on-site. Amongst these three wetland systems, it was expected that there would be limited, if any, improvement of the ecological state of the Kgaswane UCVB1 wetland system as the wetland is already in a good state; however, rehabilitation should focus on the maintenance of the existing ecological state and provision of additional management measures. Kgaswane CVB1 and CVB2 were expected to show some improvements given the level of impact on these systems, and rehabilitation activities were meant to address morphological issues identified within the wetland, including erosion and excavations amongst others. The post-rehabilitation ecological integrity assessments to be undertaken as part of this project were aimed at providing evidence of whether rehabilitation activities in these systems had improved the integrity of the wetland systems.

Table 17: Combined PES results of the assessments of the land-use impacts before rehabilitation activities using a level 1A assessment tool for the Kgaswane wetland system.

Wetland ID	Wetland type	Wetland areas (Ha)	Overall PES	PES category	Hectare Equivalents (Ha-Eq)
UCVB1	Unchannelled Valley Bottom	114.00	1.08	B	101.72
CVB1	Channelled Valley Bottom	25.00	2.33	C	19.16
CVB2	Channelled Valley Bottom	5.00	2.50	C	3.75
					124.64

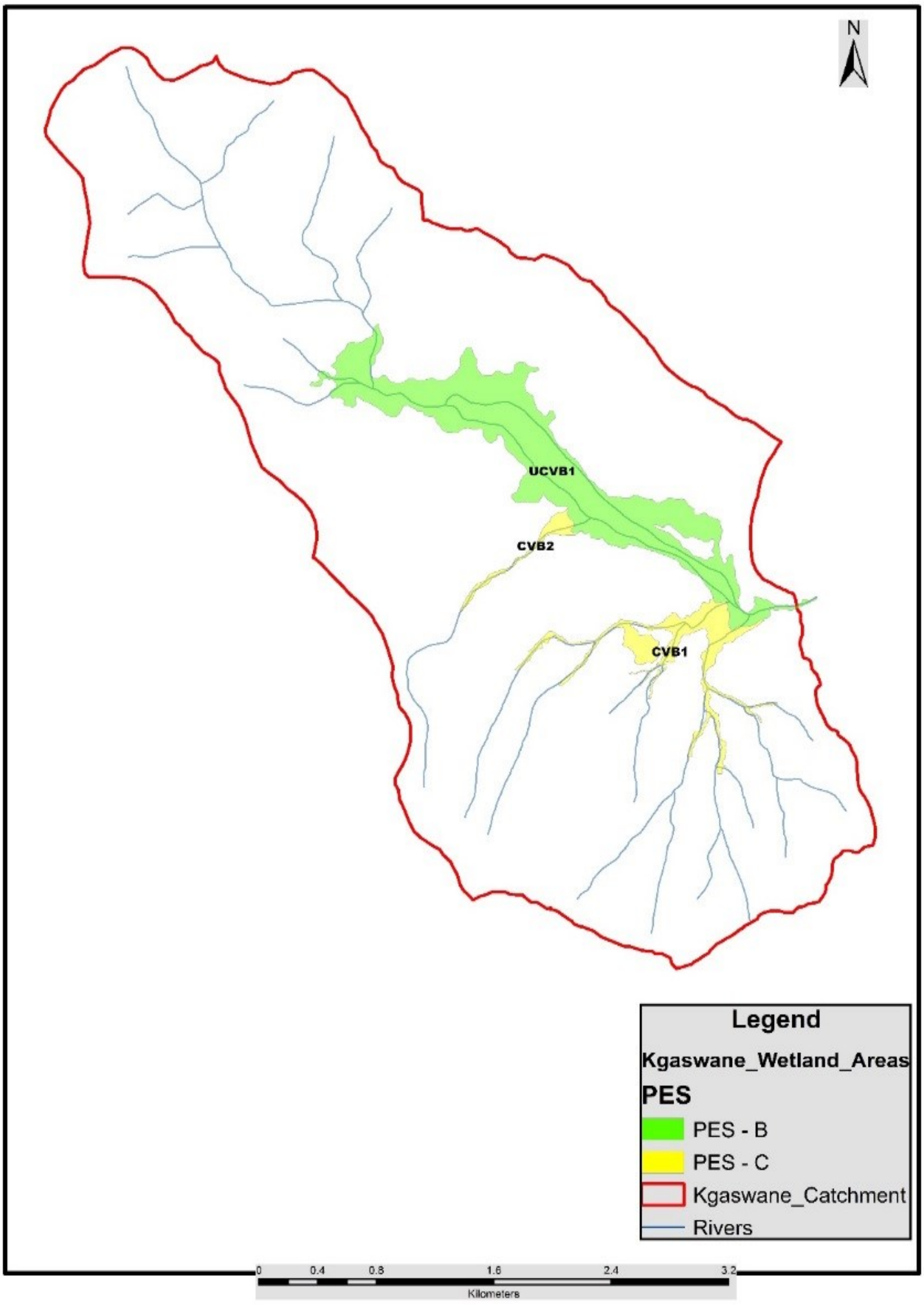


Figure 4: PES assessment of Kgaswane wetland system before wetland rehabilitation works.

4.1.5 PES for Rietfontein wetland system - Before rehabilitation

The Rietfontein wetland system was divided into two sections, namely A21K-01 (downstream portion) and A21K-02 (upstream portion) wetland systems. The downstream portion (A21K-01) was the focus of the 2009 and 2011 assessments, and the upstream portion (A21K-02) the focus of the 2014/2015 assessment; this means that the entire wetland was assessed during the period 2009-2015, before rehabilitation efforts. Table 18 provides the average PES assessment results for the 2009 and 2011 ecological integrity assessments representing baseline information before rehabilitation work on wetlands on site.

Table 18: Pre-rehabilitation average PES scores for the Rietfontein wetland system based on 2009 and 2011 assessments.

Wetland ID	Wetland type	Wetland area (Ha)	Impact Scores		
			Hydrology	Geomorphology	Vegetation
CVB	Channelled Valley Bottom	134.00	4.00	3.85	7.05

Wetland ID	Wetland type	Wetland area (Ha)	Overall PES	PES Category	Hectare Equivalents (Ha-Eq)
CVB	Channelled Valley Bottom	134.00	4.83	D	69.30

The wetland system is classified as Channelled Valley Bottom wetland system which drains the entire upper reaches of the quaternary catchment A21K. The extent of the area of investigation includes the channelled valley up to the streamflow gauge weir upstream of the Buffelspoort Dam. Figure 5 indicates the location of the Rietfontein wetland system (A21K-01 and A21K-02) in relation to its catchment area and the streamflow gauge weir.

The following problems were identified and inform the PES of the wetland:

- Channel incision and desiccation of wetland habitat, which was worsened by road construction and pipe-laying within portions of the wetland.
- Active headcut erosion, which includes small in-channel headcuts to large in-channel and proximal headcuts.
- Cultivation and water abstraction (water pumps and weirs) within the wetland area.
- Wetland area infested by alien vegetation and reed bed succession, which have resulted in channel incision and switching around the reed beds.

Overall, the wetland area was exposed to sediment loss, channel incision and extensive alien vegetation invasion resulting in the uneven distribution of water across the wetland (areas previously permanently wet are now only periodically wet). These impacts have changed the morphology and structural diversity of the wetland area, resulting in a largely modified wetland system on site in terms of Present Ecological Status. The wetland on site has been largely modified with a PES category of D, which represents a system that has had a significant change in ecosystem processes and loss of natural habitat and biota.

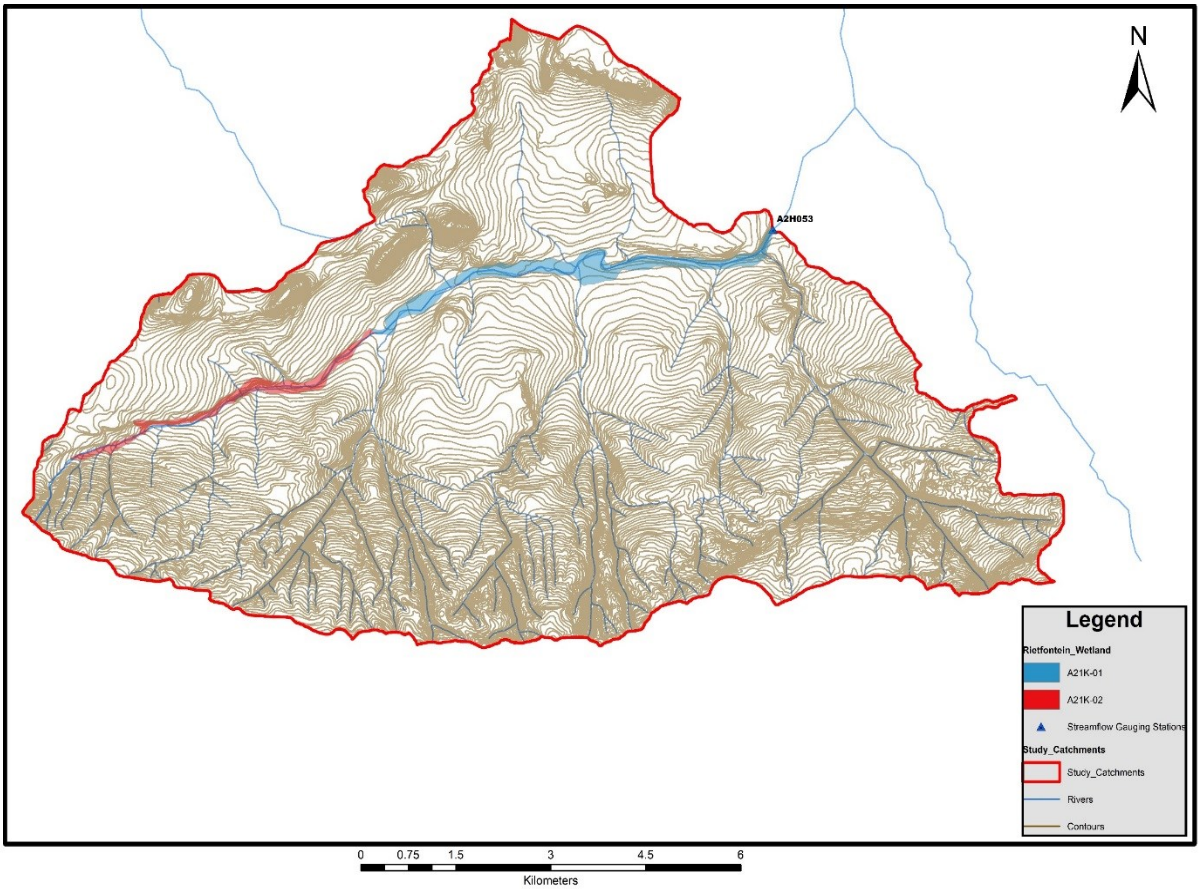


Figure 5: Extent of the two Rietfontein wetland portions (A21K-01 and A21K-02) in relation to the catchment area.

4.1.6 Kgaswane Wetland – Post-rehabilitation assessment

An assessment of the Kgaswane wetland site indicated that attempts to restore the function of the wetland had been successfully implemented on site. Various wetland rehabilitation interventions at specific areas were implemented, which include erosion control and stabilisation weirs, sediment nets for trapping sediments, and upgrades or road crossings through wetland areas. Below are some of the rehabilitation interventions recorded on site (Figures 6, 7 and 8).

Persistent impacts were assessed on site as part of the evaluation of the post-rehabilitation integrity assessment of the wetland systems. The recorded impacts under current conditions of the wetland are further discussed in the sections below and are structured as per their impact on the hydrology, geomorphology and vegetation components of the wetland system. There were three wetland HGM systems assessed within the Kgaswane Nature Reserve before rehabilitation activities:

- Unchannelled Valley Bottom Wetland (UCVB1)
- Channelled Valley Bottom Wetland (CVB1)
- Channelled Valley Bottom Wetland (CVB2)

The post-rehabilitation ecological integrity assessment, however, only focused on two systems (UCVB1 and CVB1). No rehabilitation activities were implemented on CVB2 and therefore, no post-rehabilitation assessment was done for this wetland system.

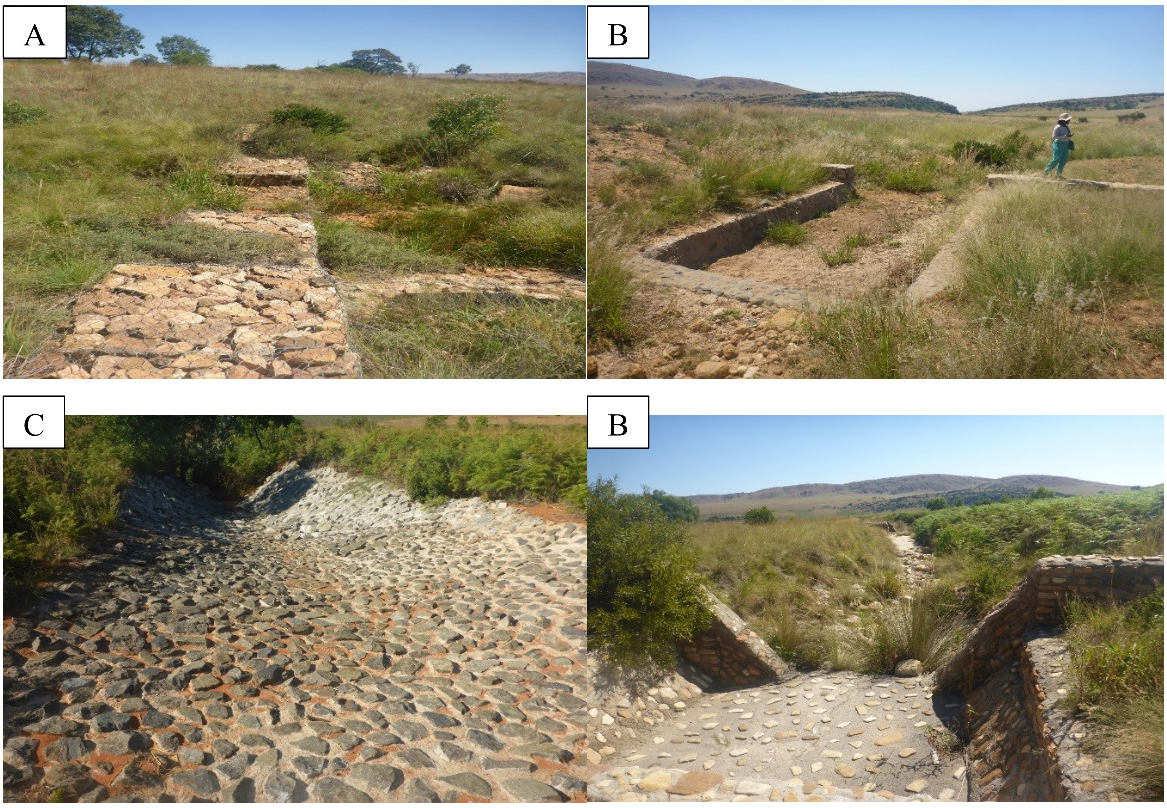


Figure 6: Erosion control and stabilisation weirs within the Kgaswane Nature Reserve (A – Gabion Weir, B - Rock masonry weirs and C- Chutes) – All these interventions are within CVB1.

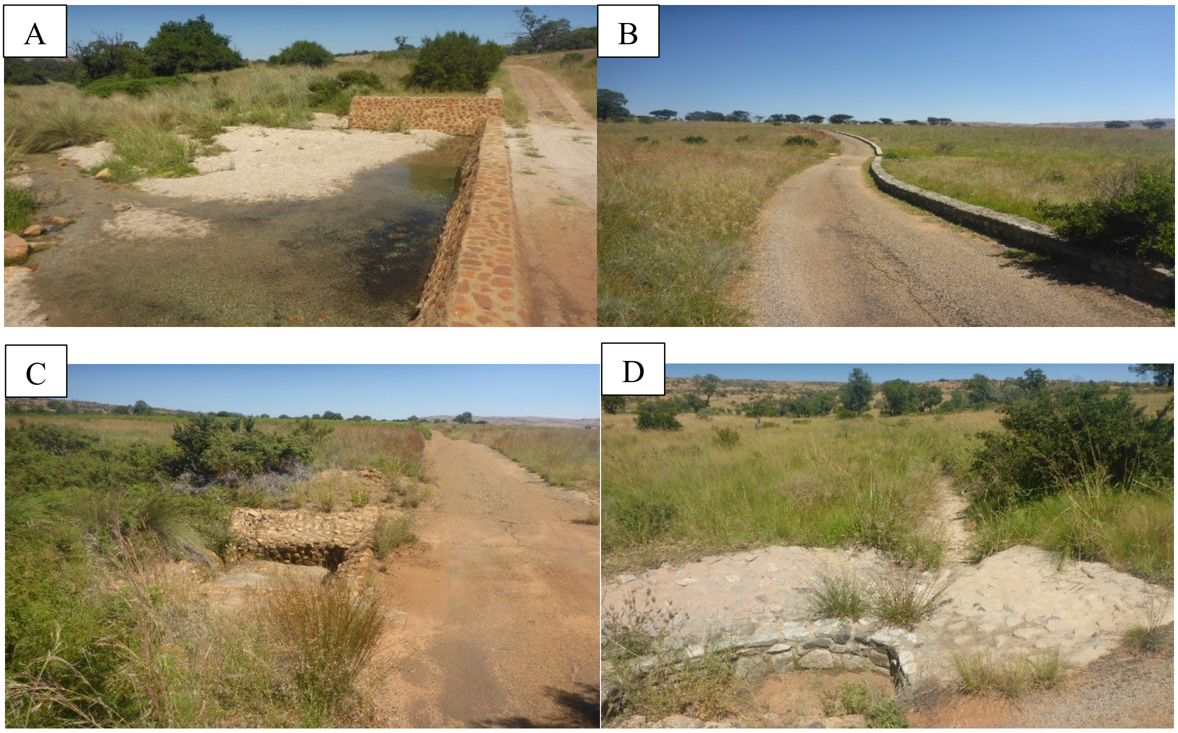


Figure 7: Road crossing interventions and supporting downstream discharge erosion control structures. (A and C pictures were taken in UCVB1) and (B and D within CVB1) within the Kgaswane Nature Reserve.

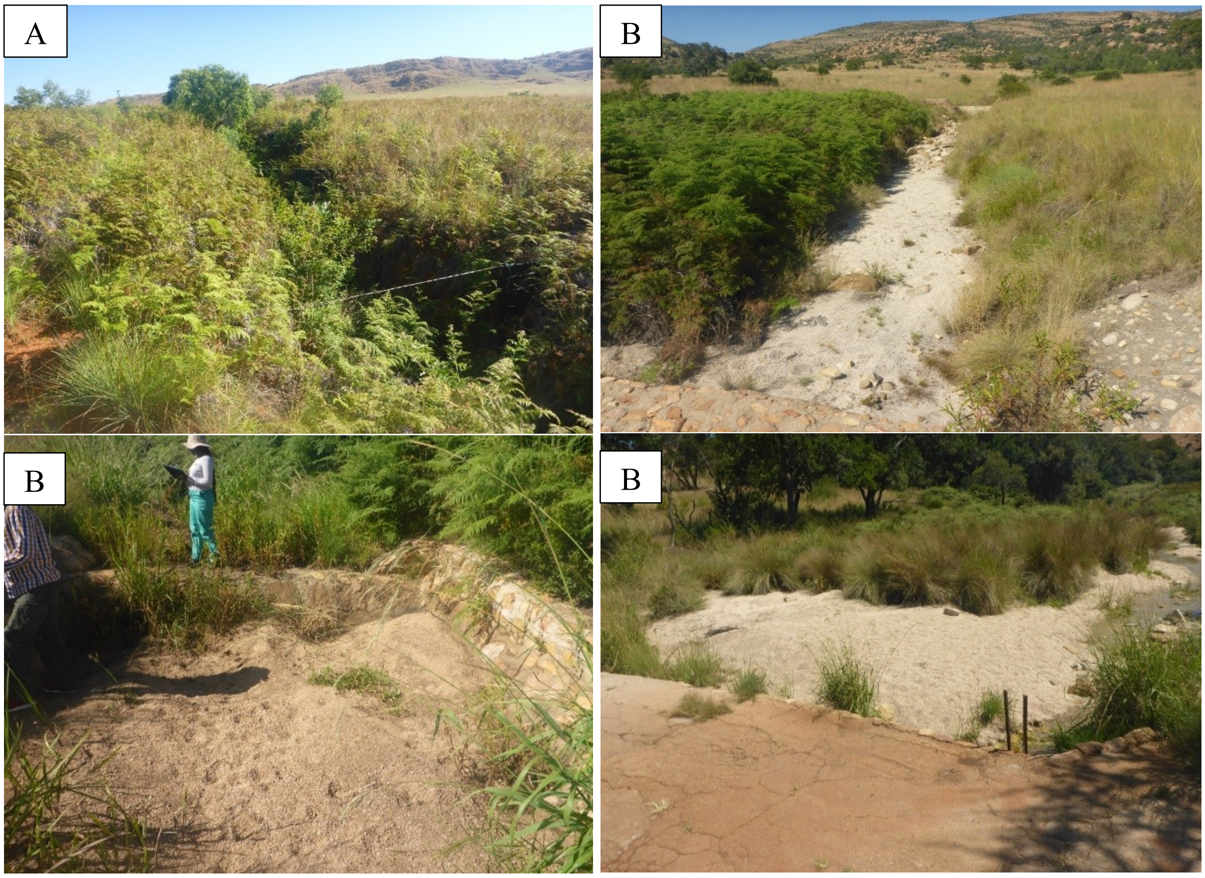


Figure 8: Channel incision and sediment fences (A) within side slopes of UCVB1, exposed sediment bars upstream and downstream of the flow impeding structures (B) within CVB1 within the Kgaswane Nature Reserve.

4.1.7 Assessment of impacts

The magnitude of the impact = Extent (%) x Intensity (Refer to Appendix 3)

- Extent was a physical mapping of the impacts on site based on high-resolution aerial imagery. These impacts were summed up to a total impact and to get proportional percentage extent of each impact, an aerial impact cover that was mapped was divided by total hectare cover of impacts and multiplied by 100.
- Intensity was a scale of range 0 – 10; default scores were provided using the WET-Health tool for individual disturbance classes on wetlands. These scores were based on extensive field investigation and local knowledge.

- The magnitude of impact score = percentage extent of Landcover x intensity
- The overall magnitude of impacts score for the HGM unit was the sum of magnitude scores for disturbance or impact classes within the wetland.

Wetlands are an expression of water moving through the landscape and occur in the landscape where water is slowed down and appears close enough to, or on the surface of, the land for a sufficiently long period to enable wetland conditions to develop. Activities that alter the movement or quality of water moving through the landscape will thus undoubtedly have a significant influence on the wetlands. The main impacts identified within wetlands on site are described below and indicated in Table 8. The extent of these impacts was area-weighted against the extent of the wetland system, as discussed in the assessment of impacts above. The impacts were separated in terms of impacting wetland health components (hydrology, geomorphology and vegetation).

4.1.7.1 Unchannelled valley bottom wetland (UCVB1)

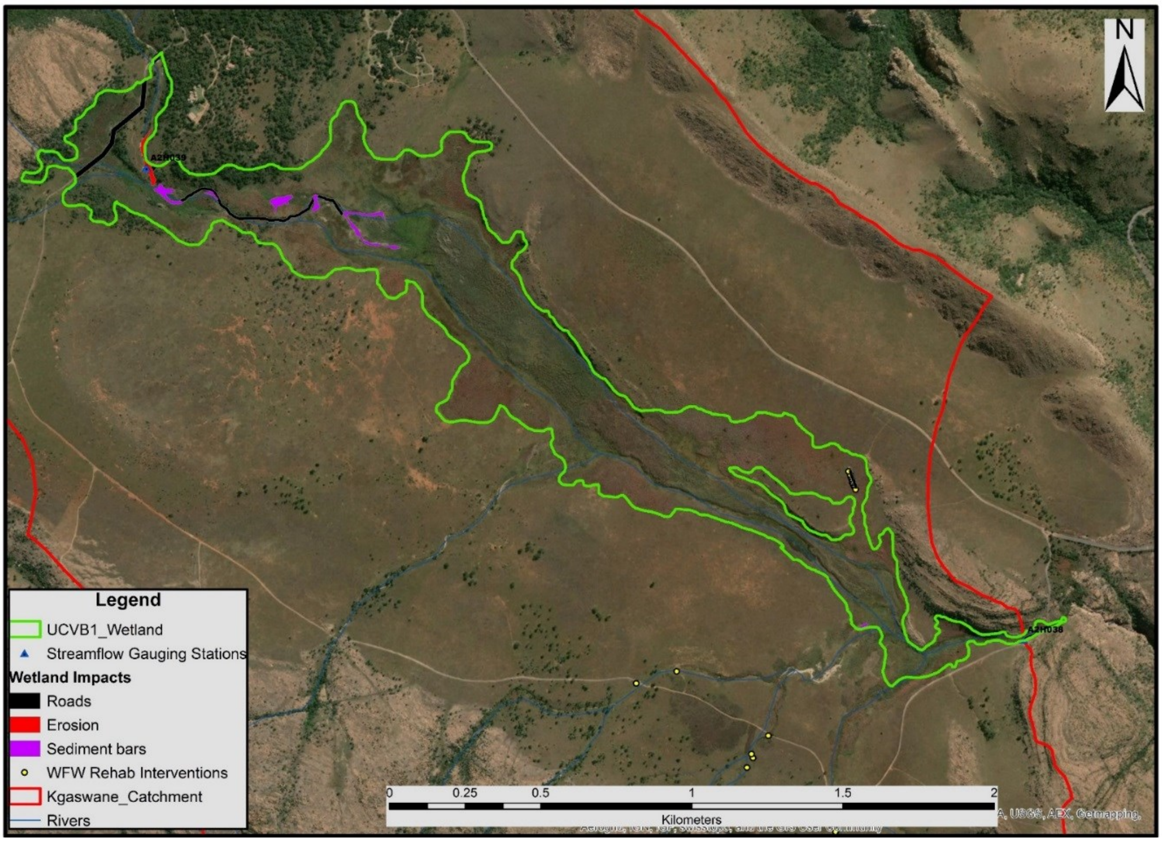


Figure 9: Extent of erosion and sediment bars within the UCVB1 wetland system, Kgaswane Nature Reserve.

<u>**Hydrological impact assessment**</u>

Kgaswane UCVB1 wetland had limited water abstraction for domestic use upstream of stream gauge A2H039. Stormwater inputs to the wetland were expected to increase slightly as a result of the road crossing and associated stormwater discharge into the wetland. Slight flood attenuation was anticipated within the wetland with attenuation capacity provided by reed beds in the central valley bottom system. Overall, there were minor changes to water input characteristics into the wetland from the catchment. Although rehabilitation activities have taken place in the wetland, there were still signs of incision and channelling in a specific part of the wetland system, particularly below gauge A2H039 and in areas where silt fences had been erected. The majority of the wetland system was well covered by vegetation except for areas immediately upstream and downstream of structures where sediments were exposed and had limited vegetation cover, the same include areas where sedimentation and sediment bars were recorded. Around the streamflow gauge A2H039, extensive areas of erosion and bare soil were recorded. There were no dams present in the wetland system; however, the presence of instream streamflow gauges creates flow impediments at the associated weirs. The road crossing also restricts upstream flow as the water passes through culverts. It appeared that water abstraction used to take place at the A2H039 weir; however, this activity appeared to have been discontinued or was only undertaken on an occasional basis. Sediment deposition was identified in various areas, particularly upstream of flow impediment structures such as weirs and roads. However, the intensity of these impacts was considered minimal as the system was considered to be a low energy flowing system and therefore changes to water distribution and retention patterns within the wetland were regarded as being moderate to high. Appendix 3 provides detailed Tables of the weighted hydrological assessment of impacts.

Geomorphological Impact Assessment

There were no dams present in the wetland system; however, instream streamflow gauges could impede flow at the associated weirs. The road crossing could also impede flow by damming flow upstream of the culverts. Part of the wetland was impacted on by a road crossing, sediment deposition and infilling, and houses built in the reserve. These activities did not appear to actively impact on the wetland and their intensities were considered to be relatively low. Stormwater associated with the hard surfaces of the road crossing and houses at various points of the wetland system was only expected to increase flow slightly. Interventions constructed in the wetland on site appeared to have halted erosion to some degree; however, there were a few areas where sediments upstream of interventions had not yet masked the entire incised areas. The intensities of these activities have been significantly reduced as a result of the implemented interventions. Sediment deposition was recorded at various areas where there was some level of flow impediment and where the slope was gentle and velocities of water relatively slow. Appendix 3 provides detailed Tables of the weighted geomorphological assessment of impacts.

Vegetation Impact Assessment

Vegetation removal had taken place particularly in areas where infrastructure had been erected within the wetland site. These activities were related to road construction that traversed the wetland at various points, streamflow gauges within the wetland, and reserve-owned houses that were located within the catchment near the upper reaches of the wetland system. No dams were present on-site, however, roads traversing the wetland, instream structures (weirs) and rehabilitation structures constructed within the wetland did have the potential to cause shallow flooding. There were areas along the margins of the wetlands that consisted of bare soil due to grazing and trampling by game. There were also patches of weeds that could be linked to the grazing on site. Sediment deposition was recorded at various areas where there were some flow impediments and where the slope was gentler and associated water velocities were slow. Part of the wetland was impacted by road crossings, sediment deposition and infilling, and houses that were built for use in the reserve. These activities didn't appear to actively impact on the wetland as their intensities were regarded as relatively low. Interventions constructed on the wetland appear to have halted erosion to some degree; however, there are few areas where sediments upstream of the interventions have not yet silted the entire incised areas. The intensities of these activities have been significantly reduced as a result of the implemented interventions. Appendix 3 provides detailed Tables of weighted vegetation assessment of impacts.

The magnitude of the impacts per each component is summarised in Table 19. The changes to water input characteristics from the catchment activities have been significantly low with only minor stormwater discharges from the reserve roads traversing the wetland. The wetland was well vegetated with reeds and bulrushes, and water distribution and retention patterns were high with very little sign of erosion within the wetland. There were no dams or impoundments in the wetland except for a few areas where road crossings impeded flows. Existing interventions have increased sediment retention in the wetland. There were a few areas where vegetation had been removed or disturbed, which included areas where the current road crosses the wetland and where houses and a weir were erected. The intensities of the activities in the wetland were significantly reduced with the implementation of existing rehabilitation within the wetlands.

Table 19: Summary of the Present Ecological State of the UCVB1 wetland system

Wetland ID	Wetland type	Wetland areas (Ha)	Impact scores		
			Hydrology	Geomorphology	Vegetation
UCVB1	Unchannelled Valley Bottom	114.00	1.00	0.33	0.82

4.1.7.2 Channelled Valley Bottom Wetland 1 (CVB 1)

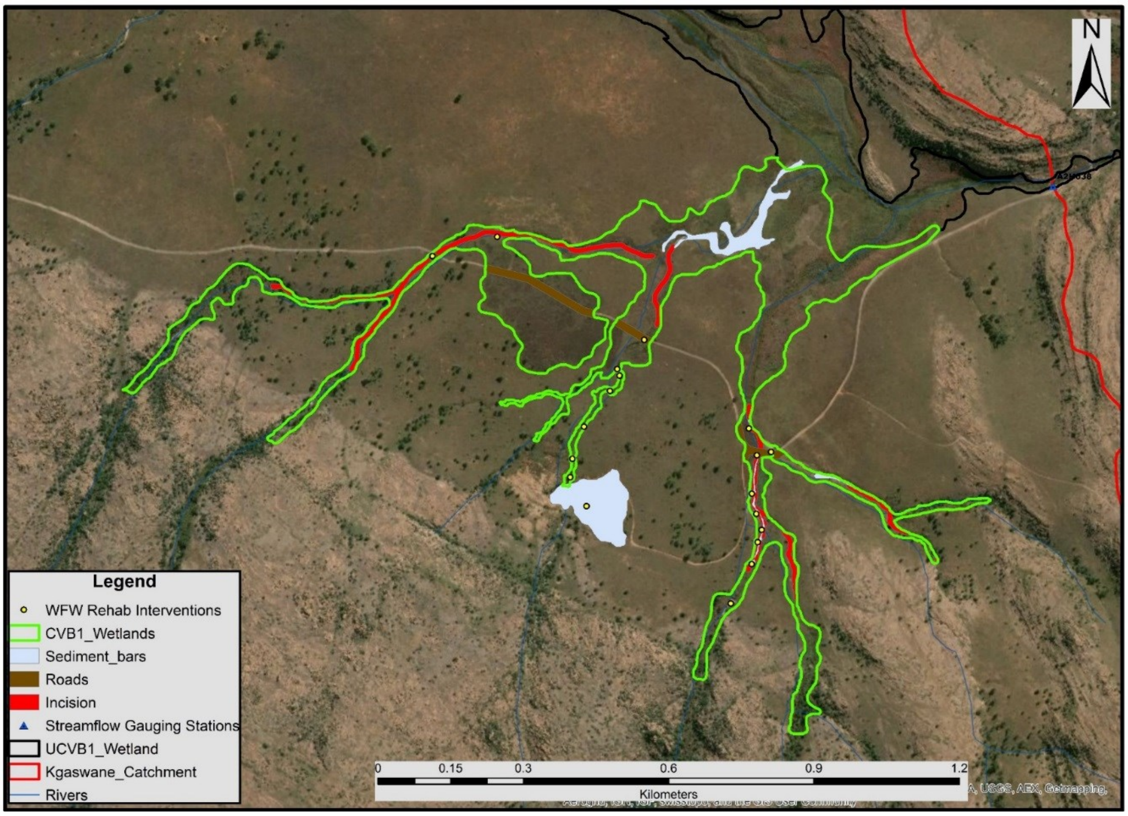


Figure 10: Extent of the CVB1 wetland system including the various impact recorded on the wetland.

Hydrological Impact Assessment

Kgaswane CVB1 wetland has experienced a negligible reduction in streamflow. The upper catchment areas of the wetland consist of indigenous vegetation and trees along the ridges and rocky outcrops. Indigenous vegetation tends not to abstract as much water through evapotranspiration as invasive species. There has been a slight increase in flood peaks, evident in the incised channels and erosion in the receiving wetlands. The landscape morphology consisting of ridges, exposed rocks and steep slopes above the wetland areas are naturally associated with high flows to downslope areas below the ridges. There has been a slight change in vegetation community structure as a result of invasive plant species, changing fire regimes and game overgrazing and concentrations based on vegetation types. McCulloch, 2015 found that within the Kgaswane Nature Reserve, the concentration of elands turns to be confirmed in the uplands (ridges) and slopes in late summer and the valley bottoms during early summer. This movement results in a change in runoff characteristics. The combination of this environment with the instream impacts on the wetland has created a niche for channel incision and erosion exacerbate within the wetland. Although rehabilitation has taken place on the wetlands, there were still signs of incision and channelling in a specific part of the wetland system. Sediments that have accumulated upstream of each intervention have not yet masked the entire incision instream. Most of the system was well covered by vegetation except for the areas upstream and downstream of physical structures, where sediments have become exposed and have limited vegetation cover. Some of the channels consisted of exposed bare soil and sediments with limited vegetation cover. There were no dams present in the systems; however, the presence of rehabilitation instream structures and the road crossing instream do have the potential to impede flow. Sediment deposition has been identified in various areas, particularly upstream of physical structures where the flow has been impeded (weirs and roads). However, the intensity of these activities was considered to be moderate due to the high slope gradients along the ridges and therefore changes to water distribution and retention patterns within the wetland were assumed to be minimal, and runoff moderately high. Appendix 3 provides detailed Tables of weighted hydrological assessment of impacts.

Geomorphological Impact Assessment

There were no dams present within the wetland system; however, the presence of rehabilitation structures in the river channel and the road crossing has the potential to impede flow. Minor infilling exists within the wetland, particularly in areas where the road crossing and existing rehabilitation interventions have been constructed. Similar to the above, the landscape morphology consisting of ridges, exposed rocks and steep slopes above the wetland areas are naturally associated with high flows to downslope areas below the ridges. There has been a slight change in vegetation community structure as a result of invasive plant species, changing fire regimes and game overgrazing and concentrations based on vegetation types. McCulloch, 2015 found that within the Kgaswane Nature Reserve, the concentration of elands turns to be confirmed in the uplands (ridges) and slopes in late summer and the valley bottoms during early summer. This movement results in a change in runoff characteristics. The combination of this environment with the instream impacts on the wetland has created a niche for channel incision and erosion exacerbate within the wetland. The extent of erosion in the receiving wetland was evident on site. Interventions constructed within the wetland on site appeared to have halted erosion to some degree although there were a few areas where sediments upstream of interventions had not yet masked the entire incised area. The intensity of flow and erosion-related impacts (incision and sedimentation) had significantly reduced as a result of the implemented interventions. Sediment deposition was identified in various places, particularly upstream of impeding structures (rehabilitation weirs and roads).

Vegetation Impact Assessment

Vegetation removal has taken place particularly in areas where infrastructure had been erected within the wetland on site, which includes areas where road construction had traversed the wetland at various points. There were no dams present on the wetland site; however, roads that crossed the wetland and rehabilitation structures constructed within the wetland could result in back flooding similar to the dams. There were bare areas of soil along the margins of the wetlands that had been created by grazing and trampling by game. There were also patches of weeds that were most likely the indirect result of grazing on site. Visible areas of sediment deposition were recorded at various areas where some level of flow impediment occurred, where the slope was gentle and water velocities were slower. Part of the wetland was impacted by a road crossing, sediment deposition and infilling. These activities did not appear to be actively impacting on the wetland and their intensities were regarded as being relatively low. Interventions constructed on-site within the wetland appeared to have halted erosion to some degree; however, there were areas where sediments upstream of the interventions had not yet masked the entire incised areas.

The magnitude of the impacts per each component is summarised in Table 20. The changes to water input characteristics from the catchment activities have shown a moderate increase as a result of the slight change in vegetation community structure from game overgrazing and concentrations based on vegetation types. These changes have resulted in a change in runoff characteristics of water towards the wetland area downslope. There have also been minor stormwater discharges from the reserve roads traversing the wetland at the upper reaches. The wetland showed signs of sediment loss with erosion visible on the slope below the road and depositional area at the confluence of CVB1 and UCVB1. There have been moderate hydrological impacts on the wetlands. There were no dams or impoundments in the wetland except for a few areas where road crossings upstream of existing wetland rehabilitation structures impounded the flows. Existing interventions have increased sediment retention in the wetland. There were very few areas where vegetation had been removed or disturbed and these included areas where the road crossed the wetland and erosion persisted, and in areas where sediments had recently been deposited in the wetlands. The intensity of the activities in the wetland was significantly reduced with the implementation of existing rehabilitation within the wetlands.

Table 20: Summary of the Present Ecological State of the CVB1 wetland system

Wetland ID	Wetland Type	Wetland Areas	Impact Scores		
		Hectares (Ha)	Hydrology	Geomorphology	Vegetation
CVB1	Channelled Valley Bottom	25.00	2.00	0.60	2.30

4.1.7.1 Channelled Valley Bottom Wetland (CVB2)

No wetland rehabilitation has been planned or implemented in this wetland system. The baseline condition assessment of the wetland indicated that the wetland was dominated by natural grasslands, which had been impacted upon by erosion and a road crossing that resulted in flow impediment and channelling within the wetland. These activities led to a wetland that is not pristine but moderately modified. The baseline assessment indicated that the extent of impacts was greater outside the wetland and within its catchment area compared to the wetland itself. The change in land use within the wetland and its catchment affected the overall ecological state of the wetland resulting in a PES category of C (moderately modified system).

4.1.8 Summary of the Kgaswane wetland system: Present Ecological State

The wetland systems where rehabilitation work had been undertaken showed some improvement in their ecological integrity after rehabilitation. The rehabilitation activities included erosion protection, sediment stabilisation and flow release interventions. The erosion and sediment trapping interventions were placed in a strategic position to stabilise erosion, raise the water level and rewet the wetland area. Where linear infrastructure (roads) traversed the wetland, flow releases and diffuse flow downstream of the crossing were encouraged and channelling of flow downstream was reduced. As a result of the implemented interventions on the wetlands to address the impacts, the PES categories of the wetland improved. The overall PES impact score of UCVB1 was reduced from 1.08 to 0.76, and in terms of PES category, this wetland was enhanced from PES category B to PES category A, the result of the implementation of rehabilitation interventions on site. The CVB1 impact score was also reduced from 2.33 to 1.69, and in terms of PES category, the wetland improved from category C to B. The improvements to the wetlands in terms of PES categories and functional hectare equivalents associated with the rehabilitation activities are illustrated in Table 21.

Table 21: Summary of the combined PES categories and associated hectare equivalents after rehabilitation activities.

Wetland ID	Wetland type	Wetland areas (Hectares - Ha)	Overall PES	PES category	Hectare Equivalents (Ha-Eq)
UCVB1	Unchannelled Valley Bottom	114.00	0.76	A	105.37
CVB1	Channelled Valley Bottom	25.00	1.69	B	20.79
					126.2

4.1.9 Rietfontein Wetland: post-rehabilitation assessment

An assessment of the Rietfontein Wetland indicated that attempts to restore the ecological function of the wetland had been implemented on site. Various wetland rehabilitation interventions at specific areas had been implemented on site. These interventions were aimed at controlling and stabilising erosion (mainly headcut erosion) and raising the water table to promote flow distribution and diffuse flow in the wetland system. The implemented structure consisted of gabion concrete cast and rock masonry weir structures at various key points within the wetland system, as indicated in Figure 11.

Figure 11: Erosion control and stabilisation interventions recorded on a wetland on site. (A) – gabion concrete cast weirs, (B) – rock masonry and (C) – concrete drop inlet weir.

There were, however, persisting impacts on the wetland recorded on-site and this included erosion (gully erosion, channel incision, headcut erosion, and excessive water abstraction to meet the water demand for irrigation of the orchards around the wetland area). A section of the wetland was burnt during the site visit, which consisted of *Gunnera purpensa*, *Alsophila dregei* and *Pteridium aquilinum*, the dominant species (Figure 12).

Figure 12: Prominent species within the wetland included tree ferns *Alsophila dregei* (tall plants) and bracken *Pteridium aquilinum* (short plants*).*

It appeared that dead wood from the fire was presumably from alien vegetation, especially around the fern-dominated wetland section that had been cut and cleared; however, not all invasive species had been removed within the wetland area. Figure 13 below illustrate the cut stumps of trees that had been burnt within the wetland system.

Figure 13: Cut tree stumps of trees that had been burnt within the wetland system.

Dense alien vegetation (*Populus* sp., *Eucalyptus* sp. and Spanish reeds) that were recorded before rehabilitation were completely cleared within a major part of the wetland area. There were still some patches of alien invasive vegetation; in addition to this, there were signs of sediment deposition at various places within the wetland system. These impacts were assessed as part of the evaluation of the post-rehabilitation integrity assessment of the wetland systems. The recorded impacts on the wetlands are discussed below, based on the hydrology, geomorphology and vegetation components. There was only a single wetland HGM unit assessed within the Rietfontein Catchment, Channelled Valley Bottom wetland (Figure 14).

Figure 14: Recorded remaining impacts on a wetland on-site, (A) – bank collapsing, (B) – water abstraction, (C) – gully erosion, (D) – headcut erosion, (E) – channel incision and (F) – alien vegetation (*Populus* sp.).

4.1.10 Assessment of impacts

The magnitude of the impact = Extent x Intensity (refer to Appendix 3 for details)

- The extent was determined using physical mapping of the impacts on site and by the use of high-resolution aerial imagery.
- The intensity was determined using a scale of 0 – 10; default scores were provided within the WET-Health tool for individual disturbance classes on wetlands. These scores were based on extensive field investigation and local knowledge.
- The magnitude of the impact = (Extent of impact/100) x Intensity of impact.
- The overall magnitude of the impact score for the HGM unit was the sum of magnitude scores for disturbance class within the wetland. Appendix 3 provides the extent of impacts and magnitude of impact calculations.

4.1.10.1 Channelled Valley Bottom (CVB)

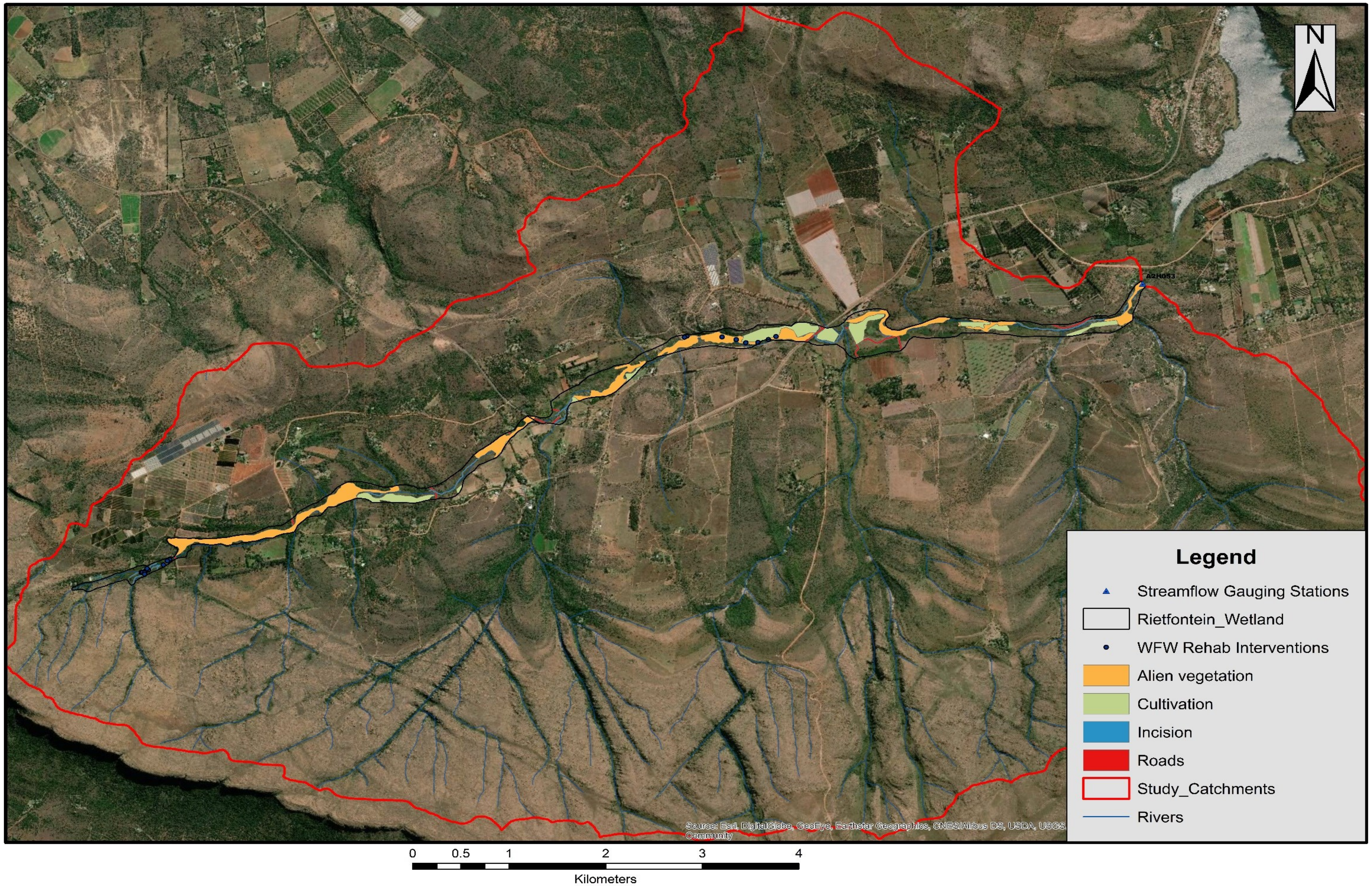


Figure 15: Extent of the Rietfontein CVB wetland system and various impacts recorded on the wetland; alien vegetation, cultivation, incision and roads.

Hydrological impact assessment

There was water abstraction for domestic use within the wetland system; borehole pumps were recorded within the wetland at various places. Stormwater inputs to the wetland were expected to be slightly elevated as a result of the road crossing through the wetland and expected return flows from irrigation activities within the broader wetland catchment. Slightly reduced flood intensities were anticipated as a result of the streamflow reduction activities (extensive alien vegetation invasive) present on site that reduce flow and take up water from within the stream channel. Although rehabilitation had taken place, there were still signs of incision and channelling in the wetland system, particularly below the road crossing and upstream and downstream of impeding infrastructures. In some areas, erosion had exposed bedrock within the stream. The majority of the system was well vegetated except for areas upstream and downstream of the rehabilitation structures, roads where sediments were exposed with limited vegetation cover and exposed rock areas where erosion had reached the riverbed. There were no dams present within the assessed wetland systems; however, the presence of road crossings and rehabilitation instream structures were likely to impede flow within the wetland area. Sediment deposition was observed, particularly upstream of impediment structures (weirs and roads). However, the intensity of these impacts was expected to be low with the implementation of various wetland rehabilitation interventions on site.

Geomorphological impact assessment

There were no flow impoundments in the form of dams that were recorded within the assessed wetland systems; however, the presence of road crossings and rehabilitation instream structures could impede flow within the wetland area. Part of the wetland area was impacted by road crossing, sediment deposition and infilling, and actively planted cultivation plots within the wetland systems. There was evidence of water abstraction for domestic use in the form of boreholes and associated pumps within the wetland systems. Stormwater inputs to the wetland were expected to increase slightly as a result of runoff from the road crossings and return flow from irrigation in the broader catchment. Instream flow patterns were likely to be altered with the presence of streamflow reduction activities (i.e. invasive, alien vegetation). Invasive aliens tend to impact on base flow and threaten perennial flow. Their impact during floods is likely to be minimal; they sometimes increase bank erosion that may even enhance flood intensity. Rocks were exposed in areas where erosion had reached the bedrock of the stream. Sedimentation within the wetland was recorded in areas where flow impediments were present, where the slope was gentle and water velocity was relatively slow and diffuse. Runoff and erosion from cultivated fields washed sediments into some of the wetland areas.

Vegetation impact assessment

Vegetation removal had occurred where infrastructural activities were erected within the wetland, particularly where roads traversed the wetland. There were no flow impoundments in the form of dams present on site; however, road crossings and instream structures such as weirs and rehabilitation structures constructed within the wetland created areas where back flooding could occur. The integrity assessment of wetland considers both inside and outside wetland impacts (i.e. within the catchment of the wetland impacts). There has been a loss of wetland vegetation in areas where agricultural activities have encroached into the wetland area. The majority of the adjacent areas to wetlands also consist of agricultural activities resulting in the loss of natural vegetation to cultivation and crop production. Dense stands of invasive alien vegetation, including *Populus* and *Eucalyptus* species, dominated sections of the wetland. There was clear evidence of sediment deposition upstream of the rehabilitation structures (rock masonry and gabion structures) and other infrastructure (roads). Rehabilitation interventions structures constructed in the wetland appeared to have stabilised and halted erosion, although there were areas where sediments upstream of interventions had not yet silted the entire incised areas. The intensities of these impact activities have been reduced significantly as a result of the implemented interventions. There were exposed rocks in areas where erosion had reached the bedrock of the stream. In addition to the morphological impacts recorded, impacts on vegetation are high, with various patches of invasive alien vegetation and cultivated lands within and around the wetlands.

4.1.11 Summary of the Present Ecological State of the CVB wetland system after rehabilitation activities

The changes to water input characteristics from the catchment activities have been moderate to low, as a result of the presence of streamflow reduction activities such as the presence of invasive alien vegetation and water abstraction. These activities affect the volume of water that would naturally be generated by the catchment and would feed receiving watercourses in the catchment. There were a few areas where vegetation had been removed or disturbed, which includes areas where a road crossed the wetland and areas where erosion still exists. The implementation of rehabilitation interventions had stabilised erosion, improved sediment trapping within the wetland area, and raised the water table, particularly upstream and around the rehabilitation structures, which had promoted diffuse flow downstream of the interventions. Sediment retention had improved upstream of the interventions and there was a reduction in the extent of invasive alien vegetation as a result of the clearing of exotic vegetation in some areas. These improvements have resulted in changes in the PES category of the wetland from a D (largely modified) to C (Moderately modified) post-rehabilitation. Persistent impacts that have kept the wetland in a C category are the result of signs of sediments loss, where erosion is visible within the wetland system and the remaining stands of invasive alien vegetation. The wetland area is extensive, so it is not possible to address all the impacts at once. To further improve the integrity of the system PES, additional interventions are required to address the existing impacts. The assessment and magnitude of impacts per each wetland integrity component (hydrology, geomorphology and vegetation), the current PES category, which indicates improvements and associated hectare equivalents calculations are shown in Table 22.

Table 22: Summary of the PES assessment, categories and associated hectare equivalents after rehabilitation activities.

Wetland ID	Wetland type	Wetland areas (Ha)	Impact scores			Overall PES	PES category	Hectare equivalents
			Hydrology	Geomorphology	Vegetation			
CVB	Channelled Valley Bottom	200.00	4.00	1.1	4.3	3.25	C	134.91

The analysis data of the changes of the ecological impact scores without and with rehabilitation interventions per individual wetland health component for the wetland systems assessed (UCVB1, CVB1 and Rietfontein CVB) indicate that there have been changes in the wetland as a result of the rehabilitation interventions (Table 23). The changes are noticeable in all wetland health components with the geomorphology and vegetation components dominating in terms of improvement of ecological conditions after rehabilitation (Figure 16). The ecological conditions of both the Kgaswane wetland systems (UCVB1 and CVB1) had improved slightly; rehabilitation had contributed to a modest 3% to 8% improvement in ecological conditions, respectively. An approximate 30% improvement in the ecological condition of the Rietfontein wetland system (CVB) was the result of rehabilitation efforts (Table 23). The significant differences between "without" and "with" rehabilitation were tested using the non-parametric Mann–Whitney U-test.

The statistical results show that there were no significant differences between the three wetland components without and with rehabilitation. It is worth noting that the distribution of the data without and with rehabilitation (Figure 16) was not identical and when considering median (central line in the boxplots) for example, one can observe that the median for without rehabilitation is higher than that with rehabilitation, particularly for the geomorphological and vegetation wetland components, and the overall Present Ecological State for the Kgaswane and Rietfontein wetlands. This suggests that rehabilitation improved the current ecological state impact score from being higher (i.e. leaning towards critically impacted) to that where the Present Ecological State impact score was lower (i.e. less impacted/intact). These differences were not statistically significant, which could be related to the small sample size (only three wetland types) and the need to use the less rigorous, non-parametric statistical analyses.

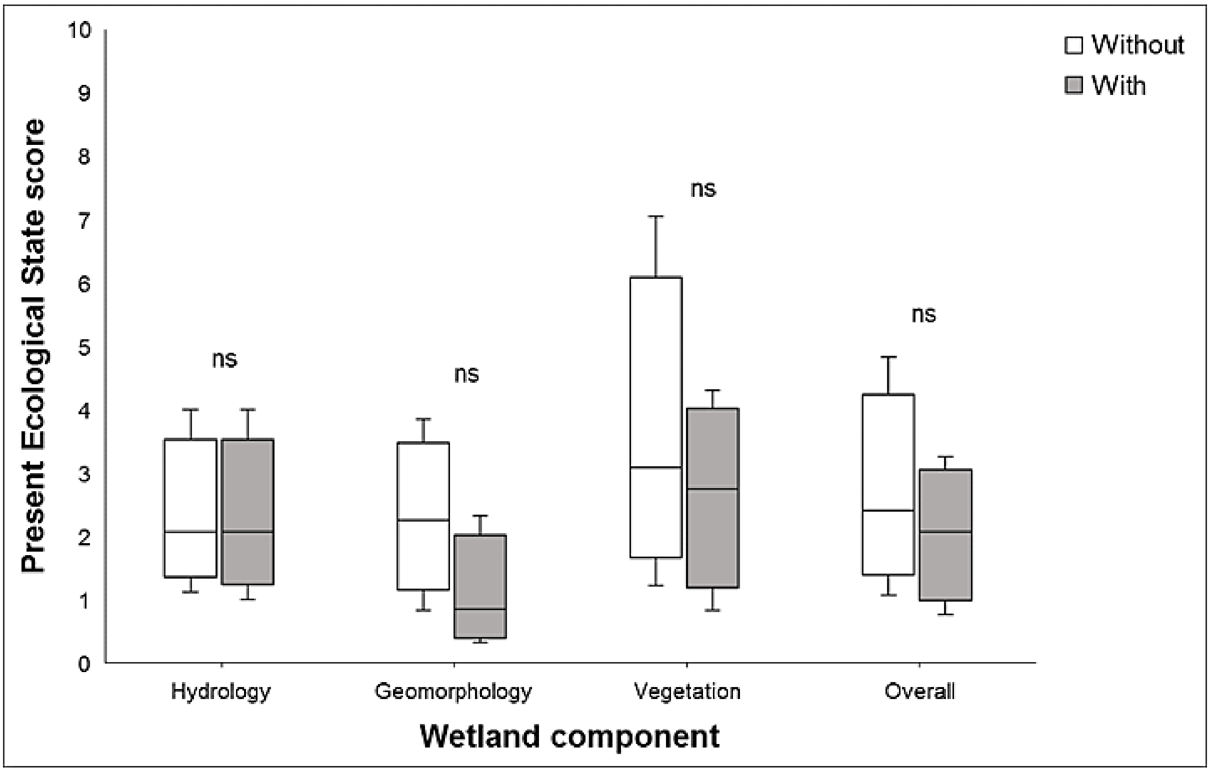


Figure 16: Wetland hydrology, geomorphology, vegetation, and overall PES scores (0 to near pristine and 10 to critically impacted) without and with the rehabilitation of the Kgaswane and Rietfontein wetlands.

Table 23: Ecological condition on an impact scale of 0 (pristine) to 10 (critically impacted) of the three assessed HGM units with and without rehabilitation interventions.

Wetlands	Wetland Type	Size (ha)	Scenario	Ecological impact scores			Overall PES (Impact score)	Overall PES (Health score)	Change	% Improvement
				Hydrology	Geomorphology	Vegetation				
Kgaswane	UCVB1	114	Without	1.13	0.83	1.23	1.08	8.92	0.32	3.59
			With	1	0.33	0.83	0.76	9.24		
	CVB1	25	Without	2.02	2.17	2.98	2.33	7.67	0.64	8.34
			With	2	0.6	2.3	1.69	8.31		
Rietfontein	CVB	200	Without	4	3.85	7.05	4.83	5.17	1.58	30.56
			With	4	1.1	4.3	3.25	6.75		

4.2 Cost-effectiveness of the implemented interventions

The categories of defining cost-effectiveness of the rehabilitation projects (Cowden and Kotze, 2008) are outlined in the methods of data analysis in Section 3. The categories provided various cost-effective thresholds depending on the cost of rehabilitation interventions per functional hectare equivalents gained or secured intact wetland associated with the implemented rehabilitation activities. Table 6 above provides the cost of rehabilitation per hectare equivalents gained and likely cost-effectiveness (Cowden and Kotze, 2008). The effectiveness of the rehabilitation interventions within Kgaswane and Rietfontein wetland was gauged according to these categories.

The important points to note around the cost of interventions is that:

1. The cost provided in the rehabilitation plans are interventions costs;
2. My assumption is that the figures have not been changed during implementation and therefore the costs become the actual cost of interventions as implemented onsite; and
3. There is no information that suggests that post-construction auditing of the interventions and quantity surveying was undertaken to confirm if there have been any changes in the cost during implementation.

4.2.1 Kgaswane wetland system

The cost effectiveness of the rehabilitation efforts is provided in Table 24 below. The estimated cost was relatively high per hectare equivalent and in terms of cost effectiveness, it falls within a low to intermediate category with an accrued improvement of approximately 5.3 ha/eq of wetland functional habitat. Based on existing rehabilitation plans, the cost of rehabilitation for the Kgaswane wetland was as follows:

- 2004/2005 – R1 038 780.00 (South African Biodiversity Institute, 2006a)
- 2014/2015 – R1 135 950.00 (South African Biodiversity Institute, 2014b)
- TOTAL SPENT – **R2 174 730.00**

Table 24: Cost effectiveness of the implemented rehabilitation activities in the Kgaswane wetland system.

Cost of interventions	R2 174 730
Hectare/Functional Equivalents of Wetland Habitat	
Future scenario with no intervention/s	120.9
Future scenario with intervention/s	126.2
Hectare/Functional Equivalents Gained or Lost	5.3
Cost per Hectare/Functional Equivalent	R413 079
Cost effectiveness	**Low to intermediate**

4.2.2 Rietfontein wetland system

The cost effectiveness of the rehabilitation efforts is provided in Table 25 below. The cost was intermediate per hectare that was incurred for by the improvement of approximately 25.3 ha of functional wetland habitat. Based on existing rehabilitation plans, the cost of rehabilitation for the Rietfontein wetland was as follows:

- 2009/2010 – R756 377 (South African Biodiversity Institute, 2009b)
- 2011/2012 – R1 244 810.00 (South African Biodiversity Institute, 2010)
- 2014/2015 – R2 946 720.00 (South African Biodiversity Institute, 2014a)
- TOTAL SPENT – **R4 947 907.00**

Table 25: Cost effectiveness of the implemented rehabilitation activities in the Rietfontein wetland system**.**

Cost of interventions	R4 947 913
Hectare/Functional Equivalents of Wetland Habitat	
Future scenario with no intervention/s	109.6
Future scenario with intervention/s	134.9
Hectare/Functional Equivalents Gained or Lost	25.3
Cost per Hectare/Functional Equivalent	R195 239
Cost-effectiveness	**Intermediate**

The ecological integrity and functional gains associated with rehabilitating the Kgaswane wetland system were low compared to the investment made to date on the improvement of the wetland conditions. The cost effectiveness of the project was low to intermediate; the calculation above indicates that R413 079 investment was made per functional hectare equivalent benefit, which means that this project's investment was intermediate to high compared to the gains achieved. The project was expensive, and therefore a strong justification is required for investing in this project. While some projects are expensive, like the Kgaswane wetland rehabilitation project, the issue of averted loss of critical functions becomes crucial in decision making around investing in those systems. Doing nothing to those wetland systems now may result in a substantial decline in terms of ecological functions and biodiversity support that the wetlands provide. The cost effectiveness of the Rietfontein wetland rehabilitation project was intermediate to high; the calculation above indicates that a R195 239 investment was made per functional hectare equivalent benefit in the wetland functions. The investment made to Rietfontein wetland rehabilitation was justifiable based on the wetland functional gains achieved as a result of rehabilitation. In order to achieve a high return on investment (High cost-effective projects), it is necessary to list all wetlands and expected costs/benefits to make an informed decision. The total budget can then be prioritised to those wetlands that will give most gains similar to that of the Rietfontein wetland rehabilitation project.

4.3 Hydrological data analysis – Flow regulation functions

4.3.1 Data preparation and analysis

The outlets of the two study catchments are monitored by flow gauging stations that are managed by the Department of Human Settlement, Water and Sanitation (formerly known as the Department of Water and Sanitation – DWS); A2H038 and A2H053. Both gauges have streamflow records of approximately 46 years, and the period October 1989 to September 2018 was considered most suitable for this assessment. The streamflow records for the 29 years are provided in Appendices 1 and 2. The selection of October 1989 to September 2018 records was to ensure that analyses included the required periods for assessments before and after rehabilitation activities were implemented on wetlands on site. The rehabilitation work within the wetland systems commenced as follows:

- Kgaswane wetland system – 2004/5 financial year
- Rietfontein wetland system - 2011/12 financial year

The pre-rehabilitation scenario was taken as the period before the initial implementation of the rehabilitation interventions on the wetlands based on the above periods. The post-rehabilitation evaluations may have included the implementation of additional rehabilitation interventions and maintenance following the rehabilitation period above to September 2018.

The full periods after rehabilitation of the two wetland areas were as follows:

- Kgaswane wetland system – 13 years (2005/6 to 2017/18)
- Rietfontein wetland system - 6 years (2012/13 to 2017/18)

Based on the above post-rehabilitation periods, it was necessary that the pre-rehabilitation records had to be of equal length as the post-rehabilitation records for similar comparison of datasets, and therefore, the pre-rehabilitation records were as follows:

- Kgaswane wetland system – 13 years (1990/1 to 2002/3)
- Rietfontein wetland system - 6 years (2005/6 to 2010/11)

Appendices 3 and 4 provide summaries of data extrapolated from the streamflow records to cover the above pre- and post-rehabilitation scenarios for further assessment and comparisons.

To assess any influence that rainfall patterns may have had on the results of the assessment, rainfall information of the rainfall gauges close to the study areas were sourced from the South African Weather Bureau (SAWB). Two gauges were identified within proximity to the study catchment areas:

- Kgaswane wetland system –Waterkloof (05115246) located 10 km east of the wetland system study area; and
- Rietfontein wetland system - Buffelspoort (0511855A9) situated below the wetland system and upstream of the Buffelspoort Dam approximately 5 km east of the wetland system.

Fortunately, the Buffelspoort rainfall gauge had comprehensive rainfall records from 1990 to 2018. However, the Waterkloof rainfall gauge records were limited to the period 1990 to 1999. Satellite rainfall datasets were used to supplement the record for the Waterkloof gauge to compile a full record for the assessment. The rainfall data (location: 27.125, -25.625) was daily satellite-derived data, was 0.25 degrees in resolution and downloaded and analysed as per the method described by Acker and Leptoukh (2007) and Huffman *et al.* (2007). Appendices 5 and 6 provide the full rainfall records for both stations, respectively, for the period October 1989 to September 2018.

4.3.2 Results

The analysis of rainfall was done to determine any influence of rainfall patterns on the results of the streamflow regulation functions associated with the rehabilitation work on wetlands onsite. The rainfall time series data was plotted against streamflow to identify any relevant patterns, and if wet and dry periods influenced the flow records. The average rainfall and stream for both Kgaswane and Rietfontein wetland systems were calculated as follows:

Kgaswane wetland system

- Average rainfall pre-rehabilitation activities = 689.74 mm
- Average rainfall post-rehabilitation activities = 616.05 mm
- Average streamflow pre-rehabilitation activities = 0.088064 m^3/s
- Average streamflow post-rehabilitation activities = 0.08408 m^3/s

Rietfontein wetland system

- Average rainfall pre-rehabilitation activities = 698.2 mm
- Average rainfall post-rehabilitation activities = 434.6 mm
- Average streamflow pre-rehabilitation activities = 0.033 m^3/s
- Average streamflow post-rehabilitation activities = 0.028 m^3/s

Linear regression in both rainfall and flow plots indicate both flow and rainfall decrease during the entire period of assessment, i.e. before and after rehabilitation activities implemented on site. The change (decrease) applies to both Kgaswane and Rietfontein wetland systems. The variation of change differs for Kgaswane and Rietfontein particularly rainfall for Rietfontein showed a noticeable decrease throughout the assessment and a slight change for the Kgaswane wetland system. It is important to note that in both wetland systems, flow and rainfall decreased for the entire period (Figure 17 and 18).

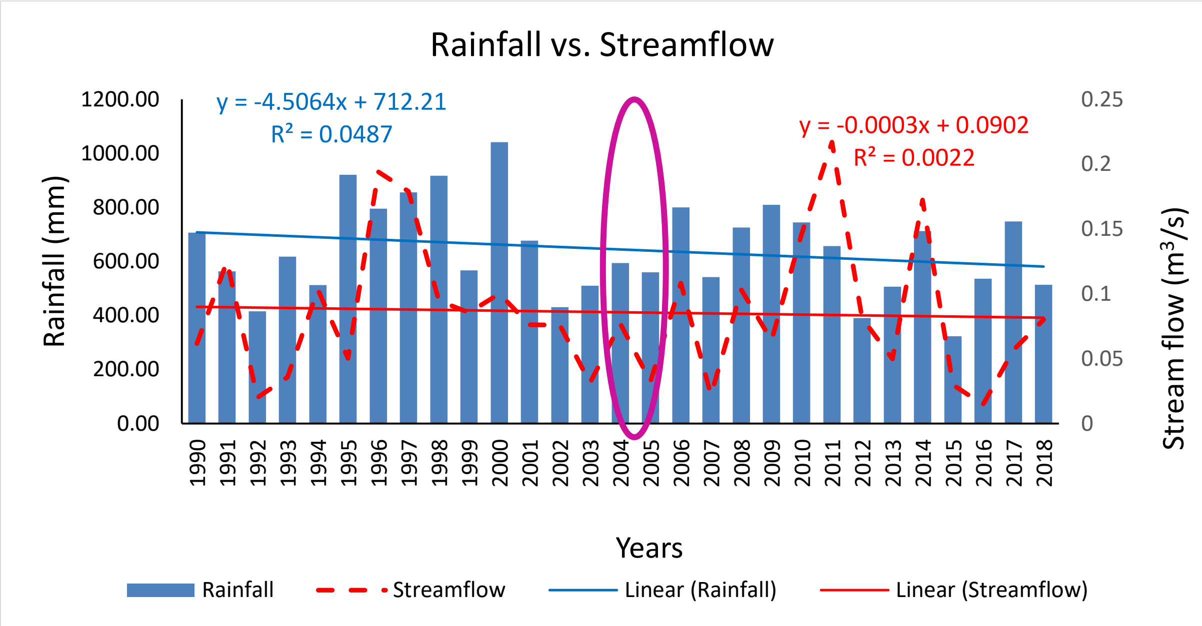


Figure 17: Comparison of rainfall and streamflow at the Kgaswane wetland system, highlighting long-term trends (linear regressions) and the period where rehabilitation was implemented (purple ellipse).

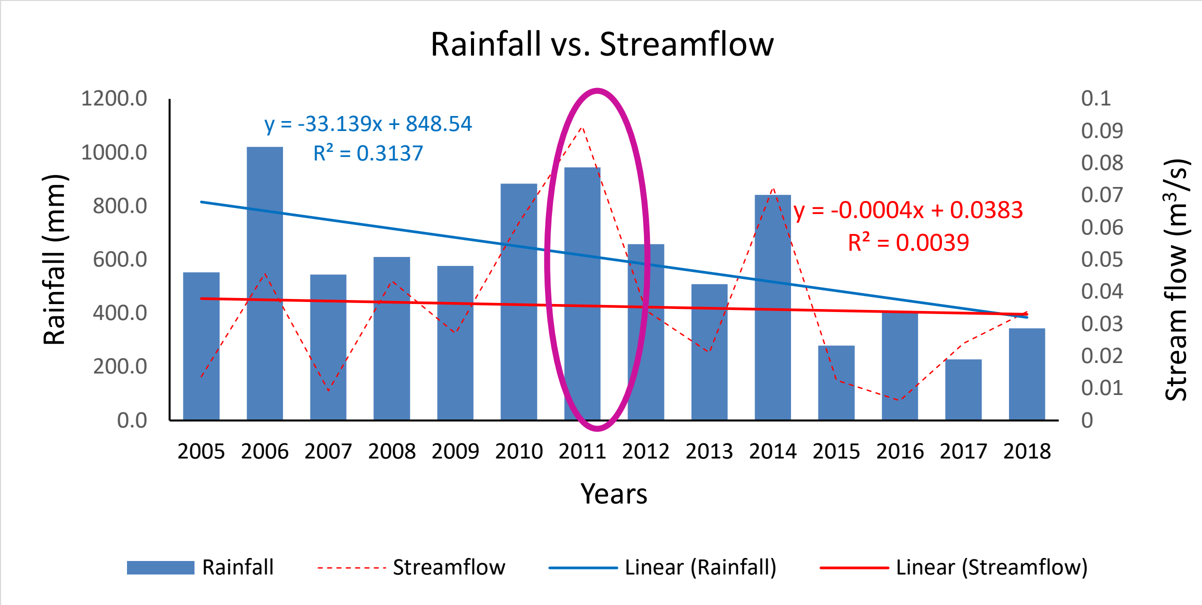


Figure 18: Comparison of rainfall and streamflow at the Rietfontein wetland system, highlighting long-term trends (linear regressions) and the period where rehabilitation was implemented (purple ellipse).

The Mean Annual Rainfall for the Kgaswane wetland system is between 600-700 mm, and that of the Rietfontein wetland is 700-800mm based on mean annual averages for rainfall records from 1920 to 2010 (WR2012) Bailey and Pitman, (2015). The average rainfall before and after rehabilitation activities within the Kgaswane wetland system is at a range of 616- 690 mm, which is well within MAP range of the area of 600-700 mm based on long-term rainfall averages for the area. The Rietfontein wetland's average rainfall pre- and post-rehabilitation ranges at 434-698 mm, and this is below MAP for the region of 700-800 mm, although the pre rehabilitation rainfall average of Rietfontein is close to the lower end of MAP, it can be argued that before the implementation of rehabilitation measures the Rietfontein wetland system was relatively wetter compared to after rehabilitation activities. However, based on these figures, Rietfontein wetland rehabilitation was implemented at a drier period, and Kgaswane within mean annual rainfall based on long-term annual averages for the area. The distribution of flow in both Kgaswane and Rietfontein wetland systems indicate no improvement of base flows in both systems after rehabilitation activities. Table 26 shows flow distribution within the Flow Duration Curve (FDC):

Table 26: Ranges Of flow distribution within an FDC (Kannan and Jeong, 2011).

Flow Distribution	Exceedance Probability %
High Flows	0 - 10
Wet conditions	11 – 40
Mid-range	41 - 60
Dry conditions	61 - 90
Low flows (base flows)	91 - 100

Distribution of flow showed that flows are attenuated in all flow ranges for both wetland systems. There is also a noticeable increase in high flow after rehabilitation for both wetland systems with Rietfontein for 1 and 5% exceedance and Kgaswane for 1% exceedance, as indicated in Figure 19 and 20. The quantification of the flow differences also shows volumetric flow differences at various flow ranges, which indicate flow attenuation of mid-range and low flows and an increase of high flows as indicated in Table 27.

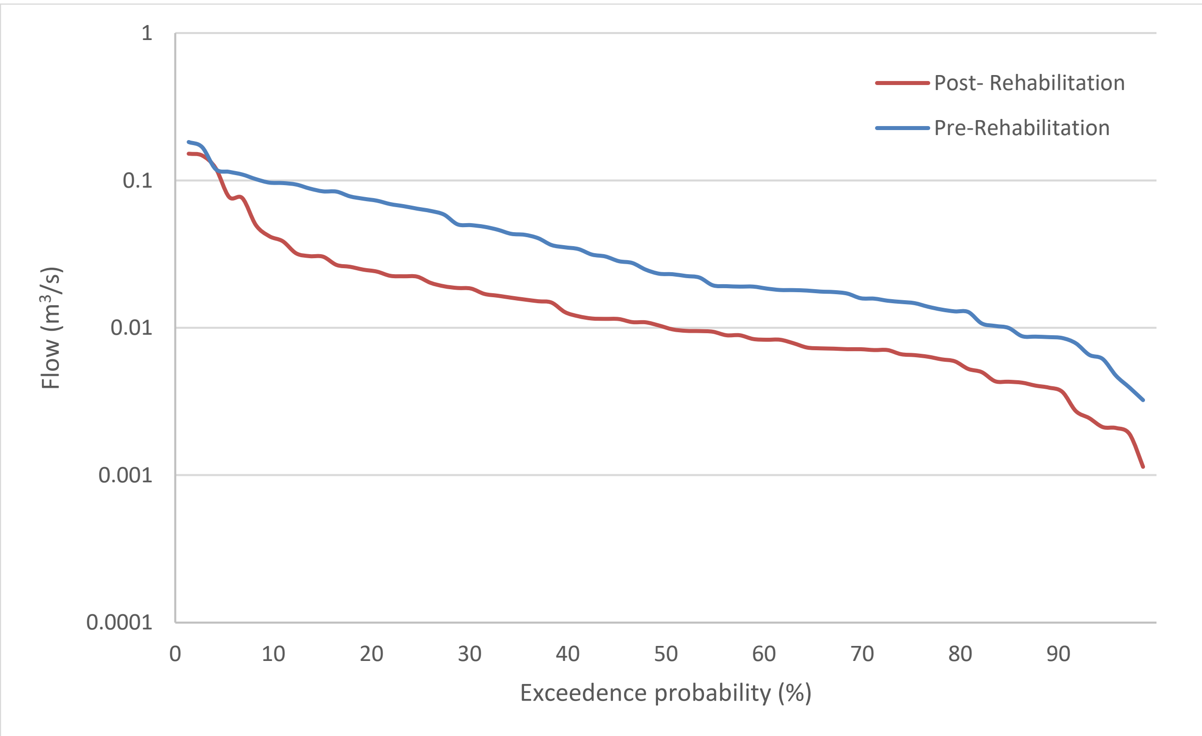


Figure 19: Comparison of FDC for pre-and post-rehabilitation activities (log scale) for the Rietfontein wetland system.

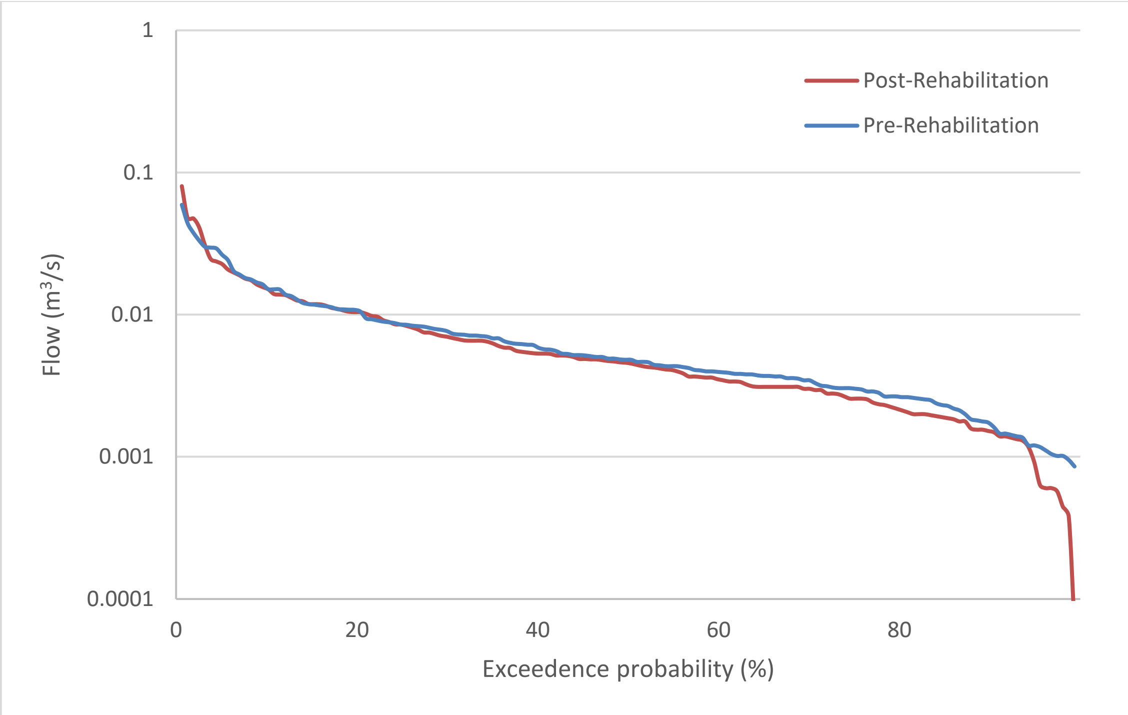


Figure 20: Comparison of FDC for pre-and post-rehabilitation activities (log scale) for the Kgaswane wetland system.

Table 27: Differences in flows vs exceedance probabilities for pre-and post-rehabilitation activities for the Rietfontein and Kgaswane wetland systems.

	Rietfontein			**Kgaswane**		
	Flow (m^3/s)			**Flow (m^3/s)**		
% Exceedance	**Pre Rehab**	**Post Rehab**	**Difference**	**Pre Rehab**	**Post Rehab**	**Difference**
99	0.11	0.08	0.03	0.08	0.03	0.05
95	0.21	0.15	0.06	0.10	0.08	0.02
90	0.29	0.25	0.03	0.15	0.13	0.02
75	0.49	0.45	0.04	0.26	0.22	0.04
50	0.78	0.67	0.10	0.41	0.40	0.01
25	2.16	1.54	0.62	0.73	0.74	-0.02
10	3.25	2.89	0.36	1.40	1.37	0.03
5	3.84	5.34	-1.50	2.25	1.98	0.27
1	6.12	10.49	-4.37	5.06	7.00	-1.94

The attenuation of flows within the Rietfontein wetland system is also evident from the statistical analysis of the flow data before and after rehabilitation. Significant differences between “without” and “with” rehabilitation were tested using a Mann–Whitney U test. The results show that there is a significant change in flows before and after rehabilitation with a p-value of <0.01*** for Rietfontein wetland system. The Kgaswane wetland systems showed insignificant changes in streamflow, this is also seen on the flow distributions in Figure 20. There was a little difference between pre- and post-rehabilitation flows. Table 27 also correlates to these findings in terms of volumetric changes and because of these minor differences, it can be expected that the changes statistically can be regarded as insignificant as indicated in Figure 21.

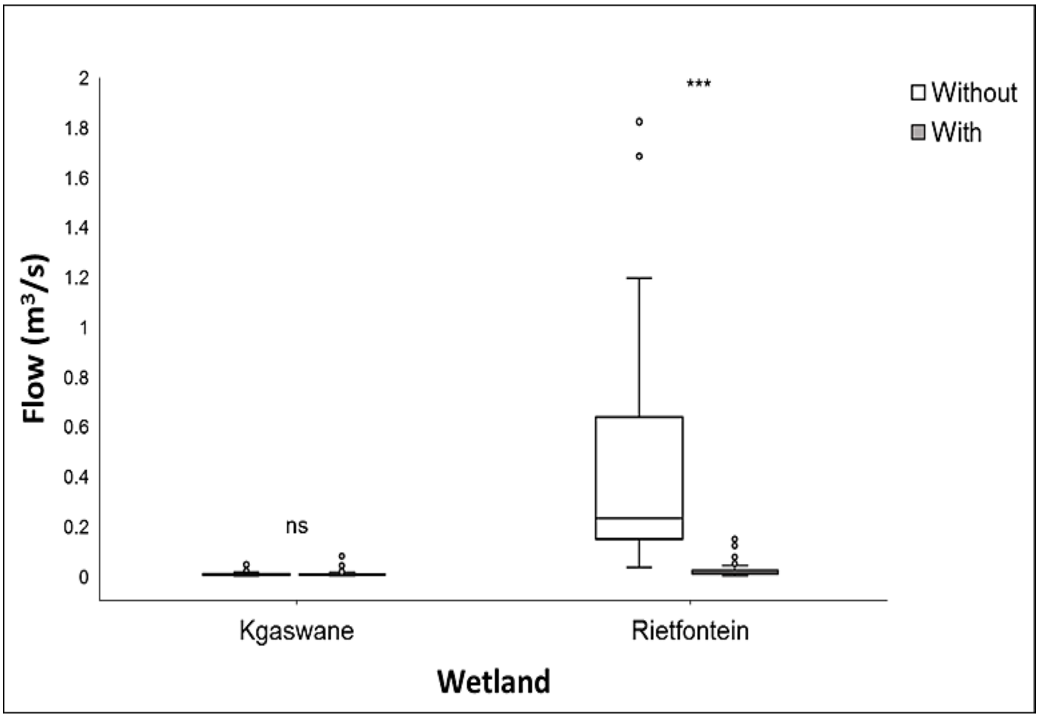


Figure 21: Streamflow results for pre- (without) and post-rehabilitation (with) of the Kgaswane and Rietfontein wetlands.

The rehabilitation with the Kgaswane wetland took place within an average rainfall period, i.e. within mean annual rainfall of the area and Rietfontein wetland rehabilitation took place within a dry period below mean annual rainfall of the area. The linear regression of rainfall and streamflow within the period of analysis, however, indicates a decrease in rainfall and streamflow through the entire period for both wetland systems. The R^2 values for the streamflow are very close to zero, where zero indicates no correlation and 1 indicates 100% correlation in the datasets, the same applies to rainfall data with R^2 ranges from 4 to 31%, this concludes that both rainfall and streamflow data is variable with a negative slope in linear equation that indicates a decrease in both rainfall and streamflow through the entire period of analysis or rehabilitation activities.

The flow distribution analysis showed improved streamflow attenuation for both Rietfontein and Kgaswane wetland systems, with Rietfontein showing apparent changes in the flow duration curves as compared to the Kgaswane wetland. The volumetric changes in stream flows for various flow ranges provided ambiguous results and indicated more intense flooding, loss of base flows and attenuation (i.e. Spreading out of flow over longer period). A common perception is that all wetlands regulate flows; however, these results are ambiguous as they show an increase in the magnitude of high flows (intensity) and a decrease in low flows as compared to our current knowledge that wetlands increase or maintain baseflows. Results of this nature are not isolated; various studies have indicated that wetlands do generate flows/floods, and some wetlands are poor in holding water and yielded little base flow (Burt, 1995 and Bullock and Acreman, 2003). The improvement in the health of the wetland system includes improving vegetation cover and compositions by removing alien vegetation invasion. The structural interventions instream of the wetlands increases sediment trapping and erosion stabilisation and assists in raising and rewetting of the wetland area. These improvements generally improve attenuation capacity of the wetland as flows become buffered as diffuse flow across the wetland increases as well as water retention time within the wetland increases. The water holding capacity of the wetland is dependent mainly on the underlying geology of the wetland systems. The improvement in health increases water retention in the wetland, but if water holding capacity of the wetland soil is poor, then water will be lost quickly without any effect on base flows.

The Coefficient of variance (Cv; standard deviation divided by the mean) was also considered for comparison of the before and after rehabilitation streamflow datasets. Twenty-eight years' streamflow data was used to analyse the changes in CV for Kgaswane wetland system. Thirteen years before rehabilitation activities, the Kgaswane wetland system had an average streamflow of $0.0075 m^3/s$, and a standard deviation of $0.0083\ m^3/s$, streamflow Coefficient of variation is 1.106. Thirteen years after rehabilitation activities, the Kgaswane wetland system has an average streamflow of 0.0073m^3/s, and a standard deviation of 0.0096 m^3/s, streamflow Coefficient of variation is 1.312. The CV has changed from 1.106 to 1.312, with an increase of 0.206 equal to 18.63% increase. The Rietfontein wetland system's, thirteen years' streamflow data was used to analyse the changes in CV for the Kgaswane wetland system. Five years before rehabilitation activities, the Rietfontein wetland system had an average streamflow of 0.413 m^3/s, and a standard deviation of 0.387 m^3/s, streamflow Coefficient of variation is 0.937. Five years after rehabilitation activities, Rietfontein wetland system has an average streamflow of 0.0199 m^3/s, and a standard deviation of 0.0293 m^3/s, streamflow Coefficient of variation is 1.472. The CV has changed from 0.937 to 1.472, with an increase of 0.535 equal to 57.1% increase.

In both wetland systems (Kgaswane and Rietfontein) the Coefficient of variation of streamflow has changed to the more extreme direction over the long term. Both Kgaswane and Rietfontein wetland systems streamflow data has more variability to their average streamflow per each system after rehabilitation activities. The higher CV after rehabilitation indicates that in both systems, streamflow data is not uniform or consistent and therefore flows are not buffered after rehabilitation. The increased variability can be seen in the flow duration curves graphs (Figures 18 and 19 and Table 28) for both systems. Peak flows were not reduced; rather, they were amplified. The increased peaks, when combined with longer dry periods and the loss of base flows, result in greater variance. The conclusion in all these analyses indicate that rehabilitation efforts in both of Kgaswane and Rietfontein systems did not contribute to flow regulation particularly with regard to improvement and maintenance of baseflows.

5. CHAPTER 5: DISCUSSION

5.1 Wetland Ecological Integrity - Present Ecological State

The implementation of rehabilitation interventions on both wetlands (Kgaswane and Rietfontein) showed improvement in their ecological conditions. The baseline ecological condition of the wetland within the Kgaswane Nature Reserve ranged from largely natural (PES = B) to moderately modified (PES = C). Kgaswane wetland system showed no statistically significant improvement of ecological conditions. The results of the before rehabilitation conditions influenced the outcomes, which indicated a system with minor impacts requiring interventions coupled with the fact that ecosystem recovery takes a long time for areas that have been rehabilitated. Implementation of rehabilitation interventions within the Kgaswane wetland system to stabilise erosion, particularly channel incision, that had developed into headcut erosion and restoration of crossings to enable evenly diffuse flow distribution has improved the ecological state of wetland. It is important to note that land use within and around the wetland had influenced rehabilitation outcomes (Grenfell *et al.,* 2005). Kgaswane wetland is located within the nature reserve where there are proper management plans in place, including regular monitoring not only for the wetland but for the broader site in general. The ecological condition of the wetland system before rehabilitation was relatively good and rehabilitation measures were meant to improve conditions where possible, and preserve and conserve the integrity of the system. The opposite can be said for the Rietfontein wetland system; the wetland is located within an area of competing land uses, including agriculture, conservation and various infrastructural activities. Rietfontein wetland system as a receiving waterbody across these land uses has responded to the impact of these activities, and its ecological state has been degraded. The objective of rehabilitation in this instance was to improve the ecological state of the wetland systems on site. The baseline ecological condition of the Rietfontein wetland systems indicated a system that was largely modified (PES = D). Rietfontein wetland system had shown statistically significant improvement in its ecological state from before rehabilitation, a result of before rehabilitation conditions and impacts on the wetland system requiring rehabilitation interventions. The ecological improvements in both systems have been primarily as a result of stabilisation of erosion, to improve the hydrological conditions of the wetlands through the installation of various instream erosion stabilisation structures.

The majority of our wetlands are vulnerable to erosion, and therefore the need for erosion control measures is high in South Africa (Ellery *et al.,* 2009). A major proportion of the Rietfontein wetland system was invaded by alien invasive vegetation and there has been an attempt by landowners to clear some of the invasive plants following a fire that burnt a portion of the upper section of the wetland system. Although the system showed improvements, there was a need for further investments in addressing both the remaining erosion issues and alien invasive vegetation. The ecological outcomes were expected to be much higher than what was achieved and more significant if all impacts were adequately addressed. The ecological conditions of both Kgaswane wetland systems showed slight improvements in ecological conditions ranging from 3 to 8% with rehabilitation activities.

In contrast, the Rietfontein wetland system showed a critical improvement in ecological conditions of 30% in comparison. Kotze *et al.* (2019) perceive that ecological outcomes can be effectively followed concerning ecological conditions in a semi-quantitative way using a wetland health assessment tool (rating hydrology, geomorphology and vegetation parts) of the ecological conditions and by utilising hectare equivalents. A similar methodology applied in the evaluations of the two wetland systems. There is likewise an acknowledgment that a similar approach doesn't determine the specific time span needed from fulfilment of the rehabilitation interventions to the subsequent evaluation. Morean-Mateos *et al.* (2012) perceived that follow-up appraisals led inside five years of execution may be an inadequate time frame for significant ecological recuperation to have occurred. In this case, for both wetland systems, the commencement of rehabilitation activities has been more than five years. There have been various maintenance and additional implementation interventions for continuous improvement of the wetlands to date. Ntshotsho *et al.* (2011) indicated a skewed emphasis on monitoring of restoration outputs. Kotze *et al.* (2019) suggested that application of existing methods, notably Wet Health, WET-EcoServices and hectare equivalents, have the potential to provide a practical basis for addressing the currently skewed approach as highlighted by Ntshotsho *et al.* (2011). The assessment in this study followed that same approach with the use of Wet Health and hectare equivalents, and now adds to the few assessments that have been done to date in South Africa using this approach.

Rehabilitation activities have mainly focused on addressing hydrological activities through the implementation of instream structures and with some clearing of alien invasive vegetation. Kgaswane wetland system is in a relatively good condition, so management and monitoring of this system should continue as part of the Nature Reserve management plans. Within the Rietfontein wetland system, removal of alien vegetation has reduced the impact of this vegetation on the wetlands, however, no active revegetation programme was conducted in areas where there has been clearing, which has limited the improvement of natural vegetation colonisation. The perception around wetland rehabilitation projects in South Africa, as recognised by Kotze *et al.* (2019), was that the focus has been almost exclusively on hydrology and geomorphology with the assumption that vegetation recovery will follow on its own, without any active planting and management. The assessment for various wetland systems in the KwaZulu-Natal Province, South Africa, by Cowden *et al.* (2013) has indicated that significant improvement in wetland rehabilitation is associated with improvement in hydrological conditions, however, evidence shows little improvement in vegetation even after more than five years of monitoring. Rietfontein wetland showed some improvement; however, the following key factors were identified as hindering the attainment of the rehabilitation objectives fully, (1) high land-use impacts arising from within the catchment, (2) remaining invasive plant species, and (3) erosion features given the extent of the system. A key exercise from this is that more prominent records should be kept of these hindering factors, especially when arranging and planning rehabilitation projects and in expecting the continuous support likely to be required. The methodology created in this investigation applies existing strategies, remarkably the WET-Health and hectare equivalents of Cowden *et al.* (2013) across two systems, from which key patterns were distinguished and lessons were distilled. This study is in line with recently proposed rehabilitation outcomes valuation methods for Working for Wetlands by Kotze *et al.* (2019).

5.2 Flow regulation

A common perception is that all wetlands regulate flows. The perception is, however, not always accurate as the functions associated with a particular wetland will depend both on its biophysical characteristics and its location in a catchment. The analyses of flow data at the outlets of the wetland catchments at streamflow gauges A2H038 and A2H053 showed that with the implementation of rehabilitation measures, flows at the gauges/catchment outlets responded positively. The results are ambiguous as they did show an increase in the magnitude of high flows but decreased low flows as compared to our current knowledge that wetlands increase or maintain baseflows (Mander *et al.*, 2017). Following the implementation of rehabilitation measures, a 2% increase in high flows was observed at gauging station A2H038 but low flows (mid-range to dry conditions flows) were attenuated. Similar results were found at gauge A2H053 where high flows following the implementation of rehabilitation measures increased by 4% and low flows were attenuated.

What is evident from the results from both catchments' rehabilitated wetlands is that the rehabilitation endeavours seem to increase high/flood streams and attenuate low stream flows. The outcomes are consistent with research conducted in southern Africa, which indicates that once saturated, headwater wetlands often function as areas of rapid runoff and sources sites for stream flow. (Riddell *et al.,* 2017). Hewlett and Hibbert (1967) also recognised that wetlands located close to river margins are flood-generating areas. In a study of headwater wetlands in the United Kingdom, Burt (1995) concluded that the majority of wetlands are poor at holding water, yield little baseflow and generate large quantities of floodwaters.

A detailed Zimbabwean study confirmed that the role of wetlands for generating flow is not static but depends on soil characteristics and antecedent moisture conditions in the soil (McCartney *et al.,* 2013). As an example, if wetland soil was dry or it was the dry season, then when rain fell there would be a delay in generating the overland flow or runoff as the soil medium will need to be saturated first before effective rainfall takes place. Effective rainfall is the one that generates runoff (McCartney *et al.,* 2013).

Flow regulation functions include flood and flow reduction, groundwater recharge and low flow augmentation, many examples where wetlands increase floods and reduce low flows are less recognised (Bullock and Acreman, 2003), which was the case in the Kgaswane and Rietfontein wetland systems. Bullock and Acreman (2003) further noted that flood peak reduction mostly occurred in floodplain and headwater wetlands. This study shows loss of flow attenuation as a result of intense flooding and less baseflow resulting in less spreading out of flow over a longer period across the two wetland systems.

It is therefore essential to consider the dry season effects of wetlands on stream flows, in terms of the commonly held perception of low flow augmentation. Based on the rainfall recorded and reported in the results section, the Mean Annual Precipitation (MAP) for the Kgaswane wetland system is between 600 and 700 mm, and the Rietfontein wetland is between 700 to 800 mm (WR2012). The average rainfall before and after rehabilitation activities within the Kgaswane wetland system was within the range of 616 to 690 mm, which is well within MAP range of the area based on long-term rainfall averages for the area. The Rietfontein wetland's average rainfall before and after rehabilitation ranged from 434 to 698 mm below the MAP for the region. Based on these figures, Rietfontein wetland rehabilitation was implemented during a drier than average period and Kgaswane within the MAP range of the area.

The linear regression of rainfall and streamflow within the period of analysis also indicates a decrease in rainfall and streamflow through the entire period for both wetland systems. The R^2 values conclude that both rainfall and streamflow data were variable with a decrease in both rainfall and streamflow through the entire period of analysis or rehabilitation activities. In both wetland systems (Kgaswane and Rietfontein) the coefficient of variation of streamflow changed to become more extreme or variable over the long term. The streamflow of both Kgaswane and Rietfontein wetland systems became more variable following rehabilitation activities indicating that flow was less buffered. The increased variability can be seen in the flow duration curves graphs (Figures 18 and 19 and Table 28) for both systems. Peak flows were not reduced; rather, they were amplified. The increased peaks, when combined with longer dry periods and the loss of base flows, result in greater variance. The conclusion is that rehabilitation efforts in both the Kgaswane and Rietfontein systems did not contribute to flow regulation, particularly with regard to the improvement and maintenance of baseflows and flood attenuation. All the wetland interventions were conducted during a drier than average period for the Rietfontein and during an average rainfall period for the Kgaswane. It is expected that with a more extended rainfall period after rehabilitation, which may include long cycles of both dry and wet periods, the results may differ from those in this study.

The lack of long-term streamflow and rainfall records after rehabilitation may be considered as a limitation to the project. There is no doubt that there is a strong correlation between rainfall and runoff. The hydrological drivers of wetland systems are fundamental in understanding the services and flow regulation functions provided by the wetlands. The water balance and inputs to the two wetlands assessed are not known, the current flow analysis was based on surface flow inputs, and there was no quantification of groundwater inputs to wetlands. This might be a relevant issue with regard to the Kgaswane wetlands, which showed no significant improvement in flow regulation function, beside rainfall period, so there may be a strong influence of groundwater to the unchannelled valley bottom wetland system, which consists of peat (fibrous material). Hydrological drivers of wetlands commonly impact the flow regime of a wetland since input and yield from the various processes vary in amount and timing (Brinson, 1993). The progressions in hydrological drivers have direct outcomes to the timing, magnitude and duration of water received by a wetland, which can bring about critical, enduring changes to the nature and capacity/function of the wetland (Mandlazi, 2017). Groundwater and surface water play huge role in the water balance of a wetland and can be an essential primary source of water in certain wetlands. Surface water enters a wetland through channel flow, overland flow and baseflow. The hydrological exchange between wetlands and groundwater happens through groundwater recharge from wetlands, groundwater release to wetlands and throughflow (Mandlazi, 2017)

5.3 Investment and cost-effectiveness

The ecological integrity and functional gains associated with rehabilitating Kgaswane wetland system are too low compared to the investment made to date on the improvement of the conditions of the wetland on site. The cost-effectiveness of the Kgaswane wetland rehabilitation project was low; the calculation indicated that a functional gain of 1-hectare equivalent required an investment of R 339 715. The combined low cost-effectiveness and the uniqueness and strategic location in a formally protected area of the wetland were used as motivation for the rehabilitation work despite the high cost and low achievement of functional ecological gains. The following were also considered for the Kgaswane wetland system:

- Kgaswane UCVB1 is a peatland; peatlands are rare wetland systems in South African due to anthropogenic impacts including mining of peat and being used for agricultural activities.
- Peatlands are essential for water quality improvement as they produce clean water from fibrous material (sponge) and are vital systems from their functional value including providing carbon sinks and maintenance of biodiversity.
- Kgaswane wetland is also rated as a Freshwater Ecosystem Priority Area (FEPA) wetland as part of the National Freshwater Priority Areas of South Africa (Nel *et al.,* 2011).

The ecological integrity and functional gains associated with rehabilitating the Rietfontein wetland system are intermediate (moderate) compared to the investment made to date on the improvement of the conditions of the wetland on site. The cost-effectiveness of the Rietfontein wetland rehabilitation project was intermediate; the calculation indicated that a functional gain of 1-hectare equivalent required an investment of R 143 358. The combined moderate to high (intermediate) cost-effectiveness and the strategic location of the wetland upstream of the Buffelspoort Dam (source of water supply and agricultural use within the area) were used as motivation for the rehabilitation work despite the moderate (intermediate) profitability in terms of achieved ecosystem services. Table 28 provides a summary of the cost associated with the rehabilitation of the two sites.

Table 28: Summary investment made, cost-effectiveness and justifications of funding.

Wetlands	**Cost (ZAR)**	**Ecological contribution (hectare equivalents)**	**Cost relative to outcomes**	
			Ecological condition	**Ecosystem services**
Kgaswane	R 2 174 730.00	5.3	R 413 079 per hectare equivalent	Well justified *
Rietfontein	R 4 947 907.00	25.3	R 195 239 per hectare equivalent	Well justified**

** Cost per hectare equivalent is too high and cost-effectiveness low, the uniqueness of the system (Peatland). Conditions, sensitivity and importance justify the money spent to improve, conserve and protect the system. The trajectory of downward change, i.e. if nothing is done, may result in the further degradation and loss of the peatland system.*
*** Cost per hectare equivalent is moderate and cost-effectiveness is intermediate. Location of the wetland upstream of a dam that is a source of water supply for domestic and irrigation provides a reason to justify an improvement of this wetland system. The trajectory of downward change, i.e. if nothing is done, may result in further degradation and loss of wetland area, siltation of the dam, and loss of capacity and yield which will result in a shortage of water supply and loss of habitat for various wetland-dependent species.*

It is important to note that ideally, the intention would be to implement high-cost effectiveness projects as the return on investment for those projects is high, i.e. maximum functional gains at a low cost or expenditure. In cases where this is not achievable, a substantiated motivation is then compiled and accompanies the planning report of the project, which was the case for the two projects described in this study. The cost-effectiveness calculation is also based on functional gains as a result of rehabilitation; it does not include the number of employment opportunities and skills development created by the projects, which are crucial from the cost-effectiveness of the project. The entire Expanded Public Works Programme, which Working for Wetlands is funded under, is primarily based on employment and skills development. At the time of writing this report, project implementation information including labour cost, created jobs, etc. was not available. The lack of such information provides a gap in the knowledge when considering all the aspects related to the projects. For example, the cost-effectiveness from functional gains may be intermediate to low. Still, the number of jobs created and skills developed within the project implementation may be high, and the latter can be used to substantiate the implementation of the project further. The study uncovered that particular rehabilitation issues are naturally significantly more expensive to deliver than others comparative with the commitment that the interventions make toward ecological conditions. Black and Turpie (2016) additionally discovered hard structural interventions to be exorbitant. This isn't to suggest that the "exorbitant" issues ought to be evaded totally. All things considered, when a number of wetlands are being targeted as possible candidates for rehabilitation, there is a need to more explicitly recognise the differential cost of various types of rehabilitation issues.

6. CHAPTER 6 – CONCLUSIONS

6.1 Ecological integrity

The study was carried out to assess the effects of rehabilitation activities on the ecological integrity of wetlands and flow regulation functions in gauged catchments. Assessment of the Kgaswane and Rietfontein wetland systems from separate catchments consisting of varying land uses indicated that the ecological integrity of the wetland systems improved with the implementation of rehabilitation measures. In general, the implementation of rehabilitation interventions on both wetlands showed an improvement in ecological conditions. The ecological conditions of both Kgaswane wetland systems improved slightly, ranging from 3 to 8% with rehabilitation activities.

The effects of the rehabilitation efforts on the Rietfontein wetland system were more obvious, where a significant improvement in ecological conditions of 30% was measured. The ecological conditions of Kgaswane wetland before rehabilitation indicated a system in relatively good condition and rehabilitation efforts were meant to improve where possible, preserve, and conserve the integrity of the system. Rietfontein wetland system showed a more stark statistically significant improvement in its ecological state from before rehabilitation, which was the result of the wetland being a profoundly impacted system prior to rehabilitation and requiring rehabilitation interventions. Although improvements in ecological integrity were accomplished with rehabilitation, wetland assessment tools utilised are mostly based on rapidly depicted indicators and subjective scoring of explicit indicators instead of on the definite/detailed description of wetland structure and process and this is recognised by Kotze *et al.* (2012) as a restriction of these assessments**.** In addition, ecosystem recovery may take a long time (> 5 years) and the period assessed post-rehabilitation may not have been long enough to realise the full extent of the responses of the system. Therefore, continuous monitoring may be required to be conclusive about long-term responses of the system under rehabilitation activities.

6.2 Flow regulation

The study was carried out to assess the effects of rehabilitation activities on the ecological integrity of the two wetlands and flow regulation functions in the gauged catchments. Assessment of the flows of the two wetland systems from two different catchments with varying land uses indicated that there had been a slight increase in high flows and attenuation of mid-range and dry condition flows from natural in both wetland systems. The analyses of flow data at the outlets of the wetland catchments at streamflow gauges A2H038 and A2H053 showed that with the implementation of rehabilitation measures, flows at the gauges/catchment outlets responded. The results, however, show an increase in the magnitude of high flows and decrease in low flows, which is contradictory to our current knowledge that wetlands increase or maintain baseflows. With the implementation of rehabilitation measures, gauge A2H038 discharge showed an increase in high flows by 2% while low flows, mid-range to dry conditions, were attenuated. Similarly, gauge A2H053 showed that high flows following rehabilitation measures also increased, by 4%, while low flows were attenuated. What is evident from the results is that the rehabilitated wetlands appeared to increase high/flood flows and attenuate low flows. The conclusion is that rehabilitation efforts in both of Kgaswane and Rietfontein systems did not contribute to flow regulation in particular with improvement and maintenance of baseflows, which was evident from both systems. The results indicate that the effect of flow regulation is directly linked to the type of wetland system, e.g. floodplains and headwater wetlands behave differently in terms of providing flow regulation functions as was the case in the two wetland systems assessed. The limitations of these results are as follows:

- The length of flow records after rehabilitation was too short;
- The gradual decrease in rainfall through the period of the rehabilitation activities (lack of both long term wet and dry circles period); and
- Lack of detailed information on hydrological drivers (water balances) of the wetlands.

The assessment is mainly informative to foster adaptive management, progressive learning and continuous improvement of our understanding of the effects of rehabilitation activities. The purpose of the assessment is to provide some direction that can be developed and refined as adequate information becomes available.

6.3 Cost-effectiveness of rehabilitation interventions

Cost-effectiveness of the rehabilitation interventions ranged from intermediate to low; Rietfontein wetland system being intermediate and Kgaswane wetland system being low. Within this range, it could be concluded that the return on investment was low. The functional gains were low at a high investment input, particularly for the Kgaswane wetland system compared to Rietfontein, which was intermediate where there are reasonable functional gains at high investment input. The intention would be to implement high-cost effectiveness projects where return on investment is high, i.e. maximum functional gains at a low cost or expenditure. In cases where this is not achievable, like in the above two projects, a substantiated motivation should be compiled and accompany the planning report of the project. The limitations of the current method of determining the cost-effectiveness of rehabilitation interventions are based on ecological functional gains.

6.4 Recommendations for further studies

The streamflow records after rehabilitation are limited, at the time of writing the report, data available for stream post-rehabilitation was 13 years for Kgaswane and six years for Rietfontein at streamflow gauges A2H038 and A2H053, respectively. To account for climatic variability a longer flow record post-rehabilitation is required. Hydrologically, simulation requires 20 to 30 years' records of data to cover the cycles of entire wet and dry periods (Schulze, 1995). The impacts of climate change and rainfall patterns on wetland hydrological functions can be thoroughly analysed in long-term streamflow data. The study has succeeded in analysing a short-term streamflow record, post-rehabilitation, and provided a platform for further studies for further comparison and discussions.

Groundwater and surface water play a critical role in water balance. Certain wetlands depend on either groundwater or surface water or both as the main drivers of their existence. The study has succeeded in analysing a short-term streamflow record post-rehabilitation focusing on surface flow drivers, and there is a need to undertake a full water balance to determine the contributions of groundwater inputs and how these impact on the results of before and after rehabilitation activities. In South Africa, monitoring and evaluation of wetland rehabilitation projects across various wetland types in different climatic conditions are required. The information could be used to feed into ecological improvements on how rehabilitation projects are planned, designed, budgeted and implemented, and how monitoring and evaluations are conducted. This will lead to learning and adaptation of our systems by reviewing approaches currently used and determining how they might be refined for broader applications. There is also a need to include socio-economic aspects in the equation of cost-effectiveness of rehabilitation interventions. This inclusion will ensure aspects such as poverty, jobs and skills development are considered per project area as part of cost-effectiveness of the project. There is a need to invest in these studies, improve our understanding of responses of different wetland systems and motivation of our investments into such projects.

7. REFERENCES

Acker, J.G. and Leptoukh G. (2007), “Online Analysis Enhances Use of NASA Earth Science Data”, Eos, Trans. AGU, Vol. 88, No. 2 (9 January 2007), pages 14 and 17.

Bailey, A.K., and Pitman, W.V. (2009), Water Resources of South Africa 2005 study (WR2005). WRC Project No K5/1491. Water Research Commission, Pretoria.

Bailey, A.K., and Pitman, W.V. (2015), Water Resources of South Africa 2012 study (WR2012). WRC Project No K5/2143/1. Water Research Commission, Pretoria.

Basson, M.S., Allen, R.B., Pegram, G.G.S., and Van Rooyen, J.A. (1994), Probabilistic Management of Water Resources and Hydropower Systems. Water Resources Publications, Colorado, U.S.A.

BGIS.SANBI.ORG. (2021), *Spatial Datasets - Biodiversity BGIS*. [Online] Available at: http://bgis.sanbi.org/SpatialDataset [Accessed 5 Jul. 2021].

Black D. and Turpie J.K. (2016), Evaluating the cost-effectiveness of ecosystem-based adaptation: Kamiesberg wetlands case study. South African Journal of Economic and Management Sciences 19:702–713.

Brinson, M. M. (1993), A hydrogeomorphic classification for wetlands. Wetlands Research Program Technical Report WRP-DE-4. U. S. Army Corps of Engineers, Waterway Experiment Station. Vicksburg, MS: Bridgham and Richardson.

Browne, M., Gavin F. and Snowball J. (2018), Economic evaluation of wetland restoration: a systematic review of the literature. *Restoration Ecology,* 26 (6), 1120–1126.

Bullock A. and Acreman, M. (2003), The role of wetlands in hydrological cycle. Hydrology and Earth Science Systems, 7 (3), 358–389.

Burt, T.P. (1995), The role of wetlands in runoff generation from headwater catchments. In: *Hydrology and hydrochemistry of British wetlands,* ed., Hughes, J.M.; Heathwaite, A.L. Chichester, UK: Wiley, 21-38.

Cowden, C. and Kotze D.C. (2008), WETRehabEvaluate: Guidelines for the monitoring and evaluation of wetland rehabilitation projects. WRC Report No TT 342/08. Water Research Commission, Pretoria.

Cowden, C., Kotze, D. and Pike, T. (2013), Assessment of the long-term response of two wetlands to WfWet rehabilitation. WRC Report No. 2035/1/13. Water Research Commission, Pretoria.

DEA, 2021. *SA National Land-Cover Datasets*. [Online] Available at: https://egis.environment.gov.za/sa_national_land_cover_datasets# [Accessed 5 Jul. 2021].

Department of Environmental Affairs (2012), 2nd South Africa Environment Outlook. A report on the state of the environment. Department of Environmental Affairs, Pretoria.

Department of Environmental Affairs (2019), Working for Wetlands. Retrieved from: https://www.environment.gov.za/projectsprogrammes/workingfowetlands (Accessed on 13/02/2019).

Department of Environmental Affairs and Tourism (2006), South African Environment Outlook. A Report on the State of Environment. Department of Environmental Affairs and Tourism, Pretoria.

Department of Water and Sanitation (2011), [Online] Available at: https://www.dws.gov.za/Hydrology/Verified/hymain.aspx [Accessed 5 Jul. 2021].

Ellery W.N., Grenfell M., Kotze D.C., McCarthy T.S., Tooth S., Grundling P-L., Beckedahl H., le Maitre D., Ramsay L. (2009), WET-Origins: controls on the distribution and dynamics of wetlands in South Africa. WRC Report No. TT 334/09. Water Research Commission, Pretoria, South Africa.

Grenfell M.C., Ellery W.N., Preston-Whyte R.A. (2005), Wetlands as early warning (eco) systems for water resource management. Water SA 31: 465–472.

Grenfell M.C., Ellery W.N., Garden S.E., Dini J. and Van der Valk A.G. (2007), The language of intervention: a review of concepts and terminology in wetland ecosystem repair. *Water SA,* 33 (1), 43-50.

Huffman, G.J., Adler, R.F., Bolvin, D.T., Gu,G., Nelkin, E.J., Bowman, K.P., Hong, Y., Stocker E.F., Wolff, D.B. (2007), The TRMM Multi-satellite Precipitation Analysis: Quasi-Global, Multi-Year, Combined-Sensor Precipitation Estimates at Fine Scale. J. Hydrometeor., **8**: 38-55.

Hewlett, J.D.; Hibbert, A.R. (1967), Factors affecting the response of small watersheds to precipitation. In: *Forest Hydrology*, ed., Sopper, W.E.; Lull, H.W. Oxford, UK: Pergamon Press, 275-290.

Kadykalo A.N. and Findlay S.C. (2016), The flow regulation services of wetlands. *Ecosystem Services*, 20, 91–103.

Kannan, N. and Jeong, J. (2011), An Approach for Estimating Stream Health Using Flow Duration Curves and Indices of Hydrologic Alteration; Report Prepared for the United States Environmental Protection Agency-Region 6; United States Environmental Protection Agency Office of Water: Dallas, TX, USA.

Kotze, D. (2016a), A method to assess wetland ecological condition based on land-cover type Part 1: The user manual. A simple Citizen Science tool to assess the ecological condition of a wetland. Version 1.4. WRC Project No.K5/2350. Water Research Commission, Pretoria.

Kotze, D. (2016b), A method to assess wetland ecological condition based on land-cover type. Part 2: Technical Background. A simple Citizen Science tool to assess the ecological condition of a wetland. Version 1.4. WRC Project No.K5/2350. Water Research Commission, Pretoria.

Kotze, D.C. and Marneweck, G.C. (1999), Guidelines for delineating the boundaries of a wetland and the zones within a wetland in terms of the South African Water Act. Pretoria: Department of Water Affairs.

Kotze, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S. Collins, N.B. (2008), WET-EcoServices: a technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report No TT 339/08. Water Research Commission, Pretoria.

Kotze, D. C., Tererai, F. and Grundling, P. (2019), Assessing, with limited resources, the ecological outcomes of wetland restoration: a South African case. *Restoration Ecology*, doi:10.1111/rec.12891, 1-9.

Kotze D.C., Ellery W.N., Macfarlane D.M., Jewitt G.P.W. (2012), A rapid assessment method for coupling anthropogenic stressors and wetland ecological condition. Ecological Indicators 13:284–293.

Macfarlane, D.M., Kotze, D.C., Ellery, W. N., Walters, D., Koopman, V., Goodman, P. and Goge, C. (2008), WET-Health: A technique for rapidly assessing wetland health. Water Research Commission. Report No. TT340/09.

Mander, M., Jewitt, G., Dini, J., Glenday, J., Blignaut, J., Hughes, C., Marais, C., Maze, K., van der Waal, B., Anthony Mill, A. (2017), Modelling potential hydrological returns from investing in ecological infrastructure: Case studies from the Baviaanskloof – Tsitsikamma and uMngeni catchments, South Africa. Ecosystem Services, 27: 261–271.

Mandlazi, N.P. (2017), Hydrological characterisation of wetlands: Understanding wetlands-catchment linkages. (Unpublished MSc Thesis). University of the Western Cape, Cape Town, South Africa.

Marneweck, G.C. and Batchelor, A. (2002), Wetland inventory and classification. In: Ecological and economic evaluation of wetlands in the upper Olifants River catchment. (Palmer, R.W., Turpie, J., Marneweck, G.C and Batchelor (eds.). Water Research Commission Report No. 1162/1/02.

Matsapola, J., 2019. *Contact Us data - SAWSWEB-PROD*. [Email].

McCartney, M.; Cai, X.; Smakhtin, V. (2013), *Evaluating the flow regulating functions of natural ecosystems in the Zambezi River Basin*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 59p. (IWMI Research Report 148). doi:10.5337/2013.206

McCulloch, D. (2015). Can the Potential for Tick Infestation Influence Patterns of Resource Use by Eland (*Taurotragus oryx*)? MSc Research Report, University of the Witwatersrand, Johannesburg, South Africa.

Mitch, W. J. and Gosselink, J. G. (2007), Wetlands. Fourth Edition. John Wiley & Sons, New York.

Moreno-Mateos D, Power ME, FA Comı'n, Yockteng R. (2012), Structural and functional loss in restored wetland ecosystems. PLoS Biology 10:e1001247. https://doi.org/10.1371/journal.pbio.1001247

Nel, H.P. (2000), Ecological management objectives and monitoring procedures for Rustenburg Nature Reserve, North West Province. Unpublished MSc. thesis. University of Pretoria, Pretoria.

Nel, J.L. and Driver, A. (2012), National Biodiversity Assessment 2011: Technical Report. Volume 2: Freshwater Component. CSIR Report No. CSIR/NRE/ECO/IR/2012/0022/A. Council for Scientific and Industrial Research, Stellenbosch.

Nel, J.L., Driver, A., Strydom, W.F., Maherry, A., Petersen, C., Hill, L., Roux, D.J., Nienaber, S., van Deventer, H. Swartz, E. and Smith-Adao, L.B. (2011), Atlas of Freshwater Ecosystem Priority Areas in South Africa: Maps to support sustainable development of water resources. Water Research Commission, Gezina. WRC Report No. TT 500/11.

Ntshotsho P, Reyers B, Esler K. (2011), Assessing the evidence base for restoration in South Africa. Restoration Ecology 19:578–586.

Oberholster, P.J., De Klerk, A.R., Cho, M., Crafford, J., De Klerk, L.P., Dini, J.A., Haeeis, K., Holness, S.D., Le Roux, W., Schaefer, L., Truter, J.C., Van Deventer, H. (2016), Assessment of the Ecological Integrity of the Zaalklapspruit wetland in Mpumalanga (South Africa) before and after rehabilitation: The Grootspruit case study. (WRC) Report No. 2230/2/16. Water Research Commission, Pretoria.

Riddell E.S., Lorentz, S.A., Kotze, D.C. (2011), The hydrodynamic response of a semi-arid headwater wetland to technical rehabilitation interventions, *Water SA,* 38 (1), 55-66.

Riddell E.S., Everson, C., Mengistu, M. (2012), The hydrological characterisation and Water budget of a South African rehabilitated headwater wetland system, *Water SA,* 39 (1), 57-66.

Schulze, R.E. (1995) *Hydrology and Agrohydrology – A text to accompany the ACRU 3.00 Agrohydrological modelling system*. WRC Report No. TT 69/95, Water Research Commission, Pretoria, South Africa.

South African National Biodiversity Institute (2006), Rustenburg Rehabilitation Plan Prepared by Land Resource International (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme.

South African National Biodiversity Institute (2009a), Rustenburg Phase 1 Planning Report Prepared by Land Resource International (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme. SANBI Report No. L02218/260309/05.

South African National Biodiversity Institute (2009b), Rustenburg Final Rehabilitation Plan Prepared by Land Resource International (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme. SANBI Report No. L02218/301009/04.

South African National Biodiversity Institute (2010), Final Rehabilitation Plan for Rustenburg. Prepared by Aurecon South Africa (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme. SANBI Report No. 5257/105782.

South African National Biodiversity Institute (2014a), Rehabilitation Plan for the Rustenburg Wetland Project, North West: Planning Year 2014. Prepared by Aurecon South Africa (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme. SANBI Report No. 109664/88224.

South African National Biodiversity Institute (2014b), Rehabilitation Plan for the Rustenburg Wetland Project, North West: Planning Year 2015/2016. Prepared by Aurecon South Africa (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme. Report No. 109664/9592.

SANBI & DWS (2016), Wetland Offsets: A Best-Practice Guideline for South Africa. South African National Biodiversity Institute and the Department of Water Affairs. Pretoria. 69 pages.

Statistics South Africa (2018), Mid-year Population estimates 2018. Retrieve from: http://www.statssa.gov.za/?p=11341. Accessed on 27/04/2019).

Turpie, J.K., Forsythe, K.J., Knowles, A., Blignaut, J., and Letley, G. (2017), Mapping and valuation of South Africa's ecosystem services: A local perspective. *Ecosystem Services*, 27, 179–192.

Thompson, M., Marneweck, G., Bell, S., Kotze, D., Muller, J., Cox, D., and Clark, R. (2002), A pilot project for the determination of methods for the National Wetland Inventory. Department of Environmental Affairs and Tourism, Pretoria.

Yao, Y., Wang, L., Hongxian, L., Xianguo, Y. and Guofu, L. (2014), Changes in Stream Peak Flow and Regulation in Naoli River Watershed as a Result of Wetland Loss. *The Scientific World Journal,* 2014, 1-10.

8. APPENDIX 1: LAND USE BASE PES ASSESSMENT FOR BASELINE ECOLOGICAL INTEGRITY ASSESSMENT FOR KGASWANE WETLAND SYSTEM

8.1 Wetland attribute data

Wetland ID	CATCH_ID	CATCH Size	BUFF Size	EXT Size	WET Size	Quaternary Catch	MAP	PET	MAP:PET	VULN_FACT	WET Set	WETLAND TYPE
UVB1	UVB1	1340.65	206.41	1547.06	113.87	A22H	658	1700	0.4	0.9	Other	UVB
CVB1	CVB1	361.96	151.52	513.48	24.74	A22H	658	1700	0.4	0.9	Other	UVB
CVB2	CVB2	94.92	38.47	133.39	4.61	A22H	658	1700	0.4	0.9	Other	CVB

8.2 The extent of land use within wetlands

	Natural / Minimally impacted	Eroded areas (& heavily degraded land)	Urban Informal	Total Area (ha)
Wetland ID	NATURAL	ERODED	INFORMAL	**AREA_TOT**
UVB1	110.66	1.85	1.36	113.87
CVB1	18.62	5.11	1.01	24.74
CVB2	3.34	1.23	0.04	4.61

8.3 The extent of land use within 200m buffer of wetlands

	Natural / Minimally impacted	Semi-natural	Mining - low risk	Eroded areas (& heavily degraded land)	Urban Informal	Urban Residential – low density	Total Area (ha)
Wetland ID	NATURAL	SEMI_NAT	MINING_L	ERODED	INFORMAL	RESIDENT_L	**AREA_TOT**
UVB1	108.19	88.8	0	1.46	6.77	1.19	206.41
CVB1	141.63	0	0.26	5.48	4.15	0	151.52
CVB2	37.42	0	0	0.2	0.85	0	38.47

8.4 The extent of land use within the wetland catchment

	Natural / Minimally impacted	Semi-natural	Mining - low risk	Eroded areas (& heavily degraded land)	Urban Informal	Urban Residential – low density	Total Area (ha)
CATCH_ID	NATURAL	SEMI_NAT	MINING_L	ERODED	INFORMAL	RESIDENT_L	**AREA_TOT**
UVB1	1093.73	480.17	0.26	37.83	46.77	2.17	1660.93
CVB1	507.41	0	0.26	24.1	6.45	0	538.22
CVB2	130.72	0	0	1.43	5.85	0	138

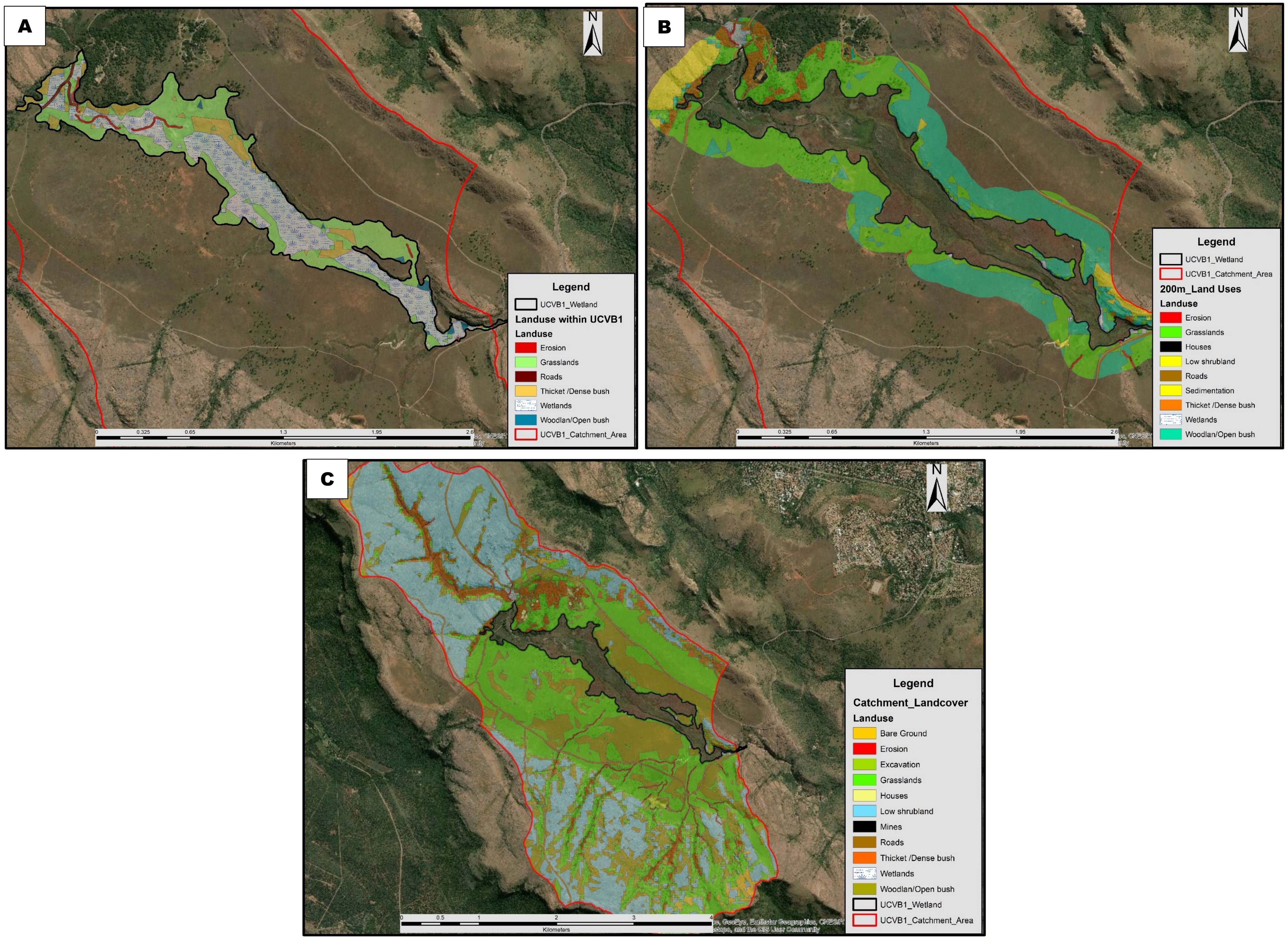
8.5 PES Results

			HYDROLOGY						GEOMORPHOLOGY				WATER QUALITY		VEGETATION
			Catchment impacts					Within-wetland impacts	Geomorphic Processes			Geomorphic Structure	Catchment impacts	Within-wetland impacts	Within-wetland impacts
			Quantity of water inputs	Seasonality of inputs	Peak flow change	*Adjusted peak flow change*	*The overall change in water inputs*	Water distribution and retention	Change in sediment inputs	Sediment distribution and retention	*The overall change in geomorphic processes score*	Change in the geomorphic template	External water quality impacts	Within-wetland water quality	Vegetation impact score
Wetland ID	CATCH_ID	WETLAND TYPE	HYDRO_MAR	HYDRO_SEAS	HYDRO_PEA1	*HYDRO_PEAK*	*HYDRO_EXT*	HYDRO_WET	GEO_SEDEXT	GEO_SEDWET	*GEO_PROC*	GEO_STRUCT	WQ_EXT	WQ_WET	VEG_WET
UVB1	UVB1	UVB	0.1	0.5	0.9	0.4	1.0	0.2	1.3	0.2	1.5	0.2	0.8	0.5	1.2
CVB1	CVB1	UVB	0.1	0.1	0.3	0.1	0.3	1.7	0.9	1.6	2.4	2.0	0.6	1.1	3.0
CVB2	CVB2	CVB	0.1	0.1	0.3	0.1	0.3	1.9	0.7	1.9	2.5	2.2	0.7	0.9	3.2

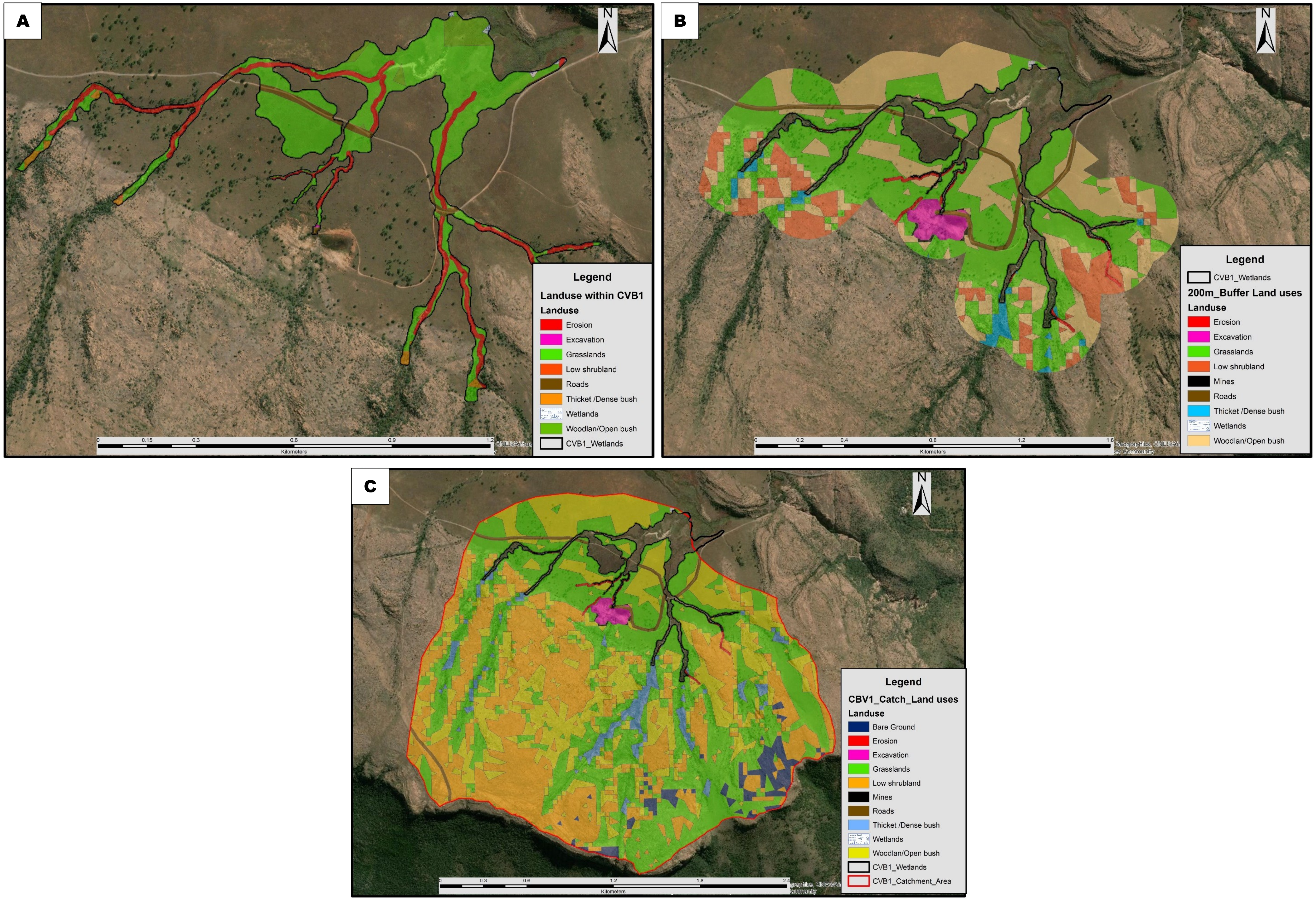
8.6 PES Summary of Results

Wetland ID	**Wetland area (Ha)**	**HYDROLOGY**			**GEOMORPHOLOGY**			**WATER QUALITY**			**VEGETATION**			**OVERALL CONDITION**			**HECTARE EQUIVALENTS (based on Overall PES)**
		Impact Score	PES Score (%)	Ecological Category	Impact Score	PES Score (%)	Ecological Category	Impact Score	PES Score (%)	Ecological Category	Impact Score	PES Score (%)	Ecological Category	Combined Impact Score	Overall PES Score (%)	Combined Ecological Category	
Wetland ID	WET_AREA	IMPACT_HYD	PES_HYDRO	EC_HYDRO	IMPACT_GEO	PES_GEO	EC_GEO	IMPACT_WQ	PES_WQ	EC_WQ	IMPACT_VEG	PES_VEG	EC_VEG	IMPACT_ALL	PES_ALL	EC_ALL	HA_EQUIV
UVB1	113.9	1.1	88.7	B	0.8	91.5	A	1.3	87.2	B	1.2	87.7	B	1.1	88.8	B	101.72
CVB1	24.7	2.0	79.8	C	2.2	78.3	C	1.6	84.2	B	3.0	70.2	C	2.2	78.3	C	19.16
CVB2	4.6	2.1	78.6	C	2.3	76.7	C	1.6	84.5	B	3.2	68.0	C	2.3	77.1	C	3.75

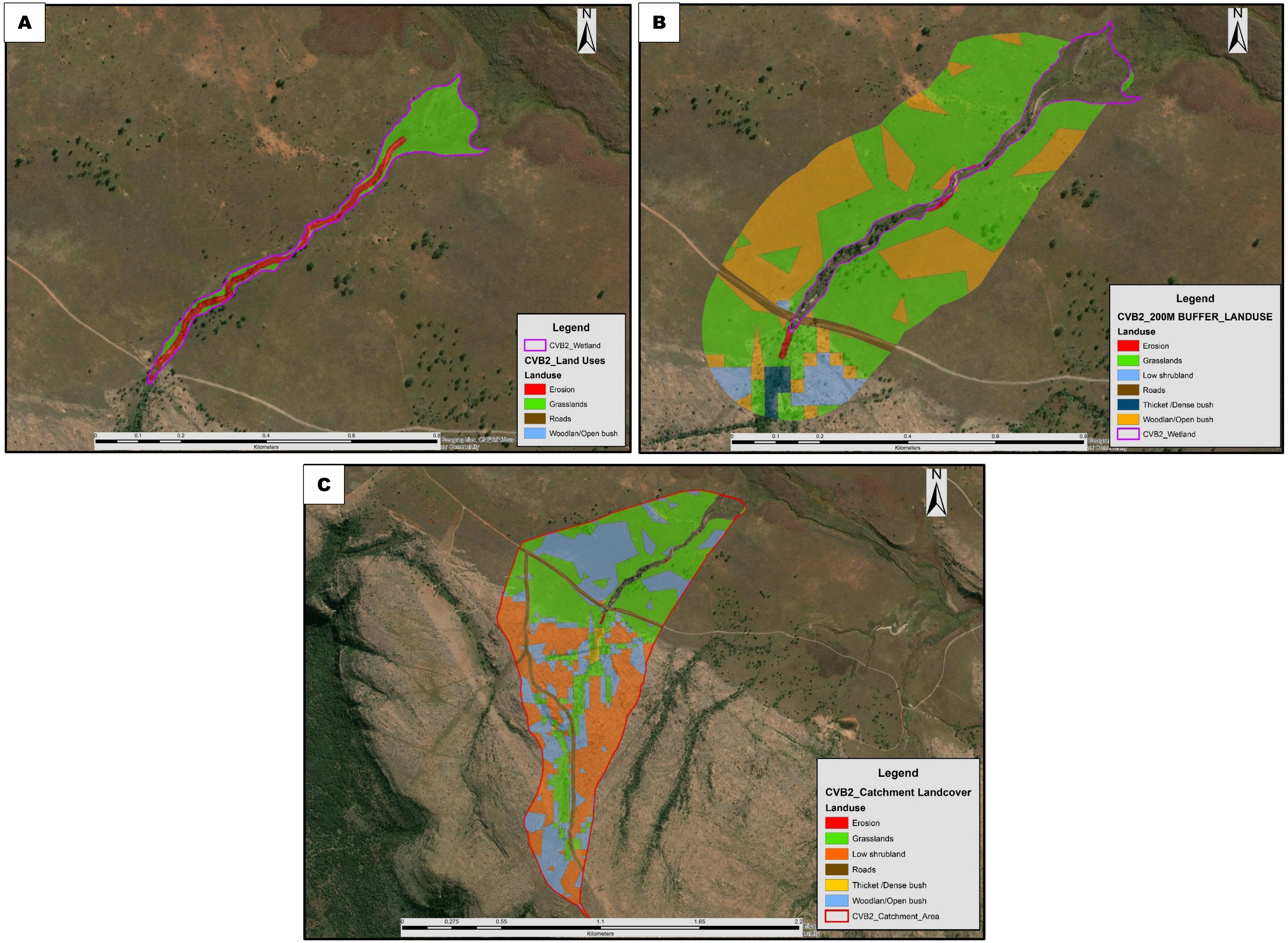
9. APPENDIX 2: MAPS INDICATING LAND USES EXTENT WITHIN THE WETLANDS, 200M BUFFER AND BROADER WETLAND CATCHMENT



9.1 Kgaswane UCVB1 wetland land uses - land-uses within wetland (A), within 200m buffer (B) and the wetland catchment(C).



9.2 Kgaswane CVB1 wetland land uses - land uses within wetland (A), within 200m buffer (B) and the wetland catchment (C).



10. APPENDIX 3: WET-HEALTH IMPACT ASSESSMENT TABLES POST REHABILITATION ACTIVITIES

10.1 Kgaswane UCVB1 wetland health impact assessment table

10.1.1 Hydrology

Changes to water input characteristics as one of the hydrological drivers from the catchment

Nature of Alteration	Intensity Class	Alteration Class Score	Land-use factors contributing to hydrological impacts
Changes in water inputs	Small	-1	• There is limited water abstraction for domestic use at stream gauge A2H039, • Stormwater inputs to the wetland are expected to slightly increase as a result of the road crossing in the wetland. • A slight change in flood pattern is expected within the wetland with attenuation capacity provided by reed bed in the central valley bottom system
Change in flood patterns (peaks)	Small Increase	2	
Magnitude of impact Score	Increase	**1.0**	

Evaluate changes to water distribution & retention patterns within the wetland

	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to hydrological impacts
Gullies and artificial drainage channels present	1	2	0.02	• Although rehabilitation has taken place on wetlands, there are still signs of incision and channelling in a specific part of the wetland system. Sediments built up upstream of each intervention have not yet silted the entire incision instream. • The major part of the system is well covered by vegetation except for the areas upstream and downstream of the structures where sediments are exposed with limited vegetation cover. Some of the channels consist of exposed bare soil and sediments with limited vegetation cover. • There are no dams present in the systems; however, the presence of rehabilitation structures instream provide an opportunity for flow impediments. • The road crossing also provides opportunities for impediment and impoundment of flow upstream. • Sediment deposition has been identified in various places particularly upstream of impediment structures (weirs and roads).
Modifications to existing channels	0	0	0	
Reduced roughness	3	5	0.15	
Impeding features (e.g. dams) – upstream effects	2	3	0.06	
Impeding features – downstream effects	2	3	0.06	
Increased on-site water use	2	3	0.06	
Deposition/infilling or excavation	5	3	0.15	
Combined impact Score			**0.5**	

10.1.2 Geomorphology

The present geomorphic state of individual HGM units

Impact type	Applicability to HGM type	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to geomorphological impacts
Diagnostic component					
(1) Upstream dams	Floodplain	2	3	0.1	• There are no dams present in the wetland system; however, the presence of instream streamflow gauges provides an opportunity for flow impediments at the weirs. • The road crossing also provides opportunities for the impediment of flow and damming upstream as the flow passes through culverts.
(3) Infilling	Floodplain, Channelled VB	3	5	0.2	• Part of the wetland is impacted by road crossing, sediment deposition and infilling as well houses built for use by the Reserve. • These activities do not appear to be actively impacting in the wetland as their intensities are relatively low.
(4) Increased runoff	Non-floodplain HGMs	2	5	0.1	• Stormwater associated with the road crossing and houses at various points of the wetland system is expected to increase flow slightly
Indicator-based component					
(5) Erosional features	All non-floodplain HGMs	1	5	0.1	• Interventions constructed on a wetland on site appear to have halted erosion to some degree; however, there are a few areas where sediments upstream of interventions have not yet masked the entire incised areas. • The intensities of these activities have significantly reduced as a result of the implemented interventions.
(6) Depositional features	All non-floodplain HGMs	10	3	0.3	• Sediment deposition was recorded at various areas where there is some level of flow impediments and where the slope is more gentle and velocities of water relatively slow.
Combined Impact Score based on a sum of all magnitude scores				**0.3**	

10.1.3 Vegetation

Disturbance Class	Extent (%)	Intensity (0 - 10)	Magnitude	Additional Notes
Infrastructure	0.8	10	0.1	• Related to road construction and traverses wetland at various points, streamflow gauges within the wetland and the Nature Reserve's houses particularly at the upper reaches of the wetland system.
Shallow flooding by dams	5	6	0.3	• No dams present on site, however, roads traversing wetland, instream structures (weirs) and rehabilitation structures constructed within wetland provide opportunities of shallow flooding similar to the dams
Dense Alien vegetation patches.	2	7	0.1	• There are areas along the margins of the wetlands consisting of bare soil due to grazing and trampling by game • There are also patches of weeds due to grazing on site
Areas of sediment deposition/ infilling & excavation	2	8	0.2	• Sediment deposition was recorded at various areas where there is some Level of flow impediment and where the slope is more gentle and velocities of water relatively slow. • Part of the wetland is impacted by road crossings, sediment deposition and infilling as well houses build for use by the Reserve. • These activities do not appear to be actively impacting on the wetland and their intensities are relatively low.

Disturbance Class	Extent (%)	Intensity (0 - 10)	Magnitude	Additional Notes
Eroded areas	2	7	• 0.1	• Interventions constructed on a wetland on site appear to have halted erosion to some degree; however, there are few areas where sediments upstream of interventions have not yet masked the entire incised areas. • The intensities of these activities have significantly reduced as a result of the implemented interventions.
Overall weighted impact score			**0.8**	

10.2 Kgaswane CVB1 wetland health impact assessment table

10.2.1 Hydrology

__Changes to water input characteristics from the catchment__

Nature of Alteration	Intensity Class	Alteration Class Score	Land-use factors contributing to impacts, and any additional notes
Changes in water inputs	Moderately small	-1	• A negligible reduction in flow, the upper catchment areas of the wetland consist of indigenous vegetation and trees around the ridges and rocky outcrops. • Indigenous vegetation tends not to abstract a lot of water as compared to invasive species. • There is a slight increase in flood peaks, as evident in incised channels and erosion in the receiving wetlands. • The ridges and exposed rocks upslope of wetlands have also contributed to the increase in velocities of water draining into the wetlands downstream.
Change in flood patterns (peaks)	Small Increase	3	
Magnitude of impact Score	No effects	**1.0**	

__Changes to water distribution & retention patterns within the wetland__

	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to impacts, and any additional notes
Gullies and artificial drainage channels	7	5	0.35	• Although rehabilitation has taken place on wetlands, there are still signs of incision and channelling in a specific part of the wetland system. Sediments built up upstream of each intervention have not yet musk the entire incision instream. • Majority of the system is well covered by vegetation except for the areas upstream and downstream of the structures where sediments are exposed with limited vegetation cover. Some of the channels consist of exposed bare soil and sediments with limited vegetation cover. • There are no dams present in the systems; however, the present of rehabilitation structures instream provide an opportunity for the flow impediments. • The road crossing also provides opportunities for impediment and impoundment of flow upstream. • Sediment deposition has been identified in various places particular upstream of impediment structures (weirs and roads).
Reduced roughness	20	5	1	
Impeding features (e.g. dams) – upstream effects	3	5	0.15	
Deposition/infilling or excavation	7	5	0.35	
Combined impact Score			**1.9**	

10.2.2 Geomorphology

Impact type	Applicability to HGM type	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to impacts, and any additional notes
Diagnostic component					
(1) Upstream dams	Floodplain	3	5	0.2	• There are no dams present within the wetland system. However, the present of rehabilitation structures instream provides an opportunity for flow impediments and impoundment. • The road crossing also provides opportunities for the impediment of flow upstream.
(3) Infilling	Floodplain, Channelled VB	7	5	0.4	• Relates to areas constructed with road and rehabilitation where there has been infilling of the wetland areas during construction of these features.
(4) Increased runoff	Non-floodplain HGMs	3	5	0.2	• Stormwater associated with the road traversing wetland at various points. The ridges upstream due to slopes and exposed rocks also contribute to an increase in surface flow and runoff to the wetland. The extent of erosion in receiving wetland is evident on site.
Indicator-based component					
(5) Erosional features	All non-floodplain HGMs	7	5	0.4	• Interventions constructed on a wetland on site appears to have halted erosion to some degree although there are few areas where sediments upstream of interventions have not yet musk the entire incised areas. • The intensities of these activities have significantly reduced as a result of the implemented interventions.
(6) Depositional features	All non-floodplain HGMs	4	5	0.2	• Sediment deposition has been identified in various places particular upstream of impediment structures (rehabilitation weirs and roads).
Combined Impact Score based on a sum of all magnitude scores				**0.6**	

10.2.3 Vegetation

Disturbance Class	Extent (%)	Intensity (0 - 10)	Magnitude	Additional Notes
Infrastructure	3	10	0.3	• Related to Roads construction traverses wetland at various points.
Shallow flooding by dams	2	6	0.1	• No dams present on site, however, roads traversing wetland and rehabilitation structures constructed within wetland provide opportunities of shallow flooding similar to the dams
Dense Alien vegetation patches.	5	7	0.4	• There are areas along the margins of the wetlands that consist of bare soil due to grazing and trampling by game • There are also patches of weeds due to grazing on site
Areas of sediment deposition/ infilling & excavation	13	8	1.0	• Sediment deposition was recorded at various areas where there is some Level of flow impediments and where the slope is more gently and velocities of water relatively slow. • Part of the wetland is impacted by road crossing, sediment deposition and infilling. • These activities do not appear to be actively impacting in the wetland their intensities are relatively low.
Eroded areas	7	7	0.5	• Interventions constructed on a wetland on site appear to have halted erosion to some degree; however, there are few areas where sediments upstream of interventions have not yet masked the entire incised areas. • The intensities of these activities have significantly reduced as a result of the implemented interventions.
Overall weighted impact score			**2.3**	

10.3 Rietfontein CVB1 wetland health impact assessment table

10.3.1 Hydrology

Changes to water input characteristics from the catchment

Nature of Alteration	Intensity Class	Alteration Class Score	Land-use factors contributing to hydrological impacts
Changes in water inputs	Moderately small	-2	• Excessive water abstraction for domestic and irrigation use at A21K-01 wetland systems with borehole pump recorded within the wetland on site. • Stormwater inputs to the wetland are expected to slightly increase as a result of the road crossing in the wetland as well as expected return flows from irrigation activities within the broader wetland catchment. • Slightly decrease in flood patterns is expected as a result of the streamflow reduction activities present on site that abstract water instream that would have resulted in a primarily increase in flood patterns.
Change in flood patterns (peaks)	Small Increase	-1	
Magnitude of impact Score	No effects	**2.5**	

Changes to water distribution & retention patterns within the wetland

	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to the hydrological impacts
Gullies and artificial drainage channels	3	5	0.15	• Although rehabilitation has taken place, there are still massive signs of incision and channelling in a specific part of the wetland system particular below road crossing and upstream and downstream of impeding infrastructures. In some areas, erosion has reached bedrock and exposed rock section of the stream is observed. • Majority of the system is well covered by vegetation except for the areas upstream and downstream of the rehabilitation structures, roads where sediments are exposed with limited vegetation cover and including bare exposed rock areas where erosion have reached the river bed. • No dams present within the assessed wetland systems; however, the presence of road crossings and rehabilitation instream structures provide an opportunity for flow impediments within the wetland area. • There is excessive water abstraction within A21K-01 wetland system, pumps and boreholes sumps at various points were recorded within the wetland systems. However, this activity now appeared to be discontinued and undertaken on an occasional basis. • Sediment deposition has been identified in various places particular upstream of impediment structures (weirs and roads). However, the intensity of these is expected to be low with the implementation of various wetland rehabilitation interventions on site.
Reduced roughness	6	7	0.42	
Impeding features (e.g. dams) – upstream effects	3	5	0.15	
Impeding features (e.g. dams) – downstream effects	2	5	0.1	
Increased on-site water use	2	5	0.1	
Deposition/infilling or excavation	15	7	1.05	
Combined impact Score			**2.2**	

10.3.2 Geomorphology

Impact type	Applicability to HGM type	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to geomorphological impacts
Diagnostic component					
(1) Upstream dams	Floodplain	3	5	0.2	• No dams present within the assessed wetland systems; however, the presence of road crossings and rehabilitation instream structures provide an opportunity for flow impediments within the wetland area.
(3) Infilling	Floodplain, Channelled VB	5	5	0.3	• Part of the wetland area is impacted by road crossing, sediment deposition and infilling as well actively planted cultivation plots within the wetland systems.
(4) Increased runoff	Non-floodplain HGMs	3	7	0.4	• Water abstraction for domestic use in the form of boreholes upper reaches of A21K-01 wetland systems is expected to reduce runoff to some extent; however, stormwater inputs to the wetland are expected to slightly increase as a result of the road crossings at various points and return flow from irrigation in the broader catchment. Flood patterns are likely to be reduced with the presence of streamflow reduction activities (alien vegetation) which uses a high volume of water that may have increased flow and flood patterns.
Indicator-based component					
(5) Erosional features	All non-floodplain HGMs	7	7	0.4	• Interventions constructed on a wetland on site appear to have halted erosion to some degree; however, there is still excessive erosion remaining within the wetland areas on site, and these impacts possess threads to the implemented interventions.

Impact type	Applicability to HGM type	Extent (%)	Intensity (0 - 10)	Magnitude	Land-use factors contributing to geomorphological impacts		
Diagnostic component							
(6) Depositional features	All non-floodplain HGMs	15	7	1.1	• Sediment deposition recorded at various areas where there is some Level of flow impediments and where the slope is more gently and velocities of water relatively slow. The cultivated fields also indicated sedimentation.		
Combined Impact Score based on a sum of all magnitude scores				**1.1**			

10.3.3 Vegetation

Disturbance Class	Extent (%)	Intensity (0 - 10)	Magnitude	Additional Notes
Infrastructure	3	10	0.3	• It is related to Roads construction and traverses wetland at various points, instream wetland rehabilitation structures and houses built within wetlands and riparian areas.
Shallow flooding by dams	3	6	0.2	• No dams present on site, however, roads traversing wetland, instream structures (weirs) particular rehabilitation structures constructed within wetland provide opportunities of shallow flooding similar to the dams.
Croplands	10	9	0.9	• The valley bottom section of the river reach where wetland and riparian areas occur is highly utilised for agricultural use, including various cultivation plots along the river reach for the crop the production purposes.
Dense Alien vegetation patches.	15	7	1.1	• It is related to the alien vegetation invasive including Populus and Eucalyptus species dominating the central part of the wetland and riparian areas on site.
Areas of sediment deposition/ infilling & excavation	10	8	0.8	• Related to sediment deposition upstream of the rehabilitation structures and weirs and other infrastructure (roads) recorded on site
Eroded areas	15	7	1.1	• Interventions constructed on a wetland on site appear to have halted erosion to some degree; however, there is still excessive erosion remaining within the wetland areas on site, and these impacts possess threads to the implemented interventions.
Overall weighted impact score			**4.3**	

11. APPENDIX 4: STREAMFLOW RECORDS FOR GAUGE A2H038 FROM 1990 TO 2018 (SOURCE: DWS HYDROLOGICAL SERVICES)

Q (Mm³/a) - A2H038

Year	October	November	December	January	February	March	April	May	June	July	August	September
1989/1990	0.100	0.144	0.104	0.170	0.122	0.250	0.258	0.241	0.173	0.154	0.125	0.104
1990/1991	0.082	0.046	0.096	0.205	0.640	1.390	0.474	0.297	0.250	0.194	0.147	0.126
1991/1992	0.117	0.072	0.099	0.057	0.032	0.030	0.032	0.033	0.035	0.038	0.045	0.038
1992/1993	0.027	0.051	0.055	0.159	0.153	0.146	0.116	0.096	0.084	0.084	0.084	0.075
1993/1994	0.128	0.097	0.089	0.362	0.922	0.572	0.344	0.247	0.175	0.133	0.113	0.080
1994/1995	0.067	0.063	0.044	0.043	0.037	0.345	0.242	0.225	0.152	0.140	0.123	0.109
1995/1996	0.083	0.332	0.948	0.437	1.870	0.764	0.476	0.366	0.293	0.225	0.179	0.152
1996/1997	0.229	0.161	0.120	0.426	0.264	1.050	0.935	0.832	0.605	0.403	0.356	0.269
1997/1998	0.163	0.159	0.121	0.516	0.382	0.477	0.282	0.223	0.197	0.184	0.164	0.121
1998/1999	0.109	0.126	0.558	0.342	0.255	0.200	0.279	0.232	0.180	0.164	0.137	0.116
1999/2000	0.100	0.096	0.137	1.190	0.215	0.371	0.262	0.215	0.155	0.139	0.155	0.125
2000/2001	0.196	0.112	0.135	0.287	0.260	0.374	0.275	0.221	0.168	0.137	0.124	0.113
2001/2002	0.193	0.341	0.532	0.268	0.228	0.167	0.118	0.120	0.129	0.147	0.081	0.069
2002/2003	0.058	0.046	0.056	0.091	0.104	0.117	0.083	0.073	0.091	0.095	0.094	0.079
2003/2004	0.091	0.118	0.053	0.397	0.345	0.483	0.285	0.184	0.149	0.130	0.106	0.083
2004/2005	0.078	0.029	0.049	0.094	0.089	0.074	0.176	0.104	0.097	0.091	0.076	0.060
2005/2006	0.041	0.042	0.044	0.305	1.300	0.566	0.309	0.216	0.173	0.153	0.163	0.107
2006/2007	0.069	0.116	0.074	0.081	0.048	0.037	0.047	0.049	0.065	0.050	0.043	0.014
2007/2008	0.087	0.076	0.153	0.437	0.515	0.747	0.373	0.270	0.198	0.163	0.132	0.098
2008/2009	0.073	0.071	0.063	0.331	0.224	0.347	0.204	0.184	0.162	0.130	0.140	0.093
2009/2010	0.095	0.098	0.185	0.656	0.374	0.338	0.779	0.976	0.415	0.320	0.221	0.146
2010/2011	0.084	0.115	0.597	2.530	0.625	0.716	0.433	0.494	0.441	0.352	0.269	0.190
2011/2012	0.168	0.168	0.476	0.329	0.236	0.237	0.212	0.167	0.148	0.143	0.126	0.154
2012/2013	0.135	0.088	0.098	0.207	0.207	0.145	0.159	0.134	0.114	0.109	0.098	0.081
2013/2014	0.098	0.049	0.106	0.263	1.510	1.500	0.551	0.392	0.329	0.280	0.207	0.151
2014/2015	0.111	0.114	0.107	0.102	0.063	0.067	0.059	0.056	0.058	0.062	0.060	0.081
2015/2016	0.044	0.029	0.020	0.019	0.002	0.018	0.063	0.080	0.019	0.095	0.012	0.061
2016/2017	0.056	0.088	0.098	0.248	0.129	0.288	0.208	0.176	0.149	0.137	0.116	0.098
2017/2018	0.093	0.099	0.169	0.397	0.375	0.365	0.256	0.230	0.171	0.154	0.122	0.098

12. APPENDIX 5: STREAMFLOW RECORDS FOR GAUGE A2H053 FROM 1990 TO 2018 (SOURCE: DWS HYDROLOGICAL SERVICES)

Q (Mm^3/a) - A2H053

Year	October	November	December	January	February	March	April	May	June	July	August	September
1989/1990	0.128	0.415	0.298	0.714	1.010	0.755	0.718	0.697	0.415	0.371	0.304	0.251
1990/1991	0.165	0.156	0.310	0.423	1.600	4.300	1.380	0.834	0.651	0.531	0.373	0.276
1991/1992	0.211	0.189	0.113	0.094	0.008	0.012	0.009	0.018	0.054	0.073	0.073	0.038
1992/1993	0.026	0.211	0.939	0.232	0.179	0.183	0.099	0.082	0.079	0.090	0.094	0.062
1993/1994	0.241	0.262	0.155	0.483	2.060	0.620	0.370	0.234	0.221	0.232	0.158	0.122
1994/1995	0.064	0.061	0.067	0.201	0.241	1.820	0.958	0.579	0.346	0.303	0.254	0.175
1995/1996	0.151	0.714	3.850	2.060	4.230	1.700	0.121	0.814	0.897	0.716	0.614	0.416
1996/1997	0.423	0.592	1.300	1.560	0.760	9.410	4.350	3.890	2.660	1.340	1.330	1.270
1997/1998	0.924	0.603	0.531	1.660	0.751	0.695	0.490	0.397	0.378	0.375	0.344	0.272
1998/1999	0.225	0.773	1.540	0.874	0.519	0.365	0.354	0.460	0.393	0.243	0.306	0.303
1999/2000	0.121	0.101	0.455	1.300	10.900	4.450	2.880	2.080	1.490	0.796	0.886	0.716
2000/2001	0.764	0.749	0.986	0.409	0.635	1.130	0.764	1.120	0.606	0.594	0.478	0.424
2001/2002	0.641	1.010	1.330	0.664	1.060	0.646	0.392	0.334	0.410	0.317	0.299	0.217
2002/2003	0.174	0.124	0.179	0.345	0.399	0.286	0.163	0.136	0.086	0.138	0.116	0.083
2003/2004	0.192	0.126	0.134	0.118	1.230	1.720	0.689	0.462	0.397	0.353	0.315	0.237
2004/2005	0.013	0.131	0.397	2.870	0.675	0.918	1.120	0.340	0.450	0.365	0.260	0.208
2005/2006	0.124	0.482	0.570	2.650	5.310	2.660	1.570	0.991	0.709	0.605	0.565	0.404
2006/2007	0.315	0.569	0.556	0.539	0.207	0.194	0.248	0.275	0.408	0.277	0.149	0.102
2007/2008	0.501	0.269	0.552	2.030	2.180	2.300	1.460	1.080	0.783	0.613	0.464	0.325
2008/2009	0.273	1.530	0.498	2.960	3.220	2.460	1.350	1.150	0.962	0.729	0.692	0.439
2009/2010	0.473	0.601	1.590	3.460	2.110	1.370	2.370	3.610	0.601	0.894	0.869	0.583
2010/2011	0.338	0.420	3.030	5.750	3.050	3.770	2.780	1.960	1.850	1.280	1.110	0.735
2011/2012	0.612	0.703	1.040	0.779	0.611	0.570	0.549	0.406	0.156	0.356	0.296	0.318
2012/2013	0.478	0.403	0.702	0.783	0.521	0.297	0.536	0.344	0.281	0.262	0.223	0.166
2013/2014	0.134	0.265	0.706	0.308	2.390	4.790	1.570	0.967	0.711	0.583	0.505	0.362
2014/2015	0.363	0.345	0.843	0.760	0.301	0.637	0.327	0.229	0.226	0.232	0.201	0.226
2015/2016	0.124	0.077	0.060	0.067	0.036	1.320	0.158	0.300	0.187	0.228	0.206	0.128
2016/2017	0.086	0.137	0.136	3.830	4.660	2.440	1.220	0.819	0.588	0.491	0.365	0.116
2017/2018	0.248	0.468	0.959	0.066	0.193	1.010	0.604	0.378	0.281	0.262	0.223	0.209

13. APPENDIX 6: PRE- AND POST-REHABILITATION STREAMFLOW RECORDS FOR GAUGE A2H038 USED FOR THE ASSESSMENT

Pre-Rehabilitation streamflow data - A2H038 (Mm^3/a)

Year	October	November	December	January	February	March	April	May	June	July	August	September
1990/1991	0.082	0.046	0.096	0.205	0.640	1.390	0.474	0.297	0.250	0.194	0.147	0.126
1991/1992	0.117	0.072	0.099	0.057	0.032	0.030	0.032	0.033	0.035	0.038	0.045	0.038
1992/1993	0.027	0.051	0.055	0.159	0.153	0.146	0.116	0.096	0.084	0.084	0.084	0.075
1993/1994	0.128	0.097	0.089	0.362	0.922	0.572	0.344	0.247	0.175	0.133	0.113	0.080
1994/1995	0.067	0.063	0.044	0.043	0.037	0.345	0.242	0.225	0.152	0.140	0.123	0.109
1995/1996	0.083	0.332	0.948	0.437	1.870	0.764	0.476	0.366	0.293	0.225	0.179	0.152
1996/1997	0.229	0.161	0.120	0.426	0.264	1.050	0.935	0.832	0.605	0.403	0.356	0.269
1997/1998	0.163	0.159	0.121	0.516	0.382	0.477	0.282	0.223	0.197	0.184	0.164	0.121
1998/1999	0.109	0.126	0.558	0.342	0.255	0.200	0.279	0.232	0.180	0.164	0.137	0.116
1999/2000	0.100	0.096	0.137	1.190	0.215	0.371	0.262	0.215	0.155	0.139	0.155	0.125
2000/2001	0.196	0.112	0.135	0.287	0.260	0.374	0.275	0.221	0.168	0.137	0.124	0.113
2001/2002	0.193	0.341	0.532	0.268	0.228	0.167	0.118	0.120	0.129	0.147	0.081	0.069
2002/2003	0.058	0.046	0.056	0.091	0.104	0.117	0.083	0.073	0.091	0.095	0.094	0.079

Post-Rehabilitation streamflow data - A2H038 (Mm^3/a)

Year	October	November	December	January	February	March	April	May	June	July	August	September
2005/2006	0.041	0.04	0.044	0.305	1.300	0.566	0.309	0.216	0.173	0.153	0.163	0.107
2006/2007	0.069	0.12	0.074	0.081	0.048	0.037	0.047	0.049	0.065	0.050	0.043	0.014
2007/2008	0.087	0.08	0.153	0.437	0.515	0.747	0.373	0.270	0.198	0.163	0.132	0.098
2008/2009	0.073	0.07	0.063	0.331	0.224	0.347	0.204	0.184	0.162	0.130	0.140	0.093
2009/2010	0.095	0.10	0.185	0.656	0.374	0.338	0.779	0.976	0.415	0.320	0.221	0.146
2010/2011	0.084	0.12	0.597	2.530	0.625	0.716	0.433	0.494	0.441	0.352	0.269	0.190
2011/2012	0.168	0.17	0.476	0.329	0.236	0.237	0.212	0.167	0.148	0.143	0.126	0.154
2012/2013	0.135	0.09	0.098	0.207	0.207	0.145	0.159	0.134	0.114	0.109	0.098	0.081
2013/2014	0.098	0.05	0.106	0.263	1.510	1.500	0.551	0.392	0.329	0.280	0.207	0.151
2014/2015	0.111	0.11	0.107	0.102	0.063	0.067	0.059	0.056	0.058	0.062	0.060	0.081
2015/2016	0.044	0.03	0.020	0.019	0.002	0.018	0.063	0.080	0.019	0.095	0.012	0.061
2016/2017	0.056	0.09	0.098	0.248	0.129	0.288	0.208	0.176	0.149	0.137	0.116	0.098
2017/2018	0.093	0.10	0.169	0.397	0.375	0.365	0.256	0.230	0.171	0.154	0.122	0.098

14. APPENDIX 7: PRE- AND POST-REHABILITATION STREAMFLOW RECORDS FOR GAUGE A2H053 USED FOR THE ASSESSMENT

Pre-Rehabilitation streamflow data - A2H053 (Mm^3/a)

Year	October	November	December	January	February	March	April	May	June	July	August	September
2005/2006	0.124	0.482	0.570	2.650	5.310	2.660	1.570	0.991	0.709	0.605	0.565	0.404
2006/2007	0.315	0.569	0.556	0.539	0.207	0.194	0.248	0.275	0.408	0.277	0.149	0.102
2007/2008	0.501	0.269	0.552	2.030	2.180	2.300	1.460	1.080	0.783	0.613	0.464	0.325
2008/2009	0.273	1.530	0.498	2.960	3.220	2.460	1.350	1.150	0.962	0.729	0.692	0.439
2009/2010	0.473	0.601	1.590	3.460	2.110	1.370	2.370	3.610	0.601	0.894	0.869	0.583
2010/2011	0.338	0.420	3.030	5.750	3.050	3.770	2.780	1.960	1.850	1.280	1.110	0.735

Post-Rehabilitation streamflow data - A2H053 (Mm^3/a)

Year	October	November	December	January	February	March	April	May	June	July	August	September
2012/2013	0.478	0.403	0.702	0.783	0.521	0.297	0.536	0.344	0.281	0.262	0.223	0.166
2013/2014	0.134	0.265	0.706	0.308	2.390	4.790	1.570	0.967	0.711	0.583	0.505	0.362
2014/2015	0.363	0.345	0.843	0.760	0.301	0.637	0.327	0.229	0.226	0.232	0.201	0.226
2015/2016	0.124	0.077	0.060	0.067	0.036	1.320	0.158	0.300	0.187	0.228	0.206	0.128
2016/2017	0.086	0.137	0.136	3.830	4.660	2.440	1.220	0.819	0.588	0.491	0.365	0.116
2017/2018	0.248	0.468	0.959	0.066	0.193	1.010	0.604	0.378	0.281	0.262	0.223	0.209

15. APPENDIX 8: RAINFALL RECORDS FOR THE PERIOD BETWEEN 1990 AND 2018 – RAINFALL GAUGE WATERKLOOF (05115246)

05115246 - WATERKLOOF

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1990	94.2	91.8	178.5	133.1	9.8	0	2.1	0.4	15.7	29.8	28.8	121.9	706.10
1991	100.3	110.6	135.9	0.1	2.1	9.8	0	0	5	92	40.7	66.9	563.40
1992	24.8	43.9	37.3	19	0	2	0	11.5	0	20.5	135.1	121.2	415.30
1993	73	130.8	46.1	21	0	0.1	0	0.1	8.7	160.6	92.5	85	617.90
1994	187.5	136.1	29.8	23.3	3.5	0	0	0	0	49.9	21.1	61	512.20
1995	80.5	75.4	240.9	38.5	27.9	0	0	2	8.1	62.9	174.6	210	920.80
1996	143.3	234.5	82.5	46.5	7.1	0	0	6.4	4.3	100.1	109.7	61.3	795.70
1997	180.7	36.1	276.7	0	135.9	0	4.5	4.2	57	22.2	78.3	59.5	855.10
1998	196.7	83.7	71.9	0	0	0	0	0	20.1	54.8	221.3	268.5	917.00
1999	73.5	35.8	48.4	97	37.3	1.1	8	0.1	1.7	48	52.6	163.6	567.10
2000	147.07	303.33	153.09	28.35	16.77	8.04	1.82	0.85	29.02	135.86	91.09	126.25	1041.55
2001	30.03	94.95	67.68	44.11	56.52	4.64	0.08	2.29	12.79	119.48	154.35	90.58	677.50
2002	80.24	82.80	28.46	15.07	43.53	5.79	0.52	21.43	1.29	42.74	16.62	92.05	430.54
2003	89.59	101.52	48.22	3.65	0.01	2.91	0.08	2.00	0.95	87.42	117.71	56.15	510.20
2004	125.27	134.93	84.36	33.54	0.08	4.55	2.27	1.08	0.22	39.08	49.83	119.20	594.42
2005	149.04	75.94	54.73	91.81	1.28	0.00	0.03	0.24	0.73	6.01	83.75	96.75	560.29
2006	225.95	198.94	83.20	16.59	2.60	2.78	0.63	31.62	1.43	38.25	92.78	105.34	800.11
2007	65.44	37.60	13.85	39.00	0.13	25.72	1.24	0.09	50.53	140.70	65.25	102.75	542.29
2008	212.65	60.75	161.71	16.46	34.09	8.68	1.37	0.07	0.27	34.95	127.32	67.44	725.75
2009	199.24	103.04	107.14	21.17	16.74	27.93	0.00	10.01	28.85	60.35	94.50	140.16	809.11
2010	180.78	65.32	76.89	104.70	61.46	0.00	0.00	0.00	0.00	8.86	100.91	145.61	744.53
2011	139.92	46.77	102.15	90.85	9.18	48.90	0.00	0.00	0.00	39.11	66.65	113.25	656.77
2012	63.79	33.05	52.48	8.80	0.00	0.00	0.00	0.01	3.60	42.22	79.89	106.44	390.28
2013	73.40	38.17	54.54	92.18	0.63	0.00	0.00	0.00	0.08	73.52	57.53	116.00	506.06
2014	105.28	164.54	197.06	11.92	0.00	0.00	0.00	0.00	0.00	24.16	90.66	119.01	712.63
2015	90.94	30.94	49.52	19.42	0.00	0.00	0.00	0.00	44.37	12.66	34.40	40.47	322.72
2016	85.86	50.98	109.21	22.81	35.26	20.66	0.00	0.00	2.76	38.44	79.19	91.37	536.53
2017	242.57	190.10	28.71	33.28	10.53	0.00	0.00	0.00	7.11	65.72	81.49	88.48	748.00
2018	74.69	67.24	81.19	55.82	13.01	0.00	0.00	0.00	11.73	44.21	36.13	129.87	513.87

16. APPENDIX 9: RAINFALL RECORDS FOR THE PERIOD BETWEEN 1990 AND 2018 - RAINFALL GAUGE BUFFELSPOORT (0511855A9)

Buffelspoort (0511855A9)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1990	51.4	73.3	105.0	133.6	6.0	0.0	1.0	0.1	0.0	19.9	39.0	197.5	626.8
1991	151.0	107.9	147.8	3.5	1.0	5.0	0.0		13.5	48.5	20.5	68.2	566.9
1992	58.5	27.0	29.0	26.3	0.0	4.0	0.0	7.0	1.0	15.9	158.5	137.5	464.7
1993	48.5	4.0	29.3	19.8	0.0	0.0	0.0	0.0	2.0	6.0	50.5	54.6	214.7
1994	149.8	47.2	72.8	16.0	0.0	0.0	0.0	0.0	0.0	15.0	15.0	77.9	393.7
1995	73.9	59.4	150.1	29.5	0.3	0.0	0.0	0.0	8.1	64.0	165.1	223.2	773.6
1996	155.1	254.8	73.7	81.0	35.3	0.0	0.0	7.5	3.0	91.8	93.4	82.3	877.9
1997	102.5	12.0	333.1	73.5	31.0	0.0	4.5	12.5	52.5	39.8	26.5	81.8	769.7
1998	90.4	67.5	58.5	0.5	0.0	0.0	0.0	0.0	15.5	77.5	45.0	151.4	506.3
1999	121.0	18.5	23.0	8.5	40.3	4.5	0.0	0.0	4.5	0.0	45.0	222.0	487.3
2000	128.0	390.5	113.0	30.5	13.5	0.0	0.0	0.0	131.0	379.0	197.7	116.4	1499.6
2001	63.0	72.3	45.7	8.1	0.0	5.6	0.0	2.0	6.5	8.3	34.3	9.1	254.9
2002	49.7	8.5	1.3	0.0	25.5	4.5	0.0	9.5	2.0	43.5	10.4	9.8	164.7
2003	141.1	102.5	51.0	4.0	0.0	0.0	0.0	0.0	0.0		62.4	77.0	438.0
2004	58.4	72.4	20.6	11.5	0.0	0.0	9.0	1.4	0.0	35.0	36.4	112.0	356.7
2005	141.5	144.0	69.5	47.5	5.0	0.0	0.0	0.0	0.0	0.0	91.7	53.5	552.7
2006	389.0	223.5	60.0	17.4	0.0	2.0	0.0	39.5	0.0	0.0	75.5	213.5	1020.4
2007	52.5	12.0	19.5	76.0	0.0	40.5	3.0	0.0	34.5	163.0	89.4	54.5	544.9
2008	205.0	76.5	119.0	26.5	0.0	9.0	5.0	0.0	0.0	37.0	110.0	22.0	610.0
2009	203.0	133.5	125.0	4.5	11.5	0.0	7.0	27.0	17.0	0.0	0.0	48.2	576.7
2010	240.6	65.0	44.6	134.0	86.6	2.8	1.6	0.2	0.2	13.2	73.2	222.2	884.2
2011	341.8	57.2	163.2	22.4	5.8	54.4	5.4	0.4	2.4	54.2	83.6	154.0	944.8
2012	123.0	40.0	89.6	7.8	0.4	4.4	1.6	0.2	96.8	137.4	54.0	103.2	658.4
2013	100.8	67.8	26.6	21.4	0.8	0.0	0.0	8.0	10.2	77.4	64.8	130.6	508.4
2014	75.4	170.2	258.8	36.0	0.2	0.0	0.0	0.0	1.8	31.6	128.2	139.2	841.4
2015	44.4	35.4	79.6	29.4	0.0	1.6	24.6	0.0	0.0	6.4	29.8	27.8	279.0
2016	108.6	26.0	138.8	36.0	45.6	16.4	34.4	0.2	0.8	0.0	0.0	0.0	406.8
2017	0.0	0.0	0.0	24.2	8.4	0.0	2.6	0.2	1.6	45.8	100.6	45.2	228.6
2018	5.4	33.6	74.6	35.6	8.0	0.0	13.4	0.0	12.4	57.2	16.6	86.8	343.6