Integrated assessment of human impacts on wetland services in the Upper Kromme River Catchment, South Africa

Illustrated by a case study of the Hudsonvale wetland




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MSc Thesis in Environmental Science
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Environmental Systems Analysis Group

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Preface

This thesis emerged from my deep, personal interest in understanding the roles and importance of wetland ecosystems in our lives as well as our influence on these ecosystems. My research interest and my dream of Africa could be fulfilled through Wageningen University, as I could join to the PRESENCE Learning Network[1], facilitated by the non-profit organization, Living Lands[2] in South Africa. As a result, I had the opportunity to conduct my research in South Africa in the frame of the project called: The Kromme Catchment –"Towards a Living Landscape". This project was granted in 2012, initiated by Living Lands and three other Dutch partners; Aqua Terra Nova; Foundation for Sustainable Development (FSD); and For Elements. This project aims to improve the hydrological functioning and sustainable use of land and water of the upper catchments by involving local people. In this way, I was one of the students who did her research in the Kromme River Catchment, particularly focusing on wetland ecosystems, and working alongside Marijn Zwinkels, the leader of the Kromme project and Lisa Nooij a BSc student (Van Hall Larenstein, The Netherlands).

[1] PRESENCE Learning network: http://www.livinglandscapes.co.za/

[2] Living Lands is a South African non-profit organization that aims to conserve and restore „living landscapes" that provides place for both ecological, agricultural and social systems.
http://www.earthcollective.net/category/living-lands/

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Acronyms

ArcGIS	Geographic Information System software product
DAFF	South African Department of Agriculture, Forestry and Fisheries
DEAT	South African Department of Environmental Affairs and Tourism
DoA	South African Department of Agriculture
DWAF	South African Department of Water Affairs and Forestry
FSD	Foundation for Sustainable Development
GIB	Gamtoos Irrigation Board
GIS	Geographic Information System
HGMU	Hydro-geomorphic unit
IAPs	Invasive Alien Plants
MA	Millennium Ecosystem Assessment
NFEPA	National Freshwater Ecosystem Priority Areas
NMMM	Nelson Mandela Bay Metropolitan Municipality
PRESENCE	Participatory Restoration of Ecosystem SErvices & Natural Capital, Eastern Cape
SANBI	South African National Biodiversity Institute
TEEB	The Economics of Ecosystems and Biodiversity
UKRC	Upper Kromme River Catchment
WfWater	Working for Water Program
WfWetlands	Working for Wetlands Program
WMA	Water Management Area
WRC	Water Research Commission

Acknowledgements

Firstly, I would like to thank the entire Living Lands team for giving me the opportunity to be a part of the PRESENCE Learning Network and to do my thesis research in South Africa. It gave me unforgettable experiences and contributed to my professional and personal development substantially.

I am thankful for my two supervisors from Wageningen University; Alexander van Oudenhoven and Dr. Dolf de Groot, for their support, guidance, and advice, particularly during my thesis-writing phase. I would like to express my special gratitude for Alexander van Oudenhoven for his great help and patience throughout the process. Thank you to Marijn Zwinkels my supervisor in South Africa for his support and facilitation of my research.

Special thanks go to Alanna Rebelo, a graduated ecology MSc student at the University of Stellenbosch for helping my research greatly by sharing her very useful GIS land use and land cover maps of the Kromme Catchment with me as well as sharing her knowledge about the study area.

I would like to express my gratitude for both the landowners and experts, who helped and supported my research by sharing a great amount of knowledge with me. Special thanks must go to:

- The landowners in the Upper Kromme River Catchment and especially the landowners at the wetland case study site for their openness and hospitality. Thank to them I could learn a lot about the area.
- Japie Buckle from Working for Wetlands for teaching me so much about the palmiet wetlands of the Kromme and the ecology of South Africa.
- Prof. Fred Ellery from Rhodes University for giving me the opportunity to join to his weeklong wetland fieldtrip. His passion towards wetlands and his encouragement inspired me substantially.
- Julia Glenday, from Living Lands for supporting me with advice, and knowledge about wetlands, but also being so kind and friendly in the PRESENCE Learning Village.

I would like to thank Lieke Jager, another PRESENCE student, for her help, which was crucial during the field measurements at the case study site.

I am also thankful for the other PRESENCE students, who made my time in South Africa special with a lot of joy and laughter. Thanks for the many nice things (e.g. braai, hiking, travelling etc.) that we did together. Special thanks go to Clara, Kobus, and Lisa for their cheerful friendships.

Furthermore, I would like to thank my family and friends for their support and encouragement, and Bart Klijn for your unending support, encouragement and love.

Finally, I would like to dedicate my thesis to the memory of my beloved mother, Beatrix Endrődi, who always believed in me.

"It is one thing to find fault with an existing system.
It is another thing altogether, a more difficult task,
to replace it with another approach that is better."
(Nelson Mandela, 2000)

Summary

The South African Kromme river and its valley-bottom wetlands provide agricultural and domestic water for local and downstream water users (e.g. the Nelson Mandela Metropolitan Municipality and Port Elizabeth). The Upper Kromme River catchment's topography consists of a middle valley surrounded by steep mountain ranges. Its bimodal climatic pattern with mostly winter rains is semi-arid. Floods are periodically experienced. The weathering of quartzitic sandstones and subordinate shales have developed extremely nutrient poor and acidic soils on the higher slopes supporting fynbos vegetation.

The 54-ha Hudsonvale wetland is the most downstream channelled valley-bottom wetland in the Upper Kromme River Catchment and collects water from an area of 18,400 ha. The wetland is characterised by mineral Westleigh and organic Champagne soils with abundant peat deposits. Nearly half of its vegetation is indigenous emergent wetland species. The rest are introduced kikuyu grass and other invasive alien plants. Severe erosion in the riverbed occurs in the downstream portion of the wetland. Livestock farming is a major land use in the catchment and dairy farming at the wetland's site. The wetlands are threatened by these agricultural practices, alien plants and severe erosion in the river system. The 'Working for Water' and 'Working for Wetlands' Programs initiated rehabilitation projects to ensure water security and to rehabilitate the wetlands. They clear invasive alien plants and construct erosion control structures in the riverbed. This affects these wetlands and their capacity to provide ecosystem services. To further rehabilitate the area and its wetlands, and to reach sustainable water use, the relationships between the different drivers and their impacts on the wetland ecosystems should be identified. This study selected the Hudsonvale wetland to achieve this in an integrated assessment.

The study assesses the impacts of agricultural land use, invasive plants eradication and erosion control structures on ecosystem services. The study's conceptual framework structures the combination of two rapid wetland assessment research tools: Wet-Health, which systematically analyses human impacts on ecological wetland health comparing to the undisturbed reference condition, and Wet-EcoServices, which provides current information on wetland services. Providing recommendations on the more effective use of these tools is also an objective of the study. Various data are collected from scientific literature review, 23 semi-structured interviews with landowners, scientific experts and informants, and field surveys.

The impacts of invasive alien plant eradication programs are poorly known because of data availability issues. The clearing of alien pants in the wetland has reduced the direct water loss from the wetland. The clearing also could potentially support the recovery of natural wetland vegetation and the eroded riverbank. Indirectly, the clearing also reduced the wetland area as some cleared areas were used for grazing land for the cattle.

The construction of the erosion control structures restored the physical properties and largely improved the water retention capacity of the wetland above-stream the structure. This improved water retention furthermore supports the recovery of natural wetland vegetation and the maintenance of peat deposits. The erosion control structures also improved the water distribution down-streams by directing water to the palmiet vegetation dominated section.

The ecological health assessment shows that local human activities have mainly modified the ecological health of the wetland in terms of its hydrological, geomorphic and vegetation components compared to the natural reference condition. Direct water extraction for irrigation, the invasive plant encroachment and severe riverbed erosion in the downstream portion drastically altered the wetland's hydrological integrity and led to water loss and further canalization. Furthermore, the conversion of wetland areas to pasture and the development of erosion gullies decreased surface roughness. This decreases the wetland's water retention capacity. However, the geomorphic integrity of the wetland was the least affected, where the peat deposit loss was the biggest impact. The impact on vegetation integrity resulted from the historically introduced kikuyu and rye-grass species. These and other invasive alien plants have replaced half of the natural vegetation.

The ecosystem services assessment shows that the Hudsonvale wetland provides an important range of regulating services, such as streamflow regulation, erosion control, and carbon storage. Flood attenuation and other regulating services related to water quality enhancement (e.g. nutrient, phosphate and toxicant removal, and sediment trapping) were somewhat less important. Providing water for direct human use and to a lesser extent to provide cultivated feed for the dairy cattle was also relevant. The wetland provided few cultivated food and natural resources. The wetland did not have any cultural relevance for the local people, but provided essential education and research opportunities because of the changes due to the constructed erosion control structures and severe riverbed erosion.

The WET-Health analysis provided detailed information on the current ecological health of the Hudsonvale wetland that was underpinned by field observations and accurate geospatial data. The agricultural practices were the greatest impact on current ecological health. The impact of the other two human drivers (i.e. eradication of invasive alien plants and construction of erosion control structure) were difficult to assess. Since WET-Health considers any changes in the wetland's health components as a deviation from the natural state, this tool was inappropriate to solely assess the impacts of the rehabilitation measures. The positive impacts of erosion control structures on improving water retention, together with the eradication of IAPs to support the re-vegetation by natural wetland species, can only be incorporated in the assessment of future changes.

The WET-EcoServices analysis could provide useful information on the importance of the Hudsonvale for providing ecosystem services. However, the characteristics used for assessing some of the ecosystem services were simplifications of the reality. Yet, in combination with the WET-Health tool ecosystem services could be linked to the impacts of human drivers and other human impacts through the current ecological health assessment.

It can be concluded that the combined use of WET-Health and WET-EcoServices tools provided a useful way to assess the impacts of human drivers, particularly the impacts of agriculture on the provision of ecosystem services through linking it to ecological health. However, to improve the effectiveness of the combined use of WET-Health and WET-EcoServices to assess the impacts of human activities on both the wetland's ecological health and its ecosystem services provisioning, these assessments should be conducted before and after the rehabilitation. Additional assessments of historical land-use change are also recommended to obtain information on the historical impacts and ecosystem services provision and define the desired situation.

1. Introduction

1.1. Background

South Africa is well-known about its high biodiversity as it is the third most biologically diverse country in the world with three globally recognized hotspots (Crane, 2006) and twenty-one wetland sites designated as Wetlands of International Importance by the Ramsar Convention on Wetlands (Ramsar Convention, 2010)[3].

However, South Africa is also a water stressed country. Its precipitation regime is characterized by an average annual precipitation of 500 mm, which is below the world average of 860 mm, erratic rainfall and unpredictable swings between dry and wet years. In addition to the climatic conditions, the increasing demand for water by growing populations and agriculture also places high pressures on its ecosystems, particularly on its surface water resources (Blignaut et al. 2007).

The largest water user is the agricultural sector (60%); the second is the urban population (24%), while the rural population account for only 3%. The agricultural sector uses approximately 60% of the available water supply for irrigation, particularly for orchards, vegetables and vineyards (DWAF 2012). Agriculture also represents one of the most important economic sectors in South Africa as it provides income and employment for about thirteen million people throughout the country. Furthermore 36% (R50 813,2 million) of the gross value of agricultural production derived from the export of citrus fruit, wine, maize, grapes and apples, pears and quinces in 2011 (DAFF 2012).

In order to increase water security and satisfy the equal distribution and sustainable use of water resources declared in the South African National Water Act (1998), effective watershed restoration and sustainable use of natural resources have been placed high on the agenda (Mander et al. 2010). National initiatives such as the Working for Water Program (WfWater) (1995) and the Working for Wetlands Program (WfWetlands) (2001) were formed to enhance conservation of water and to provide job opportunities for local people (Turpie et al. 2008).

The WfWater Program's main objective is to clear invasive alien plants (IAPs) such as Acacia and Eucalyptus species which are considered to be one of the potential causes of reduction in surface water flows (Le Maitre et al. 2002, Dye and Jarmain 2004, Blignaut et al. 2007). These alien species mainly infect riparian zones, and have higher water use than indigenous plant species (Dye and Jarmain 2004). They also have negative impacts on the integrity of ecosystems as they change the structures and functions of ecosystems, resulting in negative consequences for the delivery of ecosystem services as well as for biodiversity (Mooney et al. 2005). Furthermore, they change soil nutrient cycle, induce soil erosion and enhance fire hazard (Turpie et al. 2008, Van Wilgen et al. 2008). The WfWetlands Program originated from the WfWater Program and works in conjunction with that program to supplement and improve hydrological benefits. Its main objectives include the rehabilitation, wise use and protection of wetlands (WfWater 2008/2009).

According to the Millennium Ecosystem Assessment (MA) (2005) wetlands are particularly important ecosystems in semi-arid countries such as South Africa because they provide a wide range of services that contribute to human well-being and poverty alleviation. Ecosystem services are defined as the "benefits people obtain from ecosystem" and wetlands can provide provisioning (e.g. fish, freshwater), regulating (e.g. streamflow regulation, erosion protection), supporting (e.g. biodiversity, nutrient cycling) and cultural services (e.g. recreational, aesthetic) (MA, 2005). However, they are also the most threatened ecosystems (MA 2005c).

[3] The Ramsar Convention on Wetlands: http://www.ramsar.org/cda/en/ramsar-news-archives-2010-annotated-ramsar-16187/main/ramsar/1-26-45-437%5E16187_4000_0__ Retrieved 10-11-2012

Wetlands are defined by the National Wetland Classification (SANBI, 2009) incorporating the definition of Ramsar Convention as: "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed ten meters. Wetlands are areas where water is the primary factor controlling the environment and, therefore, wetlands develop in areas where soils are saturated or inundated with water for varying lengths of time and at different frequencies."*
According to a more practical approach, a land is called wetland if at least one of the following criteria is fulfilled (Collins 2006): presence of water; saturated (hydric) soil; hydrophytic vegetation-plants that are adopted to grow in the anaerobic conditions of hydric soils.

In South Africa, in alignment with world trends, wetlands are the most threatened ecosystems, according to its National Biodiversity Assessment (Driver et al. 2012). 65% of wetland ecosystems are threatened, of which 48% are critically endangered. The most threatened wetland types are floodplains, valley-head seeps and valley-bottom wetlands mainly because of intensive land use. The agricultural utilization of fertile areas already started in the second half of the seventeenth century when the first settlers arrived to the country. By the first half of the twentieth century, many of the fertile wetland areas have been converted for large scale production of crops and soft fruit orchards or were used for grazing lands for livestock (Kotze and Ellery 2009). According to Kotze and Breen's estimation (1994), approximately half of the South African wetlands had either been degraded or even disappeared because of agriculture, urban development, erosional degradation and dam construction. Currently, they make up only 2,4% of South Africa' s area, but this small area represents high value ecological infrastructure that provides critical ecosystem services such as water provision, flood regulation, and water purification (Driver et al. 2012)

To support better wetland management and promote sustainable use, various assessment tools have been developed in South Africa. The Water Research Commission (WRC), along with the Department of Environmental Affairs and Tourism (DEAT), WfWetlands and others have been behind these initiatives. These tools have been specifically developed for South African wetlands in order to assist wetland management in each relevant step of planning, assessment, and implementation (Kotze et al. 2008). WET-Health and WET-EcoServices both support the planning and assessment of wetland rehabilitation projects. While WET-Health is designed for rapid assessment of the ecological condition i.e. "how far a system has deviated from its historical, undisturbed reference condition", WET-EcoServices assesses services and goods provided by wetlands (Kotze et al. 2008). Both tools use the hydro-geomorphic approach, i.e. wetlands are divided into hydro-geomorphic units (HGMU)[4] and assessed individually (Macfarlane et al. 2008)

1.2. Problem statement

The South African Kromme river and its valley-bottom wetlands provide important agricultural and domestic water for local and downstream water users in the Nelson Mandela Metropolitan Municipality (NMMM) and Port Elizabeth (Mander et al. 2010). 55% of the total water demand (34 million m^3) for about 1 051 000 inhabitants of the NMMM is delivered by the Kromme system (Mander et al. 2010). The river system and its valley-bottom wetlands have been threatened by invasive alien vegetation (particularly black wattle), the construction of drainage channels, erosion and reclaims of wetland areas for agricultural use (Haigh et al. 2004). To address some of these problems, rehabilitation projects started in the upstream area in the frame of the WfWater and WfWetlands Programs. Consequently, the valley-bottom wetlands are continuously affected and altered by three main human drivers; agriculture; alien plant eradication and construction of erosion control structures as wetland rehabilitation interventions. Agricultural land use has been intensified over the past century (Kotze and Ellery 2009) and farming within the wetland areas, particularly in the fertile floodplains, is still occurring (Mander et al. 2010). Furthermore, farming practices such as

[4] A hydrogeomorphic (HGM) unit is a section of a wetland that has uniform hydrological and geomorphological characteristics" (Sieben et al., 2011).

burning and overgrazing also contribute to the degradation of wetlands (Haigh et al. 2004). Invasive alien plant clearing has effects on the hydrological state of wetlands and biodiversity. The construction of erosion control structures focuses on emphasizing certain ecosystem services, particularly water retention and sediment trapping. These drivers affect both the natural processes and structures of wetland ecosystems, and decrease their capacity to provide a full range of ecosystem services. To further rehabilitate the area and its wetlands, and to reach sustainable water use, the relationships between the different drivers and their impacts on the wetland ecosystems needs to identified. In this study these relationship will be assessed through the Hudsonvale wetland case study site.

1.3. Research objectives and research questions

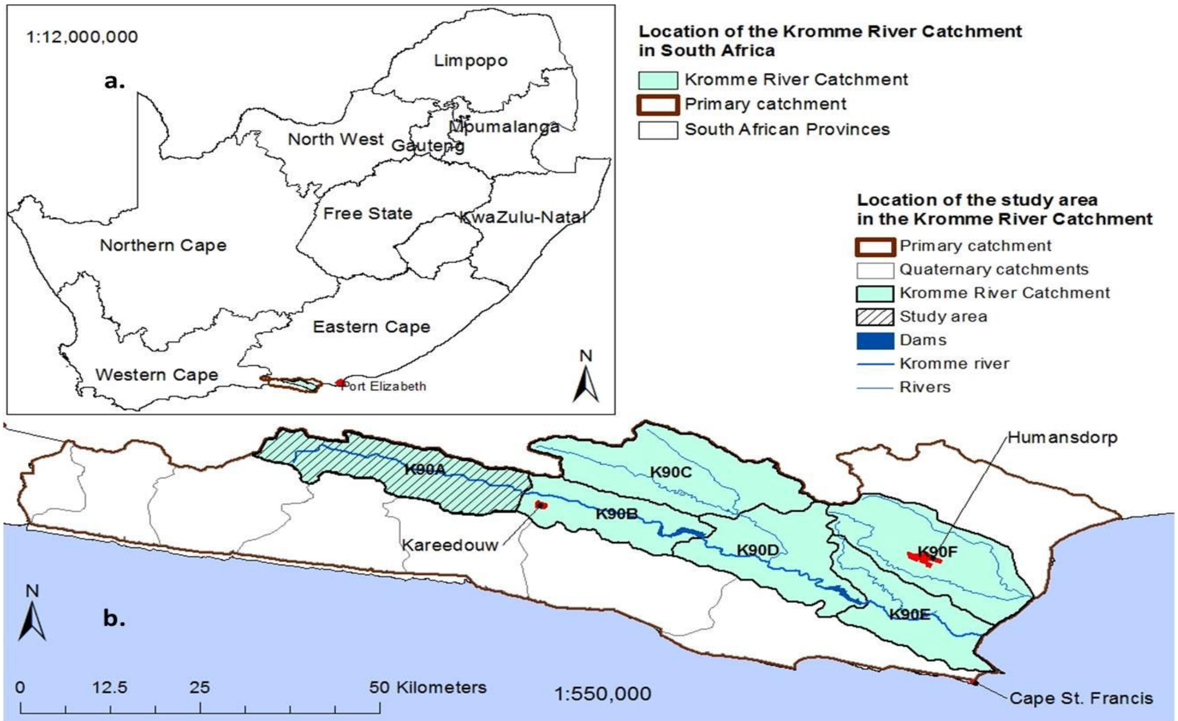
The main objective of this study is to assess the impacts of agricultural land use, eradication of invasive alien plants and construction of erosion control structures on ecosystem services of the Hudsonvale wetland, in the Upper Kromme River Catchment, South Africa. To reach the main objective, two tools, WET-Health and WET-EcoServices will be applied in combination. Regarding the innovative nature of using both tools in an integrated assessment, this study also has an additional objective to give recommendations on the possible ways to improve the effectiveness of using the tools in assessing the aforementioned three human drivers' impacts on wetlands health and services provision.

In order to achieve the main objective, the following general research questions were formulated:

1. *What biophysical structures and processes characterize the Hudsonvale wetland?*
2. *What are the impacts of agricultural land use, invasive plant eradication and construction of erosion control structures on the biophysical structure and processes of the Hudsonvale wetland?*
3. *What is the current ecological condition (health) of the Hudsonvale wetland?*
4. *What ecosystem services are provided currently by the Hudsonvale wetland?*

1.4. Study area

The Upper Kromme River Catchment is located at the southern coast of Eastern Cape province of South Africa and one of the six quaternary catchments of the Kromme River Catchment (Haigh et al. 2008) (Figure 1a.). The main river, the Kromme, flows eastwards to the coastal area near Humansdorp, entering the Indian Ocean at St. Francis Bay (Haigh et al. 2002). The uppermost (K90A) quaternary catchment, or the Upper Kromme River Catchment (UKRC), served as the study area (Figure 1b.).The study area covers an area of 21,340 ha (Rebelo 2012) and occupies the easternmost part of the Cape Fold Belt, originates in the western reaches of the valley, known as "The Heights and bordered by the Kouga and Suuranys mountains on the north and the Tsitsikamma Mountains on the south (Haigh et al. 2002). Its eastern boundary ends upstream of the main town of the region, Kareedouw. The water for downstream users is ensured by the two main dams (Churchill and Impofu) built downstream of the study area (DWAF 2004)



Data sources:
Eastern Cape Province, Cadastral data (2008)
BGIS-SANBI, NFEPA data (2011)
Rebelo, A., MSc Dissertation, Stellenbosch University (2012)
Data compiled: 14 March, 2013
By Nikolett Czeglédi

Figure 1: Location of the study area

1.5. Outline of the report

The report will proceed as follow. Starting with the introduction and research objectives of this study in Chapter 1, the conceptual framework of the study, data collection and processing methods, the tools of analyses and the selection of the wetland case study site will be described in Chapter 2.

The results of the study are presented in Chapters 3 to 6. Chapter 3 focuses on the catchment scale and consists of three sections. The first one outlines biophysical characteristics of the catchment area in terms of geology, hydrology, climate, topography, vegetation and wetlands. The second section describes the main historical drivers of wetland alteration and their impacts on the ecological health of the wetlands. The third section describes the three main current drivers i.e. agricultural land use, eradication of IAPs and the construction of erosion control structures and their impacts in the catchment.

Chapter 4 zooms into the selected Hudsonvale wetland case study site to build up knowledge about its biophysical structure and processes as well as to describe the three drivers (agriculture, eradication of IAPs and construction of erosion control structures) located adjacent to and within the wetland and to assess their impacts on the biophysical structures and processes of the wetland. The knowledge gained from chapters 3 and 4 on the biophysical characteristics and the drivers on both catchment and wetland scales provides the basis for further analysis. Chapter 5 describes the current ecological health of the Hudsonvale wetland by integrating the knowledge from the previous chapters by using the WET-Health rapid assessment tool. Next, Chapter 6 describes the current ecosystem services provision of the wetland by means of using the WET-EcoServices rapid assessment tool.

Chapter 7 discusses the used methods and results in a critical way. Chapter 8 concludes the main findings of the research in relation to the main objective and provides recommendation for the future in terms of improving the effectiveness of combining the two tools; WET-Health and WET-EcoServices.

2. Methods, literature review and selection of study site

The following chapter describes the conceptual framework of this study and introduces the most important concepts as well as the data collection and data processing methods used in this study. At last, it presents both the selection process of an appropriate wetland case study site and the spatial boundaries of the further assessments.

2.1. Conceptual framework

A step-wise conceptual framework was set up for the study to provide a logical structure and time order of the required steps of the assessment. The concepts framework was based on extensive literature review and was developed by means of using integrated frameworks of the MA (2005a), the TEEB study (2010a) and Van Oudenhoven et al. (2012). The framework is presented below in Figure 2.

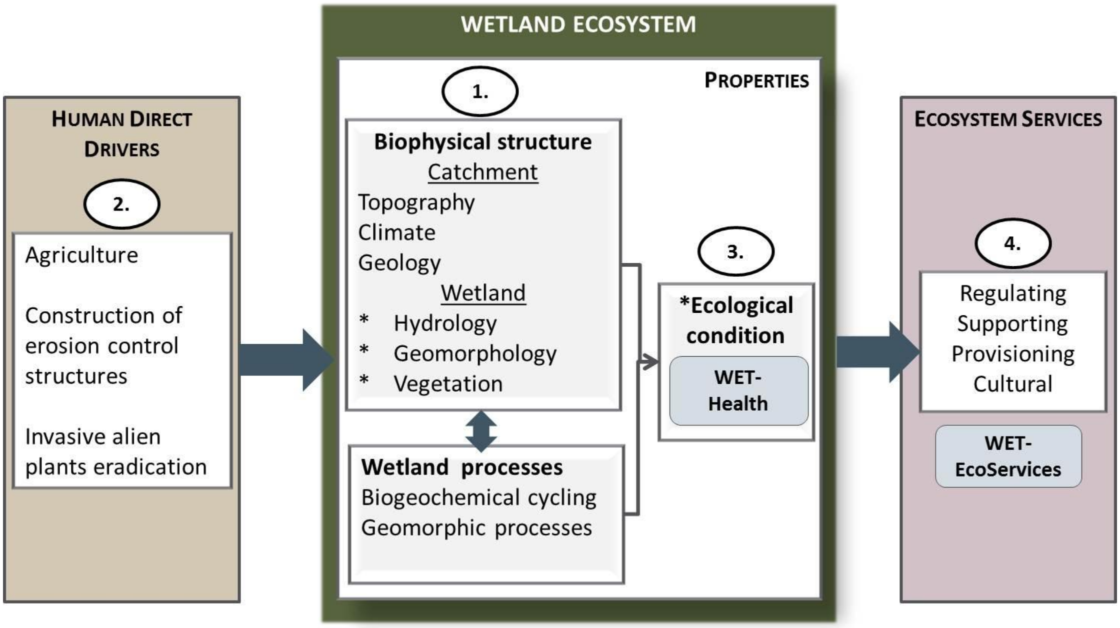


Figure 2: Conceptual framework of the study
A schematic overview of the impacts of human drivers on wetland ecosystem properties, functions, and services. The numbers correspond with the research questions (see chapter 1.3.).

The central element of the framework is a wetland ecosystem. A wetland ecosystem, is defined by the South African National Water Act (1998) as a "land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which in normal circumstances supports, or would support vegetation typically adapted to life in saturated soils."

A wetland is characterized by various properties that determine the way that the wetland potentially can function irrespectively of human use. Thus, the set of ecological conditions, biophysical structures and processes that underpin the capacity of the wetland to provide services are called **ecosystem properties** (Bastian et al. 2012). They form the basis of any kind of service provision utilizable by humans and determine whether a service by the wetland can be provided (MA 2005b, De Groot et al. 2010b, Van Oudenhoven et al. 2012). Although the term of ecosystem properties does not consider potential and actual users yet, analyzing the structures and processes that characterize an ecosystem is a prerequisite before approaching ecosystem services (Bastian et al. 2012). The most important elements of **biophysical structure** (1.) that characterize a wetland are geomorphology, hydrology and vegetation (Macfarlane et al. 2008) where hydrology is the most important determinant of a wetland's structure, processes, and functions (Mitsch and Gosselink 2007, Macfarlane et al. 2008). Biogeochemical cycling and geomorphic processes represent the main

processes of wetland ecosystems. Biogeochemical cycling refers to the transport and transformation of chemicals in the ecosystem (e.g. removal of nutrients, see Appendix 1) involving a great number of interrelated chemical, physical and biological processes (Mitsch and Gosselink 2007). Geomorphic processes involve erosional and depositional processes (Ellery et al. 2009) and are related to biogeochemical cycling. For instance, phosphorous occurs mainly in sedimentary cycle, where it is tied up in either organic material, or in inorganic sediments, depending on the type of wetland soil (Collins 2006, Mitsch and Gosselink 2007). Wetland processes are influenced by hydrologic conditions of wetland soils, which define the chemical forms of materials, thus their bioavailabity to wetland plants. Furthermore, hydrology also defines the spatial movement of materials within wetlands and with surrounding ecosystem (Mitsch and Gosselink 2007). Both biophysical structures and processes of wetlands are strongly related to the catchments' climatic, topographical, geomorphologic and hydrological characteristics.

Furthermore, human activities or **human drivers** (2.) occurring both within and outside of the wetlands may affect wetland ecosystems either directly or indirectly through altering its natural structure and processes (Zedler and Kercher 2005, Sieben et al. 2011). Since wetlands are transitional ecosystems, they are often affected by human activities (Collins 2006, Sieben et al. 2011). For instance, channelling a wetland decreases the level of water within the wetland, which may lead to its desiccation (Collins 2006, Mitsch and Gosselink 2007). In addition, other activities at the upstream such as road construction and dredging the riverbed contribute to increased sediment supply to the wetland (Forman and Alexander 1998). Agricultural runoff from up-stream as well as on-site alters water chemistry and quality which may lead to altered vegetation composition or eutrophication (Mitsch and Gosselink 2007). Direct drivers of ecosystem change, for instance, are agriculture and other forms of land use. Indirect drivers such as population growth and policy instruments affect the way people directly use and manage the ecosystems and their services (MA 2005b, De Groot et al. 2010a).

Agricultural land use is the one of the main human drivers taking place in the UKRC. Thus, this study focuses on the agricultural land use and its management practices, those that are considered to have direct impacts on the wetland ecosystem. These management practices are, for instance, irrigation, fertilizer and pesticide use, fire management etc.

Eradication of IAPs refers to activities of WfWater, which started to work in 1996 in the study area in order to enhance hydrological benefits by clearing IAPs. This activity also contributes to restoring the hydrology and vegetation integrity of wetlands by removing IAPs from the sites of the wetlands and from riparian zones in the catchment area.

In South Africa wetland rehabilitation follows a combination of arcadian and functional views (Grenfell et al. 2009a). Thus wetland ecosystems are seen as semi-natural features of a human transformed landscape that also provide some sort of value for the society (Harris and van Diggelen 2006). The WfWetlands Program was initiated by the Departments of Environmental Affairs & Tourism (DEAT), Agriculture (DoA) and Water Affairs & Forestry (DWAF) in 2001, in order to rehabilitate wetland ecosystems.

Construction of erosion control structures as wetland rehabilitation interventions was implemented along the Kromme river in order to assist in the recovery of the hydrological health of degraded wetlands and to ensure a sustained water supply to the Churchill and Impofu dams downstream (Haigh et al. 2008) (Photo 1).

Photo 1: WfWetlands in the Upper Kromme River Catchment (Photo by Author)

The changes caused in the ecosystem structure and processes can be assessed by the **ecological condition** or also called **ecological health** (3.) of the wetland which provides information on "how far a system has deviated from its historical, undisturbed reference condition" (Macfarlane et al. 2008). If the wetland has a natural level of inputs of resources and has not been modified by human interventions since European colonization, then it is considered to have a 'natural reference condition' and one can call it as a 'healthy' wetland (Kotze et al. 2012). The *sign indicates the components; hydrology, geomorphology and vegetation that are used to determine ecological condition in this study.

The wetland based on its biophysical and ecological characteristics has subsets of ecological interactions that underpin the capacity of the wetland to provide certain goods and services for humans (e.g. water, fish, nutrient removal). **Ecosystem services** provided by wetlands or **wetland services** (4.) adapted from the MA (2005) and are defined as *"benefits people obtain from (wetland) ecosystems"* (MA 2005c, b). For instance, wetlands have the ability to retain or temporarily store water and sediment, thereby contributing to the removal of nutrients and other solutes from the water as well as to sustained streamflow by recharging groundwater (Collins 2006, Mitsch and Gosselink 2007).

Although the relationship between ecological condition and ecosystem services provision is not well examined, that is assumed that a 'healthier', more natural wetland can provide a greater level of services than a degraded one (MA 2005c, Macfarlane et al. 2008, McCartney et al. 2011). Thus, the framework reflects on that human drivers influence ecosystem services either directly and indirectly by altering the natural biophysical structures and ecological processes (5.).

Based on the conceptual framework, my study was divided into two main phases, applying two different assessment tools that gave the backbone of the study. However, these tools required further steps in order to obtain specific information and answer the research questions. In this chapter the applied data collection, and data processing methods as well as the used data sources and materials are described in terms of the two main assessment tools.

2.2. Assessment Tools

The tools WET-Health and WET-EcoServices are rapid assessment methods that were developed particularly for South African wetlands. WET-Health provides a systematic way to analyze the magnitude of impacts deriving from human activities on the assessed wetland biophysical structure and processes and thereby defining current ecological health of the wetland compared to its natural state. However, it does not provide information on what benefits the wetland currently provides for humans. For that reason, the tool WET-EcoServices was developed which integrates the biophysical and ecological characteristics with human use. These tools thus provide complimentary information on the wetland ecosystem, in terms of its current ecological health and ecosystem services delivery, which motivated my decision to combine them.

2.2.1. WET-Health

To answer research questions 1 and 3, the wetland assessment tool, WET-Health tool provided guidance. The tool is introduced based on the related literature by Kotze et al. (2012) and the Water Research Commission (WRC) report on WET-Health by Macfarlene et al. (2008), unless stated otherwise.

WET-Health is a South African wetland assessment method developed for the rapid assessment of ecological condition. It was developed through an iterative process and based on expert knowledge and scientific literature. It uses mainly human activities (stressor) and some response indicators which are pre-determined and rated by means of providing clear scoring guidelines (Kotze et al. 2012). Indicators used are, for instance, level of erosion and sedimentation on-site, alien vegetation, type of irrigation (etc.) (Macfarlane et al. 2008).

The assessment can be executed at two levels, depending on the requirements and constraints of the research. Level 1 assessment usually used for assessing large numbers of wetlands based on desktop evaluation and limited field verification. The results are at a low resolution, but can provide an overview of the health of the wetlands in a whole catchment area.

Contrarily, a level 2 assessment examines a single wetland and requires a higher level of field verification. It involves structured sampling and data collection both on-site of the wetland and in its catchment. Since the results of a level 2 assessment are at a higher resolution than a level 1 and thus management planning decisions can be made with higher confidence (Macfarlane et al. 2008), this level of evaluation was chosen for my study.

a) Mapping

To conduct the assessment the tool requires generating maps of the wetland and its associated catchment providing information on the different human activities or visible features within the wetlands that are likely to have impacts on the ecological condition. If the objective is focusing on a single wetland, the mapping is based on aerial photographs or orthophotos that are of higher resolutions. It is preferably done by using Geographic Information System (GIS).

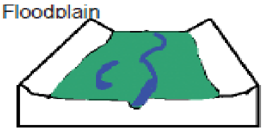
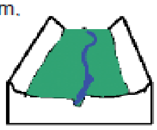
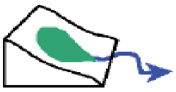
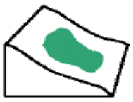
b) Delineation of wetland boundaries

Delineating the wetland boundaries is important to identify the spatial extent of the wetland and to map it. In the case of a single wetland system a level 2 assessment is recommended which requires ground-truthing and a more accurate delineation of wetland boundaries (Macfarlane et al. 2008). During the delineation procedure the aim is to identify the outer edge of the temporary waterlogged zone of the wetland (DWAF 2005).

In this study the delineation procedure followed the recommended methods of the manual "*A practical field procedure for identification and delineation of wetlands and riparian areas"* published by the DWAF (2005) of South Africa. This manual was suggested by the other assessment tool, WET-EcoServices (Kotze et al. 2008). The detailed description of the delineation procedure is presented in Appendix 2.

c) Delineation of hydro-geomorphic units

The tool is only applicable for palustrine wetlands (Macfarlane et al. 2008) which are defined as all non-tidal, freshwater wetlands dominated by emergent plants (Day and H. 2010). WET-Health requires the assessor to divide the wetland(s) being assessed into hydro-geomorphic units (HGMUs). The division of HGMUs is based on the classification system used in the South African WET-tools (Kotze et al. 2008, Macfarlane et al. 2008) (Figure 3). Then these HGMUs are examined separately in terms of three health components; hydrology, geomorphology and vegetation. The division into HGMUs helps to get a better understanding on the hydro-geomorphological dynamics and interactions within the wetland. HGMU is defined by the geomorphological setting in the landscape (e.g. hillslope or valley-bottom) and the hydrological characteristics of the wetland (water source, pattern of the water flowing through the wetland unit) (Kotze et al. 2012). The HGMUs are first identified by means of desktop analysis and later they are verified on the field.

Hydrogeomorphic types	Description	Source of water maintaining the wetland[1]	
		Surface	Sub-surface
Floodplain 	Valley-bottom areas with a well defined stream channel, gently sloped and characterized by floodplain features such as oxbow depressions and natural levees and the alluvial (by water) transport and deposition of sediment, usually leading to a net accumulation of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.	***	*
Valley-bottom, channelled 	Valley-bottom areas with a well defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterized by the net accumulation of alluvial deposits or may have steeper slopes and be characterized by the net loss of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.	***	*/ ***
Valley-bottom, unchannelled 	Valley-bottom areas with no clearly defined stream channel, usually gently sloped and characterized by alluvial sediment deposition, generally leading to a net accumulation of sediment. Water inputs mainly from channel entering the wetland and also from adjacent slopes.	***	*/ ***
Hillslope seepage linked to a stream 	Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs are mainly from sub-surface flow and outflow is usually via a well defined stream channel connecting the area directly to a stream channel.	*	***
Isolated Hillslope seepage 	Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from sub-surface flow and outflow either very limited or through diffuse sub-surface and/or surface flow but with no direct surface water connection to a stream channel	*	***
Depression (includes Pans) 	A basin shaped area with a closed elevation contour that allows for the accumulation of surface water (i.e. it is inward draining). It may also receive sub-surface water. An outlet is usually absent, and therefore this type is usually isolated from the stream channel network	*/ ***	*/ ***

[1] Precipitation is an important water source and evapotranspiration an important output in all of the above settings

Water source: * Contribution usually small

*** Contribution usually large Wetland

*/ *** Contribution may be small or important depending on the local circumstances

Figure 3: Typical wetland hydro-geomorphic types in South Africa
Adapted from Kotze et al. (2008) and Macfarlene et al. (2008)

d) Delineation of hydro-geomorphic units' sub-catchments

The delineation of HGMUs' sub-catchments is an essential step as it defines the spatial boundaries in which hydro-geomorphic dynamic occurs such as the input and movement of sediment, the sources and drainage system of the wetland. The DWAF (2005) guidelines for watersheds suggest using "The New Hampshire Method" delineation procedure.

e) Assessment of present ecological health

WET-Health provides a standardised method to assess the impacts of human stressors on the three components of health; hydrology, geomorphology and vegetation that defines the overall ecological 'health' of the wetland (Kotze et al. 2012) (Figure 4). These components are divided into three modules and assessed separately in terms of the degree of deviation from the natural reference condition.

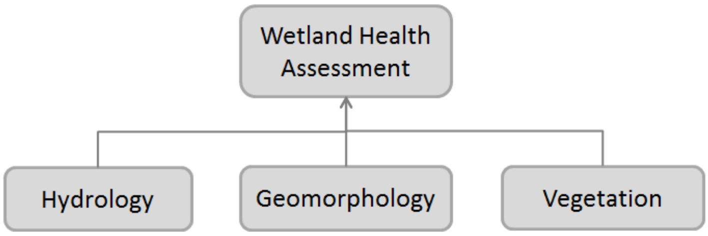


Figure 4: The modules used for Wetland Health Assessment in WET-Health Adapted from Macfarlene et al., (2008)

The **Hydrology module** investigates hydrological integrity or health of the wetland by focusing on the quantity, timing and intensity of water inputs flowing into the wetland from its catchment and by assessing the degree to which natural water distribution and retention patterns within the wetland have been altered.

The **Geomorphology module** examines sedimentary inputs and outputs as well as uses geomorphic indicators such as erosion gullies, depositional fans or extraction of peat for assessing geomorphic integrity.

The **Vegetation module** assesses the level of transformation of vegetation by alien vegetation and other land use categories compared to the perceived reference condition.

f) Scoring system

In each module, the impacts of different human activities or the visible impacts on wetland ecological health are quantified by assessing their spatial extent (%), intensity and magnitude scores in the case of each identified HGMUs.

Intensity is the degree of deviation from the natural state and it is scored on a scale of 0 (no impact) to 10 (total transformation). To get the magnitude of the impacts, the spatial extent i.e. the proportion of the wetland and/or its catchment affected by a given activity is divided by 100 and multiplied by the intensity score. The magnitude of impact score is also expressed on a scale of 0-10. Then each magnitude of impact scores of individual activities and/or indicators are combined in a systematic way to get the **impact score** for each HGMUs**.** These impact sores then combined into one impact score for each HGMUs within a module. For instance, in the case of the hydrology module, this score is called as the **Present Hydrological State** of the assessed HGMU.

Once all HGMUs are assessed, the **Overall Present Health** is calculated in each module by area weighting the Present State scores. The area weighted impact sore then applied to Table 1, which helps for describing the wetland health in terms of the assessed health component.

Furthermore, each module assesses the anticipated **Trajectory of Change** of the wetland, which indicates whether the current state is likely to change in the future, in which direction and to what extent. These changes are first scored at the level of hydro-geomorphic units and then these scores are combined into one score for the whole wetland. The scores and classes of the Trajectory of Anticipated Change are shown in Table 2.

g) Interpretation of results

The ecological condition or wetland health is described by the **Overall Present Health** categories together with the anticipated **Trajectory of Change** for each health components i.e. hydrology, geomorphology, vegetation. Although, these scores can be aggregated that is not recommended. Since in this way the results provide a good basis for identifying which health component is degraded, and where (in which HGMU). Therefore, it supports the management and the rehabilitation of wetlands.

Table 1: The Overall Present Health categories used in WET-Health
Adapted from Macfarlane et al. (2008)

Description	Impact Score Range	Overall Present Health Category
No discernible modifications or the modification is such that has no impact on the component's integrity.	0-0.9	A (None)
Although identifiable, the impact of the modifications on the component's integrity is small.	1-1.9	B (Small)
The impact of the modifications on the component's integrity is clearly identifiable, but limited.	2-3.9	C (Moderate)
The impact of the modifications is clearly detrimental to the component's integrity. Approximately 50% of its integrity has been lost.	4-5.9	D (Large)
Modifications clearly have an adverse effect on this component's integrity. 51% to 79% of its integrity has been lost.	6-7.9	E (Serious)
Modifications are so great that the ecosystem processes of this component of wetland health are totally/ almost totally, more than 80 % has been lost	8-10	F (Critical)

Table 2: The classes and scores of anticipated Trajectory of Change
Adapted from Macfarlane et al. (2008)

Change Class	Description	Change score	Symbol
Substantial improvement	State is likely to improve substantially over the next 5 years	2	↑↑
Slight improvement	State is likely to improve over the over the next 5 years	1	↑
Remain stable	State is likely to remain stable over the next 5 years	0	→
Slight deterioration	State is likely to deteriorate slightly over the next 5 years	-1	↓
Substantial deterioration	State is expected to deteriorate substantially over the next 5 years	-2	↓↓

2.2.2. Function Analysis and WET-EcoServices assessment tool

In order to answer Research Question 4, ecosystem functions and services needed to be determined, classified and described. Function analysis is a method to translate ecological complexity i.e. structures and processes into a limited number of ecosystem functions, which provide a range of ecosystem services (Vepraskas 1992). As a suitable practical tool for Function analysis, the rapid wetland assessment tool, WET-EcoServices was chosen because it assesses the provision of 15 ecosystem benefits, both goods and services that are considered as the most important for South African wetlands and can be readily and rapidly described (Kotze et al. 2008). The ecosystem services and the typology of services applied in WET-EcoServices are shown compared to the typology of the Millennium Ecosystem Assessment in Table 3. It shows that WET-EcoServices also differentiates indirect and direct benefits, in alignment with the MA categories (2005). However, it contracted regulating and supporting services into one category, particularly focusing on regulating services. Furthermore, it identifies biodiversity maintenance as a separate category.

Table 3: Indirect and direct benefits assessed by WET-EcoServices compared to MA wetland services typology

Millennium Ecosystem Assessment (2005c)	Main categories of ecosystem services		WET-EcoServices (Kotze et al. 2008)		
Natural hazard regulation	Regulating	Regulating and supporting	Flood attenuation		INDIRECT BENEFITS
Water regulation			Streamflow regulation		
Water purification and waste treatment			Water quality enhancement	Phosphate assimilation	
				Nitrate assimilation	
				Toxicant assimilation	
				Sediment trapping	
Erosion regulation				Erosion control	
Climate regulation			Carbon storage		
Soil formation	Supporting		*Not applicable*		
Nutrient cycling			*Not applicable*		
Pollination			*Not applicable*		
Biodiversity		**Biodiversity maintenance**			DIRECT BENEFITS
Fresh water	Provisioning		Provision of water use		
Fiber and fuel			Provision of harvestable resources		
Food					
Biochemicals					
Genetic materials					
			Provision of cultivated foods		
Spiritual and inspirational	Cultural		Cultural heritage		
Recreational			Tourism and recreation		
Educational			Education and research		
Aesthetic			*Not applicable*		

The description of tool and ecosystem services is based on the WRC report on WET-EcoServices by (Kotze et al. 2008), unless stated otherwise. The short descriptions of the assessed direct and indirect benefits are given below.

Indirect Benefits

These benefits include regulating and supporting services that indirectly contribute to human well-being.

Regulating and supporting services

1. **Flood attenuation** refers to reducing the severity of floods downstream and the potential damage during extreme climatic events by spreading out and slowing down of flood waters (Macfarlane et al. 2008, Turpie et al. 2008);
2. **Streamflow regulation** refers to sustaining base flows by acting as natural water storages during the dry periods.
3. **Sediment trapping** is about trapping and retaining sediment carried by runoff waters, thereby improving water quality in downstream.
4. **Phosphate assimilation** refers to the removal of phosphates carried by runoff waters.
5. **Nitrate assimilation** stands for the removal of nitrates carried by runoff waters.
6. **Toxicant assimilation** refers to the removal of toxicants such as metals, biocides, and salts (etc.) carried by runoff waters.

7. **Erosion control** refers to controlling of erosion at the site due to on-site factors, which prevent the loss of soil (e.g. vegetation cover, rehabilitation structure).
8. **Carbon storage** refers to the trapping of carbon due to the slowed down organic matter decomposition under anaerob conditions and thereby contributing positively as a carbon sink.
9. **Biodiversity maintenance** is through the maintenance of natural processes and the provision of habitat. The capacity of the wetland to maintain biodiversity depends on the ecological condition of the wetland and specific attributes such as the presence of Red Data species.

Direct Benefits
Direct benefits are those wetland goods and services that are directly provided for humans.

Provisioning services

10. **Provision of water supply for direct human use** includes water extracted from the wetland directly for domestic, agricultural or other purposes.
11. **Provision of harvestable resources** refers to the variety of harvestable natural resources that are often important for livelihoods. For instance, these are reeds for constructions, sedges for crafts, fish, game, edible plants for food, medicinal plants and grazing for livestock etc.
12. **Provision of cultivated foods** refers to the cultivation of crops within the wetland, which, however, requires the complete removal of the natural vegetation, but may results in food security of subsistence farmers.

Cultural services

13. **Cultural heritage** stands for the wetland's significance for local people in terms of their cultural beliefs, ceremonies, and cultural habits. For instance, some plants may represent important resources of traditional crafts, medicines and food, or the place is sacred due to special cleansing ceremonies etc.
14. **Tourism, recreation, and natural scenic value**, wetlands may provide opportunity for recreation and tourism due to their abundant wildlife, and scenic beauty.
15. **Education and research** can benefit from wetlands due to their special ecosystem characteristics and their considered importance in catchment hydrology.

These ecosystem benefits are assessed in terms of their potential delivery based on scoring the biophysical and ecological characteristics of the wetland per service. Further advantage of the tool is that it was developed particularly for South African palustrine wetlands and uses similar scoring system, and logic as WET-Health tool, however, it is mainly based on qualitative data. It also uses the same descriptors for describing hydro-geomorphic characteristics.

The assessment can be executed at two levels, similarly to WET-Health. Level 1 assessment is undertaken as desktop assessment. It focuses mainly on those ecosystem services that are generally assigned to HGMU types (e.g. floodplains attenuate floods) based on previous studies and experience. It has a low resolution as field verification is missing, but it can provide a useful overview of wetland services at a catchment level.

In my study, level 2 assessment was chosen because it is used when few wetlands are to be assessed. It starts with a desktop assessment of available data and is followed by a field assessment where each of 15 benefits may be assessed based on a list of attributes that are relevant to the certain benefit. It has higher resolution due to the field verification.

a) Delineation of wetland boundaries
In alignment with WET-Health, this tool also starts with delineating the boundaries of the wetlands to be assessed. To have the exact spatial extent of the wetland is important in order to have more accurate assessment outcome. (The delineation was executed according to the description of procedure in Appendix 2.

b) Delineation of hydro-geomorphic units and their sub-catchments

The assumption behind this step is that wetlands that share common hydro-geomorphic and climatic characteristics are likely to have similar structures and processes. Defining HGMUs is based on the classification system used in the South African WET-tools (Kotze et al. 2008, Macfarlane et al. 2008) introduced in Figure 3. After the division, the HGMUs are assessed separately in terms of the delivery of ecosystem services. The delineation of the associated sub-catchments is also required as human activities (e.g. irrigation, dams, pesticide use etc.) or the relative size of the HGMU to its catchment's size defines whether it can effectively deliver certain services.

c) Assessment of delivery of ecosystem services

The tool provides a checklist with guideline for assessing all relevant characteristics per service. For instance, to assess the effectiveness of a wetland in removing nitrates, characteristics includes; representation of different hydrological zones, extent of vegetation cover, extent of to which fertilizer/ biocides are used in the HGMU, etc. Some of the characteristics are important for determining more than one service, for instance, the characteristic 'representation of different hydrological zones' is important to assess flood attenuation, streamflow regulation, nitrate and toxicant removal, and carbon storage as well as water supply services.

Therefore, in order to simplify the assessment of the characteristics an Excel data sheet is used, where all characteristics are listed according to the characteristics of the HGMU's sub-catchment level and the HGMU. Furthermore, the characteristics are divided into five classes and to each class a score is assigned between 0 and 4.

d) Scoring system

All the wetland characteristics per benefit are scored based on effectiveness an opportunity rates. For each score the assessor assigns a **Confidence Score** on a scale of 1 (low confidence)-4 (very high confidence) which is based on the reliability of the data source and the level of accuracy.

The average of effectiveness rates of characteristics gives the **Effectiveness Score** of the wetland. This score indicates whether the assessed wetland is effective to supply that particular benefit. The **Opportunity Score** is calculated from the average of all opportunity rates given for all opportunity characteristics assigned to a benefit. The opportunity characteristics are those that indicate a higher supply of benefit.

For instance, in the case of sediment trapping, direct evidence of sediment deposition in the HGMU is effectiveness characteristic and the extent to which dams are reducing the input of sediment is an opportunity characteristic. If there is sediment deposition that would be direct evidence that the HGMU currently traps sediment and if the reduction of sediment input by dams upstream is low, that increases the likelihood that more sediment can be trapped by the wetland. However, it might result in a reduction in the ecological condition of the wetland (Kotze et al. 2008).

e) Interpretation of results

The **Overall Score** is the average of the **Effectiveness** and the **Opportunity Scores** calculated for each benefit. The score is represented in a spider diagram or in a tabular form. The overall score is between the range of 0.0 and 4.0 which is divided into five categories for interpreting it. Based on the overall score the likely extent to which the ecosystem is being supplied by the wetland can be: low (<0.5), moderately low (0.5-1.2), intermediate (1.3-2.0), moderately high (2.1-2.8) and high (>2.8). WET-EcoServices takes into account both current and future potential benefits that are inferred from the effectiveness and opportunity scores. It is not recommended that agglomerate all the individual scores for each of the different services into one score for the HGMUs.

f) Assessing threats and future opportunities

Threat means potential pressures that are likely to impact detrimentally on the ecosystem services delivered by the HGMU. Such threat can be an active erosion gully, or development plans to transform the HGMU. On the contrary, future opportunities are opportunities that enhance the supply of benefits by the HGMU. This opportunity can enhance the effectiveness of the HGMU, for instance, the direct use by sustainable harvesting of reeds that was not done before or restoring hydrological conditions.

2.3. Data collection and analysis

Data collection was based on both secondary and primary data sources and used different methods such as literature study, interviews, field observation, participatory mapping and field measurements.

2.3.1. Data collection phases and methods

The data collection was conducted in two phases. The first phase focused on building up a broader knowledge about the UKRC. Data was collected on biophysical characteristics, wetland ecosystems and both historical and current human drivers in the study area. The data was obtained by literature study, observation and interviews with landowners and local residents of the catchment, informants and experts. The obtained data supported both the selection of an appropriate wetland study site for applying the framework of this study and served as input data for the wetland assessment tools.

Thus, the second phases focused on collecting detailed data on the site of the selected wetland in terms of the human drivers and the wetland's biophysical structure and processes. During this phase, data collected additionally derived from interviews conducted with the previous and the current landowners, participatory mapping, field observation and field measurements.

2.3.2. Literature study

Secondary data was obtained through literature study from written documents as well as from GIS maps and spatial data.

Written documents provided specific insights into the characteristics of the study area, wetland ecology, vegetation, hydro-geomorphology, ecological condition, ecosystem services, human activities and the applied methods. They contributed to answer Research Question 1, 2, 3 and 4. Literature consisted of scientific articles, books, governmental publications, reports, statistics and web pages. The documents were obtained from scientific journals (articles about e.g. concepts of the conceptual framework), official websites (e.g. about invasive alien plant clearing by WfWater), library (books about e.g. wetland ecology), the host organization's database and from contacts.

GIS maps, aerial photographs and GIS data sets (Table 4) provided geospatial data on the locations, types and extents of agricultural lands, invasion of IAPs and degraded areas in the UKRC. Furthermore, these maps and data contributed to the creation of new spatial information for other assessment steps (e.g. sub-catchment boundaries, vegetation and disturbance maps of the wetland site). Maps provided important data for addressing Research Question 1, 2, and 3.

Table 4: GIS maps and data used in the study

GIS maps and data	Source
Aerial-photographs (1: 20 000) (2007) Land use and land cover maps (1986, 2007*) Quaternary catchments (K90A and B) boundaries Farm boundaries	National Geo-Spatial Information(NGI), Rebelo, A. (2012) MSc. Stellenbosch University
Google Earth image (2011)	Google Earth
National Freshwater Ecosystem Priority Areas data set (NFEPA) (2011); water management areas (WMAs), rivers, dams	BGIS-South African National Biodiversity Institute website
Eastern Cape Cadastral spatial data (2008); provinces, towns and cities South African National Land Cover map (2001)	PRESENCE data base, Living Lands
Topographic map (1: 50 000)	National Geo-Spatial Information (NGI)

*Rebelo's land use and land cover map (2007) is the most recent spatial information about the UKRC.

2.3.3. Field survey

Field survey served to collect recent primary data and to verify data on the field for the wetland assessments.

1. Interview

Interview results helped to answer Research Question 1, 2, 3 and 4. Interviews were particularly important to address Research Question 2 and 4. The interviews were both unstructured and semi-structured. The latter included both open and closed ended questions that were prepared in an interview guide, but the structure of the interview allowed flexibility (Kumar 2005). The interviews aimed to get comprehensive information on the human drivers (agriculture, IAPs clearing) and on biophysical structures (e.g. vegetation, hydrology, soil, peat) processes (e.g. erosion, deposition), and services of wetland ecosystems at both spatial scales. Since local people's knowledge has been recognized being valuable for research (Robenson and McGee 2003), the interviewees were both landowners and experts. A preliminary list of interviewees was established based on the likelihood of a person to provide insights into the topics of interest. The interviewees were contacted via e-mail and phone to arrange meetings. Regarding the experts the snowball technique was applied as the interviewed persons usually provided further contacts.

Interviews were conducted with thirteen local landowners, eight experts (South African National Biodiversity Institute (SANBI); Rhodes University, International Mire Conservation Group), and two informants (Gamtoos Irrigation Board, (GIB), DWAF). A number of interviews, made with landowners were carried out in union with another PRESENCE student Lisa Nooij (Van Hall Larenstein, The Netherlands) and the project leader of the Kromme project, Marijn Zwinkels (Living Lands, South Africa).

2. Participatory mapping

Participatory mapping was applied during the second phase of the data collection. It focused on collecting specific spatial data on the wetland's spatial scale. Therefore, after selecting the case study site, previous and current land owners were asked to indicate significant changes in the land use and land cover on the wetland's site (e.g. which areas were cleared from invasive alien vegetation etc.) before and after WfWater cleared the site and the erosion control structure was built. Furthermore, they also provided insights into the hydrological characteristics of the area, which contributed to the determination of wetland boundaries. Maps were compiled by using land use maps and associated aerial photographs. It helped to address Research Question 1, 2, 3 and 4.

3. Field observation

Field observation was important during both data collection phases. This method was applied to collect and verify data for the delineation of wetland boundaries, and provided relevant data on the biophysical characteristics (e.g. hydrological, geomorphic and vegetation characteristics) of the catchment area, and the selected wetland' site. Regarding the vegetation compositions the WRC report by Van Ginkel et al., (2011) "*Easy Identification of some South African Wetland Plants*" was used for identifying vegetation on the site of the Hudsonvale wetland. In order to get familiar with the 'natural' vegetation cover first, two more intact valley-bottom wetlands were visited at the upstream. Furthermore, field observation besides interviews helped to find out more about current human activities in the catchment and on the site of the selected wetland. The data on biophysical characteristics and human activities provided relevant inputs for the tools WET-Health and WET-EcoServices to assess current ecological condition and current wetland functions and services, therefore field observation helped to answer Research Question 1, 2, 3 and 4.

4. Field measurements

Field measurements were applied during the second data collection phase, thus it gathered data at the selected wetland's spatial scale. Two types of field measurements were applied in order to obtain data primarily for delineating the wetland's boundaries that was required by both WET-Health and WET-EcoServices assessments. Furthermore, these measurements provided data for determining the ecosystem structure and processes. Therefore, this data collection method contributed to answer Research Question 1, 3 and 4. The field measurements were soil and topographic surveys and were executed together with another PRESENCE intern student, Lieke Jager (Van Hall Larenstein, The Netherlands).

The topographic survey consisted of leveling operation which is used for determining elevation of points and the differences in elevations between points (Highway 2005). The elevation was measured by using equipment: a surveyor's level (dumpy level) which consists of a telescope mounted on a tripod, a 5 m long leveling staff that was graduated in dm, flags and a compass.

The soil survey was conducted along the cross-sectional transects and focused on soil characteristics that serve as indicators for determining the soil wetness. Therefore the first 50 cm of the soil profile was examined by means of a soil auger, starting from the wettest part of the wetland and proceeding outwards towards the estimated edge (DWAF 2005). The described soil characteristics were: horizons and depths, matrix color, soil texture, redoximorphic features (mottling) (amount, depth, color), wetness, compaction and land cover of the auger point. Materials used for the survey were soil auger, Munsell color chart, field soil texture diagram, and tape measure and Garmin eTrex GPS. Most of the measuring tools were provided by the Department of Environmental Sciences of the Rhodes University (Grahamstown, South Africa).

2.3.4. Data processing methods

Literature review, interview and observation reports and GIS processing were carried out to process the different data sources. WET-Health, WET-EcoServices assessment tools were used to analyze and structure information in order to answer the main research questions (Table 5).

Table 5: Summary table of data sources, corresponding data processing methods, tools and research questions

Data source			Data processing methods	Tools	Research questions*
Secondary data	**Literature**	Governmental publications Reports Scientific articles and books Statistics Web pages	Literature review	WET-Health, WET-EcoServices	1, 2, 3, 4
	Maps	GIS maps and data sets	GIS processing	Map generation	1, 2, 3
Primary data	**Interviews**	Landowners (13), experts (8) and informants (2)	Interview report	WET-Health WET-EcoServices	1, 2, 3, 4
	Participatory mapping	Landowners (2), prepared maps	Maps, interview report	WET-Health WET-EcoServices Map generation	1, 2, 3, 4
	Field observation	Observation notes & photos	Observation report	WET-Health WET-EcoServices, Map generation	1, 2, 3, 4
	Field measurements	Soil and topographic surveys	Soil data assessment Excel analysis	WET-Health, WET-EcoServices, Map generation	1, 3, 4

*For research questions see chapter 1.3.

2.4. Selection of an appropriate case study site: Hudsonvale wetland

Three palmiet-dominated wetlands were considered for this research. These wetlands were located on the farms Krugersland, Companjesdrift and Hudsonvale and were potential candidates for the study as they were located at the valley-floor, thereby being linked to the river system (palustrine wetland), which is a prerequisite of using the WET-tools (Figure 5).

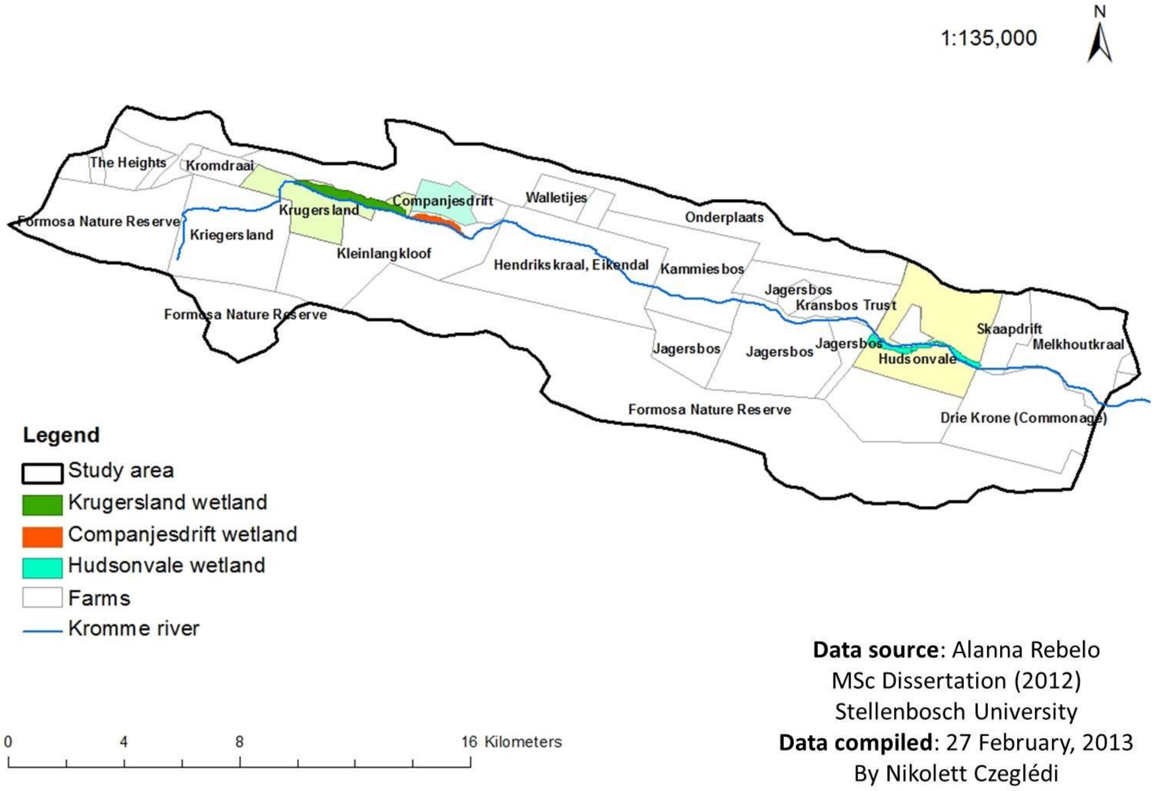


Figure 5: Location of palmiet wetlands in the Upper Kromme River Catchment

Eleven criteria were established in order to evaluate which wetland is the most appropriate for applying the framework and assess the impacts of the three human drivers on wetland services. In the criteria, both spatial scales were incorporated i.e. the catchment and the wetland scales as not only human activities on-site, but also activities upstream can affect wetlands (Mitsch and Gosselink 2007). Criteria were, for instance, the type and intensity of agriculture on the lands adjacent to the wetland, IAPs clearing already took place, presence of an erosion control structure. Then these criteria were assessed based on information obtained during the first phase of data collection (Table 6).

Table 6: Criteria used for selection of appropriate case study site

Spatial scale	Nr.	Criteria of selection	Wetland name		
			Krugersland	Companjesdrift	Hudsonvale
Wetland site	1	Agricultural use of lands adjacent to the wetland	Yes	Yes	Yes
	2	Intensity of agricultural activity close to the wetlands	Low	Low	High
	3	Level of historical wetland transformation	Low	Intermediate	High
	4	Erosion control structure present within the wetland	No	Yes	Yes
	5	Position of erosion control structure within the wetland	-	Downstream end of the wetland	Middle of the wetland
	6	Location of the wetland within the study area	Uppermost	Upstream, next to Krugersland	Downmost
	7	WfWater already cleared	Yes	Yes	Yes

		IAPs on the farm			
	8	Accessibility	Good	Good	Good
	9	Level of spoken English language	Intermediate	Poor	Native
Upstream catchment	**10**	Number of erosion control structures upstream to the wetland	4	4	9*
	11	Intensity of agricultural activity in the vicinity upstream of the wetland	Low	Low	High

*The erosion control structure in the Hudsonvale wetland is the down most located structured in the UKRC, all the other erosion structures are located upstream.

Finally, the Hudsonvale wetland was selected because it greatly differed from the two other wetlands, particularly, in terms of its location within the UKRC, the position of the erosion control structure within the wetland and the intensity of agricultural use of lands adjacent to and upstream to the wetland. Furthermore, other considerations such as the level of English spoken by the owner and accessibility of the wetland were also considered relevant for the research. The Hudsonvale wetland is shown on Photo 2.

Photo 2: The Hudsonvale wetland (Photo by Author)

2.5. Spatial boundaries of the assessments

The study uses both catchment and wetland scales. The hydro-geomorphic dynamics and biophysical properties of the wetland are influenced by the biophysical characteristics of its catchment and land use activities located upstream or upslope of the wetland (Mitsch and Gosselink 2007, Macfarlane et al. 2008). The catchment area of the Hudsonvale wetland is the area, which collects all rain and runoff water that eventually flows into the wetland. Human drivers in the catchment of the wetland can also alter hydrological characteristics such as the quantity and flow patterns of water inputs, as well as the amount of sediment and nutrients delivered to the wetland. The delineated catchment area of the Hudsonvale wetland has an area of 18,399 ha and covers 86% of the UKRC. This catchment formed the spatial boundaries of the analysis of human drivers described in chapters 3.2 and 3.3 Furthermore, this catchment area is also the summed area of the delineated sub-catchments of the HGMUs. The HGMUs and their sub-catchment areas are used in the analyses in Chapters 5 and

6 to assess the current ecological health and current ecosystem services of the Hudsonvale wetland. Sub-catchment 1 is the catchment area of HGMU 1 and sub-catchment 2 is the catchment area of HGMU 2. The areas of the HGMUs and their associated sub-catchments are shown in Table 7 and the different spatial boundaries used in this study are shown in Figure 6.

Table 7: Extent of hydro-geomorphic units and associated sub-catchments

	Area (ha)	Sub-catchment area (ha)
Hydro-geomorphic unit 1	28	15,549
Hydro-geomorphic unit 2	26	2,850
Total (Hudsonvale wetland)	**54**	**18,399**

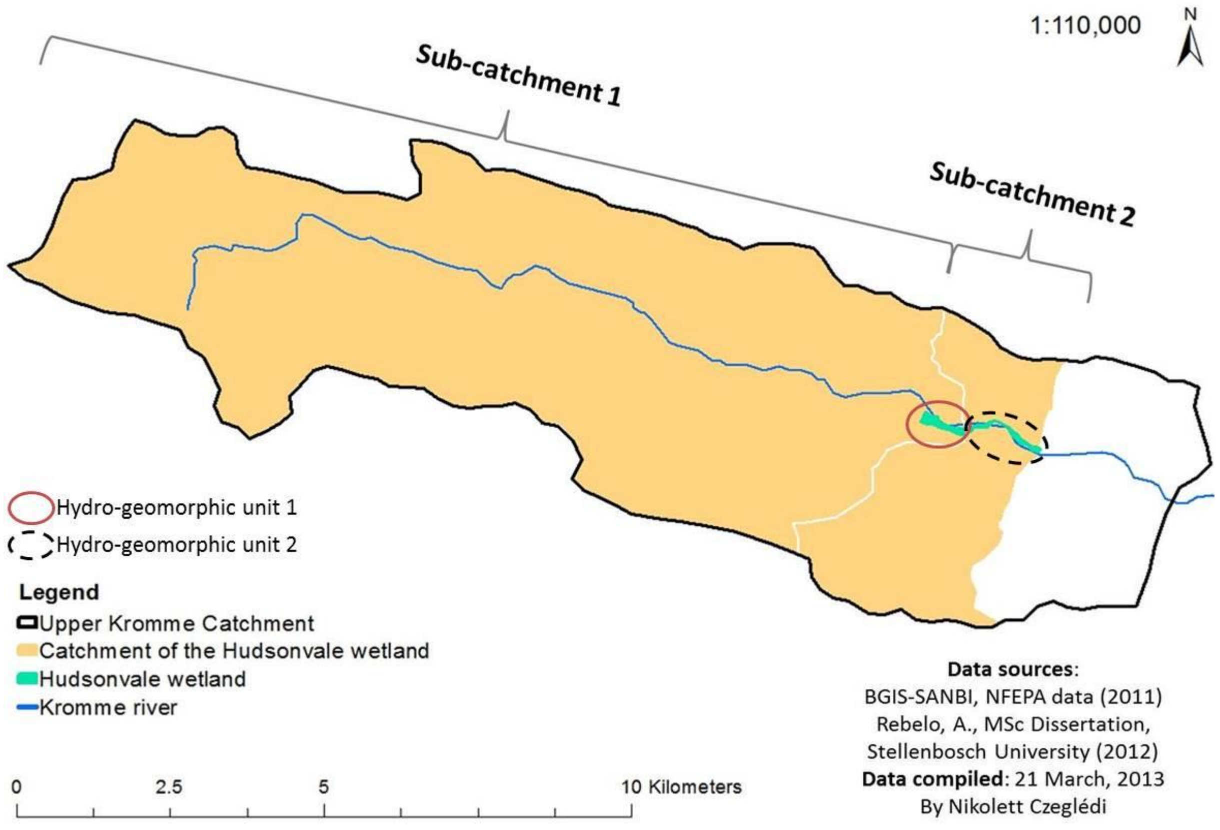


Figure 6: Spatial boundaries of the analysis of human drivers

3. Inventory of biophysical characteristics and human drivers in the Upper Kromme River Catchment

The following chapter focuses on the biophysical characteristics and human drivers of the UKRC, and consists of three sections. The first section describes the biophysical characteristics; the second provides an overview on the historical human drivers that contributed to alterations in the ecological condition of the valley-bottom wetlands in the catchment area. The third section presents the results on the current human drivers; agricultural land use, IAPs eradication and constructed erosion control structures in terms of their characteristics and impacts in the catchment.

3.1. Biophysical characteristics of the assessment area

a) Location

The Catchment of the Hudsonvale wetland has an area of approximately 18,399 ha, which covers 86.4% of the UKRC (Figure 6).

b) Geology and soil

The evolution of the Kromme River Basin is associated with the Pan-African orogenic (mountain building) event which had led to the evolution of Gondwana supercontinent. In that tectonic event, rifting occurred along the southern Cape and deposited sedimentary mudstones and sandstones of the Cape Supergroup in the resulting rift valley basin (Mucina and Rutherford 2010). 300 million years ago the rift started its closure, and the rocks of the Cape Supergroup began to fold resulting in the formation of the Cape Fold Belt (Ellery et al. 2009). During this process the Kromme River valley evolved (Haigh et al. 2002).

The main rock horizons of Cape Supergroup (Table Mountain Group) (Mucina and Rutherford 2010), the mid- Palaeozoic quartzites and subordinate shale horizons form the bedrock of the Kromme River basin (Haigh et al. 2002). The youngest shale horizons are on the surface in the center of the valley axis and derive from the Devonian Gydo Formation (Bokkeveld Group). Towards the mountain ranges, the age of rock horizons increases. The oldest rock horizons are the dominant quartzitic sandstones (Ordovician Penninsula Formation) of the Tsitsikamma and Surranysberge mountains (Haigh et al. 2002). On the top of these horizons are the thin organic and loam rich shale beds of Cedarberg Formation, which were formed in a deep – water environments. Some of the quartzite of Table Mountain, and Bokkeveld Groups enhance both the exploitation potential and quality of the groundwater due to their medium to coarse grain size, relative purity, well indurated nature and fracturing in the fold belt (Wu 2005).

The parent material i.e. the underlying rock type or the recent deposits are the primary factors determining the physical and chemical nature of the different soil types. Thus, the soil type of the lower slopes is heavy structured dark soil with large fine sand and loam fractions. These soils a form a very thin soil cover because of the shale horizons of Bokkeveld and Cedarberg Groups they developed. The slow weathering of quartzitic sandstone of the Suuranysberge and Tsitsikamma mountains resulted in the development of the extremely nutrient-poor, acidic lithosol soils on the higher slopes (Mucina and Rutherford 2010).

Hydric soils are mainly located at the valley-bottom, and in pans and seeps on the slopes, but particularly where peat lands are formed. Champagne and Katspruit soil forms characterize the peat basins. The previous has high organic content and deep profile, the latter has pale acidic soils with darker A horizon over deeper mottled G horizon (Haigh et al. 2002).

c) Sedimentary sources

The primary sources of sediments are the in situ weathering of bedrock and the downhill transport of colluvial sediments. The secondary sources of sediments are reworked fluvial sediments that derive from channel incision and/ or lateral channel migration. Due to the dominance of the quartzitic sandstone in the tributary catchments, sand and large-clast characterize the channel sediments.

Little sediment is stored on the lower valley slopes due to the thin soil cover and coarse clastic nature of the colluvium on the lower valley slopes (Haigh et al. 2002).

d) Climate and hydrology

The average daily temperatures for the region range from 17.7 C° in July to 24.9 C° in February (Saexplorer 2011)[5]. Although rain can occur at any period of the year, it has a bimodal climatic pattern characterized by more rain in the winter. Therefore, May (53.07 mm) is usually the wettest month and January (32.91 mm) is the driest (Haigh et al. 2002). The mean annual precipitation is around 600-700 mm, and the mean annual potential evapotranspiration is about 1400 mm in the Catchment K90A (Haigh et al. 2008) (Figure 7).

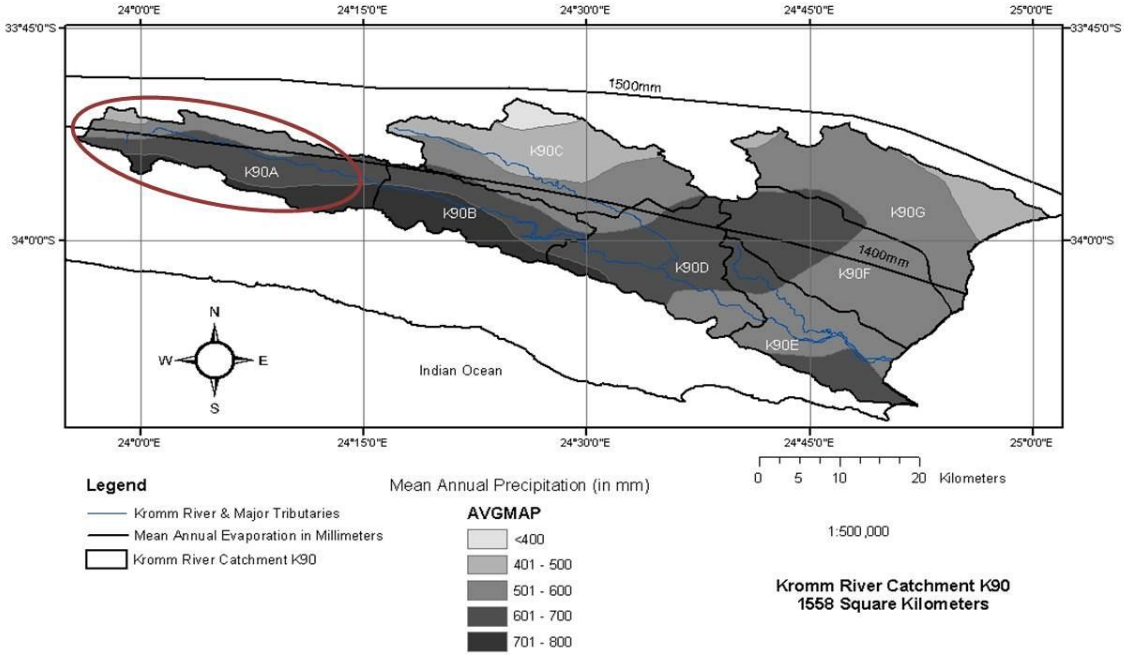


Figure 7: Mean Annual Precipitation and Mean Annual Evaporation (mm) in the Kromme River Catchment
The circle indicates the Catchment of the Hudsonvale wetland; the figure is adapted from Haigh et al., (2008).

Floods are periodically experienced in the area (Haigh et al. 2004). One of the largest floods happened on August in 2006, when 397 mm precipitation was measured in Kareedouw. It was estimated that the likelihood of the recurrence of such a flood event is fairly high within 50 years (Haigh et al. 2002, Van der Merwe et al. 2011). It seems to be underpinned as another extreme flood event caused a lot of damage in the upper catchment, in the middle of July, 2012 (Schafer, pers. comm., 2012) Smaller floods, such it was on March of 2007 (205 mm), are experienced every five years (Kotze and Ellery 2009, Van der Merwe et al. 2011).

Due to two geological uplift events there are also differences in the distribution of precipitation in the catchment, in general the precipitation increases towards the coastal areas as well as to the mountainous ranges (Ellery et al. 2009). Therefore, the southern (coastal) side of the Tsitsikamma Mountains gets more rainfall than the northern (Kromme) side (Buckle, pers. comm., 2012).

[5] Saexplorer (2011). "Kareedouw climate." Retrieved 10-09-2012 http://www.saexplorer.co.za/south-africa/climate/kareedouw_climate.asp

e) Topography and drainage system

The slopes of the valley sides are between 25% and 60% on the south facing mountains and between 20% and 30% on the north facing mountains. The maximum elevations are 1073 m in the Surranysberge to the north and 1250 m in the Tsitsikamma mountains to the south (Haigh et al. 2004). In the upstream area, the average longitudinal slope is 0.6% towards sea (Haigh et al. 2002). The average longitudinal slope of the Kromme Valley was calculated from the plotted Longitudinal Valley profile (Figure 8) for the catchment of the Hudsonvale wetland as 0.97%.

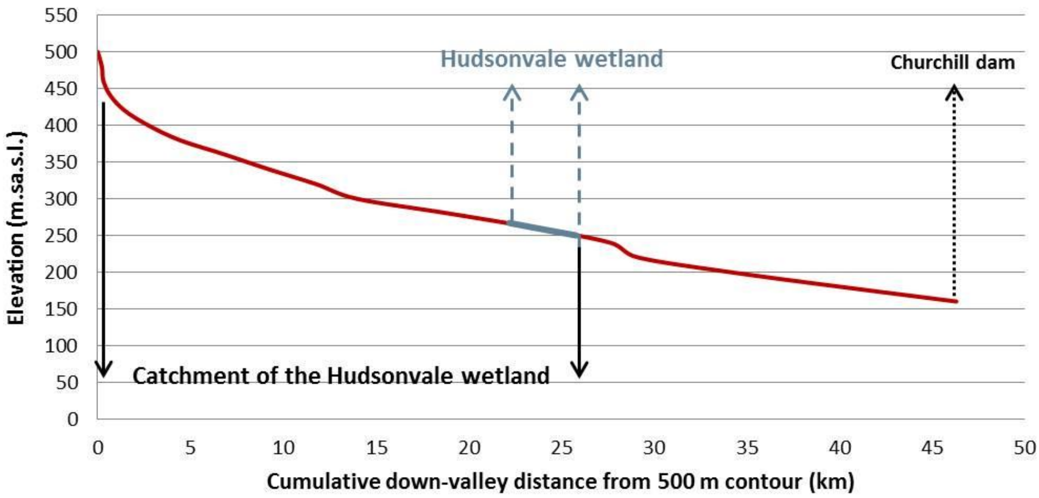


Figure 8: Longitudinal gradient of the Kromme valley

The UKRC has a trellis drainage system which is a typical feature of folded mountains (Haigh et al. 2004). A strike valley and the presence of small tributary rivers that feed into the valley from the steep slopes of the mountains at about 90 degree angles characterize it. That causes the trellis-like pattern (Ritter 2003)[6] (Figure 9a.). The routes of rivers are determined by the presence of softer –less resistant to erosion- and resistant rock formations (Mucina and Rutherford 2010).

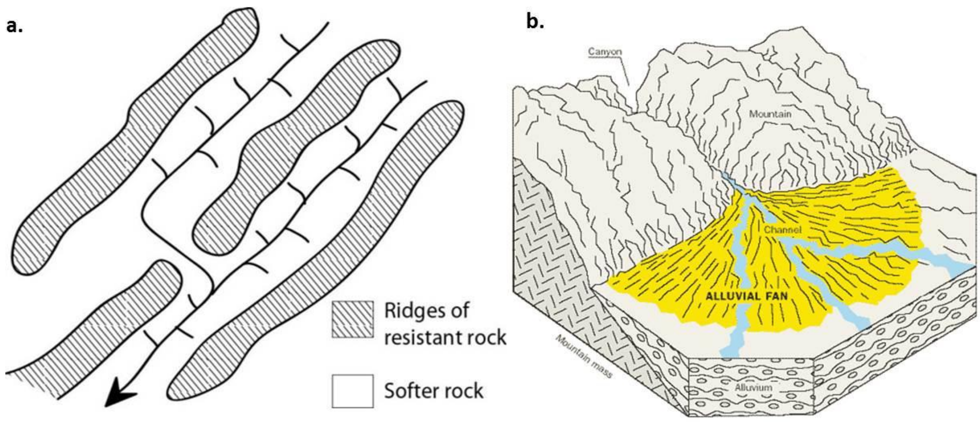


Figure 9: Trellis drainage pattern (a) and a typical alluvial fan (b)
Adapted from Ritter (2003)

From the wetter south side there are six large and five smaller tributaries. The most important ones considered by this study are Tierkloof, Eerstedrif and Witels rivers. From the dry northern side there

[6] Ritter, M. E. (2003). The Physical Environment: an Introduction to Physical Geography. Retrieved 10-09-2012 http://www.earthonlinemedia.com/ebooks/tpe_3e/title_page.html

are seven large and numerous short, mainly temporary tributaries that enter the main channel (Haigh et al. 2008). The water in the main river is acid and fairly corrosive (Haigh et al. 2002).

Alluvial fans are evident features in the UKRC (Haigh et al. 2002, 2008) Alluvial fans are sedimentary deposits delivered by a stream from the mountainous upland to the adjoining valley (Blair and McPherson 1994) (Figure 9b). In the catchment the sediment is delivered at the distal ends of the tributaries and they function as ‘sediment blockages’ in the main stream, that limit the spatial extent of the palmiet wetlands (Haigh et al. 2008).

f) Vegetation

The natural vegetation is strongly linked to the geology, soil and climate properties. In the catchment, the main vegetation types are sandstone fynbos and shale renosterveld. These vegetation types typically occur in areas with bimodel rainfall and on rocks of the Cape Supergroup. The fynbos vegetation is well adapted to the nutrient-poor soils, developed on quartzitic sandstone, while the renosterveld vegetation grows on places where there is thin clay or silt layer, usually derived from remnants of overlying shale, covers the bedrock. Therefore, the fynbos species characterizes the northern slopes of the Tsitsikamma Mountains and southern slopes of Suuranysberge, with a transition of vegetation on the lower slopes of narrow shale bands. Both fynbos and renosterveld are fire maintained systems, which need fire in order for the dormant seeds to germinate (Mucina and Rutherford 2010).

Photo 3: Palmiet (*Prionium serratum*) (Photo by Author)

The valley-bottom wetlands are mainly dominated by palmiet (*Prionium serratum*) (Photo 3), but other sedge and grass species are also present as well as invasive aliens such as Conyza albida, Acacia mearnsii and Hypochaeris radicata (Ayine 2007, Kotze and Ellery 2009).

Palmiet is a robust indigenous, emergent macrophyte which is able to change its own environment to favour itself and its associates (Sieben 2012). Thus it is also called as ecosystem engineer (Jones et al. 1994). Furthermore it is well-adapted to high energy river systems with periodically occurring floods due to its strong and deep, extensive rooting system and clonal growth (Sieben 2012). It occurs on gradients up to 3%, which is unusual for wetland plants. In general, wetland plants occur on gradients between 0.01-1 % (Buckle, pers. comm., 2012). Palmiet is also adapted to nutrient-poor, acidic water conditions, but sensitive to being shaded (Boucher and Withers 2004).

BOX 1: Black wattle (*Acacia mearnsii*) – The No.1 invader in the Kromme

Black wattle is a tall woody, fast growing tree, which is originally native to Australia. It was brought to South Africa for its timber, but became one of the most aggressive invading species in the country. Due to its extremely rapid growth, drought resistance and high seed production it is also the principal IAP in the UKRC (McConnachie et al. 2012). It has shallow root system, thus it is easily ripped out by floods, which may result in instable riverbank and erosion gullies in the river channel. Similarly to Eucalyptus species, it also mainly infects riparian areas, which contributes to easy disperse of the seeds towards downstream (Le Maitre et al. 2002). Studies have shown that with other IAPs together it uses more water than indigenous species and thereby contributes to decreased streamflow and baseflow in the river system (Le Maitre et al. 2002, Dye and Jarmain 2004, Everson et al. 2006). A. mearnsii also changes the natural nutrient cycle in the soil by enriching it with nutrients. The Kromme catchment is characterized by nutrient poor acidic soil and increased nutrient content of the soil threatens the natural vegetation structure and biodiversity of the natural fynbos and renosterveld vegetation (Mooney et al. 2005). It can grow 5-10 m tall, which can shade out other native species such as palmiet (Boucher and Withers 2004).

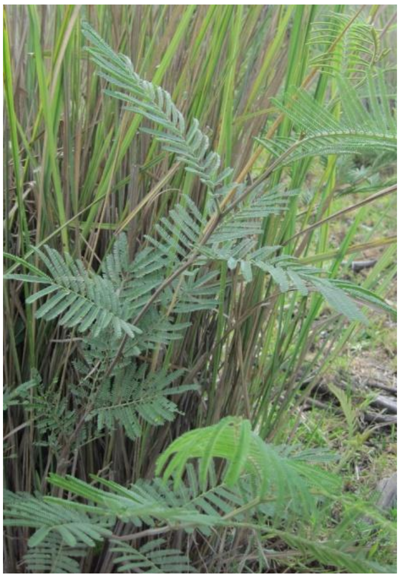


Photo 4: Black wattle (*Acacia mearnsii*) seedling (Photo by Author)

g) Valley-bottom wetlands

There are several types of wetlands occurring in the catchment area (Haigh et al. 2004). Some of them are located on the slopes (seeps and marshes); others are connected to the main river (floodplains, and riparian zones). The most typical ones are the palmiet dominated valley-bottom wetlands. These wetlands are also called fens as they accumulate peat (Haigh et al. 2002). The downstream end of the catchment of the Hudsonvale wetland is also the boundary of the 48 km long peat complex, which is from the upstream divided into three peatland basins (Haigh et al. 2002, Haigh et al. 2008). The eastern peat basin includes the Hudsonvale wetland. The two western valley-bottom fens are located on the farms called Krugersland and Companjesdrift (Haigh et al. 2002) (Figure 10). The palynological analysis of peat cores taken from the central peatbasin indicated that the peat accumulation started around 5620+70 years ago and has an accumulation rate of 0.72 mm/year. The peat thickness varies between 0.5 m to up to 2.8 m with an average of 1.6 m. Palmiet builds up a sandy, medium fine to fibrous peat (Haigh et al. 2002).

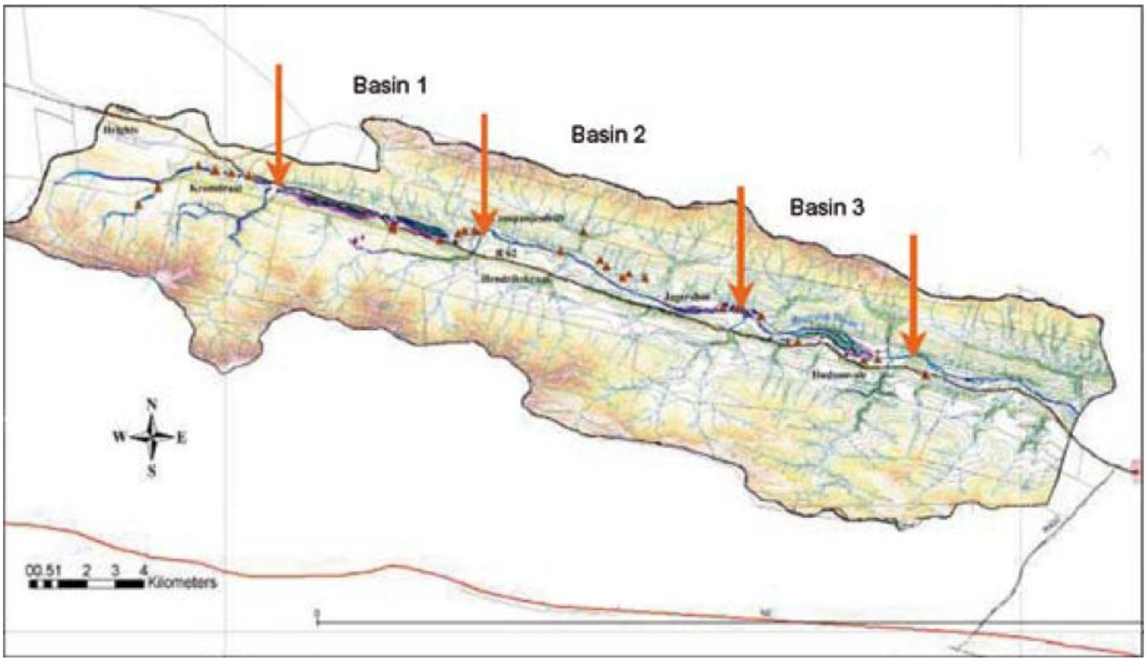


Figure 10: Peatbasins of the Upper Kromme River Catchment
Adapted from Haigh et al. (2008)

3.2. Historical human drivers of wetland alteration

This chapter describes the most relevant human drivers such as farming history and land use change that historically affected the UKRC and contributed to alteration in the valley-bottom wetlands.

3.2.1. Farming history

The description of farming history of the area was mainly based on the study by Haigh et al. (2008) which used a number of sources such as the National Archives in Cape Town, maps, annual reports of the Cape Colony and Cape Province, travel writings and interviews made with land owners.

The agricultural land use of the catchment started when Jagersbos - including the land of the Hudsonvale farm that time - was occupied for grazing livestock in 1775. The top end of the valley was occupied during the same period. Further farming developments and logging of indigenous trees, took place as Mossel Bay and Plettenberg Bay were developed as harbors. Between 1800 and 1940's the most common land use forms were orchards and grazing. Further developments such as building the precursor road R62, establishment of the principal town Kareedouw and the railway line between Kareedouw and Port Elizabeth contributed to improved transport opportunities, thus the intensification of agriculture became possible in the region. The fruit production decreased when a big flood damaged and washed away many orchards in the valley in 1931. The flood caused severe erosion and was the first time when black wattle started to invade the Kromme catchment. Black wattle was originally planted for its tannin and fuelwood. After the flood, many farmers changed into meat and dairy production and established kikuyu pastures in the temporarily flooded zones of the valley-floor. However, the expansion of orchards continued along the valley-floor and after 1942 the production of soft fruit and vegetables become even more important as sources of income, besides dairy and sheep farming. In the uppermost peatbasin, 40% of the lands adjacent to the wetlands were transformed for grazing lands and cultivation and all the alluvial fans were cultivated.

In 1965, floods washed away the orchards again. As a result, many farmers raised the riverbanks and laid drainage ditches in order to preserve the orchards. It led to severe channel erosion and damage in the wetlands. Between 1950 and 1970, infrastructure construction took place, which included bridge building, re-routing, tarring and building of roads. Further series of floods occurred during the 1980 to 1985 drought and caused severe damages to lands in 1981 and 1983. All these contributed to accelerated erosion and sedimentation along the Kromme.

3.2.2. Change in land use and cover between 1986 and 2007

In 1986, the total area under irrigated agriculture, dryland and orchard farming reached about 1,450 ha, and more than half of the valley-floor had been converted to agriculture. Dryland farming made up 82.6%, and 17.2% of the total agricultural land was under irrigation. By 2003, the greatest degree of wetland transformation has occurred between Companjesdrift and Jagersbos as 75% of the smaller wetlands completely disappeared (Haigh et al. 2008).

In 2007, dryland farming was still the dominant land use type that made up 73.6% of the total agricultural land. By 2007, all three farming activities have expanded, resulting in a 28% increase in the total area used for agriculture. Particularly, the extent of orchards increased significantly from 2.6 hectares up to 97.3 ha of which more than a half (56 ha) was located along the Kromme.

In 1986, black wattle made up the majority of IAPs, but there was a significant increase in the area covered by pine from less than one hectare up to 325.3 hectares by 2007. As the agriculture and invasion of IAPs have expanded, the natural palmiet and fynbos vegetation decreased by 1,200.26 ha by 2007. Table 8 shows the different land cover types and changes in their area between 1986 and 2007.

Table 8: Change in land use and land cover in the Catchment of the Hudsonvale wetland

Type of land cover	1986		2007		Change
	Area (ha)	%	Area (ha)	%	Area (ha)
Irrigated fields	249.07	17.2	397.11	21.2	148.04
Orchard	2.60	0.2	97.30	5.2	94.70
Drylands	1198.37	82.6	1376.05	73.6	177.68
Total of agricultural	**1450.04**	**100.0**	**1870.46**	**100.0**	**420.42**
Black wattle	1110.86	98.4	1286.61	76.7	175.75
Pine	0.47	0.0*	325.32	19.4	324.85
Other alien trees	17.54	1.6	65.68	3.9	48.14
Total of woody invasive alien	**1128.87**	**100.0**	**1677.61**	**100.0**	**548.74**
Palmiet	237.87	1.7	207.83	1.6	-30.04
Fynbos	13663.37	98.3	12493.15	98.4	-1170.22
Total of natural vegetation	**13901.24**	**100.0**	**12700.98**	**100.0**	**-1200.26**

*Actual value is 0.04%

Three significant changes in land cover; pine encroachment on the upslope, extended dryland areas and orchards along the main river, are pointed out on the two land cover maps of 1986 and 2007 in Figure 11.

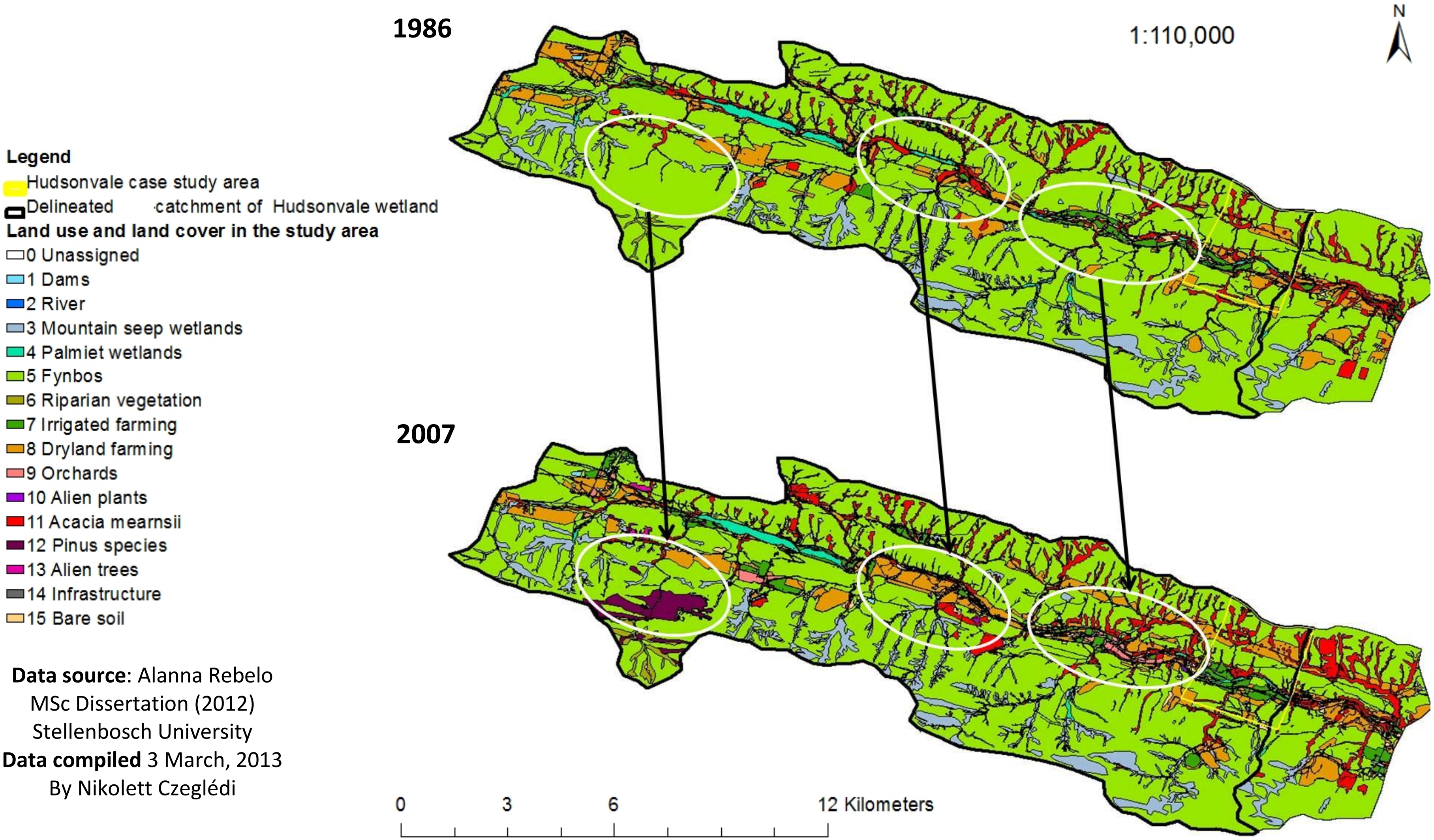


Figure 11: Land cover change in the Upper Kromme River Catchment between 1986 and 2007
The white circles and black arrows indicate the most significant land cover changes between these years. From left to right: pine encroachment, expanded dryland farming, establishment of orchards.

3.2.3. Impacts of historical human drivers on wetland health

The construction of roads and bridges, the expansion of agriculture and invasive alien vegetation, land management practices such as ploughing, cultivating on the alluvial fans and within the flooding zones of the valley-floor, and draining the wetlands all had direct impacts on the valley-bottom wetlands. It contributed to reduced wetland area and degradation in their ecological health by increased level of erosion and sedimentation in the upper catchment area (Haigh et al. 2008). According to Rebelo (2013) the extents of wetlands decreased by 69, 6% between 1954 and 2007, when the extent of wetlands decreased from 754 ha to 234 ha. The magnitude of transformation was the largest in 1986 based on the assessments of aerial photographs. Then five out of the eleven valley-bottom wetlands that were visible on the aerial photographs of 1942, become destroyed. In fact, among the remaining wetlands only one did not deteriorate, all the others did. The main causes were the expansion of agriculture and the invasion of alien plants (Haigh et al. 2008).

3.3. Current human drivers of change

This chapter presents the current human drivers; agriculture, IAPs eradication and construction of erosion control structures, in terms of their current state and impacts in the catchment.

3.3.1. Agricultural land use and land management practices

The catchment of the Hudsonvale wetland consists of 25 private farms and the Formosa Nature Reserve. The farms and the Formosa Nature Reserve occupy 70% and 30% of the sub-catchment area, respectively. In 2007, the total land used for agriculture was around 1,871 ha, of which the majority (74%) was under dryland farming and the rest (26%) was irrigated farming.

The main farming types are related to farming with dairy, fruit trees, livestock, vegetable as well as harvesting honeybush tea and organic farming. Lifestyle farming in this context refers to a way of living when farming is more like a hobby and not a profit-oriented activity. Figure 12 shows the spatial distribution of different farming types per farm in the catchment of the Hudsonvale wetland.

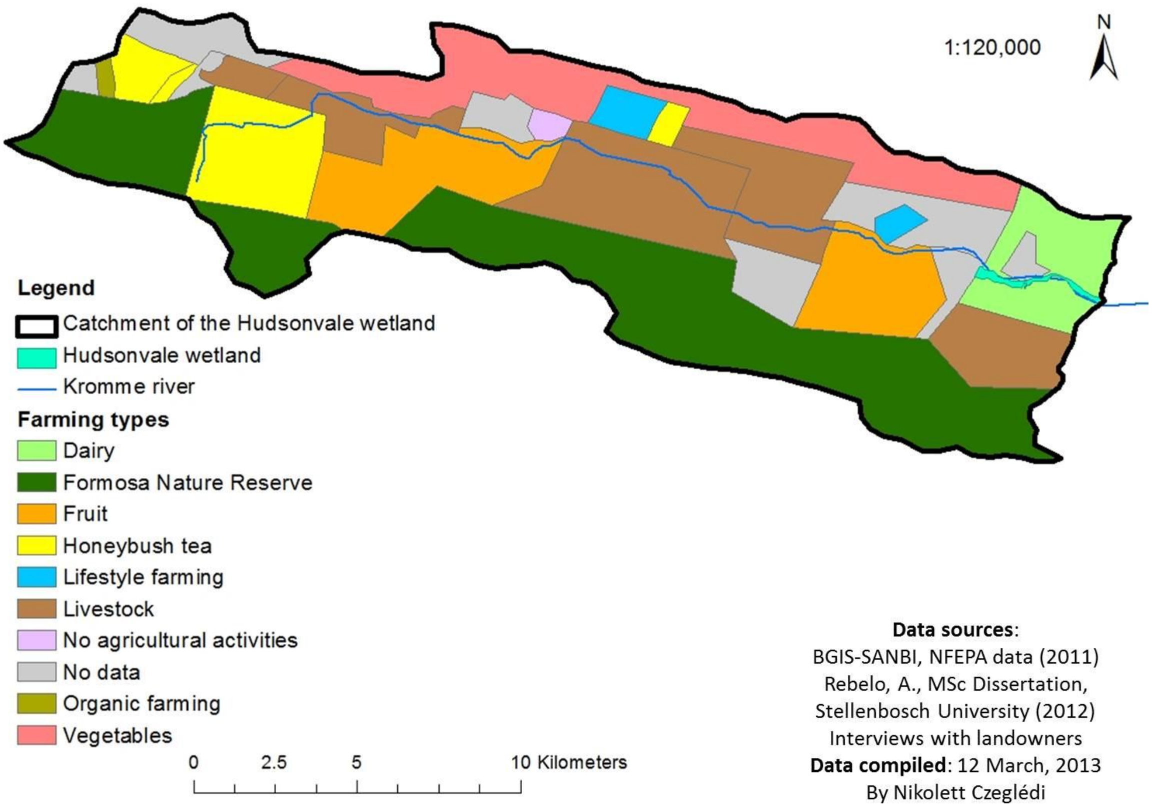


Figure 12: Farming types in the catchment of the Hudsonvale wetland

The status of the farms can be divided into three categories; agriculturally active, agriculturally not active and status unknown. Data was not available in the case of eight farms, thus their status have been defined as unknown. Only 14 farms out of the 25 have been defined as 'agriculturally active'. A farm is defined as 'agriculturally active' if it produces for commercial purposes. Those farms that either does not farm at all or only at a small scale but not for commercial sale (e.g. 'lifestyle farmers') have been characterized as 'agriculturally not-active'.

Table 9: The status of farms in the catchment of the Hudsonvale wetland

Farm status	Number of farms
Agriculturally active	14
Agriculturally not-active	3
Status unknown	8
Total	**25**

The agriculturally active farms can be further divided into six farm types based on their dominant farming activities. Although the farms are usually characterized by mixed farming, with various farming activities, the majority of them (5) are livestock farms (Table 10).

Table 10: Farm types in the catchment of the Hudsonvale wetland

Farm type	Number of farms
Livestock	5
Honeybush tea	4
Fruit	2
Vegetable	1
Dairy	1
Organic	1
Total	**14**

In the case of livestock farms, Merino sheep and Nguni cattle are the most common species of choice, but other animal species such as dairy cattle, pigs and boerbokke goats are also kept in the catchment. The number of sheep per livestock farm varies between 69 and 1,000 animals, with an average number of 484 sheep. The numbers of cattle varies between 50 and 150 per farm with an average of 86 heads of cattle.

Based on the total number of livestock animals, including other farm types as well, sheep grazes in the biggest number (2620 animal) in the catchment. It is followed by beef cattle (850 animal), goats (400 animal), dairy (350 animal) and pig (150 animal) (Table 13).

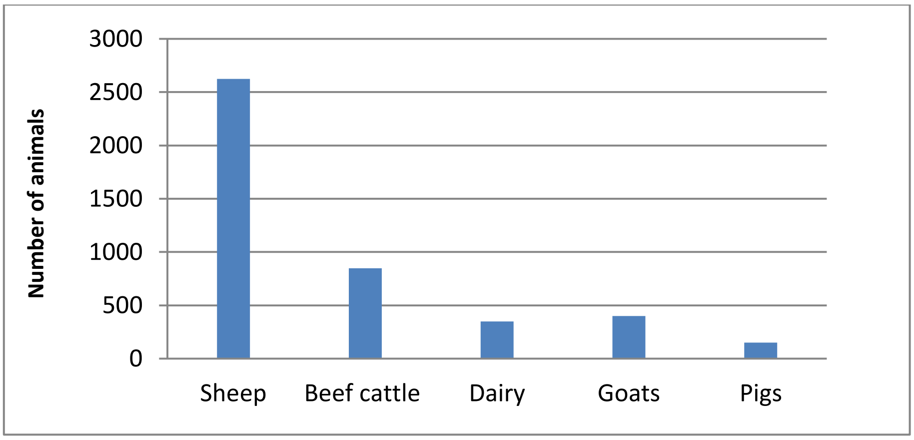


Figure 13: Number of livestock animals in the catchment of the Hudsonvale wetland

The second main group farms with honeybush tea. *Cyclopia intermedia* is a fynbos species which is harvested in the mountains and on the hillslopes usually every second year, which allows time for regeneration. Honeybush tea is in the process to get commercialized and more popular in the catchment as well as abroad.

Only two main commercial fruit farms remained in the catchment of the Hudsonvale wetland. One of the farms is located in the Kromme valley upstream of the Hudsonvale wetland, where the fruit trees are planted on the alluvial fan and on lands adjacent to the river. The other farm is situated further upstream in the valley of the Eerstedrift tributary stream. These farms produce apple, pear, orange and plum fruits for international export.

Vegetable, dairy and organic farming categories include one farm each. The main income of the vegetable derives from growing tomatoes, but it also farms with sheep and beef cattle (Rebelo 2012). The dairy farm is located at the site of the Hudsonvale wetland. It has more on-site effects on the wetland, therefore it will be discussed in more details in Chapter 4.2.

a) Water abstraction and irrigation management

In the catchment, all the farmers have a tributary stream on their farms that provides water for the farms. The water quality of the tributaries is of high quality, so that they are primarily used for drinking without any further treatment (Interviews with landowners). However, this water also used for irrigation together with the Kromme, particularly on lands located in the valley-bottom.

The basic method used for water abstraction in the catchment consists of a built weir or in-stream dam within the tributary stream from which the water is delivered to the house and/or to a separated dam and/or to the sprinklers on the field under irrigation by means of a gravity driven pipe system (Figure 14).

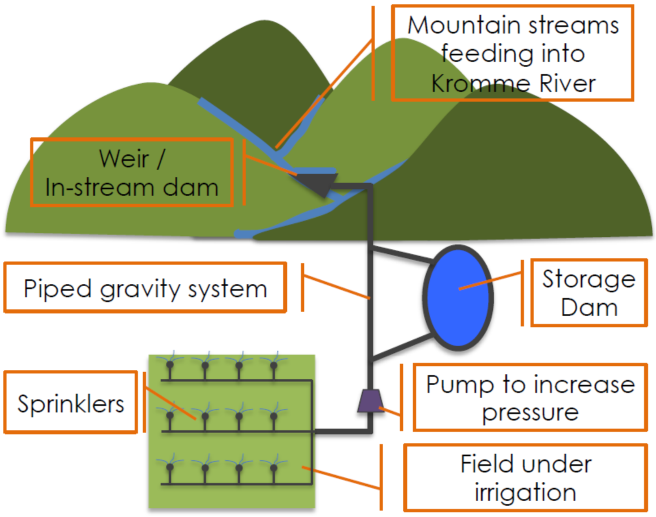


Figure 14: A typical irrigation system in the Upper Kromme River Catchment Adapted from De Jong (2012)

These weirs can range from some sand bags and stones up to a 3 m high dam wall. If the gravity is not sufficient to transport the water (e.g. for irrigation), pumps are set up to increase the pressure (De Jong 2012). Most farms also have dams outside of the streams for storing water, and the numbers of farm dams are expected to increase in the future (Interviews with landowners). Data was not available on the capacities of the dams, yet high density of farm dams can significantly reduce baseflow as a cumulative impact (Mantel et al. 2010). In general, small dams are less efficient for storing water than a large dam with the same storage capacity due to the greater summed evaporation surface area of the small dams (Roberts 2013)[7] . Thus, the decreased baseflow could lead to decreased water input to the Hudsonvale wetland during dry season.

Water saving irrigation systems are used in the catchment such as micro-sprinklers for irrigating the orchards and vegetables, and sprinklers for the field crops such as kikuyu grass and Lucerne. However, many of the irrigation systems are old and leaking, thus there would be a 'room' for more water use efficient irrigation systems (De Jong 2012). The field crops are usually irrigated seasonally during the dry months, therefore the duration of the irrigation greatly depends on the weather conditions.

After the New Water Act was enforced in 1998, all the landowners in the catchment had to register the amounts of water they use to the DWAF in the process of compulsory licensing for water rights (Joubert, pers. comm., 2012). Yet, exact data on the amounts of water used for irrigation and domestic purposes per farm were lacking, because these registered amounts never have been monitored and validated (Joubert, pers. comm., 2012) and the water is readily available for the landowners. In two recent studies, estimations were made on the annually irrigated amounts of water in the two Kromme catchments (K90A and K90B). Gull (2012) based her estimation on the spatial extent and water requirements of each crops. De Jong (2012) relied on farmers survey. While Gull (2012) estimated that 4.59 million m^3 water irrigated annually, according to De Jong (2012) this amount was between around ± 3.6 and 7.3 million m^3 water depending on if it was a "normal/wet year" or a "dry year", respectively. They both found that the most water was used for the kikuyu fodder crops produced for the dairies.

In the catchment of the Hudsonvale wetland, water used annually for irrigation was 0.98 million m^3 water, of which 0.49, 0.02 and 0.24 million m^3 water is used for irrigating kikuyu (73 ha), tomato (4.5 ha) and apple (38 ha), respectively. This estimation was based on Gull's method. It shows that the most irrigated water is used for the kikuyu pastures located next to and within the wetland, which will be elaborated in Chapter 4.2.

b) Grazing and fire management

16.2% (2,980 ha) of the catchment of the Hudsonvale wetland is characterized as 'degraded shrubland and fynbos' according to the National Land Cover (2001) (Figure 15). This degradation is strongly linked to both increased grazing pressure and frequency of fire management (WfWater 2008/2009). Grazing by beef cattle, and sheep takes place both in the fynbos dominated hillslopes and mountains as well as along the Kromme river in the valley (Interviews with landowners).

The exact area used for grazing is difficult to estimate as grazing occurs extensively within the catchment. Fynbos vegetation supports large herbivores (Mucina and Rutherford 2010), but the livestock, particularly sheep and goats prefer to graze on the grassy species (Buckle, pers. comm., 2012).

Fire naturally occurs in the fynbos biome and has a major role in determining species composition and community type. It also germinates the dormant seeds and promotes the re-growth of grassy species (Mucina and Rutherford 2010). In order to promote the re-growth of both grassy species for the livestock, and the honeybush species for harvesting, man-made fires are common practices in the catchment. Some farmers burn their fields frequently in every 4 years; others burn it less frequently once in every 7-10 years. Not all farmers burn their lands, but the total number of landowners using fire as a management practice is unknown.

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[7] Roberts, P. (2013). "Dams in South Africa." Retrieved 25-03-2013 http://www.sancold.org.za/index.php?option=com_content&view=article&id=63&Itemid=73

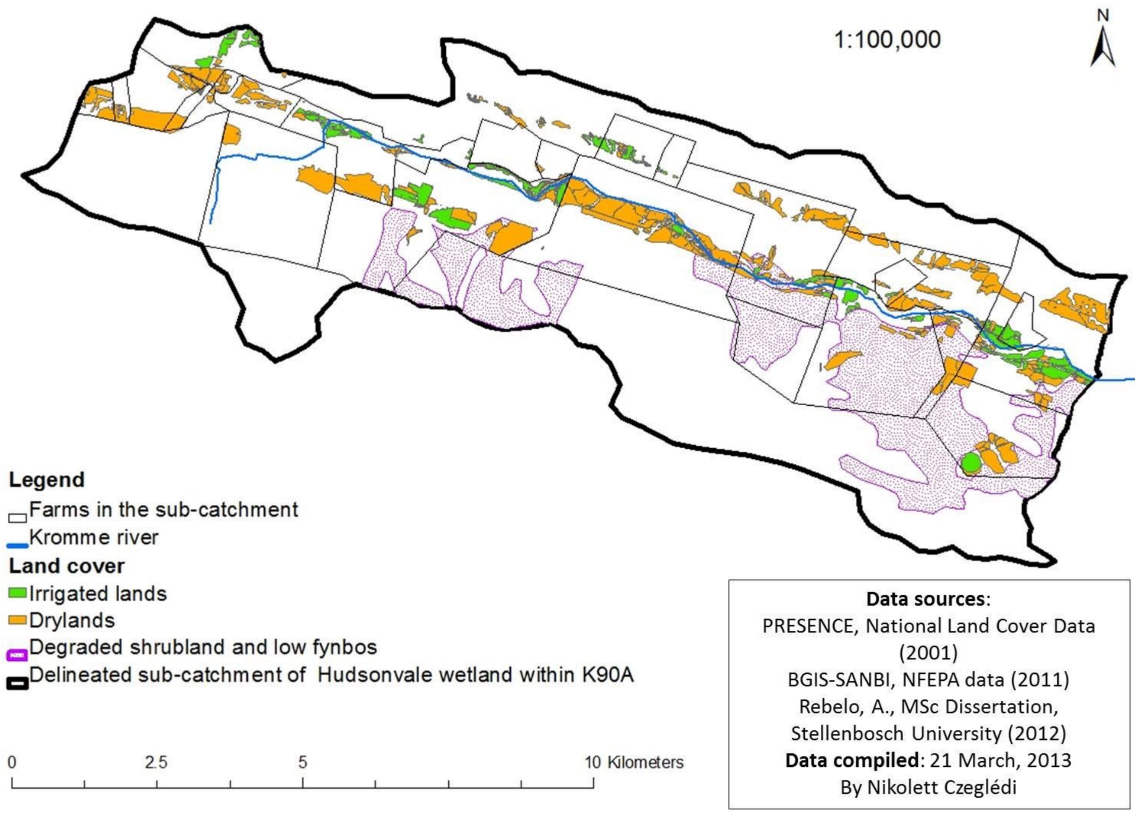

Figure 15: Degraded fynbos vegetation and agricultural land use in the catchment of the Hudsonvale wetland in 2007

The land usually is burnt in blocks. One farmer stated that the freshly burnt land provides good pasture for the sheep in the first two years. In the third year, it provides half of the grass yield than in the previous year. In the fourth year, the land needs to be left resting before burning it again. If the land is not burn for five years, then the fynbos takes over and the grass disappears. However, ecologists suggest that the optimal burning frequency of fynbos in the catchment should be once in every 10-15 years (Cowling, pers. comm., 2012). Other important aspect of using fire management is that fire also stimulates the germination of dormant IAPs seeds, which after a short time start to disperse their seeds and invade downstream areas (Le Maitre et al. 2002).

c) Fertilizer and biocide use

Mainly nitrogen and phosphorous fertilizers are applied on the pastures and vegetables due to the low nutrient content of the soil. However, data is missing about the exact types and amounts used by the landowners. Herbicides are applied on the fruit orchards, vegetables and the dryland pastures.

d) Impacts of agriculture and land management practices in the catchment

Farm dams and irrigation in the catchment of the Hudsonvale wetland could lead to decreased baseflow in the Kromme, thereby influencing the water inputs to the Hudsonvale wetland. Particularly during the dry season, when the water level is the lowest, but the most irrigation takes place.

Increasing number of grazing livestock and more frequent burning in the catchment may increase the magnitude of floods and the sediment load delivered by the river. Degradation of the natural fynbos vegetation on the hillslopes and the trampling effect of the grazing livestock could result in erosion gullies and increased runoff during high rainfall events. When the fynbos vegetation cover is degraded on the hillslopes, the majority of the water becomes runoff during high rainfall and the high velocity of runoff water can remove the uncovered soil easily.

Fynbos vegetation supports infiltration of water due to its physiology (small leaves) adapted to semi-arid conditions (Mucina and Rutherford 2010). Therefore, it has an important role both in decreasing floodwaters during high rainfall events by retaining water, but also in sustaining baseflow during the dry months. Since 16.2% of the fynbos and shrubland vegetation has already been degraded due to overgrazing and fire events, it is likely that the extent of degraded vegetation could further increase due to the increasing grazing pressure. The effects of trampling within the riverbed can lead to the development of headcuts towards upstream and sediment deposition towards downstream.

Fire can have also severe impacts if it happens in the riverbed as it was the case in 2012. During the dry summer, a human initiated fire escaped from a land adjacent to the main river, not far away upstream from the Hudsonvale wetland. The vegetation burnt along and within the riverbed hundreds of meters long. Vegetation cover is usually important for reducing water velocity, retaining water and protecting the soil from erosion, particularly at higher water levels (Collins 2006). That section of the riverbed was already characterized by high disturbance levels such as channelized by gully erosion, high grazing pressure, and sand depositions.

Since the Hudsonvale wetland is located down most in its catchment, it is likely that the amounts of sediment (chemical and suspended) and water delivered to the wetland during high rainfall events have been increased. However, it is influenced by many other factors such as the presence of farm dams, other wetlands, erosion control structure (etc.), thus it is difficult to determine to what extent it has been influenced by the aforementioned practices.

3.3.2. Clearing of invasive alien plants

In 1996 WfWater started to work in the UKRC with the aim to increase the provision of water both for the catchment area and the NMMM by removing IAPs with high water consumption rates, such as black wattle (WfWater 2008/2009). It was based on that the water demand by NMMM was predicted to increase from 100 Mm^3/year in 2008 by about 30 Mm^3/year by 2017 (Murray et al. 2008). Estimation has been made that eradication of IAPs clearing in the Kromme River would generate addition 15 million kilolitres of water per year, which is equivalent to 32 kiloliters per day per hectare cleared (WfWater 2008/2009). Specific data was not available on the cleared sites and rates of clearing in the catchment of the Hudsonvale wetland, only for the two upper catchments (K90A and K90B).

It was estimated that around 824 ha was cleared altogether in these catchments between 2002 and 2008 (McConnachie et al. 2012). Rebelo et al., (2013) in her study estimated that WfWater clears IAPs on average 138.34 ha/ year, which is three times the average rate of invasion of black wattle (46 ha/ year). In the case of the catchment of the Hudsonvale wetland, it would mean that at least twelve years would be necessary to remove IAPs, considering the extent of invasion in 2007.

a) Practices of alien clearing

The IAPs clearing started from the uppermost part of the catchment in order to avoid reinvasion towards downstream by water delivered seeds. Before WfWater starts to work on an area the WfWater managers allocates contracts that specify the treatment site that needs to be cleared in one month. In the UKRC, all the landowners signed these contracts (Joubert, pers. comm., 2012). Each treatment site is assigned to a team, which consists of 10-15 labourers, who are usually recruited from local unemployed people. After clearing the site, three follow ups are provided by WfWater, then it will be the landowners' responsibility to do the follow ups.

The physical clearing method consists of felling, which is followed by herbicide application on the stem to prevent coppice re-growth (McConnachie et al. 2012). Clearing stimulates the germination of the soil stored seeds, thus regular and numerous follow-ups are needed to keep the area free from IAPs (Holmes et al. 2008). Both landowners' observations and spatial maps indicated that mainly those parts of the land were cleared that were easily accessible. For instance, areas that were located along the river were more likely to be cleared due to the presence of roads than those that are up on the slopes of the mountains, in the ravines or within the wetlands. However, the IAPs vegetation from those places imposes a great threat to invade downstream areas by continuously dispersing their seeds (Le Maitre, 2002). After clearing, the felled stems are usually left at the site due to the high costs of transport and the lacking market for the timber. The problem that landowners experienced with this is that, these stems impose serious fire hazards and can become debris during floods, which can cause erosion in the riverbed (Interviews with landowners).

b) Impacts of invasive alien plant clearing in the catchment

In terms of hydrological impacts, earlier studies have shown that IAPs use more water than indigenous species and thereby they contribute to decreased streamflow and baseflow in river systems (Le Maitre et al. 2002, Dye and Jarmain 2004, Everson et al. 2006, Clulow et al. 2011). Therefore, if the average rate of clearing exceeds the average rate of invasion by three times in the catchment of the Hudsonvale wetland as well, the clearing could potentially lead to increased streamflow and baseflow. It means that more water could be available for both agriculture and for ecosystems during dry season. Consequently, whether there is an increase in the quantity of water input to the wetland from its catchment, greatly depends on the level of change in water abstraction for irrigation. If the level of irrigation does not increase significantly, the Hudsonvale wetland could get more water inflow from its catchment area.

Furthermore, clearing IAPs has positive impacts on the geomorphology by decreasing the risk of bank erosion in the riparian zone during floods.

3.3.3. Construction of erosion control structures

When WfWater started to work in the UKRC, it revealed that many of the valley-bottom wetlands were in a poor condition due to bank and gully erosion as well as headcuts in the riverbed (WWG 1998, Haigh et al. 2008). The subsequent wetland survey conducted by the non-governmental Rennies Wetlands Project (currently Mondi Wetland Project) in 1997 estimated that 78 % of the wetlands needed urgent rehabilitation measure due to their ecological conditions were so severely degraded (WWG 1998). Ten erosion control structures have been built along the Kromme to halt the headcuts and to stop the degradation of the three peat basins by slowing down water velocity, trapping sediment and improving water retention of the wetlands. The erosion control structure at the Hudsonvale wetland is the down most structure, all the others are located upstream. The locations of the ten structures are shown in Figure 16.

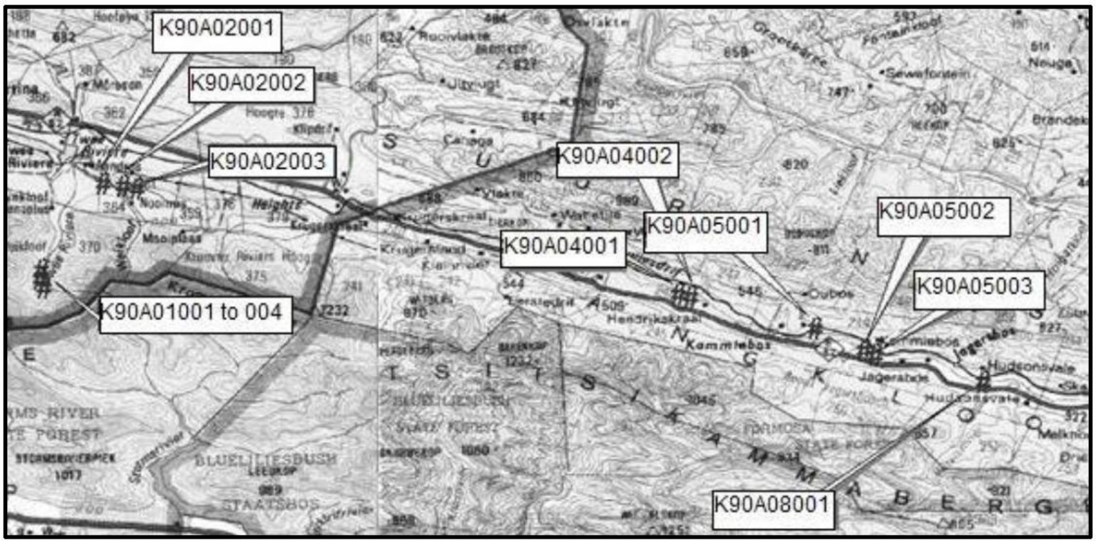

Figure 16: Location of erosion control structures in the Upper Kromme River Catchment (2000-2010) Adapted from Gull (2012)

a) Impacts of erosion control structures in the catchment

In the study by Haigh et al., (2008) the WET-Health tool was used to assess the ecological health of the three peat basins of the UKRC after a big flood in 2007. The results showed that the biggest peatbasin upstream (including the two biggest wetlands; Krugersland and Companjesdrift) was in the best condition and the erosion control structures contributed to maintaining the integrity of the peatbasin. Then the likely loss of their ecological health was assessed for the situation if the headcuts were not halted through the construction of erosion control structures. The results of these assessment indicated that the likely loss of ecological health would be large without the structures. The erosion control structures were found important in stopping the erosion and thereby improving water retention, supporting the reestablishment of natural vegetation and preventing further loss of peat.

4. The impacts of human drivers on the Hudsonvale wetland

The following chapter describes the biophysical structures and processes that characterize the Hudsonvale wetland as well as the three main drivers (agricultural land use, invasive alien plant eradication and construction of erosion control structures) on the site of the wetland and their impacts on these properties of the wetland .

4.1. Biophysical structure and wetland processes of the Hudsonvale wetland

The biophysical properties are presented at the wetland scale and include the wetland boundaries, the hydro-geomorphic units and the main hydrological, geomorphologic and vegetation characteristics of the wetland, described for each unit separately.

4.1.1. Wetland boundaries and hydro-geomorphic units of the Hudsonvale wetland

The gravel road crossing on the western boundary of the farm was defined as being the upstream longitudinal boundary of the wetland. This decision was based on that road crossings usually act as impeding features to natural water distribution and stream flow (Macfarlene et al., 2009). Furthermore, the accessibility of the floodplain further upstream was hampered by higher water level of the river. The eastern farm boundary was assigned to be the distal end of the wetland towards downstream direction, because beyond that point, the palmiet vegetation disappeared and the river entered the neighbouring floodplain at Skaapdrift, the neighbour farm.

The lateral boundaries of the wetland were determined through the delineation procedure, which revealed that most of the currently visible parts of the wetland belonged to the permanently waterlogged zone; however, there are areas that still inundated seasonally or temporally. These areas were found in the perennial pastures, indicated mainly by the presence of redoximorphic features found within the upper 50 cm of the soil profile and the concave shape of slopes of the lands adjacent to the wetland. For detailed description of the results of the delineation, see Appendix 3.

The delineated wetland had an area of 54 hectares and was divided into two HGMUs; HGMU 1 was located upstream, HGMU 2 was downstream of the confluence of the Witels tributary (Figure 17. HGMU 1 and 2 had similar sizes, 28 ha and 26 ha, respectively. The HGMUs were identified as channelled valley-bottom wetlands because they were both located at the valley-floor, linked to the main watercourse, and were lacking the characteristics of floodplains such as oxbow lakes, and levees. However, HGMU 2 in some respects showed similarities to some characteristics of a floodplain, for instance, due to a change in the longitudinal slope of the valley at the confluence of the Witels tributary, and the presence of a well-defined stream channel. Yet, the characteristics of channelled valley-bottom wetlands prevailed, since the majority of HGMU 2 was confined into a narrow valley-floor compared to the width of the valley, and was dominated by palmiet vegetation. Palmiet is commonly associated with valley-bottom wetlands (SANBI 2009) and it made up 44 % of the whole unit. The river channel was deeply incised that might give rise of similar features of a floodplain because of changing hydrological characteristics. The presence of a massive palmiet patch (approx. five ha) at the downstream part indicated that the existence of the HGMU was less dependent on the overspill of the flooding stream channel than floodplains generally are (SANBI 2009). Furthermore, the average wetland gradient (0.47 %) together with the small size of the whole wetland (54 ha), indicated that the wetland should be considered rather a valley bottom wetland, than a floodplain, because the latter one usually has a much bigger extent and located on landscapes with lower gradient (Ellery et al. 2009).

The HGMUs were differentiated and assessed separately because of the differences in their geomorphic settings. The boundary was defined between the two HGMUs at the gabion weir. This decision was based on the elevation difference between HGMU 1 and 2, which was likely caused by both the three meters deep headcut of the past, and the natural change in elevation at the confluence of the Witels tributary. Meantime, the headcut has been halted this elevation change remained, indicating a transition within the wetland area.

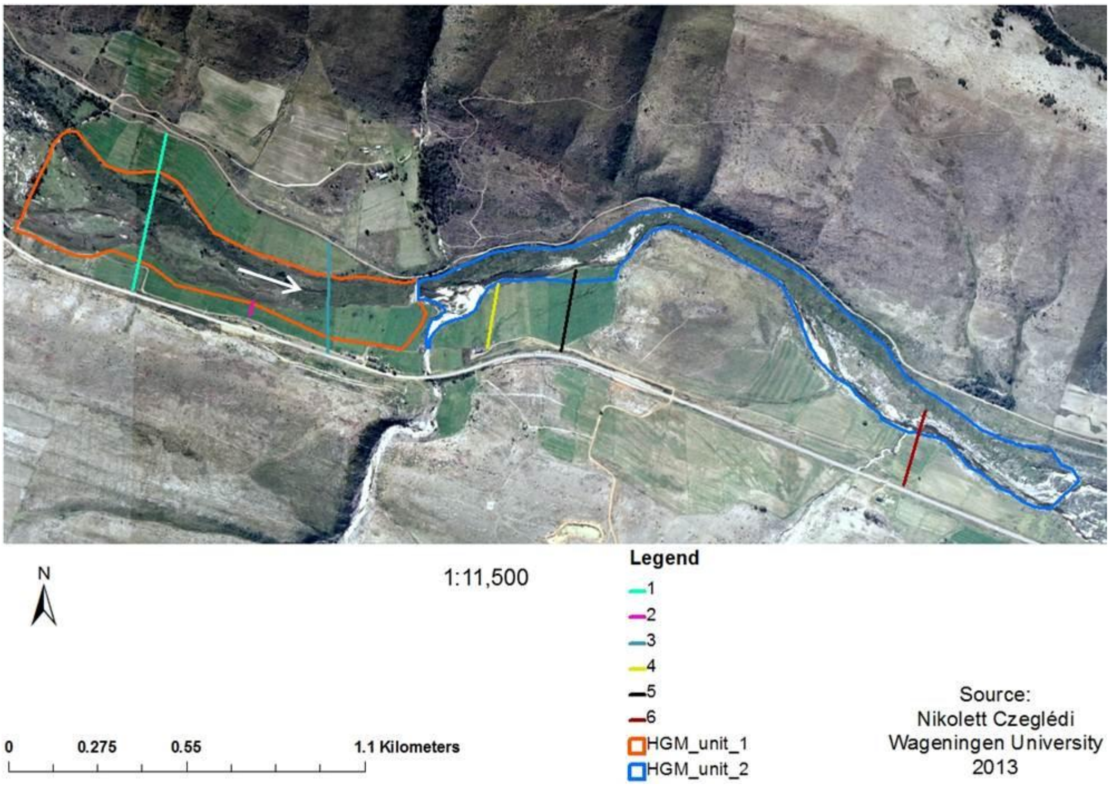

Figure 17: Wetland boundaries and hydro-geomorphic units of the Hudsonvale wetland
Map indicating the location of the six surveyed transects and the delineated hydro-geomorphic units. The white arrow indicates the direction of the stream flow

4.1.2. Hydro-geomorphic characteristics and wetland processes

a) Wetland hydrology

Hydrology has been recognized to have primary influence on wetland development and existence (Mitsch and Gosselink 2007, Macfarlane et al. 2008). Hydrological characteristics such as the source of water, the way how the water moves through and exits in the wetland, the frequency and duration of floods, as well as the quantity of water define the development of anaerobic conditions in the soil, availability of nutrients and other solutes, the transport and properties of sediment (Mitsch and Gosselink 2007, Macfarlane et al. 2008, Ellery et al. 2009).

Therefore hydrologic conditions can directly modify or change physical and chemical properties (Mitsch and Gosselink 2007), thus wetland processes and functions. For instance, anaerobic (flooded) conditions slow down the decomposition of organic material, which contributes to trapping carbon as soil organic matter. Most peat has at least 20% organic carbon by weight (Collins 2006). Furthermore, also anaerobic conditions are required for denitrification, which is considered as the most important process in the nitrogen cycle to remove nitrate from the through flowing water to the atmosphere as nitrogen gas (Appendix 1), thereby decreasing the concentration of nitrates in the out flowing water (Verhoeven et al. 2006). The general rule is that the higher the level of alteration in wetland hydrology, the greater the effects will be on the functions and services (Collins 2006).

Hydrological and geomorphic characteristics together also define the functions of wetlands and classify the type of wetland units (Brinson 1993). The HGMUs' dominant water inputs were from the main channel and its overspill as well as from the adjacent slopes. It is very likely that the wetland discharged by groundwater because of its sustained streamflow, the characteristics of soil mantle and underlying sandstone of the catchment that is prone to fissures and aquifers (Haigh et al.

2002, Wu 2005). The main water transfer mechanisms of a surface and groundwater fed valley-bottom wetland that also characterized the Hudsonvale wetland is illustrated in Figure 18.

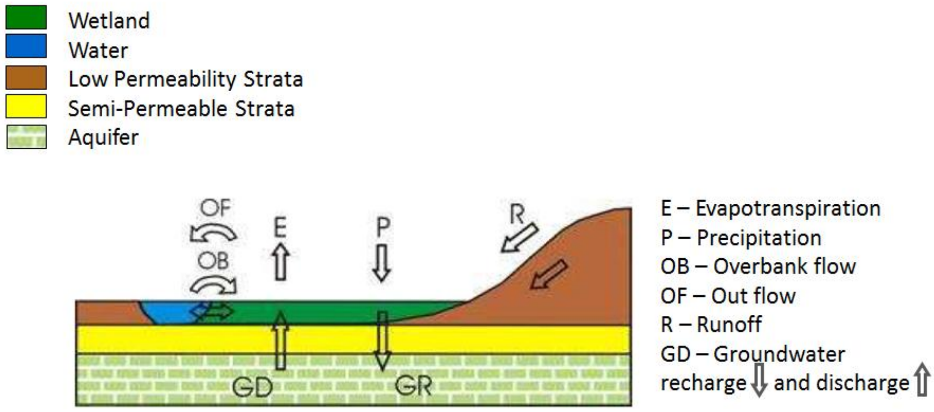

Figure 18: Schematic illustration of water transfer mechanisms of a valley-bottom wetland Adapted from Collins (2006).

The streamflow feeds into HGMU 1 through a bigger and a smaller channel. While the former was located on the left side of the wetland, the latter was on the right. The gravel road (western boundary of the wetland) crossed these channels; the water could flow through culverts built under the road. During drier months, when the river level is low, it is likely that the road does not limit the movement of water significantly. In contrary, during higher water levels, the water floods the road, and then it is only possible to cross the channels by 4x4 cars. The bigger channel had an open surface in the middle section of the HGMU, however, its surroundings were highly vegetated and the channel eventually disappeared under the dense palmiet vegetation. The smaller 'channel' after passing the road also disappeared within a short distance under the vegetation cover. HGMU 1 was not fed by any discrete tributary stream, even though there were three big erosion gullies on the slopes of the pasture adjacent to the unit. These gullies indicated the route of runoff from the slopes. On the right side of the river, these gullies were likely to be the results of the culverts built under the main road 62, running next to the farm. The biggest gully was measured to be 0.8 m deep and 8.2 m wide in its middle section close to the right side of Transect 1. Roads and culverts may confine the diffuse water runoff coming from the hill slopes and cause erosion gullies (Forman and Alexander 1998, Macfarlane et al. 2008). On the left side, one larger erosion gully was observed, but smaller than the ones on the other side.

By the gabion weir, the stream flows in two channels into HGMU 2; a main and a small channel. Into the main channel, the water can flow over the weir's spillway and through the gabion baskets. The main channel of the river, was separated from the other smaller one by the remaining 'palmiet island' of old wetland on the similar elevation as HGMU 1. The main channel was three meters incised after the confluence of the Witels and was characterized by bank erosion. The bank erosion expanded around 150 m further downstream, but the bank was vegetated. The river channel is around 15 m wide after the confluence of the Witels and has open water surface. The incision and the missing emergent wetland vegetation of the channel indicated that the water tends to have higher water velocities when the water level is high. In general, the velocity of surface water was influenced by the slope, the roughness (e.g. vegetation cover, hummocks) and the cross-sectional area of the channel (Ellery et al. 2009). Where the channel is eroded within a wetland it causes concentrated flow and increases the water velocity that may drain the wetland and lead to its desiccation (Collins 2006).

The other smaller 'channel' was on a higher elevation than the main one and after a short distance from the weir, it disappeared under the extensive wetland vegetation, mainly palmiet. This dense palmiet vegetation is likely to reduce the water velocity and enable diffuse water flow in the further sections. It is assumed that this part of the HGMU 2 was a remain of the original wetland.

Two significant tributaries the perennial Witels and the non-perennial Booiskloof streams feed HGMU 2.

b) Geomorphology and geomorphic processes

There are strong linkages between geomorphology, hydrology and vegetation where geomorphic processes controlling and shaping wetland structure and dynamics through depositional and erosional geomorphic processes that take place within the wetland (Macfarlane et al. 2008, Ellery et al. 2009). While depositional processes are characterized by deposition of different types of sediment (clastic, organic, dissolved) within the wetland, erosional processes refers to removal and transport of sediment from the wetland (Ellery et al. 2009). Whether erosion or deposition takes place, the size of the sediment particles and the velocity of surface water flow determine it (Figure 19). High water velocities are needed for lifting large particles up such as pebbles and cobbles, but also the very small ones (silt, clay) that are bound strongly to each other by electrostatic forces. To lift medium sized particles up lower water velocities are needed (Ellery et al. 2009).

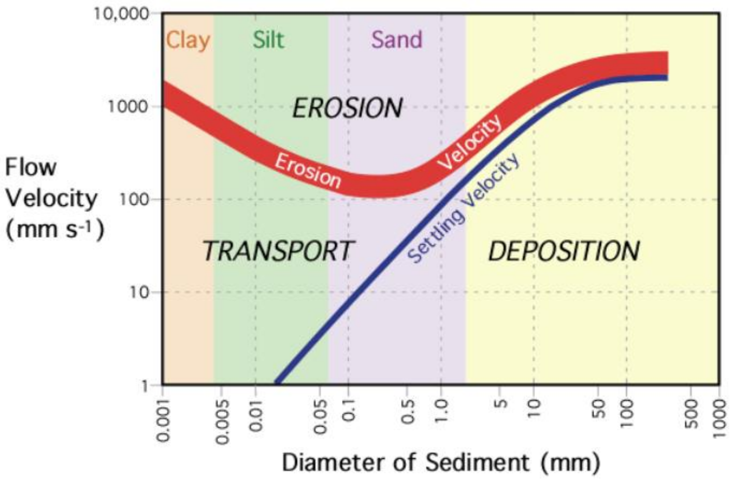

Figure 19: Hjulstrom's diagram of erosion, transportation and deposition of sediment in relation to grain size and velocity of surface water flow (Pidwirny, 2006)[8]

The higher the mean velocity of the stream, the more sediment can be transported. Wetlands in general are characterized by lower velocities (Kotze 2000) which enables them to be sinks for suspended (e.g. sand, silt) and dissolved sediments (e.g. nutrients) (Verhoeven et al. 2006, Mitsch and Gosselink 2007, Ellery et al. 2009). Suspended sediments play particularly important role in water purification by removing phosphorus and toxicants (e.g. heavy metals and biocides) from the water column as they are bound to sediment particles (Collins 2006). However, uptake by wetland plants is also an important way to remove excess nutrients. For instance, in the case of phosphorus, the slower flow rate of water allows suspended soil particles to settle, which releases phosphorus in a soluble and bio available form for plant uptake, thereby enhancing water quality of the outflow (Appendix 1).

Sedimentation has a dynamic nature and it changes over time depending upon the rates of sediment influx and patterns of sedimentation (Ellery et al. 2009). Furthermore, a range of landscape processes, both natural and anthropogenic, affect the quantity of the eroded soil and delivered sediment to aquatic systems (Apitz 2012) and the storage capacity of the wetland ecosystem.

Clastic sedimentation

Although, only small amounts of recent clastic sediment deposits were found at the head of HGMU 1 where the dirt road crosses the valley-bottom, stromflows can bring a huge amount of silt and sand

[8] Pidwirny, M. (2006). Erosion and Deposition. 2nd Edition. Retrieved 21-02-2013 http://www.physicalgeography.net/fundamentals/10w.html

particles along the HGMU (Appendix 4). Clastic sedimentation takes place when the stream loses its ability to carry its sediment load, for instance, due to a decrease in the valley gradient or the lateral expansion of a river valley (Collins 2006, Ellery et al. 2009). In HGMU 1, the concave contours of the adjacent slopes on the river's right side allowed the lateral expansion of the river flow when the water level was high. It increased the cross-sectional area of the river so that the river could spread across the pasture. This together with the vegetation cover of the wetland can reduce the water velocity, thus the suspended clastic sediments together with the tied up phosphorus and toxicant sediments can be deposited. The aggradation of the land surface within the wetland was also likely to be the results of depositional processes of the past.

Furthermore, old deposits of colluvium were found at the toes of the left side hillslopes adjacent to the wetland during the soil survey. Colluvium is gravity transported unconsolidated sediment of the upslope which is usually delivered by the runoff or sheetwash (Kolka and Thompson 2006). In the UKRC transport of the colluvium is one of the primary sources of sediment among in situ rock weathering (Haigh et al. 2002).

In HGMU 2 where the Witels and Booiskloof tributaies enters the wetland, sand, pebbles and cobbles, courser sediment materials get deposited (Photo 5a., 5b.). There is usually a net sediment accumulation where tributary stream enters the main trunk (Ellery et al. 2009).

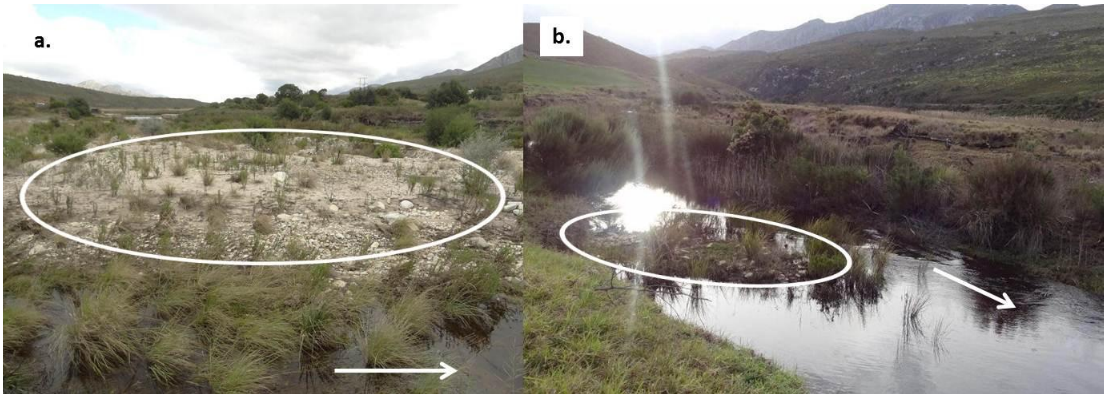

Photo 5: Fan-like clastic sediment deposits in hydro-geomorphic unit 2 (Photo by Lieke Jager)
The location of clastic sediment deposits delivered by the Witels river (a.), and the Booiskloof non-perennial stream (b.) in hydro-geomorphic unit 2. (The arrow indicates the flow direction of Witels stream (a.) and the Kromme river (b.).

Towards the downstream edge of the wetland, around six ha next to main channel were located on similar elevation as the edge of the pasture. On Photo 5a. that area can be seen on the other side of the river channel of the place where the photo was taken. That elevated area is likely to be a result of depositional process to a certain extent; however, it is also possible that it indicates the original elevation of the area before the river was incised.

Organic sedimentation

The delineated wetland was part of the eastern peatbasin analyzed by Haigh et al. (2002). The whole eastern peatbasin was identified to cover an area of 150 ha and the peat attains a depth of at least 2.2 m at some places. It was estimated that it contains 2 250 000 m^3 peat if the average thickness of the peat assumed to be 1.5 m for the whole basin (Haigh et al. 2002).

Peat is important to trap carbon as it consists of soil material with a high organic content and to retain water by acting as a natural water storage during low base flow (Mitsch and Gosselink 2007, Kotze et al. 2008). It was estimated that $1m^3$ of peat can store 700 litres of water in the peat basins of the UKRC area (Buckle, pers. comm., 2012).

Peat accumulation takes place where organic material, mainly plants are present, the water slows down allowing flooding settings and anaerobic conditions to evolve. For instance, if a tributary stream enters at the lower reaches of a wetland and brings a large amount of clastic sediments, it possibly leads to the formation of low-energy backwater at the upstream where peat can be formed

(Ellery et al. 2009). Therefore, it is likely that it was the case in HGMU 1, before the headcut erosion developed. After halting the headcut, however, the water retention time probably has increased in the unit creating preferable conditions for further peat formation.

Considering the conditions that are required for peat accumulation and existence, it is likely that peat is still being formed and maintained in the wetland in areas, where dense wetland vegetation is still present under anaerobic conditions. Peat layer that built up over thousands of years is often can be found under palmiet wetlands (Grundling 2004). The size of the area that potentially supports organic sedimentation was estimated to be about 25 hectares for the whole wetland due to the presence of palmiet and other emergent wetland vegetation. In terms of the HGMUs, it was estimated as 13.38 ha in unit 1 and 11.62 ha in unit 2. The wetland could potentially contain 375,000 m^3 peat in total; 200,700 m^3 in HGMU 1 and 174,300 m^3 in HGMU 2 by calculating with an average peat depth of 1.5 m based on the study by Haigh et al. (2002),

Based on the potential water storing capacity of the peat calculated from the previously made estimation on the peat volume and the estimated 700 litre water storing capacity of one m^3 Kromme peat (Buckle, pers. comm., 2012), the results indicate that the total Hudsonvale wetland potentially could store 262.5 mega litres of water. HGMU 1 could retain 140.5 mega litres and HGMU 2 could retain 122 mega litres of water (Table11).

Table 11: Potential water storing capacity of the peat of the Hudsonvale wetland

Portion of the wetland	Estimated area of peat (ha)	Peat volume (m^3)	Potential water volume (ML)
Hydro-geomorphic unit 1	13.4	200,700	140.5
Hydro-geomorphic unit 2	11.6	174,300	122.0
TOTAL	**25.0**	**375,000**	**262.5**

Nevertheless, such estimation has to be made carefully as peat deposits can be destroyed during a short period of time since they are continuously exposed to human activities, droughts and fires in South Africa (Ellery et al. 2009). In the case of the eastern peatbasin ash layer was identified between 0.8 m and 0.2 m, and desiccated layer was found between 1.1 m and 0.8 m in the peat profile, indicating the occurrence of fire (Haigh et al. 2002).

Erosion

In HGMU 1, only small active erosional feature was found in the left channel, where the water exited the culverts. It might be the result of the effects of culverts that concentrate flow (Kotze 2004), thereby also increasing the water velocity (Ellery et al. 2009). Higher velocities do not support removal of nutrients and toxicants.

There were more signs of erosion found in the case of HGMU 2. Bank and channel erosions, incised by around three meters at some places, characterized the beds of both tributary streams. Looking at the longitudinal gradients of the tributaries it is revealed that both the Booiskloof (8%) and the Witels (3%) have quite steep slopes that were likely to increase water velocity of flooding waters and the high energy caused severe erosions. The longitudinal slopes of the HGMUs were only 0.47 % (Figure 20).

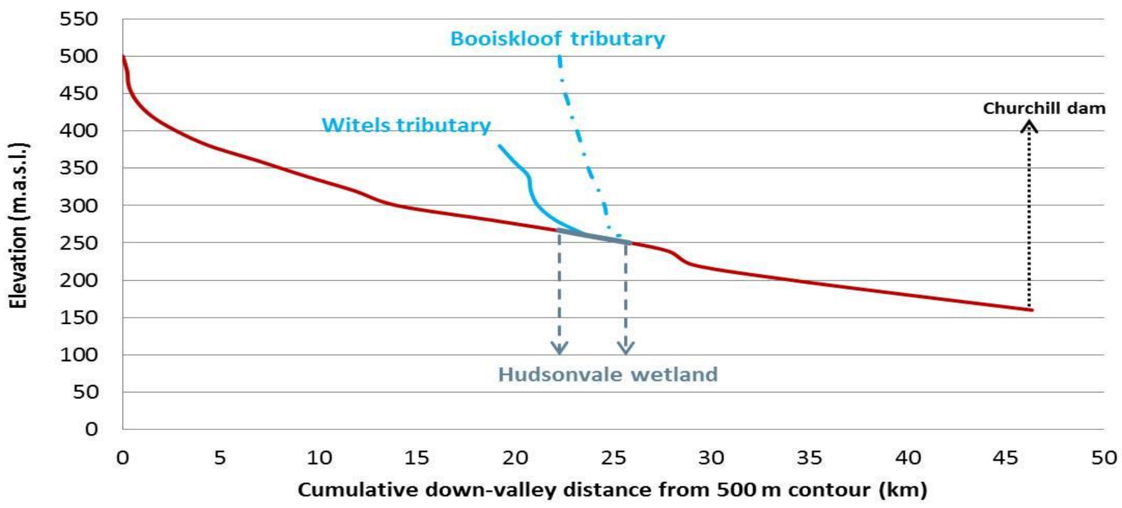

Figure 20: Longitudinal gradients of the Kromme valley and the tributary streams of Hudsonvale wetland

4.1.3. Vegetation composition

The type and extent of vegetation cover that characterizes a wetland defines the capacity of the wetland to decrease water velocity, trap sediment, stabilize soil and assimilate dissolved solutes (Collins 2006). Therefore, vegetation cover is important for erosion control, flood attenuation and water purification services. Furthermore, vegetation also provides shelter for animal species thereby contributing higher biodiversity within the wetland.

The natural vegetation cover, nearly the half of the HGMU 1 (14 ha) was assigned to the category of palmiet (*Prionium serratum*), and common reed (*Phragmites australis*) which were the dominating wetland species, however, the presence of other wetland species made it more diverse. In addition, a mixture of fynbos species was found along the HGMU's edges and on the higher parts within the wetland. Palmiet and common reed were located in the shallow permanently wet zones of the wetland; however, reed was seen all over the wetland, particularly in huge numbers at the edges, close to the pasture. Both are indigenous wetland species in South Africa, however, reed is considered as invasive. The vegetation cover of HGMU 1 is shown in Figure 21.

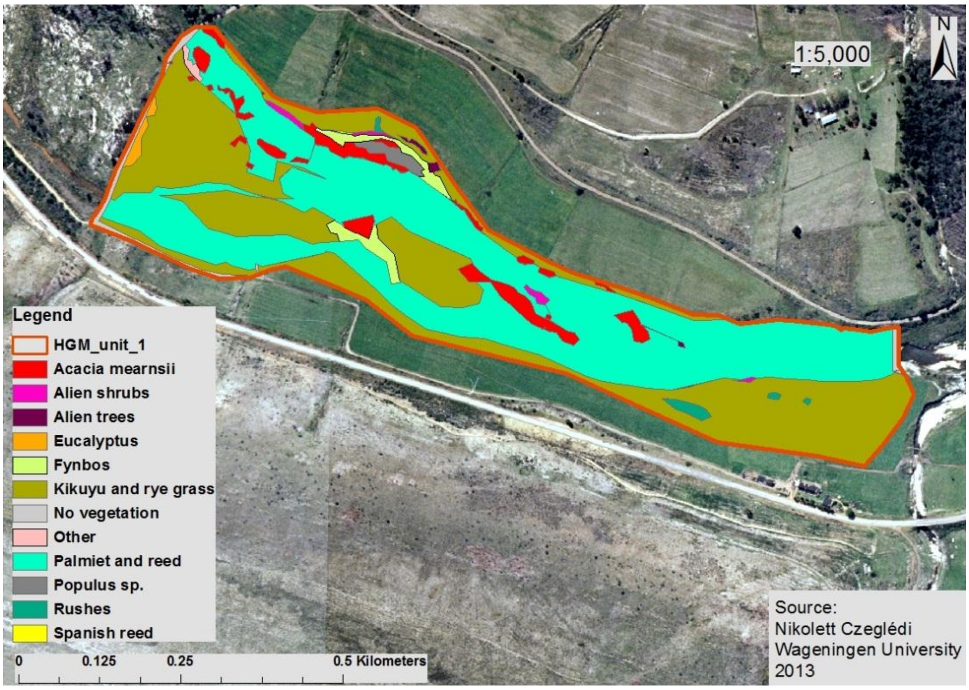

Figure 21: Vegetation composition of hydro-geomorphic unit 1 in 2012

Reeds usually can be found in places where wetness is stabilized, the level of nutrients increased, more sediment gets deposited and/or the level of disturbance is higher (Macfarlane et al. 2008). It is an ecologically very important species because it stabilizes river banks, filters water, prevent soil erosion and offers shelters for animals (Van Ginkel et al. 2011, Wentzel and Van Ginkel 2012). Reed is also used as a thatching grass, basketry and mats (Van Ginkel et al. 2011).

Palmiet tends to trap alluvial sediment in its clumps (Boucher and Withers 2004, Wentzel and Van Ginkel 2012), and by the old remains of leaves on the stems that form very dense nets of fibres (Buckle, pers. comm., 2012). To trap sediment is probably linked to its ability to slow down stream flow (Boucher and Withers 2004, Wentzel and Van Ginkel 2012). Furthermore, palmiet is likely to contribute to making its habitat diverse and more suitable for species that do not naturally occur in peatlands by "leaking" oxygen into the peat substrate preventing complete anoxia (Pugnaire and Valladares 2007, Wentzel and Van Ginkel 2012). The young flower shoots of palmiet are eatable and can be used as vegetable for human consumption, furthermore, its leaves are also used as fibre for basketry work, making hats and mats (Wentzel and Van Ginkel 2012).

The other half of the HGMU was covered by alien plant species of which the majority (12 ha) was dominated by kikuyu (*Pennisetum clandestinum*), and rye grass (*Lolium spp.*) of the pastures. The IAPs covered 1.9 ha and consisted of dense patches of black wattle (*Acacia mearnsii*) within the wetland, a group of *Eucalyptus spp*. next to the dirt road, dense stands of spanish reed (*Arundo donax*) and scattered alien shrubs of European bramble (*Rubus fruiticosus*) invading the drier parts within the wetland and the edges of pastures. Although, Spanish reed is an invasive alien species, it is used in making musical instruments, for making mats, lattices, screens, ceilings, and as a source of industrial cellulose (Van Ginkel et al. 2011).

In the case of HGMU 2, the natural wetland vegetation (13 ha) was also dominated by palmiet and reed, however, the reed was less abundant than in HGMU 1. Fynbos species were found on parts of the sediment deposit of the Witels and further downstream. In this unit, more areas were found without vegetation, referring to recent depositional or erosional processes. Around six hectares were assigned to the category of 'Other' at the downstream edge of the wetland, located on the 'elevated ground' within the wetland. It was difficult to identify, however it was clearly dominated by grass species. Black wattle and a mixture of alien shrubs represented the alien vegetation and covered an area of two hectares (Figure 22).

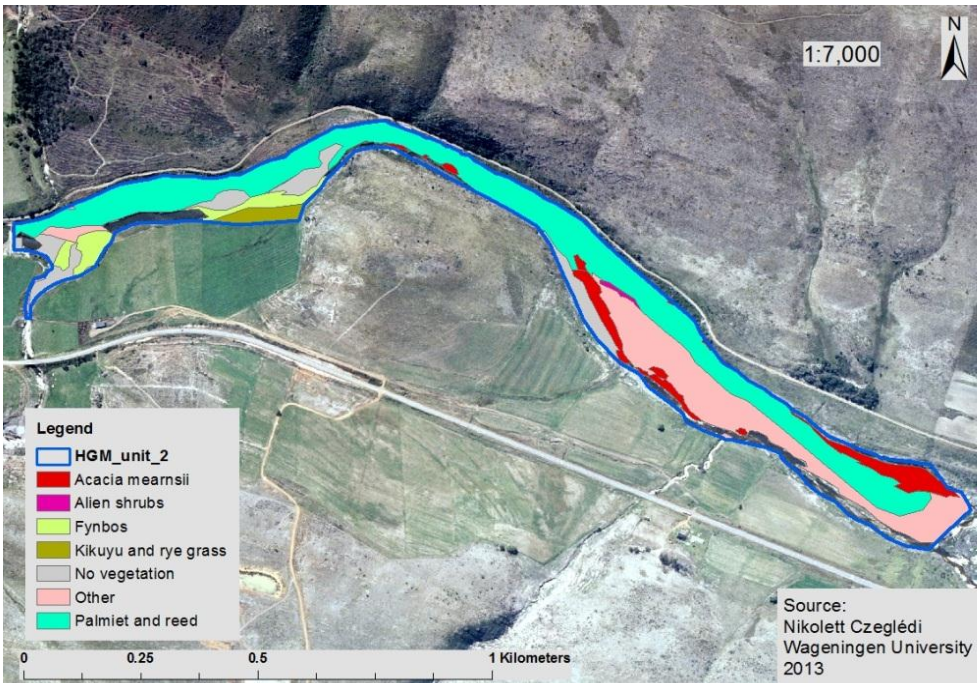

Figure 22: Vegetation composition of hydro-geomorphic unit 2 in 2012

4.2. Changes in human drivers and impacts

This chapter describes the characteristics of the main drivers (agricultural land use, invasive alien plant clearing and construction of the erosion control structure) at the site of the wetland and their impacts on the biophysical properties of the Hudsonvale wetland.

4.2.1. Agricultural land use and land management practices

The agricultural land use change, current land use and management practices are described at the scale of the Hudsonvale wetland.

a) Farming history

The farm Hudsonvale was originally part of the neighbouring farm Jagersbos but became divided in around 1835 as the population of the area started to grow (Haigh et al. 2008). In the first half of the 20th century, the main agricultural land use types were orchard and grazing. The previous owner's grandfather bought the farm in 1959. The original size of the farm was bigger and it became divided later into two separated farms. In this study, the Hudsonvale farm stands for the land that is located in the Kromme valley and bordered by Jagersbos farm in the upstream and Skaapdrift farm in the downstream. This area has a size of about 1150 ha and the family owned that land for three generations until they eventually sold it for the present owners in 2010.

In 1959, the land use types were orchard (plum and apricot) and livestock farming. They kept both sheep and cattle and started the dairy farming with 70 dairy cows. In 1979 when the interviewee's father took over the farm, the orchards became removed and the number of dairy cows reached up to 150. Kikuyu and rye grasses were planted for both the dairy and sheep at the lands of adjacent to the river and within the wetland on the drier, elevated parts (Local resident, pers. comm., 2012). Kikuyu (Pennisetum clandestinum), a perennial tropical grass, started to be planted widely in the Kromme Catchment after a big flood in 1931 ripped out many orchards established in the floodplains along the river and farmers changed into meat and milk production (Haigh et al. 2008). Kikuyu is considered as a suitable pasture grass (Haigh et al. 2008), since it has a potential to support higher grazing capacities and to stabilize the soil with its robust creeping stolons and rhizomes (Van der Colf 2011). They stopped farming with sheep in around 2000 but the dairy was expanding continuously. By 2010, before they sold Hudsonvale, the dairy counted 300 cows (Local resident, pers. comm., 2012). The new owners took over the dairy in 2010.

b) Change in land use and land cover between 1986 and 2012

By 2012 the farm Hudsonvale has been divided into two farms, including the dairy farm (1060 ha) and another farm (92 ha) on the other side of the Kromme river. In this study, the two farms were assessed as one (1150 ha) in order to be able to compare the changes in its land use and land cover. The changes in land cover of the adjacent lands of the Hudsonvale wetland between 1986 and 2007 shown in Figure 23.

The total size of agricultural lands was around 294 ha in 2012, of which 109 ha was under irrigation and 185 ha was characterized as dry land farming, mainly used for grazing. Regarding the Hudsonvale wetland, around twelve hectares of the delineated wetland area are used as irrigated and dryland perennial pastures for the cattle, located mainly in HGMU 1, and additional four hectares of the area in HGMU 2 are used during droughts as temporary grazing land.

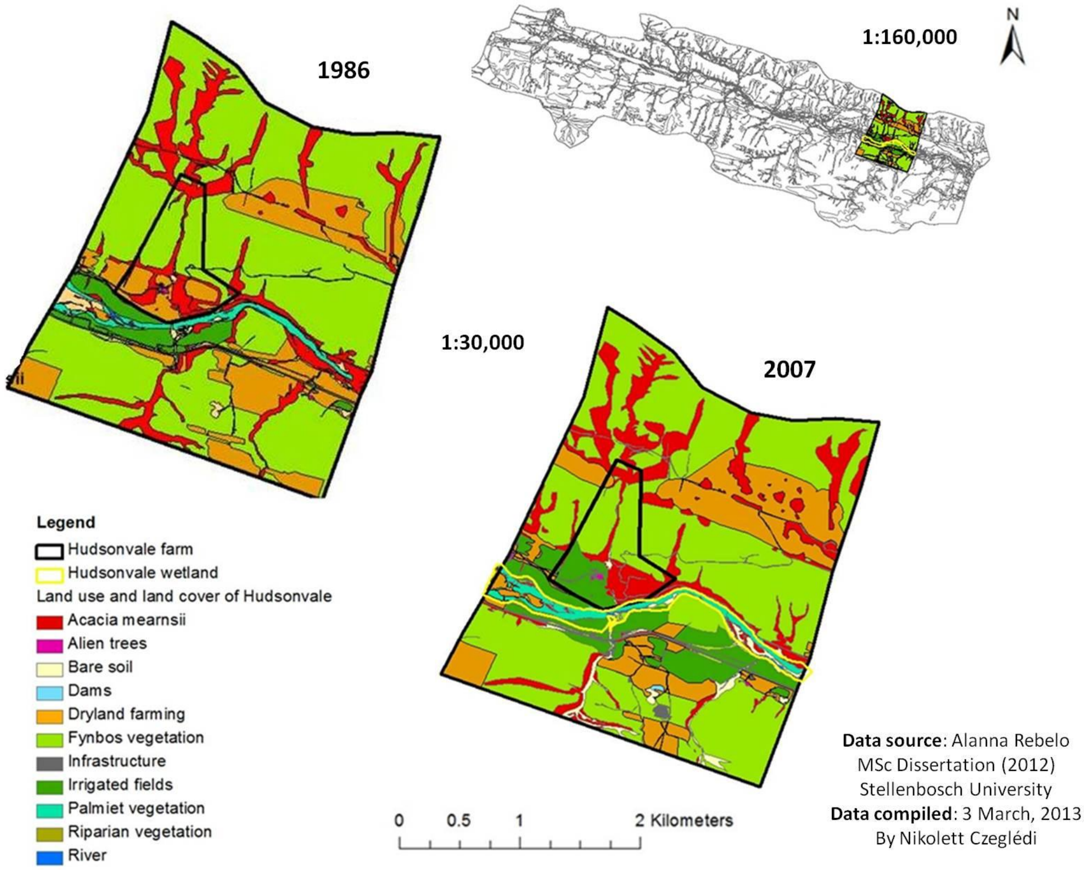

Figure 23: Change in land cover at the lands adjacent to the Hudsonvale wetland between 1986 and 2007

In total 26%, more land is used for agriculture than in 1986 at the level of the farm. Particularly, the total size of irrigated lands has increased, 180% more land has become irrigated compared to 1986, while the extent of drylands has decreased slightly. Furthermore, all the irrigated lands were kikuyu and rye grass planted perennial pastures in 1986, while other irrigated crops were also produced in 2012. However, still the kikuyu pasture dominates for the dairy. Eight hectares are used for producing 'mielies' (maize) and additional crops such as winter oats. The remaining 28 ha belongs to the other farm and due to the missing specification on the irrigated land, it is defined as other (Table 12).

Table 12: Change in land use and land cover between 1986 and 2012

Type of land cover	1986	2012	Difference (ha)	Change in area by 2012
	Area (ha)			%
Irrigated				
Perennial pastures	39	73	34	
Crops	-	8	8	
Other	-	28	28	
Total of irrigated lands	39	109	70	+180
Dryland	195	185	-10	-5
TOTAL	234	294	60	+26

The increase in the collective size of the perennial pasture indicates gradual intensification of the dairy production, which is also underpinned by the aim of the owner i.e. to extend the number of cattle up to 600. The farm currently has 500 cattle of which 350 cows are being milked, and the remaining 150 consist of different aged cattle. There is no other livestock kept on the farm.

Land management practices

It has to be noted that the data on the land management practices entirely derives from the owner of the dairy farm as data on the farming activities of the other farm was missing. The management practices of the dairy farm indicated many similarities with the practices used in the past.

c) Water abstraction

Water is used for both domestic purposes and irrigation of the kikuyu and rye grass pastures. For domestic purposes, they only use water provided by the Witels tributary. The water is delivered into the house from the upstream of the tributary by means of a gravity driven pipeline system and a weir that was built in around 1982 up on the Witels. For irrigation, the Kromme provides the water; however, water from Witels is also used for that purpose.

The irrigation takes place seasonally, mainly during the warmer months from September to April/May. Dragline sprinklers are used for irrigation, by means of using pumps; two are located in HGMU 1 and one pump in HGMU 2 and one is situated in the Witels tributary. There is also one dam at the farm but it is not used because of leakage. However, the owners has the intention to build more dams in the future. Data was not available on the annual water used for irrigation, thus it was estimated that the annual amount of water for irrigating 73 ha kikuyu pasture is around 0.49 million m^3/year, This estimation is based on data from a previous study (Gull 2012) (see Chapter 3.3.1./a). This amount of water was 88% more than in the past (Table 13). The water use for growing maize on the farm was calculated by using existing data on maize in the Gamtoos Catchment (Gull 2012). Thus, it was estimated that additional 0.05 million m^3 water is used on the 8 ha land if the crop is only maize. Altogether, considering only the irrigation of perennial pastures and crop field the amount of water has increased by 105.8 % by 2012.

Table 13: Estimated water used for irrigation in 1986 and 2012

Type of irrigated land	1986		2012		Change in water use by 2012
	Area (ha)	Water use (million m^3/year)	Area (ha)	Water use (million m^3/year)	%
Perennial pasture	39	0.26	73	0.49	+88%
Crops (maize)	-	-	8	0.05	
Total	39	**0.26**	110	**0.54**	**+105.8**

d) Grazing livestock

Most of the irrigated pastures are located next to the river. The locations of agricultural lands around and within the HGMUs are shown in Figure 24.

Kikuyu and rye grass dominated pastures have replaced around 42 % (11 ha), of the original wetland vegetation in HGMU 1, of which around seven ha of land is under irrigation. Another four hectares is under dryland farming. The dryland pasture are located on the elevated part next to the gravel road, - which was used as grazing land for calves in the past - currently is used for adult cows. Throughout the year, that area stays dry, but a bigger flood could mean a significant threat as that area could be washed away by the river. For instance, the previous owner lost sheep and cattle there during a large flood event. At most places the cattle cannot go to graze in HGMU 1 due to the established fencing system around the pastures. Nevertheless, there are some places where it is possible. Both the current and previous owners mentioned that the cattle sometimes eat palmiet.

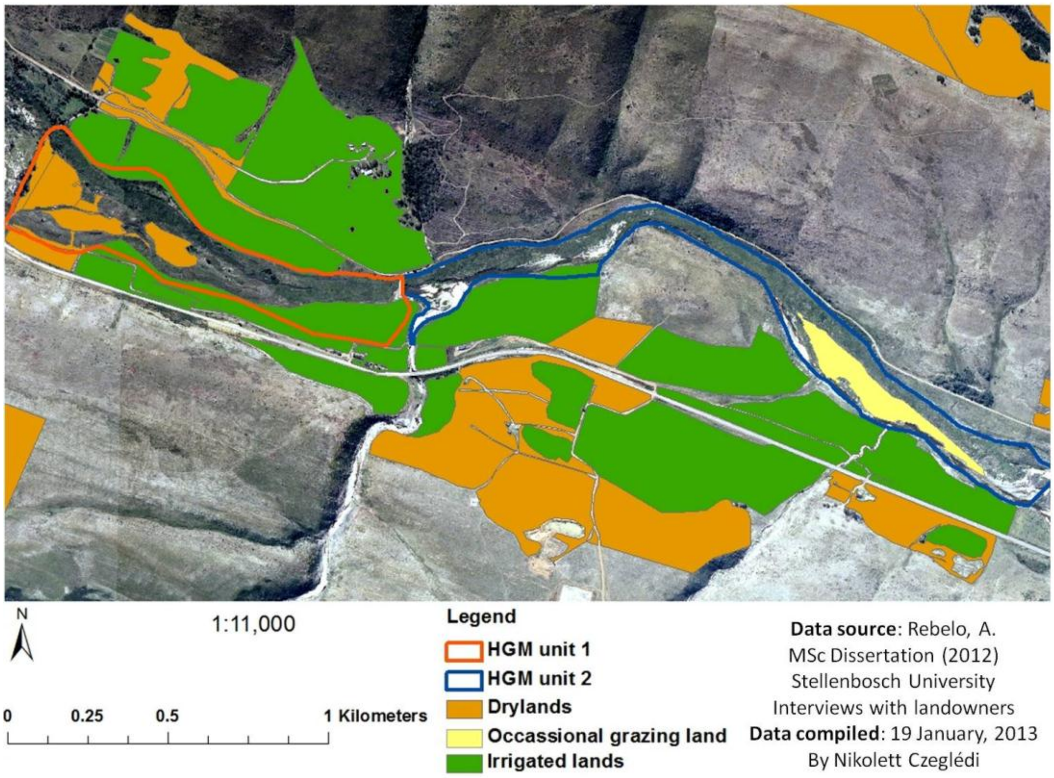

Figure 24: Irrigated lands and drylands around and within the Hudsonvale wetland in 2012

In HGMU 2, around half a hectare of the wetland area belongs to the irrigated kikuyu pasture, and an additional four hectares of the unit is occasionally used as grazing land during droughts. It is located on an elevated part within the unit, indicated by yellow polygon on the map. This area has become used only after WfWater cleared it. Before that the entire area was infested by black wattle, making it impossible for utilize the area in any way.

The wetland has been exposed regularly to trampling by livestock since 1959. The cattle and sheep could go into the wetland as well as graze on the established perennial pastures. In the past, in order for the cattle to reach the dryland pastures located in the mountains they had to cross the river. By now, it has changed as the dairy farm got the permission to use the gabion weir for such purposes. However, until now the cows used the same pathways through the 'natural' parts of HGMU 1 (Photo 6) and across the Witels tributary in HGMU 2, in order to reach the dairy and the perennial pastures within HGMU 1. Trampling by heavy grazing affects wetlands, particularly wetlands with unstable soil, and natural diffuse water flow across the wetland. Trampling by cattle can contribute to the development of small channels which concentrate water flows, thereby increasing the risk of development of erosion gullies (Collins 2006). In HGMU 1, however, the low number of erosional features indicates that the effects on the geomorphic processes by trampling are not significant.

In HGMU 2, trampling by cattle in the Witels tributary might accelerate the development of headcut erosion within the tributary upwards and the clastic sedimentation at the confluence of the tributary.

Photo 6: Cattle trampling in the wetland on its way towards the dairy (Photo by Author)

e) Fire management

In the past, the dryland velds burnt on the slopes in every 3-5 years in order to support the growth of the grassy species in the fynbos. Since 2010, the velds did not burn, but it is planned for the future to start to burn the velds again in the mountains that are under fynbos vegetation, by using a fire frequency of 4 to 6 years.

Burning of the irrigated lands during winter has been stopped around 15 years ago. Before it was burnt, when there was frost the kikuyu leaves laid down, died, thus in order to remove these dead leaves, and to prepare the area for planting ryegrass. During these fires, the wetland also got fire once in every 3-4 years, but it was not intentional. However, these practices stopped when the landowners started to use a new technology, so after cutting the kikuyu short, the drilling machine drilled the rye grass seeds into the ground between the kikuyu.

f) Fertilizer and herbicide use

Nitrogen and phosphorous and potassium fertilizers are applied on the kikuyu pastures. 50 kg N/ha is applied monthly for a six month period which means an annual 300 kg N/ha. Phosphorous is applied only once a year. The soils are very acidic, therefore, they also applied some lime, but the data about the amount is missing.

Herbicides are applied two times a year, around late spring and autumn to keep the weeds out of the dryland pastures when the weeds start to take over. They do not use herbicides on the irrigated pastures near the river, only on the pastures after the railway line up in the mountains.

4.2.2. Invasive alien plant clearing

a) Change in area covered by invasive alien vegetation between 1959 and 2007

In 1959, a significant part of the farm was already invaded by IAPs, mainly by black wattle. The infested places were located in the riparian zone of the Kromme, within the wetland area and up to the upstream neighbour Jagersbos as well as on the elevated parts between Hudsonvale and the downstream neighbour Skaapdrift. Furthermore, IAPs were located in the Witels tributary and on the south slopes of the Tsitsikamma Mountains (Local resident, pers. comm., 2012). According to Haigh et al. (2008), the wetland on Hudsonvale was in an excellent condition between 1942 and 1969 based on the assessment of the magnitude of wetland transformation. From 1969 on, it started to deteriorate as alien vegetation, particularly black wattle invaded the riparian zone as well as the inner part of the wetland. The invasion rate of *Acacia mearnsii* was the greatest between 1954 and 1969 in the Kromme River Catchment (catchment area from the Churchill dam up to the upstream, K90A and B), when each year average 96 hectares became invaded (Rebelo et al. 2013). As a result, the wetland was in a poor condition in 1986 (Haigh et al. 2008) but the invasion rate slowed to 12 ha/year (Rebelo et al. 2013). On Hudsonvale 148 ha, 13% of the farm was invaded by alien vegetation.

In 1997, WfWater started to work on the farm and cleared about 20 ha from black wattle. It was beneficial for the landowner because the cleared areas could be converted into grazing lands for the cattle and sheep (e.g. occasional grazing land in HGMU 2) (Local resident, pers. comm., 2012). Apart from the efforts, that WfWater made the expansion of IAPs continued and 19% more land was invaded by 2007 than in 1986 (Table 14).

Table 14: Change in land cover in terms of, Acacia mearnsii, irrigated and drylands between 1986 and 2007

Land cover	1986	2007	Difference (ha)	Difference (%)
	Area (ha)			
Acacia mearnsii	148	176	28	**+19**
Irrigated	39	110	71	**+182**
Dryland+ Occasional grazing land	195	189	-6	**-3**

This increase in the expansion of IAPs on the farm also reflected the trend in the entire catchment area. However, not only the extent of IAPs changed but also the spatial distribution of the invaded areas compared to the past. The newly invaded areas were still primarily located up in the tributaries in 2007 and on those areas that were most likely not used for farming activities anymore (Local resident, pers. comm., 2012) (Figure 25 and 26).

By 2007, the alien vegetation within the Hudsonvale wetland covered around 4.4 ha, which was approximately five ha less than in 1986. Most of it was cleared from HGMU 2, which then could be used for grazing during dry season. The change in the spatial distribution of alien vegetation along the wetland is likely to relate to WfWater. The case of Hudsonvale shows that there is a link between eradication of alien plants and expansion of agriculture along the river. However, it might be not the same at other farms.
There was no quantitative data available on how many hectares has been cleared at the site of the wetland by 2012, but based on Google Earth image (2011) and field survey IAPs covered around four ha (approx. two-two hectares in each HGMUs), which is slightly less than in 2007. The farm, however, is still described by the owner as “full with black wattle”. WfWater started to eradicate the alien vegetation in the Witels tributary, but according to a local resident “the black wattle stands still so dense that it is hardly possible to walk up” (Local resident, pers. comm., 2012).

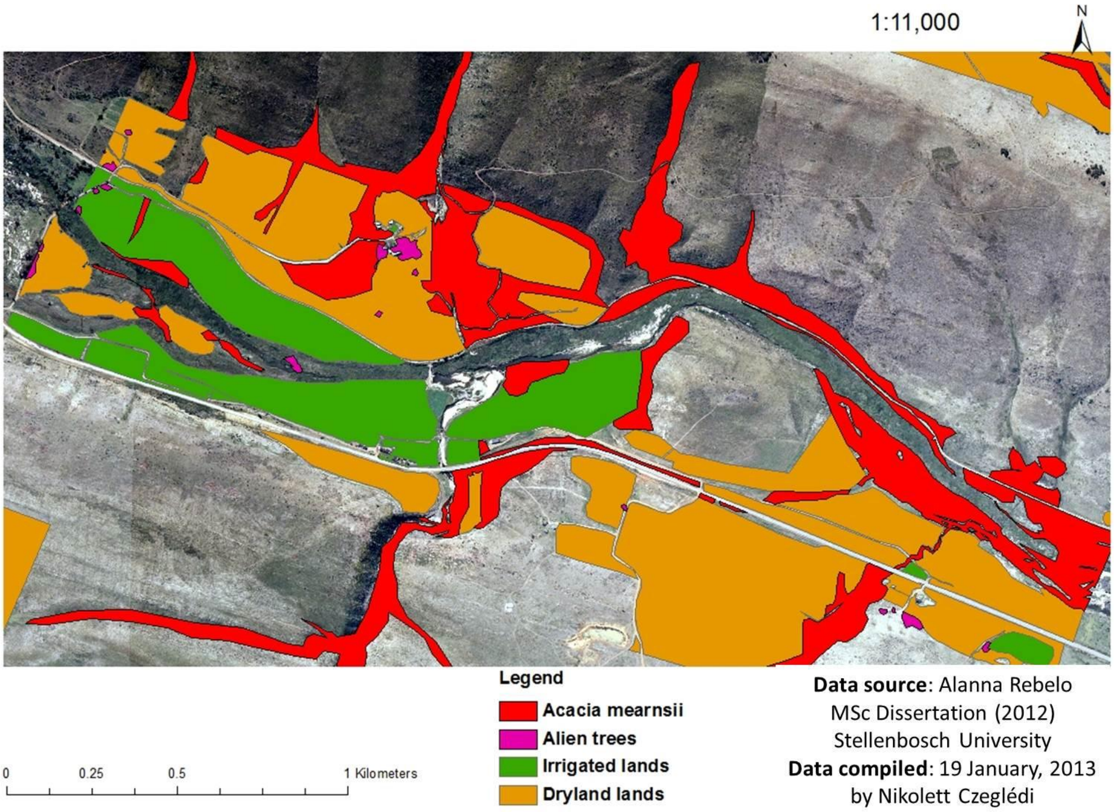

Figure 25: Extent of invasive alien plants and agricultural lands in 1986

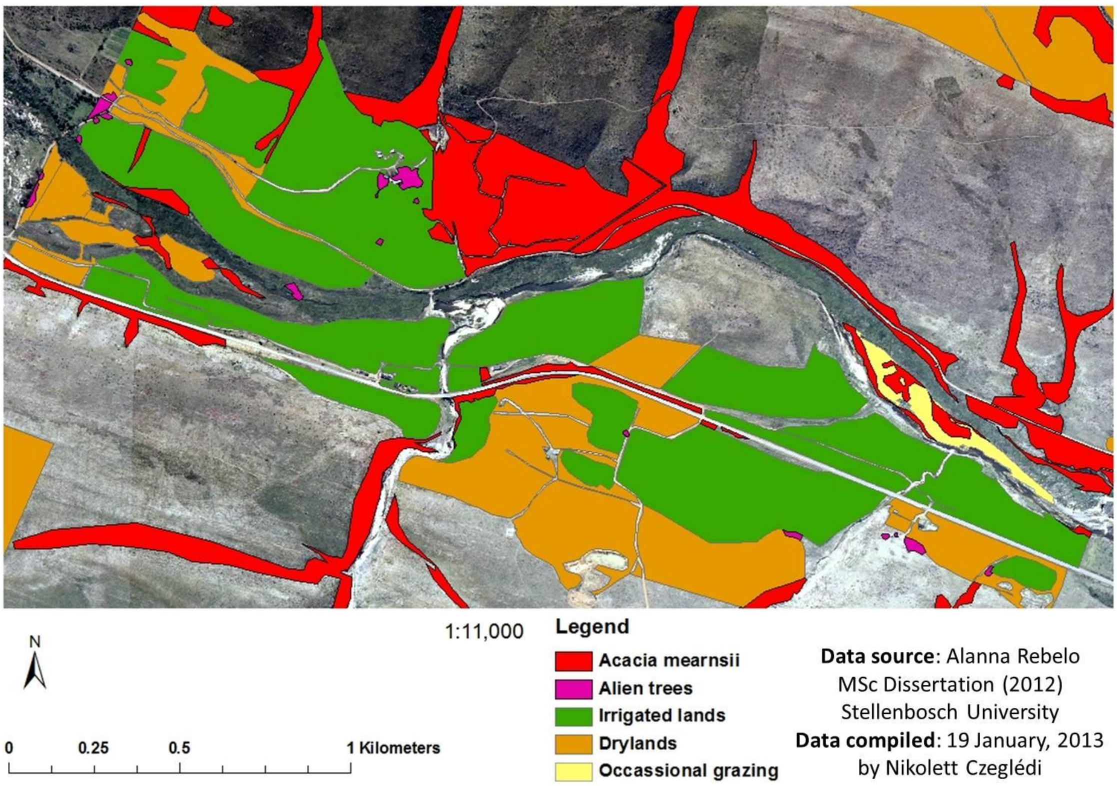

Figure 26: Extent of invasive alien plants and agricultural lands in 2007

b) Impacts of invasive alien plant eradication on the Hudsonvale wetland

IAPs clearing can have positive effects on the recovery of the natural wetland vegetation. IAPs, particularly black wattle shades out the native wetland species such as palmiet, which eventually get outcompeted. Half of the Hudsonvale wetland is still dominated by palmiet and reed vegetation. Before WfWater cleared the wetland, the riverbank in HGMU 2 was severely invaded by black wattle, which probably, has contributed to the erosion of the riverbank (Photo 7). Therefore, another positive effect of clearing riparian zones and riverbank from black wattle is that it has decreased the risk of further bank collapses and erosion as the clearing made it possible that indigenous vegetation re-establish on the banks and protect the soil from further erosion.

Photo 7: Bank erosion and black wattle before alien clearing in the Hudsonvale wetland (Photo by Lil Haigh)
The exposed bank consists of peat

IAPs clearing also contributed to expansion of land used for agriculture along and within the wetland. That might negatively influence the wetland area as the trampling by the dairy cattle increases.

4.2.3. Construction of erosion control structure within the Hudsonvale wetland

When WfWater started to work in the upper catchment, it revealed that many of the valley-bottom wetlands in the UKRC were in a poor condition due to gully erosion and headcuts in the riverbed (Haigh et al. 2008). The subsequent wetland survey conducted by the non-governmental Rennies Wetlands Project (currently Mondi Wetland Project) in 1997, discovered that the wetland on Hudsonvale was threatened by a huge 10m to 15m wide, 3 m deep and 200 m long headcut located upstream of the Witels confluence (WWG 1998, Haigh et al. 2008) (Photo 8a.). Furthermore the water rushing down from the tributary also caused severe riverbank erosion and lead to channel erosion in the wetland towards downstream (WWG 1998).

WfWetlands started to build the rehabilitation structure in 2000 and was completed in 2003 (Photo 8b.). The main aims were to halt the headcut in order to prevent further degradation of the wetland, stop erosion gully, raise water level, and trap silt. The rock gabion weir was built on soil foundation and has a 21 m spillway, which is located 3 m above the riverbed. It consisted of two sections with a support wall in the centre to make it more stable. The original structure had to be extended and mended a couple of times after experiencing some bigger floods (e.g. in 2006 and 2007) (Haigh et al. 2008). As a result of this a second structure was built to support the main structure against the pressure exerted by the water in the wetland (Buckle, pers. comm., 2012) and the gabion baskets also became covered by concrete to make them stronger (Haigh et al. 2008). Eventually the weir became so stable that the dairy farm got allowance in 2012 to use the structure as a walkway for the cattle to cross the river when they needed to go to the mountains (Local resident, pers. comm., 2012).

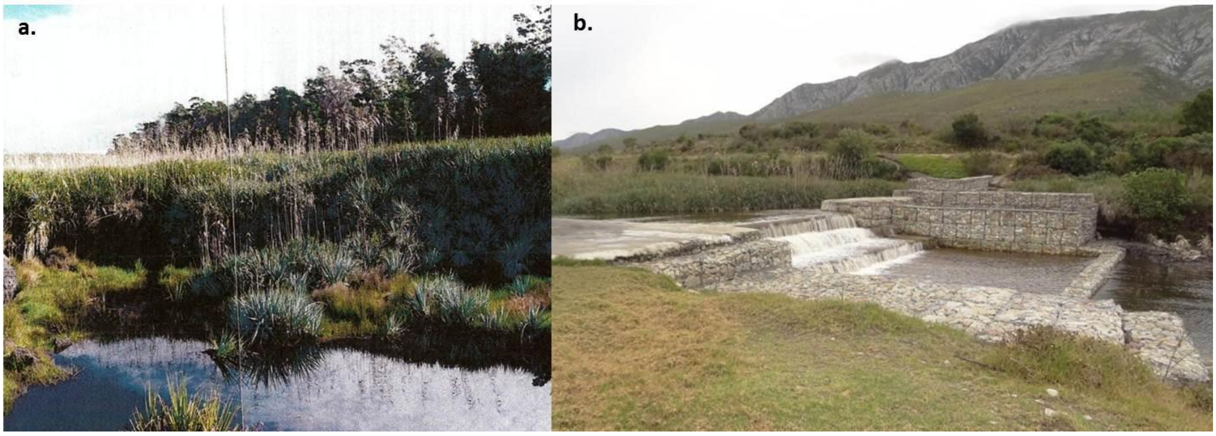

Photo 8: From headcut erosion to erosion control structure in the Hudsonvale wetland
(a.) Headcut degrading the peat basin in the Hudsonvale wetland in October, 1997 (WWG, 1998). In the background dense stands of black wattle visible.
(b.) The view of the wetland after the rehabilitation in June, 2012. (Photo by Author)

Impacts of the construction of erosion control structure on the Hudsonvale wetland

According to (Haigh et al. 2008), the erosion control structure contributed to an increase in the ecological health of the wetland, after the headcut was halted. Based on the aerial photograph assessment and WET-Health assessment in 2007 after a big flood, the Hudsonvale wetland and its peatbasin was assessed as largely modified, but its ecological health was ranked to be moderate.

The impacts of the erosion control structure are multiple. It has slowed down the velocity of the flow and has improved the water retention capacity of HGMU 1. These all allowed suspended and dissolved sediment (latter is often bound to clastic sediment) to settle down from the water and for biogeochemical processes to take place such as removal of nutrients and toxicants and accumulation of peat. Furthermore, the increased water retention within the unit is likely to promote the recovery of wetland vegetation, which in return also contributed to sediment trapping. In HGMU 2, the erosion control weir has improved the water distribution by leading the water into the smaller channel. In this way, the remaining wetland vegetation in the unit together with the peat deposits underneath have been saved from drying out because of the drop of water table in the main channel.

5. Use of the WET-Health tool to analyse the current ecological condition of the Hudsonvale wetland

The following chapter describes the current ecological condition of the Hudsonvale wetland based on the results of the assessment by using the WET-Health tool. The tool provided a systematic way to assess the magnitude of human impacts on the hydrological, geomorphic and vegetation integrity of the wetland compared to its natural reference condition. In this chapter information on the biophysical characteristics and human drivers of both the upper catchment area and the Hudsonvale wetland were integrated.

The sub-chapters are structured in such a way that the main findings of the assessment are placed at the beginning of this chapter, and the main assessment steps of the hydrological, geomorphic and vegetation assessment modules are described following that. Thus, the sub-chapters describe the reference condition of the Hudsonvale wetland, the overall health of the wetland (summary of results), the overall present hydrological, geomorphic and vegetation health together with the main steps of these assessments.

5.1. Reference condition of the Hudsonvale wetland

To be able to analyse the current ecological condition and the provision of ecosystem services provision (Chapter 6) of the Hudsonvale wetland, the reference condition needed to be defined. According to (Kotze et al. 2012) reference condition in South Africa is the state when a wetland has a natural level of inputs of resources and has not been modified by human interventions since European colonization.

The reference, undisturbed natural condition of Hudsonvale wetland was difficult to define as the first aerial photographs taken about the area (1942) already showed a certain degree of wetland transformation by agricultural activities in the valley-floor (Haigh et al. 2008). Even though it was claimed that the peatbasin was in an excellent condition in 1942 (Haigh et al. 2008), the Kromme River was likely to be originally an unchannelled valley-bottom wetland (Rebelo et al. 2013).

It was assumed that in its undisturbed reference condition, the original extent of the wetland was equal with current delineated size (54 hectares) and had the characteristics of an unchannelled valley-bottom wetland with no visible channel and erosion gullies on the surface. In this way, the movement of the water was characterized by diffuse flow through the wetland, even during and after high rainfall events (SANBI 2009). The vegetation cover was likely to be similar to the last remaining intact palmiet wetland of the Kromme River Catchment, located on the farm Krugersland (Rebelo et al. 2013).

The Krugersland wetland recorded the highest diversity index of plant species, mostly herbs and grassy fynbos species compared to the other remaining peat-basins and was still in good condition in 2008 (Nsor 2008). Its vegetation consisted of predominantly indigenous wetland species such as *Typha capensis, Prionium serratum, Phragmites australis, Juncus lomotophylus* (etc.), mixed with other terrestrial plants (e.g. *Persicaria lapathifolia, Bidens pilosa*) (Nsor 2008).

5.2. The Overall Present Health of the Hudsonvale wetland

This chapter provides a summary of the current ecological health of the Hudsonvale wetland based on the results deriving from chapters 5.3-5.5.

The result of the Hydrology module indicated that more than 80% of the hydrological integrity of the wetland has been lost and its functioning and ecological processes have been drastically altered. Particularly, the on-site activities affected the wetland negatively like the eroding riverbed and the irrigation of the kikuyu pastures which resulted in canalization of the wetland and loss of water. The changes caused in the input water quantity to the wetland by activities in the catchment were rather low.

The geomorphic integrity of the wetland was the least altered compared to the two other health components. The Overall Present Health Score was 2.8, indicating moderately alterations, where the biggest impact was on the loss of organic sediment, but the integrity remained predominantly intact.

The Overall Present Vegetation Health of the wetland was calculated as 4.3, referring to a largely altered vegetation composition compared to the reference condition. The abundance of alien and/or ruderal species is approximately equal with the abundance to the characteristic indigenous wetland species.

After combining the final scores of the health components, the Overall Health Score for the Hudsonvale wetland was assessed 5.5., indicating large modification in the ecological health of the wetland. The anticipated trajectory of change scores were also combined, and it was -0.3, which means that the ecological health of the Hudsonvale wetland is likely to decrease slightly in the next five years (Table 15).

Table 15: Combined final health score

Module	Impact Score	Category	Change Score	Change Symbol	Health Class
Hydrology	8.2	F	-1	(↓) slight decrease	F(↓)
Geomorphology	2.8	C	0	(→) no change	C(→)
Vegetation	4.3	D	0.4	(↑) slight increase	D(↑)
Overall Health Score for entire wetland*	**5.5**	**D****	**-0.3**	**(↓) slight decrease**	**D(↓)**

*Formula provided by WET-Health: ((Hydrology Score x 3) + (Geomorphology Score x 2) + (Vegetation Score x 2))/ 7

** The Overall Health Score of 5.5 corresponds with the health category 'D' (score range is between 4-5.9). The impact of the modifications is clearly detrimental to the health of the wetland. Approximately 50% of its health has been altered compared to the reference condition.

5.3. Assessment of current hydrological health

This chapter describes the main assessment steps required to determine the current hydrological health of the Hudsonvale wetland. The impacts of drivers on the water input quantity, flow patterns, water distributions and water retention were assessed for the previously defined two hydro-geomorphic units of the wetland. Then, these impact scores were combined and area weighted to get the Overall Present Hydrologic Health of the Hudsonvale wetland. The structure of this chapter follows this assessment logic.

5.3.1. Changes in water input quantity and in the pattern of water delivery from the sub-catchments of the hydro-geomorphic units

To determine to what extent the water quantity and the flow patterns of water arriving to the wetland from its upper catchment area have been altered, the impacts of water abstraction, alien plant encroachment, dams, roads, bare soils were assessed for each hydro-geomorphic unit that steps are described in points from a) to c).

a) Change in water input quantity

The overall magnitude of reduction in water inputs from the upper sub-catchment areas to the HGMUs were calculated as -1.0 and -0.8 for HGMU 1 and 2, respectively. Indicating that HGMU 1 was more influenced by its upstream water reducing activities, than HGMU 2, however, the impacts in both cases were very small on the scale of -10 to 0. (The assessment table is shown in Table 34, Appendix 5.)

Irrigation and water abstraction for domestic use had a limited extent in both sub-catchments, however, HGMU 2 had a slightly higher extent of irrigated lands (2.71%) relative to the sub-catchment area. HGMU 1 had a 9.35% invasive alien plant encroachment, mainly by black wattle in its sub-catchment. Apart from the pine infested areas on non-riparian areas, the rest of the invasive alien trees were mainly distributed in riparian areas. In the case of HGMU 2, this extent was slightly lower and made up 7.67%.

No large impoundments were in upstream neither of the HGMUs, however, small farm dams were present. Therefore, farm dams were included in this assessment step, but their water reducing impacts were assessed to be low relative to the sub-catchment areas. None of the catchments had plantations for wood or sugar production, thus scores of zero were assigned.

b) Change in flow patterns of water delivery

The floodpeak magnitude and/or frequency received by both HGMUs decreased slightly compared to its natural water flow pattern due to the overall magnitude of impacts of hardened surfaces, bare soil, and degraded fynbos velds. The score was -2.0 on a scale between 0 and -10 for both HGMUs' sub-catchments, however, the extent of degraded fynbos veld was almost 2.5 times larger in the case of HGMU 2 than 1 relative to the catchment area.

c) Combined impact of altered quantity and timing of water inputs

After combining the scores of the previous assessment steps, HGMU 1 got the score of 2.5, and HGMU 2 scored 1.0. Therefore, the drivers located in the upper sub-catchments modified to a small extent and moderately the hydrological integrity of HGMU 2 and 1, respectively (Table 16).

Table 16: Guideline for interpreting the magnitude of impact on the hydrological health of a hydro-geomorphic unit

Impact Category	Description	Score
None	No discernible modification or the modification is such that it has no impact on hydrological integrity.	0 – 0.9
Small	Although identifiable, the impact of this modification on hydrological integrity is small.	1 – 1.9
Moderate	The impact of this modification on hydrological integrity is clearly identifiable, but limited.	2 – 3.9

The magnitude of impact of altered quantity and pattern of water inputs on hydro-geomorphic unit 1

The magnitude of impact of altered quantity and pattern of water inputs on hydro-geomorphic unit 2

5.3.2. Changes in water distribution and retention within the hydro-geomorphic units

Activities on-site of the Hudsonvale wetland affected HGMU 2 more severely in terms of its water retention and distribution than HGMU 1. The former scored 8.8 and the later scored 6.0. Particularly the canalizing effects of the eroding riverbed increased the total impact score of HGMU 2 that directly affected 70% of the unit and scored 4.9 out of 10. In the case of HGMU 1, the irrigation of the kikuyu pastures had the highest impact on water retention (score of 3.6) among the other activities assessed. The magnitudes of impacts of each assessed activity and the summed total scores are shown in Table 17 for both HGMUs.

Table 17: Magnitude of impacts on water distribution and retention patterns in the hydro-geomorphic units

Activity	Magnitude of impact	
	Hydro-geomorphic unit 1	Hydro-geomorphic unit 2
(a) Calculated magnitude of impact of canalization and stream channel modification	**0.2**	**4.9**
(b) Calculated magnitude of impact of impeding features	**0.7**	**0.0**
(c) Calculated magnitude of impact of altered surface roughness	**1.5**	**2.0**
(d) Calculated magnitude of impact of direct water losses by aliens and direct water abstraction	**3.6**	**1.5**
(e) Calculated magnitude of impact of recent deposition/excavation	**0.04**	**0.4**
Total score of magnitude of on-site activities in the Hydro-geomorphic unit (sum of the above scores *)	**6.0**	**8.8**

* If score is > 10, then magnitude of impact = 10

a) Impacts of canalization and stream modification

While HGMU 1 scored very low (0.2) in this assessment, HGMU 2 got a much higher score (4.9).

Compared to the reference condition, it was assessed that the two channels at the head of HGMU 1 affected only 20% of the unit referring to a very small impact on the unit's water retention and distribution patterns. On contrary, the riverbed incision in HGMU 2 had a much larger impact due to the proceeding erosion in the riverbed that directly affected 70% of the unit. The remaining 30% was considered as less affected by the erosion because the gabion weir ensures continuous water supply to the smaller channel, which is particularly important during dry season in maintaining palmiet vegetation. Thereby, the gabion weir was likely to compensate to a certain extent the desiccating effect of the riverbed erosion.

There was not any artificially modified stream channel found in neither of the HGMUs and thus this was omitted from the assessment.

b) Impacts of impeding features

The magnitude of impacts score of impeding features was 0.7 in both HGMUs.

In HGMU 1 this assessment considered two impeding features; the erosion control structure and the gravel road that crossing the head of the unit. The gabion weir scored zero because it was likely to retain water successfully, close to its natural state by impeding the water flow, but not negatively damming the unit. On contrary, the road was likely to cause a slight interruption in the flow distribution by damming towards upstream direction during low flows, even though there were culverts built under it.

In the case of HGMU 2, there was not any road crossing through the wetland, only the erosion control structure was present, but it scored zero. The gabion baskets and the wide spillway enabled continuous flow to HGMU 2, so it was assumed not to impede the water flow during low flows. The step that assessed the impact of the water used for irrigation from the dam was omitted because the structure was not build with aim to enhance water abstraction and to avoid unrealistic magnitude of impact and double counting of direct water loss (see point d).

c) Impacts of change in surface roughness

The magnitude of impact score was 1.5 for HGMU 1 and slightly higher, 2.0 in the case of HGMU 2. Surface roughness in both HGMUs was modified mainly by converting some of the parts into pasture, invasion of alien vegetation, development of erosional processes and presence of open stream channel. 49% of the unit's surface roughness was altered into kikuyu and ryegrass pastures in the case of HGMU 1. 42% of HGMU 2 was modified regarding surface roughness, of which the irrigated pasture made up only 2%. Other factors such as alien vegetation, bare soil and open stream channel and erosional channels had higher effects.

d) Impacts of direct water losses

The direct water losses similarly to the assessment of water quantity inputs was calculated from more the magnitudes of impact of invasive alien vegetation, water abstraction, and plantations within the HGMUs. The magnitude of impact score was 3.6 for HGMU 1 and 1.5 for HGMU 2. The evaluated effect of land use activities in the HGMUs on water loss is shown in Table 35 in Appendix 5.

HGMU 1 was more affected by water abstraction for irrigation than HGMU 2 due to the extent and water needs of kikuyu pasture. Two water abstraction points were found in the middle section of the unit, and thus 50% of the downstream part of HGMU 1 was assessed as being affected by the water abstraction.

In HGMU 2, there was only one water pump close to the end of the unit. Thus, only 21% of the unit was affected by water abstraction for irrigation, the area that was located downstream of the abstraction point.

Both HGMUs scored zero for the evaluation of the effect of 'commercial plantations or stands of evergreen crops growing in the wetland' due to they were not present.

Invasive alien trees were present within both units. They made up 6% and 11% of HGMU 1 and 2, but the magnitudes of impact were quite low; 0.5 and 0.9, respectively.

e) Impacts of recent deposition, infilling

In the case of HGMU 1, the gravel road and the erosion control structure were assessed as infillings. The magnitude of impact by these infilling was very small only 0.04 in HGMU 1 and slightly higher 0.4 in HGMU 2. The extent of infillings and depositions as well as the magnitude of impacts are shown in Table 36 in Appendix 5. HGMU got such a small score because the gabion structure was considered, as it did not alter the vertical drainage properties of the uppermost soil layer towards making it more free draining. It is built on concrete base that impedes the vertical movement of water.

In the case of HGMU 2 the assessment included a part of the gabion structure located in this unit, but it mainly recent depositional features, which consisted of course clastic sediments such as pebbles, cobbles and sand, enhancing at an intermediate level the vertical drainage of water.

5.3.3. Present Hydrological State of the hydro-geomorphic units

After combining the impact scores of ‘Changes to water inputs’ and ‘Changes to water distribution and retention patterns’ the Present Hydrological State of each HGMU was determined shown in Table 38, in Appendix 5.

HGMU 1 scored 7.5, and got the health category ‘E’, which indicates that the hydrological integrity of the unit has been adversely affected by modifications and the loss of integrity is between 51 and 79%. HGMU 2 scored 9.0, meaning that its hydrological integrity has been drastically altered and more than 80% of its hydrological integrity has been lost.

5.3.4. The Overall Present Hydrological Health of the wetland and the anticipated Trajectory of Change

The Overall Hydrological Health of the entire Hudsonvale wetland was 8.2, which score was calculated by area weighting the Present Hydrological State scores of the HGMUs and then summing them. This score indicated that the Overall Present Health of the Hudsonvale wetland belonged to the worst health category '**F**', which refers to that more than 80% of the hydrological integrity of the wetland has been lost and its functioning and ecological processes has been drastically altered (Table 18).

Table 18: The Overall Present Hydrological health impact score of the Hudsonvale wetland

Hydro-geomorphic unit	Area (Ha)	Extent (%)	Hydro-geomorphic unit magnitude of impact score	Area weighted impact score*	Present Hydrological Health category
1	28.3	52	7.5	3.9	
2	26.0	48	9.0	4.3	
Total	**54**	**100**	**Overall weighted mean impact score****	**8.2**	**F*****

*Area weighted impact score = HGM extent /100 x impact score
**Overall area weighted impact score = sum of individual area weighted scores for each HGMU
***The overall impacts score of 8.2 corresponds with the health category 'F' (impact score range is between 8.0-10.0). This health category indicates that modifications are so great that the hydrological functioning has been drastically altered. 80% or more of the hydrological integrity has been lost.

In order to get a more comprehensive diagnosis of the health of the wetland, the likely future changes in hydrological health were also assessed. It was assumed that the wetland was likely to slowly deteriorate in the next five years (indicated as F (↓)), because some of the farmers intended to build new dams in the upstream area and to extend their farming activities, particularly livestock farming. The water amounts used by the landowners never have been monitored (Joubert, pers.comm., 2012) and there is no local implementation body to manage and coordinate water management in the area. These loops in the regulation of water resources provide a great degree of freedom for the local landowners to achieve their plans. Therefore, the land use activities together with the increasingly erratic rainfall are likely to have negative effects on the water input quantity to the wetland. Furthermore, the gabion weir is likely to promote diffuse flow to the HGMU 2, thereby providing the remains of the palmiet-dominated wetland section by water. However, the erosion in the riverbed is likely to continue until it reaches its base level[9], thereby threatening the entire HGMU by lowered water table and desiccation.

5.4. Assessment of current geomorphic health

This chapter describes the main assessment steps required to determine the current geomorphic health of the Hudsonvale wetland. In order to assess the current geomorphic integrity of the Hudsonvale wetland both diagnostic and indicator-based components were assessed. In the study both HGMUs are characterized as channelled valley-bottom type, thus only those assessment steps were conducted which were assigned to this type by the guideline of the assessment (Table 19).

Table 19: Guideline for assessing the impacts of human activities according to hydro-geomorphic type Adapted from WET-Health (Macfarlane et al., 2008)

Hydro-geomorphic type to assess	Activity/Indicator that should be assessed	Assessed
Diagnostic component		
Floodplain	Dams upstream of or within floodplains	-
Floodplain, channelled valley bottom	Stream shortening or straightening	√
Floodplain, channelled valley bottom	Infilling that leads to narrowing of the wetland	√
All non-floodplain	Changes in runoff characteristics	√
Indicator-based component		
All non-floodplain	Erosional features	√
All non-floodplain	Depositional features	√
All non-floodplain	Loss of organic sediment	√

[9] Base level is the lowest level to which a stream can erode its bed (Ellery et al, 2009).

5.4.1. Assessment of diagnostic features

Diagnostic features refer to identifying those activities that may be leading to decrease in geomorphic health. Assessed features are modification of channel, artificial wetland infilling, and changes in runoff characteristics. The assessment of diagnostic features provides complementary information with the latter indicator-based assessment.

a) Impacts of channel shortening or straightening

This assessment was omitted because neither HGMU was affected by any channel modification as it was already revealed in the assessment of current hydrological integrity.

b) Impacts of artificial wetland infilling

HGMU 1 was assessed for two artificial infillings located at its two ends; the gravel road and the gabion weir, similarly to the assessment step in the hydrological module (see chapter 5.3.2/e). Since the road and the gabion weir were located far away from each other, they were assessed separately and the magnitudes of impacts were summed at last, giving the score of 0.4, which is very low on a scale of 0-10.

The extent of the impact by the road was estimated as 9.8% of the HGMU based on the proportion of the unit area filled plus the area that is geomorphologically inactivated by flow confinement. It was estimated that the road by its flow confining effect prevented the adjacent kikuyu pasture within the unit from natural erosion and depositional processes to take place.

In the case of HGMU 2, a small portion of the gabion weir was the only artificial infilling within the HGMU located at the beginning of the unit. The magnitude of impact score was very low, only 0.1 due to small extent (3%) of the whole unit that was affected by the weir.

c) Impacts of changes in runoff characteristics

This diagnostic component is related to increased quantity and pattern of floodpeaks to the wetland. This assessment scored zero in the case of both HMUs because the Hydrology module revealed that there was no increase in either of these variables.

5.4.2. Assessment of erosional and depositional indicators

This assessment focuses on directly visible impacts of activities such as erosion gullies, peat fires or depositional fans.

a) Impacts of erosion

In HGMU 1, there was only one active erosional feature, which was estimated to have an extent of 5% based on its width and length. More erosional features such as bank and channel erosion as well as incised riverbed characterized HGMU 2, thus a significant part, 40 % of the unit was affected.
The magnitude of impact scores for erosional features were 0.1 and 0.7 for HGMU 1 and 2, respectively. To define these scores indicators such as width and depth of gullies were assessed as well as the pattern of sedimentation and signs of natural recovery (Table 20).

Table 20: Intensity and magnitude of impact scores of erosional features

Factor	Hydro-geomorphic unit 1 score	Hydro-geomorphic unit 2 score
Mean depth of gullies	2	4
Mean width of gullies	2	3
Number of headcuts present	-	1
Unscaled intensity of impact score (means score of highest 2 scores in above 3 rows)	2.0	2.7
Scaling factor	HGMU 1 factor	HGMU 2 factor
Extent to which sediment from the gully is deposited within the HGMU or wetland downstream of the HGMU (as opposed to being exported)	0.5	0.7
Extent to which the bed and sides of the gully have been colonized by vegetation and/or show signs of natural recovery	0.5	0.7
Scaling factor score: mean of above 2 rows (value is between 0 and 1)	0.5	0.7
Scaled intensity of impact score = unscaled intensity of impact score x scaling factor score	1.0	1.9
Magnitude of impact score for erosional features: (extent of impact score/100) × scaled intensity of impact score	**0.1**	**0.7**

b) Impacts of deposition

Fan-like active depositional features were only found in HGMU 2 at the confluence of the tributaries. HGMU 1 was characterized with a small recent depositional feature at the head of the unit. The impact of depositional features was assessed based on indirect indicators of recent anthropogenic activities taking place within the catchment or the wetland.

30% and 25% of HGMU 1 and 2, respectively was likely to be affected by deposition assessed by indirect indicators (Table 21). The two HGMUs only scored differently in the case of two indicators. For the indicator of 'breaching of upstream dams in the catchment' HGMU 1 scored 3 because of the presence of large earthen dams in its sub-catchment area. On the contrary, HGMU 1 only score 1 because there was only very small earthen dams found in its sub-catchment. The other indicator was the 'extent of decreased vegetation cover in the catchment', where HGMU 1 scored 2, referring to high extent of decrease in vegetation cover, particularly in the fynbos vegetation.

Table 21: Extent of depositional features based on indirect indicators of recent anthropogenic activity
Adaptad from WET-Health (Macfarlane et al., 2008)

Indicator	Hydro-geomorphic unit 1 score	Hydro-geomorphic unit 2 score
Presence, size and distribution of gullies or active erosion of drains within the catchment or wetland	3	3
Presence / extent of dirt roads in the catchment	1	1
Breaching of upstream dams in the catchment or wetland	3	1
Extent of decreased vegetation cover in the catchment	2	1
Mean of two highest scores from the above	**3.0**	**2.5**
Extent of impact score of depositional features as a percentage is calculated as the score from the above multiplied by 10.	**30**	**25**

The magnitude of the impact of depositional features was calculated as 0.5 for both HGMUs. It means a very low impact on the geomorphic integrity on the HGMUs. Both deposits were found at the head of the units, only HGMU 2 was likely to be affected slightly more by the deposition than HGMU 1, so it scored 1 for the second indicator shown in Table 22.

Table 22: Intensity and magnitude of impact of depositional features

Indicator	HGMU 1 score	HGMU 2 score
The position of fan-like deposits within the wetland	3	3
Impact of depositional features on existing wetland features	0	1
Intensity of impact score of depositional features: mean of two rows above	1.5	2
Magnitude of impact score of depositional features: (extent of impact score (Table 21) / 100) x intensity of impact score	**0.5**	**0.5**

c) Impacts of the loss of organic sediment

The assessment of organic sediment loss uses both direct and indirect indicators in order to estimate the magnitude of impact. Direct indicators focus on human activities that affect directly the organic sediment deposits such as peat mining, tillage or subsurface peat fires. Indirect indicators are related to changed hydrological characteristics such as reduced water inputs and reduced residence time of water within the HGMUs due to that organic sediment is dependent on permanently saturated conditions to be maintained and to accumulate. First, the aerial extents of the direct and indirect indicators of organic sediment loss were assessed as proportion of the extent of the total HGMU (Table 23).

Table 23: Estimation of impact of loss of organic sediment for direct and indirect indicators

	HGMU 1	HGMU 2
Extent of impact score based on direct indicators (if present)	0 %	10 %
Additional extent of impact score based on indirect indicators (if present)	47 %	44 %

Human activities that directly affected the peat deposits were only identified in the case of HGMU 2, where about 3 m deep incised peat wall was exposed at 10 % of the unit, close to the erosion structure (Photo 9).

The extent of impact based on the indirect indicators was determined by means of the estimated extent of peat deposits (see Chapter 4.1.2.) relative to the extent of the HGMU. It was assumed that there were around 13.4 ha of peat deposited in HGMU 1 and 11.6 ha of peat in HGMU 2. These deposits were likely to be exposed to negative impacts due to the largely altered hydrological characteristics, particularly due to the reduced water inputs coming from the sub-catchments and the altered water retention of the HGMUs (see Hydrology module in Chapter 5.3.1. and 5.3.2.).

Photo 9: Incised peat wall exposed to desiccation in hydro-geomorphic unit 2

In HGMU 2, the intensity and magnitude of impact of loss of organic sediment based on the direct indicators were estimated at 4.0 and 0.4, respectively. In the case of HGMU 1, this step was omitted

(Figure 24). Direct indicators were "depth of the peat fires or extraction of peat relative to the depth of the peat deposit" and "the duration of tillage"; however, the latter one was not practised. Indirect indicator assessed the level of desiccation of the region of the HGMU.

Table 24: Intensity, magnitude and overall magnitude of impact of loss of organic sediment

	Intensity		Magnitude*		Overall magnitude of impact score**
	Indirect indicators	Direct indicators	Indirect indicators	Direct indicators	
Hydro-geomorphic unit 1	3	-	1.4	-	**1.4**
Hydro-geomorphic unit 2	4	4	1.8	0.4	**2.2**

* Extent of impact score (Table 23) /100) × intensity of impact score
** Sum of magnitude scores

5.4.3. Present Geomorphic State of the hydro-geomorphic units

The results of the assessment of geomorphic health of the HGMUs are summarized as the Present Geomorphic State. Since the HGMUs were classified as channelled valley-bottom wetlands, not all the individual assessment were conducted. The impacts of assessed diagnostic features and indicators were low on a scale of 0 to 10. HGMU 2 scored 3.4, which indicated higher impacts on its geomorphic integrity than HGM 1 , which score 2.3. The summarized scores are shown in Table 25.

Table 25: Overall magnitude of impact scores by combining scores from individual assessments

Impact category	Hydro-geomorphic unit 1	Hydro-geomorphic unit 2
1. Magnitude of impact of dams	NA	NA
2. Magnitude of impact of channel straightening	NA	NA
3. Magnitude of impact of infilling	0.4	0.1
4. Magnitude of impact of changes in runoff characteristics	0.0	0.0
5. Magnitude of impact for erosional features	0.1	0.7
6. Magnitude of impact for depositional features	0.5	0.5
7. Magnitude of impact for loss of organic sediment	1.4	2.2
Overall Present Geomorphic State = Sum of three highest scores	**2.3**	**3.4**

5.4.4. The Overall Present Geomorphic Health of the wetland and the anticipated Trajectory of Change

In order to get the Overall Present Geomorphic Health of the Hudsonvale wetland, first the area-weighted impact scores had to be calculated by means of the extents of HGMUs relative to the whole wetland area and the magnitudes of impact scores deriving from Table 25. Then the sum of the area-weighted impact scores gave the Overall Present Geomorphic State for the wetland, which was calculated as 2.8, representing "**C**" category (Table 26), indicating that there is a moderate change in the geomorphic processes, but the system remains predominantly intact.

Table 26: The Overall Present Geomorphic Health of the Hudsonvale wetland

Hydro-geomorphic unit	Area (ha)	Extent (%)	Hydro-geomorphic unit magnitude of impact score (Table 25)	Area weighted impact score*	Present Geomorphic Health Category
1	28.3	52	2.3	1.2	
2	26.0	48	3.4	1.6	
Total		**100**	**Overall weighted impact score** **	**2.8**	**C*** **

Area weighted impact score= HGM extent/100 impact score
**Overall area weighted impact score= sum of individual area weighted score for each HGMU
***The overall impacts score of 2.8 corresponds with the health category of 'C' (impact score range is between 2.0-3.9). This health category stands for that the geomorphic integrity of the wetland is moderately modified. A moderate change in geomorphic processes has taken place but the system remains predominantly intact.

In order to get a more comprehensive diagnosis of the health of the wetland, the likely future changes in geomorphic health were also assessed. It started with assessing the vulnerability of the HGMUs to geomorphological impacts. It was defined based on the size and the longitudinal slope of the wetland (Figure 27). The vulnerability score was zero because the longitudinal slopes of the HGMUs were very small (0.47 %). The reasoning behind it is that the steeper the slope the more likely a headcut will erode (Ellery, 2009) and in this case, the wetland area is used as a proxy for discharge.

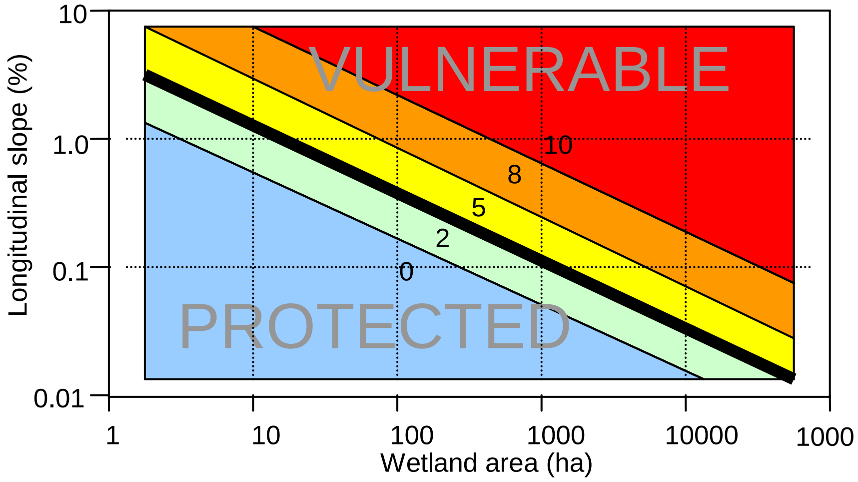

Figure 27: Assessment of vulnerability to erosion

It was assumed that geomorphic health of the Hudsonvale wetland remains stable in the next five years, indicated as C (→). The geomorphic integrity of HGMU 1 is likely to improve due to the erosion control structure, but HGMU 2 will further deteriorate, as the erosion will continue in tributaries and in its riverbed.

5.5. Assessment of current vegetation health

This chapter describes the main assessment steps required to determine the current vegetation health of the Hudsonvale wetland. First, the impacts of identified disturbance classes on wetland vegetation are assessed in each hydro-geomorphic unit of the wetland. Then, these impact scores were combined and area weighted to get the Overall Present Vegetation Health of the Hudsonvale wetland. As a last step the likely future changes in vegetation health were also assessed in order to get a more comprehensive diagnosis of the health of the wetland. The structure of this chapter follows this assessment logic.

5.5.1. Present State of wetland vegetation within the hydro-geomorphic units

a) Extent of each disturbance class in the hydro-geomorphic units

After identifying the general structure and composition of wetland vegetation in the Hudsonvale wetland, which was introduced in Chapter 4.1.3., the wetland was divided into eight disturbance classes, of which one was representing the natural indigenous wetland vegetation. The disturbance classes were defined in accordance with the list provided in the Vegetation module of the WET-Health tool of common disturbance classes occurring in South Africa (Appendix 6). Each class was mapped based on the information gained from interviews, field observations and aerial images.

Six disturbance classes characterized HGMU 1, while eight were identified in the case of HGMU 2. In the case of the latter around one hectare was not assigned to any of the disturbance class due to insufficient information. In both HGMUs the 'natural' disturbance categories dominated, making up nearly the half of the units. In HGMU 1, the disturbance classes of 'perennial pasture' had the second largest extent by 41.7% and it was followed by the 'dense alien patches' class making up only around 6.6% of the HGMU. In the case of HGMU 2, the disturbance class category of 'minimal human disturbance' stood for the area used for grazing the cattle occasionally during droughts and it represented the second largest class by 19.7% relative to the area of the unit. It was followed by the category of 'eroded areas' that made up 10.7% (Table 27).

Table 27: Description and extent of each disturbance classes within each hydro-geomorphic unit

Disturbance class	Brief description of disturbance class	Hydro-geomorphic unit 1		Hydro-geomorphic unit 2	
		Extent (ha)	Extent (%)	Extent (ha)	Extent (%)
1	Infrastructure (gravel road and cattle path)	0.43	1.54	0.02	0.06
2	Perennial pasture (irrigated and dry lands)	11.78	41.68	0.56	2.16
3	Dense alien vegetation patches	1.87	6.62	2.11	8.10
4	Sediment deposition and infilling (gabion weir)	0.07	0.23	1.89	7.26
5	Eroded areas (including incised riverbed)	0.06	0.22	2.79	10.73
6	Minimal human disturbance (grazing occurs)	-	-	5.12	19.67
7	Shallow flooding by dams (below the gabion)	-	-	0.12	0.47
8	Natural (indigenous wetland vegetation)	14.06	49.73	12.70	48.78
	Total	**28.28**	**100.0**	**25.31**	**97.2**

The category of 'eroded areas' in HGMU 2 included the incised riverbed, which was likely to cause significant changes in the natural vegetation cover through changing the natural hydrological conditions within the unit, leading to lowered water table. Furthermore, the incision of the riverbed was likely to make it no possible for emergent plants to grow, resulting in the dominance of submerged aquatic plants and open water surface. Figure 28 shows the locations of each disturbance class within the two HGMUs.

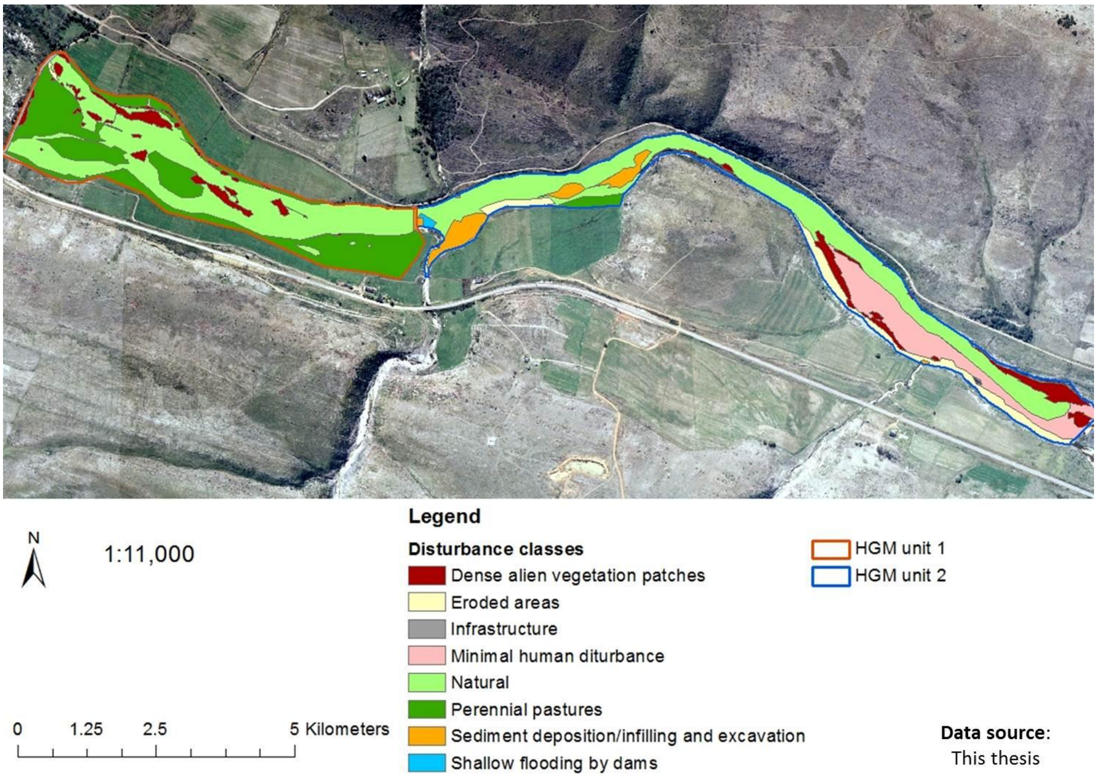

Figure 28: Vegetation disturbance classes of the hydro-geomorphic units of the Hudsonvale wetland

b) Intensity and magnitude of impact for each disturbance class separately for the hydro-geomorphic units

For each disturbance class the intensity score of the impact was assign based on the degree to which the vegetation of the disturbance class deviated from the reference conditions on a scale of 0 (no impact) to 10 (total transformation). The impact categories and associated intensity scores defined by WET-Health are shown in Table 39 in Appendix 6. After the intensity scores were defined, the magnitude of impact score for each disturbance class were calculated. In the case of HGMU 1 the perennial pasture had the biggest impact on the vegetation integrity but still was quite low on a scale of 0 to 10. By summing the magnitude of impact score the overall impact score was 4.9 (Table 28).

Table 28: Magnitude of impact score for each disturbance class of hydro-geomorphic unit 1

Disturbance class	Disturbance class extent (%)	Intensity score*	Magnitude of impact score**	Factors contributing to the impact
Infrastructure – gravel road	1.54	9.0	0.14	Wetland vegetation is replaced by the gravel road
Perennial pasture	41.68	9.0	3.75	Historically introduced terrestrial kikuyu and ryegrasses replaced wetland vegetation, only small patches of sedges remained within the pasture
Dense alien vegetation patches	6.62	3.0	0.20	Alien vegetation, mainly black wattle, but also patches of Spanish reed and Eucalyptus
Infilling by gabion weir	0.23	9.0	0.02	The construction of gabion weir replaced wetland vegetation which already had been affected by the headcut
Eroded areas	0.22	1.5	0.00	Presence of bare soil, but dominated with wetland vegetation
Natural	49.73	1.5	0.75	Wetland vegetation largely intact, however the abundance of indigenous

				invasive species (reed) is higher than would be naturally and scattered patches of bramble are present
Overall weighted impact score* **			**4.9**	

*Intensity score is defined on a scale of 0 (no impact) to 10 (total transformation)
** Magnitude of impact score is calculated as extent / 100 x intensity of impact
***Overall weighted impact score for the HGM unit = sum of magnitude scores for each disturbance class

In HGMU 2, all disturbance classes had minimal impacts on the wetland vegetation and scored lower than one. Therefore the overall weighted impact score was 3.8, lower than in the case of HGMU 1 (Table 29).

Table 29: Magnitude of impact score for each disturbance class of hydro-geomorphic unit 2

Disturbance class	Disturbance class extent (%)	Intensity score*	Magnitude of impact score**	Factors contributing to the impact
Infrastructure – cattle path	0.06	9.0	0.01	Wetland vegetation is not present at the cattle path to the dairy
Perennial pasture	2.16	7.0	0.15	Historically introduced terrestrial kikuyu and ryegrasses
Dense alien vegetation patches	8.10	3.0	0.24	Alien vegetation, mainly black wattle
Sediment deposition/ infilling (gabion weir)	7.26	7.0	0.51	Only some characteristic wetland species are present on the sediment deposits, but mainly bare soil. No wetland vegetation grew on the gabion weir.
Eroded areas	10.73	7.0	0.75	Eroded riverbed resulted in the lack of emergent wetland plants, thus only submerged aquatic plants were found.
Minimal human disturbance	19.67	7.0	1.38	Grazing by cattle during droughts, presence of alien vegetation, likely desiccation due to incised riverbed
Shallow flooding below the gabion weir	0.47	1.5	0.01	The seepage below the weir is likely to contributed to an increase in hydric species over the assumed reference condition supporting emergent wetland plants
Natural	48.78	1.5	0.7	Mainly intact, however, indigenous invasive species (reed) were more abundant than would be naturally
Overall weighted impact score* **			**3.8**	

*Intensity score is defined on a scale of 0 (no impact) to 10 (total transformation)
** Magnitude of impact score is calculated as extent / 100 x intensity of impact
***Overall weighted impact score for the HGM unit = sum of magnitude scores for each disturbance class

The overall weighted impact scores derived from summing the magnitude of impact scores of each disturbance classe, giving the Presence Vegetation State for HGMU 1 and 2. The scores were 4.9 and 3.8, respectively, indicating that changes in the composition of the wetland vegetation compared to the assumed reference condition were higher in HGMU 1 than in HGMU 2, particularly due to the establishment of the perennial pastures.

5.5.2. The Overall Present Vegetation Health of the wetland and the anticipated Trajectory of Change

In order to get the Overall Present Vegetation Health of the Hudsonvale wetland, first the area-weighted impact scores had to be calculated by means of the extents of HGMUs relative to the whole wetland area and the magnitudes of impact scores deriving from Table 30 and 31. Then the sum of the area-weighted impact scores gave the Overall Present Vegetation Health for the wetland, which was calculated as 4.3, representing "**D**" category, which refers to a largely altered vegetation composition compared to the reference condition. The abundance of alien and/or ruderal species is approximately equal with the abundance to the characteristic indigenous wetland species (Table 30).

Table 30: The Overall Present Vegetation Health of the Hudsonvale wetland

Hydro-geomorphic unit	Area (ha)	Extent (%)	Hydro-geomorphic unit magnitude of impact score	Area-weighted impact score*	Present Vegetation Health category
1	28.3	52	4.9	2.5	
2	26.0	48	3.8	1.8	
		100	**Overall area - weighted impact score****	**4.3**	**D*****

Area weighted impact score= HGM extent/100 impact score
**Overall area weighted impact score= sum of individual area weighted score for each HGMU
***The overall impacts score of 4.3 corresponds with the health category of 'D' (impact score range is between 4.0-5.9). This health category stands for that the vegetation composition has been largely altered and introduced; alien and/or increased ruderal species occur in approximately equal abundance to the characteristic indigenous wetland species.

In order to get a more comprehensive diagnosis of the health of the wetland, the likely future changes in vegetation health were also assessed. It involved the assessment of each disturbance class within both HGMUs in terms of the likely changes in their extent, nature and direction of change in the next five years from the present state, based on both on-site and catchment related factors.
HGMU 1 had a score of 1.1 and HGMU 2 scored -0.22 for the anticipated changes. It was assumed that the vegetation in HGMU would slightly increase in the next five years because of the improved water retention in HGMU 1, which supports wetland vegetation. On the contrary, the vegetation integrity in HGMU 2 would slightly decrease as the erosion of the riverbed and grazing within the wetland would continue. The descriptions of anticipated changes for each disturbance class as well as the calculation of scores are presented in Table 42 and 43 in Appendix 6. The scores of the HGMUs were then area weighted and summed, which gave the final anticipated future change score of 0.4 for the entire Hudsonvale wetland (Table 31). This score indicates that the vegetation health of the wetland is likely to slightly increase in the next five years.

Table 31: Evaluation of Trajectory of Change of vegetation in the entire Hudsonvale wetland

Hydro-geomorphic unit	Extent (%)	Hydro-geomorphic unit change score (Table 31 and 32)	Area-weighted change score*
1	52	1.06	0.6
2	48	-0.22	-0.1
		Overall weighted threat score**	**0.4*****

*Area weighted changescore = HGM extent /100 x HGM change score
**Overall area weighted change score = sum of individual area weighted scores for each HGMU
*** The score of 0.4 indicates a slight increase in the next five years.

6. Use of the WET-EcoServices tool to analyse the current services of the Hudsonvale wetland

The results of the rapid assessment indicating that HGMU 1 was likely to provide more ecosystem services to a greater level compared to HGMU 2. Eleven services were likely to be provided at intermediate or higher levels in the case of HGMU 1, while this number was ten regarding HGMU 2. HGMU 1 got the highest score for erosion control service, while HGMU 2 got a high score for carbon storage service. None of the HGMUs represented any cultural significance to the local people. The results are shown in Table 32. The summary of calculated scores of ecosystem services is shown in Appendix 7.

Table 32: Overall scores of ecosystem services and the associated level of ecosystem service delivery

Main categories of ecosystem services	Ecosystem services	Hydro-geomorphic unit 1		Hydro-geomorphic unit 2	
		Overall Scores	Level to which the service is being supplied	Overall Scores	Level to which the service is being supplied
Regulating and supporting services	Flood attenuation	1.9	Intermediate	1.8	Intermediate
	Streamflow regulation	2.3	Mod. high	2.2	Mod. high
	Sediment trapping*	2.0	Intermediate	1.9	Intermediate
	Phosphate trapping*	1.8	Intermediate	1.4	Intermediate
	Nitrate removal*	1.9	Intermediate	1.4	Intermediate
	Toxicant removal*	1.8	Intermediate	1.4	Intermediate
	Erosion control*	3.2	High	2.5	Mod. high
	Carbon storage	2.7	Mod. high	3.0	High
Maintenance of biodiversity		1.5	Intermediate	1.1	Mod. low
Provisioning services	Water for human use	2.1	Mod. high	2.2	Mod. high
	Cultivated foods	0.8	Mod. low	0.6	Mod. low
	Natural resources	0.0	Low	0.4	Low
Cultural services	Cultural significance	0.0	Low	0.0	Low
	Tourism and recreation	1.0	Mod. low	1.0	Mod. low
	Education and research	2.0	Intermediate	1.3	Intermediate

* Services contributing to water quality enhancement

The overall score is between the range of 0.0 and 4.0, which is divided into five categories for interpreting it. The categories indicate the likelihood of ecosystem services provision by the HGMU (Table 33).

Table 33: Categories to identify the likelihood of ecosystem service provision based on overall scores

Score	<0.5	0.5-1.2	1.3-2.0	2.1-2.8	>2.8
Likely extent to which an ecosystem service is being supplied	Low	Moderately low	Intermediate	Moderately high	High

6.1. Regulating and supporting services

The results of WET-EcoServices indicate that HGMU 1 was likely to perform better than HGMU 2, in terms of supplying regulating and supporting services.

6.1.1. Flood attenuation and streamflow regulation

Flood attenuation

Based on the assessed characteristics both HGMUs were assessed as they attenuate floods at an intermediate level with HGMU 1 being slightly more effective (1.9) than HGMU 2 (1.8). This difference is partly because HGMU 2 scored lower for surface roughness due to its incised riverbed (see Chapter 5.3.2). The incised river channel, at some places three meter incised, not only concentrates the water flow, and drains most of the wetland, but also hampers the water from spreading out thereby attenuating flood towards downstream. It has to be noted that no discrete indicator represented the potential impact of erosion control structure on flood attenuation.

Streamflow regulation

Both HGMUs were likely to provide streamflow regulation at moderately high levels, but HGMU 1 scored slightly higher (score of 2.3.) as it was characterized by more abundant fibrous peat, than HGMU 2 (score of 2.2). The presence and abundance of peat was scored based on the estimation of peat volume made in Chapter 4.1.2.

6.1.2. Carbon storage

HGMU 2 scored higher (3.0) than HGMU 1 (2.7) in terms of carbon storage. Although, the peat was estimated to be more abundant in the case of HGMU 1, other characteristics of HGMU 2 such as the "representation of different hydrological zones" and the "level of soil disturbance" scored higher compared to HGMU 1, which has led to a higher average of scores (Appendix 7).

6.1.3. Bundle of services for enhanced water quality; sediment trapping, nitrate, phosphate, toxicant removal and erosion control

Sediment trapping

HGMU 1 scored only slightly higher (2.0) than HGMU 2 (1.9) in the case of sediment trapping, but both were likely to supply the service at intermediate levels. The capacity of the HGMUs were related to their effectiveness to attenuate floods, since the more the water can slow down and spread out the more sediment can be deposited. HGMU 2 scored lower because the sediment was reduced at a moderately high extent, due to presence of the gabion weir upstream to the unit and the other weirs up in the Witels, decreasing its opportunity to trap sediment.

Nitrate, phosphate and toxicant removal

The differences in scores were the biggest between the two HGMUs in terms of their capacity to remove phosphates, nitrates, and toxicants as well as to control erosion. In all cases, HGMU 1 scored better than HGMU 2 did (Table 32). Common effectiveness indicators for assessing the removal of nitrates, phosphates and toxicants were "the pattern of low flows within the units", "the extent of vegetation cover" and "the fertilizer/biocides use" that was directly applied in the HGMUs. Furthermore, since phosphorous and toxicants (e.g. biocides and heavy metals) occur in the sedimentary cycle (Mitsch and Gosselink 2007), the effectiveness of the HGMUs in trapping sediments were also part of the phosphate and toxicant assessments.

The patterns of low flows in HGMU 1 were channelled at an intermediate level, where both channelled and diffuse water flow patterns occurred during low water levels. On the contrary, HGMU 2, was strongly channelled. Erosion gullies lead to increased water velocity by concentrating water flow, which does not allow sediments to settle out from the flowing water, therefore decreasing the phosphate and toxicant removing capacity of the unit.

HGMU 2 was reasonably well covered with permanent vegetation, but the extent of bare soil was larger than in the case of HGMU 1, thus the former had and intermediate vegetation cover, while the latter was highly covered. Vegetation is important supplier of both soil organic matter and habitat for the microbiota that assimilates nutrients (Kotze et al. 2008).

The applied level of fertilizer was assessed to be high in both HGMUs, due to the use of fertilizer on the kikuyu pastures within and adjacent to the units (see Chapter 4.2.1.). However, no biocide was applied directly to the units.

Considering the opportunity characteristics, the sub-catchment of HGMU 1 was assumed to have higher potential sources of phosphates, nitrates and toxicants than HGMU 2, because the former has a significantly larger catchment area with more agriculturally active farms (fruit and livestock farming) of which many are located along the Kromme in the valley.

Erosion control

Erosion control service was likely to be supplied at the highest extent among all other services by HGMU 1 with a score of 3.2. HGMU 2 scored 2.5, still indicating a moderately high supply of the service. HGMU 1 had lower level of erosional features present, higher vegetation cover and higher surface roughness than HGMU 2.

The level of soil disturbance in HGMU 1 was considered intermediate, while it was moderately low in HGMU 2. In both HGMUs, trampling by cattle meant the main disturbance in the soil and no other activities (e.g. use of heavy machinery, sand winning or other kind of excavation) took place, that are considered as having high soil disturbing impacts.

Trampling affected HGMU 1 (42% of the unit) more than HGMU 2 (22% of the unit). It took place with different frequencies by the cattle (see Chapter 4.2.1.) ranging from daily use (the pathway to the dairy) to seasonal use (the elevated part).

As influential factors, the opportunity characteristics included the slope of the HGMUs, the erodibility of the soil, and the runoff intensity from the unit's sub-catchments. These characteristics were similar for both HGMUs. They both had gentle slopes (0.47 %) that make the units less prone to erosion, but sandy loam and loamy sand soils; which have high erodibility. The runoff intensities were only different 2.25 for HGMU 1 and 2.50 for HGMU 2. These characteristics were the reasons that the final score of HGMU 2, increased from 1.8 (effectiveness score) to 2.5.

6.2. Maintenance of biodiversity

HGMU 1 scored 1.5, indicating that it contributed to the maintenance of biodiversity at a slightly higher level than HGMU 2, which scored 1.1. However, these scores are not very high, mainly because the HGMUs did represent a rare wetland type or had any special features (e.g. breeding or feeding sites for a large number of birds) that could have increase their noteworthiness. HGMU 1 was considered more valuable than the other unit because of the high level of cumulative loss of wetlands (decrease by 70%) in its sub-catchment. They had some sort of importance, as both HGMUs were likely to support endemic RED list fish species; redfin minnow (*Pseudobarbus sp*.) and a species of *Galaxias that* inhabit the Kromme. Furthermore, the maintenance of biodiversity by the units were also not high, because of the alteration in their ecological integrity. The Integrity assessment was based on indicators, specifically related to hydrology, geomorphology and vegetation. Both HGMUs had a low extent of buffer zone of semi natural vegetation to support habitat for wildlife surrounding the unit. The connectivity to other natural areas in the landscape was also very limited due to the units were located within the valley surrounded by pastures. However, HGMU 2 showed higher integrity than HGMU 1. It was because the hydrological and sediment regimes in the case of HGMU 2 were less altered (based on the calculated scores), the smaller extent of indigenous vegetation removal by human activities and had less obstructive barriers (fences, roads) to fauna around the unit than in HGMU 1.

6.3. Provisioning services

Water supply for direct human use

Both HGMUs were assessed to deliver water for direct use at moderately high levels with HGMU 2 scoring slightly higher (2.2) than HGMU 1 (2.1). The assessment was based on both indicators of the capacity of the units to supply water and the actual use of the service by people.

HGMU 2 scored slightly higher because of its higher collective extent of seasonally and permanently wet zones relative to the HGMU's extent. The reasoning behind is that the more prolonged waterlogged an area, the more reliable it is potentially for water supply for human use (domestic and agricultural).

Water was only used for irrigation from both units of the Hudsonvale wetland, and the current level of water use for agricultural purposes was assessed high in both cases (see Chapter 4.2.1.). Although, water was also used for irrigation from the tributary, the majority derived from the HGMUs. The landowners emphasized that the wetland is particularly important for the water, "We feel privileged to have a wetland on our farm because it means water". The substitutability of the wetland water was assessed as moderately low because of the increasing water scarcity in the catchment.

Provision of cultivated crops and harvestable natural resources

Both HGMU 1 and 2 were likely to provide cultivated crops at moderately low levels, where HGMU 1 had a slightly higher score (0.8) than HGMU 2 (0.6). Kikuyu and rye grasses were cultivated in both HGMUs as fodder crops for the cattle; and no crops were cultivated for human consumption within the units. The size of areas converted into perennial pastures differed between the two units, in HGMU 1 the extent of pastures were ten times larger than in HGMU 2 (see Chapter 4.2.1).

In terms of natural resources, HGMU 2 had a score of 0.4 meaning a low service supply. HGMU 1 scored zero. Although, both HGMUs potentially could provide many harvestable natural resources such as dense stands of reeds and palmiet, which could be used as fibre or food (see Chapter 4.1.3), harvest did not take place anytime of the year. Thus, only natural vegetation in HGMU 2 was considered as one natural resource because the cattle occasionally grazed it.

In the case of the assessment of cultivated crops and the assessment of harvestable natural resources, the characteristics of "the level of poverty in the area", "the location of the HGMU in a rural communal area" and "the number of households that depended on these benefits" were omitted. The Hudsonvale wetland is located entirely on the dairy farm, and that area was not linked to any communal area, or was characterized by poverty. The landowners were divided into three households but they were not dependent on the wetland provided crops and natural resources for their livelihoods. Therefore, the substitutability of HGMU 1 and 2 in terms of cultivated crops was moderately high and high, respectively. In the case of natural resources, while HGMU 2 had moderately high substitutability due to its slight importance during droughts, these resources in HGMU 1 could be easily replaced, as they were not recognized as being important for use.

6.4. Cultural services

Cultural significance

The HGMUs did not represent any cultural significance in the area based on the assessed indicators that are mainly related to rural communities. No cultural belief, taboo or traditional local practice were revealed or mentioned during the data collection that could be potentially considered to have some sort of cultural importance for local people. The wetland and its surrounding have belonged to a privately owned farm for many decades.

Tourism, recreation and natural scenic value

The HGMUs were found to have small importance in terms of providing tourism or recreation for people. The scores were 0.6 for HGMU 1 and 0.9 for HGMU 2, representing that these services were likely to be provided at moderately low levels. The HGMUs scored the same for most the assessed characteristics, except for "the extent of open water", which resulted in the difference in the scores between the two units. One has to note though, that open water in this case did not provide more opportunities for recreational activities such as swimming, fishing, kayaking etc.

In terms of their scenic beauty, HGMU 1 had moderately high and HGMU 2 had moderately low significance based on their view. HGMU 1 provided a wide variety of colours from the fresh green pasture to yellowish reed through the colours of fynbos on the beautiful mountain slopes in the background. HGMU 2 was less visible and mainly disappeared in the incised riverbed.

Other reasons why the units of the wetland scored low were that there were other wetlands located upstream (Companjesdrift and Krugersland), which were more easily available than the Hudsonvale wetland and could provide similar experience to the tourists travelling through the area. It also did not support high biodiversity with birding opportunities.

The main road, R62, historically was the connecting road between Port Elizabeth and Cape Town. Since R62 is situated between the beautiful Tsitsikamma and Kouga Mountain ranges, local landowners, particularly those who became more interested in tourism, started to advertise it in order to attract more tourists to the area. However, tourists did not often visit the area yet

(Interviews with landowners). Furthermore, the Hudsonvale wetland is located within the fence of the dairy farm, and it is less visible from the road.

Education and research

HGMU 1 and 2 both provided interests for research and education purposes at intermediate levels, mainly because of the built erosion control structure, located at the boundary of the two units. The previous owner of the Hudsonvale farm underpinned the trend indicated by other landowners that researchers and students began to visit the UKRC more often since WfWater and WfWetlands started to work in the area and rehabilitation measures took place. He also mentioned that before the gabion weir had been built, nobody came to his farm because of the wetland. It reflected on that the HGMUs were currently used by research and particularly the site of HGMU 1 provided more interest due to the location of the erosion control structure.

The availability of existing data about the wetland site indicated that the area was subject to several previous researches of which some were conducted over longer period. In order to decide upon the score, the levels of available and obtained data as well as the detail they provided about the site were considered based on collected reports, articles and information gained from the interviews with the experts who had worked in the area.

Neither of the HGMUs were suitable as reference wetland sites of the area, as they were largely modified in terms of their hydro-geomorphic and vegetation integrities (see Chapter 5.5).

6.5. Future threats and opportunities to ecosystem services supply

Threats to ecosystem services supply

'Future threats' refer to potential or impeding pressures that are likely to affect detrimentally the HGMUs ecosystem services supply. In this assessment, HGMU 1 scored 2 and HGMU 2 scored 3, meaning that while the ecosystem services delivery by HGMU 2 was likely to be threatened to moderately high extent, it was likely to be intermediate in the case of HGMU 1.

The ecosystem services delivery of HGMU 1 was likely to be negatively influenced by decreased water input from its sub-catchment and increased trampling by cattle within the unit. Decreased water quantity input to the unit, could potentially influence the water provision, maintenance of biodiversity and carbon storage services. The increased trampling due to the increased number of dairy cows could lead to erosion channels within the unit, which then would lead to a decrease in the ability of the unit to control erosion, remove nitrates, phosphates and toxicants.

The biggest threat to the ecosystem services delivery of HGMU 2 was the eroded riverbed and the assumed increase in trampling during the dry months. These both would affect negatively all of the regulating services, the water use provisioning service and biodiversity through negative alterations in the hydro-geomorphic processes.

Opportunities to ecosystem services supply

'Future opportunities' refers to the visions of enhancing the supply of services. In this sense, HGMU 1 scored 1 and HGMU 2 scored 3, referring to that HGMU 2 had a moderately high opportunity for enhancing the effectiveness of the unit than HGMU 1, which had only moderately low.

In the case of HGMU 1 the effectiveness of the unit in removing nutrients as well as the direct use of harvestable resources could be improved by sustainable harvest of reed, which abundant in the unit.

The effectiveness of HGMU 2 to deliver ecosystem services, particularly water regulation, and water quality enhancement could be significantly enhanced by improving its hydrological characteristics such as water retention and diffuse water flow within the unit, by halting the erosion.

7. Discussion

The robustness of this research resides in its interdisciplinary nature, which is one of the most important characteristics of integrated assessments (Toth and Hizsnyik 1998). This study integrated disciplines of natural sciences (e.g. wetland ecology, soil science, hydro-geomorphology) with social science (local knowledge) to assess the impacts of human drivers on the ecosystems services delivery of the Hudsonvale wetland.

As the previous chapters revealed, the research involved a great amount of complexity, due to not only the dynamic and complex nature of the wetland ecosystem itself, but also from the complex relations between the ecological and social systems that interact at multiple spatial and temporal scales. In order to deal with this complexity, integration of methods and many additional assumptions were required in many cases to be able to obtain and integrate different types of data. It inevitably involved chances of uncertainties and weaknesses that need to be discussed before drawing conclusions. This chapter, thus, provides a critical review on the methodology in terms of data sources and data collection methods and tools used for analyses, as well as on the results.

7.1. Discussion of methodology

In order to achieve my research objective a variety of data needed to be collected and analyzed by applying different methods.

7.1.1. Combining data collection methods

Literature study was conducted throughout the research. It provided basic information on the UKRC, (e.g. the valley-bottom wetlands, historical and current human drivers and impacts). Scientific articles, books and assessment manuals also helped to recognize, describe and analyze data obtained on the field through observations and field measurements (e.g. biophysical structures, hydrological zonation, geomorphic features, and vegetation cover). GIS maps were important sources of quantitative and spatial data on land use and land cover, thereby providing input data for the assessments of current ecological condition and current ecosystem services.

Literature study and interviews with experts served to understand better the linkages between human activities and alterations caused in the ecosystem properties and services. For instance, when there was no data available on the actual impacts of certain agricultural practices, I used empirical studies that provided insights into the potential impacts.

However, the best way was to talk with landowners in order to obtain specific information on the agricultural land use and practices at both catchment and wetland scales. For instance, at the site of the Hudsonvale wetland, local knowledge on the regularly water logged areas within the pasture during higher water levels provided useful information for the wetland delineation.

Field measurements combined with observation not only provided data for determining wetland boundaries but also for later assessments. For example, defining the outer edge of the wetland revealed the different hydrological zones that characterize the wetland. This information was also important for assessing the level of delivery of ecosystem services such as flood attenuation, streamflow regulation, nitrate and toxicant removal in WET-EcoServices.

7.1.2. Dealing with bias in the field

Fieldwork was an important part of the research because it provided site-specific information, which I could not obtain from other data sources. The soil survey, topographic survey and observations of vegetation and geomorphic processes provided data for defining the biophysical structures and processes of the Hudsonvale wetland, but the results were also inputs for the assessments of current ecological health and provision of ecosystem services. The soil survey and observations on vegetation, and geomorphic features were greatly dependent on expert judgement, which can be a source of bias deriving from the subjective interpretation of the observer (Kumar 2005). The topographic survey, which measured the relative elevation by means of using dumpy level, also can source of bias deriving from incorrect measurements. In order to minimize the bias in the case of the observations and measurements as well as improve the accuracy of results, I consulted with assessment manuals and experts on the methodology and on the correct use of equipments that I planned to use during the fieldwork. In the field, I also consulted with a soil scientist to ensure data accuracy of the soil assessment. Yet, it has to be noted that other factors such as climatic conditions and accessibility might have influenced the accuracy of results. The observations and measurements were executed during the rainy season. Although it supported the reliability of the delineation results (hydrological zonation was easier to identify), the high water level was impeding other fieldwork. The topographic survey, the verification of both vegetation cover, and geomorphic features were more difficult because some of the wetland parts were not accessible. To be able to update information and deal with missing data on the vegetation cover and geomorphic features, I combined data from different sources for crosschecking data. The land use map of 2007 served as a baseline and its spatial data was updated based on information from interview, photos (taken during the field survey), and Google Earth image of 2011. In some cases, I still needed to make assumptions, where interpretation was not obvious. Furthermore, assumptions were also required on the flow patterns within the Hudsonvale wetland during dry season. Although I made the assumptions to the best of my knowledge, they might have contributed to a certain level of inaccuracy in data. Therefore, it is recommended that the fieldwork be repeated also during the dry season.

7.1.3. The usefulness of interviews

Interviews were conducted with landowners, informants and experts for obtaining a variety of information. For instance, at the beginning of the research, I did not have sufficient data about UKRC to be able to make the selection of an appropriate case study site. Therefore, I conducted interviews with experts, landowners and informants in order to obtain a broader knowledge about the area (inventory). Experts and informants provided information on the biophysical characteristics of the UKRC (e.g. hydrology, geology, vegetation, climate, and the valley-bottom wetlands), historical and current human drivers (e.g. erosion control structures, IAPs clearing and their impacts) as well as on the wetland hydro-geomorphology, processes, structures and services relevant in the South African context. All this information served as a good basis for understanding the ecological system of the catchment and contributed to the selection of the Hudsonvale case study.

Data obtained from interviews with landowners on the agricultural land uses and practices had also important role in the selection of the case study site. In fact, some interviews were only useful for supporting the site selection. For instance, data from interviews with landowners located downstream of the Hudsonvale wetland became irrelevant to use for the further assessments, as they were located outside of the catchment of the wetland. Yet, I found these interviews very useful and important since the information that they gave on the IAPs clearing and wetlands, significantly contributed to my decision to select a wetland case study site at the upstream.

As a result of site selection, data could be only used from thirteen interviews out of the total 25 farms located in the catchment area of the Hudsonvale wetland. In order to fill the knowledge gaps, I consulted with other students who have previously done interviews with some of the 'missing' landowners. It allowed me to get an overview about their current agricultural activities, but could not provide details. This incomplete information still required assumptions on the agricultural practices (e.g. irrigation) that I based on the data from the land use and land cover map of 2007.

Site-specific data was obtained in the second data collection phase, when interview with the landowner provided reliable information on the agricultural practices used at the site of the Hudsonvale wetland (e.g. animal number, grazing areas, irrigation, fertilizer and herbicide use). The obtained information supported more accurate assessments of the current ecological health and provision of ecosystem services.

In general, the data collected from interviews was mainly qualitative, and was not always possible to obtain quantitative information. For instance, the quality of data regarding amounts of water, fertilizer and biocide used by the landowners were rather low, as no precise quantities were mentioned. It might be because these questions were either too specific to answer or too sensitive for them to share. I also realized that those landowners who had wetlands at their lands were quite suspicious and looked at me as a nature conservationist. Sensitive topics and the background of the interviewer can influence the interviewee's replies (Southwold 2002). In order to minimize the bias deriving from these reasons and improve the data reliability, I informed them that I was a student and ensured them that everything that was said remains confidential. Moreover, I tried to be open-minded and avoid any kind of judgmental expression.

7.1.4. The usefulness of using geospatial information and ArcGIS

GIS maps and data sets provided important geospatial information about the UKRC. Particularly, the land use and land cover maps of 1986 and 2007 were useful for the assessments. Both maps had accurate data because they were made based on high-resolution aerial imageries and had the same land use and land cover categories, making comparison easier. Since these maps covered a larger area than my study area, data from these land use maps were not readily applicable. In order to be able to retrieve quantitative and specific information relevant for the study area, ArcGIS was used to process and analyze the data.

Once geoprocessing was done, the maps provided information on the geographic locations, and area extents of the agricultural land uses, IAPs vegetation and other types of land covers (e.g. roads, bare soils etc.) at the scale of study area. Using maps from two different times (1986 and 2007) also allowed calculating the changes in agricultural land uses and IAP vegetation on both catchment and wetland scales. For instance, it revealed that the area under irrigated agricultural farming has increased over time, particularly along the main river as well as next to the Hudsonvale wetland. These changes might have considerable effects on the hydrological cycle of the catchment and thus on the wetland.

Furthermore, looking at changes in IAPs cover was informative about the expansion of IAPs between the two years, but it could not be used for assessing the extent of IAPs that has been cleared by WfWater. One of the main reasons were that WfWater started to clear IAPs in the UKRC in 1996, but the only land use map that was available closest to that time was the one of 1986, which still shows the land use from 10 years earlier. Moreover, it is also important to know the average expansion rate of the IAPs in order to be able to better estimate the impact of IAPs clearing that could not be precisely based on solely comparing two years. Thus, in order to fill these gaps, I had to obtain information from other data sources such as from literature study and interviews with landowners and informants (GIB).

The land use map of 2007, furthermore, provided important data input to the WET-Health assessment tool and to a lesser extent to WET-EcoServices as well. To be able to assess the current ecological condition of the Hudsonvale wetland extensive use of quantitative data was required at both the catchment and the wetland scales. The WET-Health tool itself suggests the use of spatial data and GIS applications for mapping and quantifying the extents of different land uses and impacts. Since the case study site was relatively small, it was possible to update the spatial data of the land use map of 2007 based on the field observations and interviews. On the contrary, spatial data was not up to date at the catchment level. Thus, in those assessment steps where data was needed at the catchment scale, I used data consistently, deriving from the land use map of 2007. Therefore, using GIS data and ArcGIS provided a more efficient way to obtain quantitative as well as geographic data for the assessments than other data collection methods.

7.1.5. Strengths and weaknesses of the WET-Health rapid assessment tool

The WET-Health rapid assessment tool is a novel and good approach that assesses and summarizes the ecological health of wetlands through representing the current condition and anticipated changes of the key components of health (hydrology, geomorphology and vegetation).

One of the main strengths of WET-Health is that it was developed (together with other WET-tools) during a nine-year long collaborative and iterative research process involving a great amount of expert knowledge and knowledge gained from scientific literature. It contributed to the continuous improvement of the tool so that it could be applied in practice to assess wetlands in South Africa. WET-Health also has a clear and detailed documentation with clear justifications for scoring, which makes the assessment steps and the method very transparent and open for adjustments.

Other strength of WET-Health is that it is a rapid assessment tool. Thus, it requires less resources and time for the execution, which is particularly important in the case of developing countries, where resources are generally lacking to carry out detailed assessments. Yet, WET-Health supports the use and integration of detailed quantitative and qualitative data in a highly structured way. For instance, by means of using spatial data, the extents, intensities and magnitudes of each land use, and land cover types (e.g. irrigation, invasive alien plants encroachment) can be calculated more precisely. One of the strongest points of the tool is that it uses area weighting for calculating the overall health of the wetland in each module. It ensures that the results are more realistic and avoids exaggeration of impacts.

Furthermore, in order to avoid double counting of human impacts, the tool assesses hydrology, geomorphology and vegetation separately in three modules. Yet, the tool recognizes the strong interrelations between the three health components to a certain extent in its approach by using the results of previous assessment steps for inputs in another module (e.g. assessing the effects of altered runoff (flows and floodpeaks) on wetland geomorphic integrity). These interlinkages are also incorporated in the documentation and the calculation of a composite overall ecological health score for the wetland.

Being a rapid assessment method WET-Health also has a few weaknesses. It requires a number of assumptions and simplifications to reduce complexity of the assessment, which are inherent sources of uncertainties. For instance, in order to be able to assess current ecological health by the tool, the wetland being assessed needs to be compared to its natural reference condition. In the case of the Hudsonvale wetland, information about the natural, undisturbed condition was not available, as the earliest aerial photographs already indicated modifications of the wetland. Related to this dilemma, one should also keep in mind that wetlands are dynamic systems which naturally go through changes over time (Ellery et al. 2009). Therefore, in order to minimize the impacts of this, I used another wetland in the catchment as reference site, which was claimed to be close to natural state. It was a good point of reference that helped me to determine the likely hydrological, geomorphic and vegetation characteristics of the Hudsonvale wetland in a natural state.

According to Fennessy et al. (2007) some of the ways to deal with uncertainties and measure the validity of a wetland rapid assessment method is looking at the metrics and the calculation of the final score as well as the provided documentation on the method. The validity is higher, if the metrics can be supported by more intensive data, the calculation of the final score clear and repeatable and if the documentation thorough as well as transparent regarding the assumptions made in the rapid method. Considering these criteria and the fact that WET-Health has been validated against some detailed field assessments as well (Grenfell et al. 2009b, Riddell 2011), the tool deals with uncertainties appropriately to make its use highly relevant.

7.1.6. Strengths and weaknesses of the WET-EcoServices rapid assessment tool

The WET-EcoServices rapid assessment tool is a unique approach that assesses the importance of wetland in delivering 15 ecosystem services. It is unique, because while a host of different functional assessment techniques have been developed to assess wetlands in the northern hemisphere, none of them is applicable to the South African situation, to assess wetlands in the southern hemisphere, where livelihoods tend to be more directly dependent on wetlands (Kotze et al. 2008).

Similar to WET-Health, the main strengths of WET-EcoServices are that it has also been developed in a long collaborative and iterative process involving a great amount of expert knowledge and can be executed rapidly and readily at the field. These strengths make this tool highly relevant to be applied in South Africa, as well as in other developing countries.

A further strength is that WET-EcoServices makes a link between the related ecosystem services as the scores for some of the ecosystem services are used as characteristics for other ecosystem services. For instance, the effectiveness score for sediment trapping is used as a characteristic to assess phosphate and toxicant removal, given that the more sediment is trapped the greater will be the extent to which the wetland removes these pollutants that are absorbed to sediments.

It also provides a detailed documentation on the assessment procedure, and the rationales and methods used for scoring wetland characteristics per each service. The documentation also includes the main limitations of the tool such as being a qualitative method, which does not provide a single overall measure of value or the importance of the wetland and cannot assess wetland health. This dissemination of the limitations makes the tool more transparent for using.

However, the level of documentation is not always sufficient regarding the scoring procedure. Particularly, when assigning a score for a single characteristic requires assessing a set of other indicators. For instance, in order to be able to select the right score for the characteristic of 'level of soil disturbance' that is used for assessing the services of erosion control and carbon storage, the assessor needs to combine information about the extent, frequency, location and intensity of the disturbance. No systematic method is provided for combining this set of information, 'only' the rationale and an example to illustrate what the assessor should consider when assigning the score. Therefore, in these cases, the scores given for the characteristics greatly depend on the expert judgement of the assessor, which makes this tool more susceptible for misuse. The tool, however, allows rating the confidence that the assessor place in the scores, based on the reliability of the source of information. In order to avoid the bias deriving from my subjective interpretation and to improve the validity of the results, I aimed to obtain information from reliable sources such as interviews with the landowners and field observations and measurements. However, it requires more time and makes the process less rapid.

Another weakness of the tool is that unlike WET-Health, WET-EcoServices does not have a systematic way to use more intensive data (e.g. precise extent of vegetation cover, grazing area) if available. The categories provided are qualitative (e.g. low, moderately low, intermediate) and thus, if quantitative data is available, the assessor's decision how to incorporate that information in the score. Furthermore, the tool calculates the final scores of the ecosystem services by taking the average of the scores given for each characteristic per service. I consider it as a weakness, because in some cases where size is an influential factor, the use of area-weighting would be necessary. In that way, the score could provide better information on the level of service provision, for instance, on flood attenuation, sediment trapping, and phosphate removal (etc.).

Nevertheless, WET-EcoServices is a useful and valid tool, because it is based on scientifically underpinned relationships between ecosystem properties (structures and processes) and services by means of using a wide range of indicators relevant for assessing wetland services in the South African context. Furthermore, the actual use of the delivery, as well as the future threats and opportunities to ecosystem services supply also links human drivers to ecosystem services to a certain degree.

7.2. Discussion of results

7.2.1. Current ecological health

The results of current ecological health assessment indicated that all the health components assessed in WET-Health have been modified compared to the reference condition of the Hudsonvale wetland. One of the most important assumptions that influenced the results in all modules was the natural condition of the Hudsonvale wetland. In this study, I assumed that the reference condition was an unchannelled valley-bottom wetland without any visible channels or erosion gullies within the wetland and covered by natural wetland vegetation. This assumption was based on using a wetland as reference site, located upstream. Since, the reference condition is the undisturbed condition of the wetland, it is important to keep in mind that the alterations in the different health components are not only the results of the current human influences, but also indicate changes caused historically by both human disturbances and natural processes. An earlier study by Haigh et al. (2008) has shown by means of using a sequent of aerial photographs that the Hudsonvale wetland was in an excellent condition between 1942 and 1969 based on the assessment of the magnitude of wetland transformation. From 1969 on, it started to deteriorate as alien vegetation, particularly black wattle invaded the riparian zone as well as the inner part of the wetland. As a result, the wetland health of Hudsonvale wetland was in poor condition by 1986. The wetland was also threatened by a huge headcut in 1997, when IAPs clearing started. It became halted by the constructed erosion control structure in 2000 and the ecological health was assessed moderate in 2007 and largely modified based on the categories used in WET-Health.

In this study the combined health score of the present ecological health assessed by WET-Health was 5.5 on a scale of 0 (no impact) to 10 (total transformation), indicating large modifications, which have altered around 50% of ecological health of the wetland. Thus, it seems that the wetland did not change much since 2007 compared to the results of the previous study.

Based on the WET-Health assessment it was shown that the hydrological integrity of the wetland has been modified the most by human impacts compared to the other health components (geomorphology and vegetation). The score of Overall Present Hydrological Health was 8.2 on a scale of 0 (no impact) and 10 (total transformation), indicating that more than 80% of the hydrological integrity of the wetland has been altered compared to its natural reference condition. This score was based on assessing both the impacts of human activities in the catchment on the water input quantity and patterns to the Hudsonvale wetland as well as the impacts of human activities at the site of the wetland on the distribution and retention of water within the wetland. Particularly, the on-site activities affected the hydrological integrity negatively such as the eroding riverbed in HGMU 2 and the irrigation of the kikuyu pastures in HGMU 1, which resulted in canalization of the wetland and loss of water, respectively. The decrease in surface roughness caused by conversion of wetland to pasture, invasion by IAPs, erosion (etc.) had also an important role in altering the natural hydrological process. HGMU 2 was more altered than HGMU 1 in terms of its hydrological integrity. The tool uses area-weighting to assess the magnitude of impacts more precisely, but in some cases it was still likely that some of the impacts have been underestimated. Direct water abstraction from HGMU 1 was assessed high based on the water needs of the kikuyu pasture, the location of the pumps in the unit and the duration of the water abstraction. Water was used for irrigating the pastures only seasonally, but what was not possible to incorporate in the tool was that irrigation was particularly high during the dry months when the water level is also lower in the wetland. Furthermore, the results of the assessment regarding the changes caused in the water quantity and patterns by human activities in the catchment were also assessed rather low. Since these impacts were assessed based on spatial data from 2007, and assumptions made on the collected volume of the farm dams, it might be that the magnitude of impacts on the water quantity and patterns are inaccurate. Therefore, it would be recommended to repeat the assessment with more recent data.

The geomorphic integrity of the wetland was the least altered compared to the two other health components. The Overall Present Geomorphic Health of the Hudsonvale wetland had a score of 2.8, which indicated that the integrity was moderately altered. The geomorphology module predominantly used direct and indirect indicators for assessing geomorphic features such as erosion and deposition within the wetland, and only in some cases made a link with human activities (e.g. wetland infilling, channel straightening, and excavation of peat). The used set of indicators were quite complex and required very specific data that was difficult to assess properly in some cases, for instance, when assessing the extent of area that became geomorphologically inactivated as a result of the road that crossed the wetland. The loss of organic sediment represented the biggest alteration in the geomorphic integrity compared to the reference condition, however, was still low. It was mainly associated to decrease water inputs and altered water retention within the wetland. Although, the incised riverbed in the downstream portion of the wetland (HGMU 2) had negative influence on the geomorphic integrity, this influence was much less than on the hydrological integrity. The impacts of erosion and deposition were very low in both HGMUs, because most of the sediment deriving from erosion was assumed to be also deposited within the wetland. However, HGMU 2 indicated slightly higher impact due to the eroded riverbed.

The Overall Present Vegetation Health of the wetland was calculated as 4.3, referring to a largely altered vegetation composition compared to the reference condition. The vegetation module has the clearest structure, which assesses the area-weighted impacts of different disturbance classes on the natural wetland composition. In this study six disturbance classes were defined that were likely to directly affect or alter the vegetation integrity of the wetland per HGMU. This result indicated that the abundance of alien species and other disturbances were approximately equal with the abundance of indigenous wetland species, compared to reference condition. It was quite in alignment with the fact that in both HGMUs nearly half of the units were characterized by natural wetland vegetation. The changes in the composition of the wetland vegetation compared to the assumed reference condition were higher in HGMU 1 than in HGMU 2, particularly due to the establishment of the perennial pastures. In HGMU 2, the eroded areas within the wetland unit had the most impacts on its geomorphic integrity, due to its desiccating affects.

The results of WET-Health provide a robust information base about the current ecological health of the Hudsonvale wetland. Since the assessment steps were provided by data deriving from reliable data sources, and data was verified on the field by means of using a variety of methods, the results could be used in follow up research to monitor changes in the ecological health of the wetland.

7.2.2. Linking current ecological health and current human drivers

The results of WET-Health provided detailed information on how the ecological health of the Hudsonvale wetland (in terms of its hydrological, geomorphic and vegetation integrities) has been altered based on the assessed indicators of the tool. However, it was not always possible to make a clear link between the alterations caused in ecological health and the roles of human drivers (i.e. agriculture, eradication of IAPs and construction of erosion control structure) in these alterations.

Since the reference condition is the natural, undisturbed condition, any changes caused to the health components of the wetland are considered as deviation from the natural state. Therefore, WET-Health was not the appropriate tool solely to assess the impacts of rehabilitation measures such as clearing of IAPs and the construction of erosion control structure. The positive effects of these drivers could not be incorporated in the score appropriately and the best way to avoid assigning wrong impact scores was to give the score of zero, indicating no impact.

The eradication of IAPs is a long-term process, which has to deal with continuous re-infestation and different rates of clearing, but the tool can only take a snapshot of the time of the assessment. Thus, it could only provide information on the impacts of current IAPs cover. The impacts of the erosion control structure at the wetland site were assessed in all three modules. The positive impacts of erosion control structure on improving water retention and together with the eradication of IAPs to support the re-vegetation by natural wetland species could be only incorporated in the anticipated trajectory of changes to assess the future changes in the coming five years.

WET-Health could provide the most information on the impacts of current agricultural practices that were included in the most assessment steps compared to the other drivers. Water abstraction (irrigation, domestic use, farm dams) at both the catchment and wetland scales was important to measure its impacts on hydrological health, particularly on changes caused in the water quantity. Indirectly the impacts of too frequent fire management and grazing were also assessed in the hydrology module by using the extent of degraded velds on the water input patters. Trampling by cattle was also assumed to have impacts on the geomorphic integrity of the wetland, but the geomorphology module did not provide information on to what extent trampling contributed to the presence of erosion in the wetland. However, the direct impacts of trampling on the vegetation integrity could be assessed partly (as the disturbance class 'minimal human disturbance'). WET-Health does not have a module for assessing water quality, only provides a very basic and coarse description on determining the intensity of altered water quality. I found it insufficient to be able to base any scientifically sound findings on the impacts of practices of fertilizer and biocide use.

Therefore, it is recommended that water quality assessment is conducted on the site of the Hudsonvale wetland, because the fertilizer used for ensuring the yield of the kikuyu and rye-grass pastures are likely to have effects on the water quality, but also on the natural vegetation composition.

7.2.3. Provision of current ecosystem services and ecological health

Ecological health is closely related to the delivery of ecosystem services (Cairns Jr and Pratt 1995) and the generally accepted view is that natural or semi-natural ecosystems provide a full range of services for humans than degraded ones (Lu and Li 2003, MA 2003, Macfarlane et al. 2008, McCartney et al. 2011). Therefore, it should be expected that impacts on the wetland should be also linked to reduced provision of ecosystem services by wetlands. It is likely to be true in the case of the regulating services, but provisioning services depend on the intensity, duration and the way of use these services. Therefore, provisioning services may have a negative influence on the ecological health of the wetland and consequently on the provision of regulating services. In the WET-EcoServices assessment, the results showed that the Hudsonvale wetland is the most important for providing regulating services to a greater degree than provisioning services in both assessed hydro-geomorphic units. It has to be note that the WET-EcoServices tool is not able to quantify the level of provision, thus the interpretation of the final scores for the ecosystem services are rather qualitative. The links with the human drivers and current ecological health could be made by comparing the two HGM units in terms of their likely importance for providing the different ecosystem services.

Regulating services with the highest scores were erosion control, carbon storage, and streamflow regulation. These services all had their scores above 2.1 (on a scale between 0 and 4), indicating that the likely provision of these services was moderately high (2.1-2.8) or high (>2.8). These scores were in alignment with the findings of the current ecological health assessment in the case of HGMU 1, where the hydrological and geomorphic integrities were less altered. In the case of HGMU 2, however, the incised riverbed affected the majority of the unit and contributed to severe alterations in the hydrological integrity. Therefore, it should have been expected that HGMU 2 gets lower scores for these services instead of high scores similar to the other unit. It indicates that the used characteristics in these assessments might not entirely be sufficient in reflecting on the reality. In the case of streamflow regulation and carbon storage, one of the characteristics was the 'representation of the hydrological zones'. HGMU 2 was lacking the temporarily waterlogged zone, but the collective extent of seasonal and permanent zones relative to the unit size was still high, which has led to higher ecosystem scores. However, the eroded riverbed concentrates the water flow and drains the majority of the unit, thus the streamflow regulation and carbon storage services would be expected to be lower. Regarding the provision of erosion control service, HGMU 2 also got a high score, because of the influence of the opportunity characteristics scores (e.g. slope of the wetland, erodibility of the soil) on the final score. It is surely the case in those parts of the unit, which are covered by dense palmiet vegetation, and might be also true for the rest of the unit if we consider the results of the current ecological health assessment regarding the low impacts of erosion on the geomorphic integrity of the unit. HGM unit 1 was assessed to provide this service at a high level, but it is likely that it is even higher, regarding the impacts of the erosion control structure, which were not possible to include in the assessment.

Flood attenuation and other regulating services related to water quality enhancement such as nutrient, phosphate, and toxicant removal and sediment trapping, were also provided by the wetland at intermediate levels. These scores were considered as having good reflection on the differences between the current ecological health of the two HGMUs. HGMU 1, which has been less altered in terms of its hydrological and geomorphic integrities than HGMU 2, had higher final scores, indicating higher services provision than HGMU 2.

The most important provisioning service was the provision of water for direct human use, which provision was assessed moderately high. In this assessment, HGMU 2 had a higher score, which was because of the bigger collective extent of seasonal and permanent hydrological zones and the final score of streamflow regulation service. However, if we consider the aforementioned discussion on the service of streamflow regulation, the importance of HGMU 2 in terms of water provision should be also lower. Furthermore, WET-EcoServices only considers the importance of water provision for the people who directly use the wetland, and does not consider downstream users in its assessment. Since the Kromme system is one of the most important water sources for the NMMM and Port Elizabeth, it is likely to be important for the downstream users as well. An important concern that WET-EcoServices does not provide a link between the services of water provision and those regulating services that might be affected by it due to tradeoff such as carbon storage, nutrient removal, and biodiversity maintenance (etc.).

The Hudsonvale wetland was assessed to have low and moderately low importance in terms of providing cultivated food and natural resources, respectively. The characteristics used in these assessments were mainly based on indicators linked to poverty such as number of households dependent on these services, level of poverty in the area (etc.). Poverty was not a driver behind the use of the Hudsonvale wetland, thus most of these characteristics needed to be omitted. The most important cultural service was education and research, which was delivered at intermediate level (1.3-2.0) and had a strong relation to the presence of the erosion control structure and the incised riverbed.

The wetland was not important in having any cultural significance for the local people based on the assessment. Yet, maybe the wetland contributes to the farming family’s way of living as being part of the farm and the landscape. Therefore, it might provide some sort of attachment feeling to the wetland.

As it shows, the WET-EcoServices tool could provide useful information on the importance of the Hudsonvale for providing ecosystem services, which in combination with the WET-Health tool could be linked to the impacts of human drivers and other human impacts through the assessment of current ecological health.

8. Conclusions and Recommendation

The final chapter presents the conclusions in line with the research questions. Then it is followed by the recommendation on how to improve the effectiveness of the combined use of the WET-Health and WET-EcoServices rapid wetland assessment tools.

8.1. Conclusions

8.1.1. Biophysical structures and processes of the Hudsonvale wetland (RQ 1)

The Hudsonvale wetland is situated in the valley-bottom of the UKRC. The wetland has an area of 54 ha and collects water from its catchment area of 18,400 ha. The topography of the catchment is characterized by the striking valley in the middle, and the surrounding steeper Surranysberge and Kouga Mountains on the north and the gentle sloping Tsitsikamma Mountains on the south.

The catchment has a bimodal climatic pattern with generally more rain occurring in the winter, but it can rain at any period of the year. The main annual precipitation is quite low around 600-700 mm, compared to the world average (860 mm), which makes the area semi-arid. Floods are periodically experienced, causing both environmental and economic damage.

Different horizons of quartzitic sandstones and subordinate shales of the Table Mountain and Bokkeveld Groups under lay the catchment area that determine the soil characteristics and the vegetation structure. The weathering of these rocks has led to the development of extremely nutrient poor and acidic soils on the higher slopes providing ideal environment for the fynbos vegetation. Heavy structured, fine sand and loam rich dark, more fertile soils developed on the lower slopes of the catchment, which is more favourable for the renosterveld vegetation. The Hudsonvale wetland is characterised by the mineral Westleigh soil formation in its temporarily wet zones (wetland boundary), which expands into the surrounding irrigated pasture. The permanently wet zone, situated in the middle of the river has organic Champagne soil with abundant peat deposit. Nearly half of the vegetation composition is characterized by indigenous emergent wetland species (e.g. reed and palmiet). The other half consists of the constituent species of the irrigated pasture (kikuyu and ryegrass) established in the wetland area for the dairy and invasive alien plants (e.g. Acacia meransii, Eucalyptus sp. and Spanish reed).

The most important water sources of the wetland are the Kromme, and the two tributary streams (Witels and Boosikloof) that originate from Tsitsikamma Mountains. Additional water derives from the adjacent slopes and from groundwater discharge. Hydrological characteristics such as water input quantity, water retention and flow pattern influence biogeochemical processes such as nutrient and carbon cycling within the wetland and the transport of sediments. The wetland is channelled.

Geomorphic processes are very important shaper of the structure of the Hudsonvale wetland through erosional and depositional processes. The perennial Witels enters the wetland in the middle section of the wetland, (below the constructed erosion control structure). It divides the wetland into two hydro-geomorphic units (HGMUs), of which the first is located upstream, and the second downstream of the confluence of the tributary. Erosion is most severe in the second unit, where the riverbed is three meters incised. The incision of the river renders important biogeochemical processes such as nutrient removal. The tributaries also deposit fan like deposits consisting of significant amounts of coarse clastic sediment (sand, pebbles and cobbles) in the wetland. Fine clastic sediments (sand, silt) are delivered by the Kromme and deposited at the head of the wetland, mainly in the first HGMU. Sediment also arrives from the hillslopes by colluvial, gravity-laden movements from the slopes of the valley. Organic sedimentation i.e. accumulation of peat takes place in the wetland, where dense wetland vegetation still present under anaerobic conditions.

8.1.2. The impacts of agricultural land use, invasive alien plant eradication and construction of erosion control structures on the biophysical structure and processes of the Hudsonvale wetland (RQ 2)

a) Impacts of agricultural land use

Dairy farming and the related management practices of lands adjacent to and within the Hudsonvale wetland pose the most direct impacts on the biophysical structures and process of the wetland. The wetland has been already subject to continuous farming activities since the end of the 18th century. Over the years the agriculture became more intensified and extended, leading to that about one - fourth (12 ha) of the natural wetland vegetation has been converted into irrigated and dryland pastures, dominated by kikuyu grass for the dairy. Additional wetland area also became used for grazing during droughts after it was cleared from the invasive alien plants by Working for Water as it was revealed form interviews with the landowners. The conversion of the wetland area and vegetation has changed the physical structure vegetation composition and coverage of the wetland. The replacement of emergent vegetation to low terrestrial grasses resulted in lower surface roughness that influences wetland hydrology and geomoprhic processes.

Water abstraction for irrigation (pastures, orchards and vegetables) and domestic purposes both in the catchment area and directly from the wetland on-site, has considerable effects on the wetland hydrology. Farm dams are also prominent in the catchment, which further influence the hydrological cycle by retaining water. Since the intensity of irrigation is the highest during the dry months, the decrease in water quantity input to the wetland and the high amount of water extracted to irrigate the kikuyu pastures can decrease water levels in the wetland and thereby impeding bio-geochemical processes to occur such as peat accumulation or nutrient cycling.

Trampling by cattle within the wetland affects the geomorphic processes in the wetland, which is more visible through higher numbers of erosional features in the downstream portion of the wetland, but it is not clear to what extent trampling has contributed to the erosion. Furthermore, the degradation of 16% of the catchment's fynbos vegetation caused by the high levels of trampling pressures and intensive use of fire on the hillslopes and in the mountains affects the sedimentary and hydrological cycle of the catchment of the wetland.

The high amount of fertilizer used for the irrigated pastures at the site of the wetland also affects the nutrient cycling and the wetland vegetation composition. The high levels of nutrients in the wetland support the invasion of ruderal and invasive species against the indigenous wetland species, which prefer the nutrient poor, acidic conditions. Field observation revealed it because reed was much more abundant in the Hudsonvale wetland than in the two upstream wetlands. Fertilizer and biocides are also used in the catchment of the wetland, but the impact on the Hudsonvale wetland is uncertain due to lacking data on the amounts, duration of use and the complexity of nutrient cycling in the catchment.

b) Impacts of invasive alien plant eradication

The impacts of invasive alien plant eradication programme in the catchment of the Hudsonvale are poorly known because of the continuous re-infestation and clearing processes and data availability issues. The impacts of the clearing processes at the site of the Hudsonvale wetland on its biophysical structures and processes indicates positive impacts if the before and after situations are considered.

Before Working for Water cleared the farm, invasive alien plants, particularly black wattle densely invaded the Hudsonvale wetland and its riparian zone. Some of the infested riparian zones also showed severe bank erosion as result of floods that ripped out the black wattle. The clearing of the wetland's riparian zone and some of its inner parts has had positive impacts on the wetland hydrology, vegetation and geomorphology. The clearing enhanced the water retention capacity of the wetland because the clearing has decreased the direct loss of water from the wetland due to the high water use of invasive alien plant species. The clearing also could potentially support the recovery of natural wetland vegetation as the negative shading by the alien invasive species has decreased. The wetland geomorphology has been influenced by decreasing the risk of further bank collapse and erosion as indigenous vegetation could re-establish on the cleared banks. Indirectly, this driver also had negative impacts on the Hudsonvale wetland as some of the cleared areas became used for grazing land for the cattle during droughts.

c) Impacts of the construction of erosion control structure

The construction of the erosion control structure within the Hudsonvale wetland has contributed to restore the physical structure, and some of the natural geomorphological and hydrological processes within the wetland portion located upstream to the structure. The structure has significantly improved the water retention capacity of portion of the wetland located above the structure by halting the severe headcut erosion. The erosion control structure also improved the water distribution below it in the other part of the wetland by directing water to the palmiet vegetation dominated section. This improved water retention, furthermore, potentially support the recovery of natural wetland vegetation and the maintenance of peat deposits in the Hudsonvale wetland.

8.1.3. The current ecological condition of the Hudsonvale wetland (RQ 3)

The current ecological health assessment of the Hudsonvale wetland shows that human activities, predominantly those that are located at the site of the wetland, have largely modified the ecological health of the wetland in terms of its hydrological, geomorphic and vegetation health components compared to the natural reference condition. Among the three main drivers (agriculture, eradication of IAPs and construction of erosion control structure), the magnitude of impacts of agricultural practices on the current ecological health could be assessed to the greatest extent by means of using the WET-Health tool. The hydrological integrity of the wetland has been drastically altered due to direct water abstraction from the wetland for irrigation, the encroachment of invasive alien plants and the severe erosion of the riverbed in the downstream portion of the wetland have led to the loss of water and the canalization of the wetland. Furthermore, the conversion of wetland areas to pasture and the development of erosional gullies have decreased surface roughness, thereby leading to decreased water retention capacity of the wetland. The wetland also gets slightly less water input from its catchment area because of the level of water abstraction for both agricultural and domestic purposes, the water retaining effects of farm dams, and the level of invasive alien plants encroachment in the catchment area. The geomorphic integrity of the wetland was the least affected compared to the other two health components, where the peat deposit loss was the biggest impact as a result of decreasing water inputs and altered water retention capacity of the wetland. The vegetation integrity of the wetland has been largely altered as introduced kikuyu and rye-grass species, invasive alien plants have replaced about half of the natural wetland vegetation.

8.1.4. Current ecosystem services of the Hudsonvale wetland (RQ 4)

The current ecosystem services assessment shows that the Hudsonvale wetland is important for providing a variety of ecosystem services. The wetland is most important for providing a range of regulating services such as streamflow regulation, erosion control, carbon storage and those services that contribute to improved water quality i.e. sediment trapping, removal of nutrients and toxicants. The level of these services provision varies along the wetland depending on the ecological condition of the biophysical structures and processes, being less where there is more erosion and lower surface roughness in the downstream portion of the wetland. The Hudsonvale wetland is also important for providing water for irrigation directly from the wetland as the interviews and observations also revealed. The WET-EcoServices tool does not incorporate the downstream users into its assessment, but the interviews and the management of the catchment area indicates that the water is also important for downstream water users. The wetland is less important in terms of providing and supporting the cultural services and biodiversity.

8.1.5. Main conclusion

The combined use of WET-Health and WET-EcoServices tools provided a useful way to assess the impacts of human drivers, particularly the impacts of agriculture on the provision of ecosystem services through linking it to ecological health.

The case study of Hudsonvale wetland has revealed that agriculture, eradication of invasive alien plants and construction of erosion control structures affect the valley-bottom wetland in a complex way, with some impacts being synoptic, while others being antagonist regarding the ecosystem services provision. The wetland is influenced to the greatest extent by on-site activities, but also by its catchment, which may accumulate impacts. In terms of agriculture, water abstraction has the highest magnitude of impact on the ecological health of the wetland, through decreasing water quantity and water retention. It indicates the importance of water provision by the wetland, which in turn has negative impacts on the majority of regulating services (e.g. streamflow regulation, services enhancing water quality) but also negatively influence long-term water provision. On the contrary, the construction of erosion control structure within the wetland enhances water retention in the portion of the wetland located above the structure. Thus, it is very likely to enhance its ecological health and supports the delivery of all regulating services and biodiversity maintenance, as well as water provision for direct use, and research and education opportunities. The clearing of invasive alien plants also supports water provision by removing alien trees with high water consumption, but also improves regulating services such as erosion control. The possible impact of invasive alien plant clearing is that it can induce an increase in agricultural land use, and thus higher impacts on ecological health and use of water.

8.2. Recommendations

Improving effectiveness of combined use of WET-Health and WET-EcoServices

To improve the effectiveness of the combined use of WET-Health and WET-EcoServices rapid assessment tools in assessing the impacts of human drivers associated with wetland rehabilitation (e.g. the construction of erosion control structure) on both the ecological health and the provision of ecosystem services of the wetland, it is recommended that these assessments are conducted before and after the rehabilitation. However, assessment of historical land use change would be also recommended, so that information could be obtained on the historical impacts. The time of return after the rehabilitation for repeating the assessments should be defined in consideration of the expected time that is necessary to be able to assess changes related to the rehabilitation intervention. In this way, the score of each health component i.e. hydrology, geomorphology and vegetation could provide meaningful and useful information on the impacts related to the rehabilitation after being compared. The returning time, thus should be based on the type of rehabilitation intervention applied, the type of the wetland and its biophysical structures and processes. Additionally, it is also recommended that the assessments be conducted in the same season both times, thereby minimizing the influence of weather conditions. It is also recommended to combine more data collection methods (e.g. interviews, observations) to obtain specific information about the wetland site both about the biophysical properties, and activities done in the wetland but also about the use of the wetland. Furthermore, using recent GIS maps (e.g. land and land cover) at the scale of the catchment of both years would improve the reliability and efficiency of the assessments.

Nevertheless, in some cases these tools are not recommended to be used. For instance, if the focus is on assessing the impacts of long-term restoration efforts such as IAPs eradication, the use of these rapid assessment tools are not recommended, because it is a complex process and these tools cannot provide sufficient information. It is more useful to use mapping and modelling techniques to assess the long-term changes.

9. References

Apitz, S. E. 2012. Conceptualizing the role of sediment in sustaining ecosystem services: Sediment-ecosystem regional assessment (SEcoRA). Science of the Total Environment **415**:9-30.

Ayine, N. C. 2007. Plant community distribution and diversity, and threats to vegetation of the Kromme River Peat Basins, Eastern Cape, South Africa. Master Thesis. Rhodes University, Grahamstown.

Bastian, O., D. Haase, and K. Grunewald. 2012. Ecosystem properties, potentials and services - The EPPS conceptual framework and an urban application example. Ecological Indicators **21**:7-16.

Blair, T. C. and J. G. McPherson. 1994. Alluvial fan processes and forms. Pages 354-402 Geomorphology of desert environments. Springer.

Blignaut, O., C. Marais, and J. K. Turpie. 2007. Determining a charge for the clearing of invasive alien plant species (IAPs) to augment water supply in South Africa. Water SA **33**:27-34.

Boucher, C. and M. Withers. 2004. Palmiet. Prionium serratum, a Cape river plant. Veld and Flora **90**:26-28.

Brinson, M. M. 1993. A hydrogeomorphic classification for wetlands. DTIC Document, East Carolina Greenville NC.

Cairns Jr, J. and J. R. Pratt. 1995. The relationship between ecosystem health and delivery of ecosystem services. Pages 63-76 Evaluating and Monitoring the Health of Large-Scale Ecosystems. Springer.

Clulow, A., C. Everson, and M. Gush. 2011. The long-term impact of Acacia mearnsii trees on evaporation, streamflow, and ground water resources. Water Research Commission Report No. TT505/11, WRC, Pretoria, South Africa.

Collins, N. B. 2006. Wetlands: The basics and some more. Free State Department of Tourism, Environmental and Economic Affairs, Republic of South Africa.

DAFF. 2012. Abstract of Agricultural Statistics. Pages 4, 76-78. *in* F. a. F. Department of Agriculture, editor. Department of Agriculture, Forestry and Fisheries, South Africa, Pretoria.

Day, E. and M. H. 2010. Tools and metrics for assessment of wetland environmental condition and socio-economic importance. WRC Report No. TT 433/09, Water Research Commission, Pretoria.

De Groot, R., B. Fisher, M. Christie, J. Aronson, L. Braat, R. Haines-Young, J. Gowdy, E. Maltby, A. Neuville, and S. Polasky. 2010a. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. TEEB Ecological and Economic Foundations. Earthscan, London:9-40.

De Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010b. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity **7**:260-272.

De Jong, T. 2012. Fragmentation as a collective interest. A case study about irrigating farmers, water scarcity, and collective action in the Upper Kromme River Catchment, South Africa. Master Thesis. Wageningen University, Wageningen.

Driver, A., K. J. Sink, J. N. Nel, S. Holness, L. Van Niekerk, F. Daniels, Z. Jonas, P. A. Majiedt, L. Harris, and K. Maze. 2012. National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report, South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

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

DWAF. 2012. Proposed National Water Resource Strategy 2 (NWRS-2). Summary. Department of Water Affairs and Forestry, Pretoria.

Dye, P. and C. Jarmain. 2004. Water use by black wattle (Acacia mearnsii): implications for the link between removal of invading trees and catchment streamflow response.

Ellery, W., M. Grenfell, S. Grenfell, D. Kotze, T. McCarthy, S. Tooth, P.-L. Grundling, H. Beckedahl, D. le Maitre, and L. Ramsay. 2009. WET- Origins. Controls on the distribution and dynamics of wetlands in South Africa. WRC Report TT 334/09, Water Research Commission, Pretoria.

Everson, C., M. Moodley, M. Gush, C. Jarmain, M. Govender, and P. Dye. 2006. Can effective management of riparian zone vegetation significantly reduce the cost of catchment management and enable greater productivity of land resources. Water Research Commission, Pretoria, Report K **5**.

Fennessy, M. S., A. D. Jacobs, and M. E. Kentula. 2007. An evaluation of rapid methods for assessing the ecological condition of wetlands. Wetlands **27**:543-560.

Forman, R. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual review of ecology and systematics.

Grenfell, M., W. Ellery, S. Garden, J. Dini, and A. Van Der Valk. 2009a. The language of intervention: A review of concepts and terminology in wetland ecosystem repair. Water SA **33**.

Grenfell, M. C., W. N. Ellery, and S. E. Grenfell. 2009b. Valley morphology and sediment cascades within a wetland system in the KwaZulu-Natal Drakensberg Foothills, Eastern South Africa. Catena **78**:20-35.

Grundling, P. L. 2004. Peatlands on the brink of the final phase in the extinction of a unique wetland type in southern Africa. IMGG Scientific Symposium, September 2004. Working for Wetlands Programm, National Botanical Institute, Pretoria.

Gull, K. 2012. Water Supply in the Eastern Cape. An economic case study of land rehabilitation in the Kromme River Catchment. Master Thesis. University of Cape Town, Cape Town.

Haigh, E. H., L. R. Bosman, R. R. Jones, and P. M. Illgner. 2004. Wetland Mapping And Assessment In Selected Metropolitan Water Supply Catchments In The Eastern Cape. Kromme Report., Institute for Water Research Rhodes University., Grahamstown.

Haigh, E. H., P. M. Illgner, and P.-L. Grundling. 2002. The Wetlands of the Southern Cape Fold Belt Mountains. Pages 77-84 *in* F. Department of Agriculture, editor., Pretoria.

Haigh, E. H., P. M. Illgner, J. Wilmot, and J. Buckle. 2008. The Wetland Rehabilitation Project in the Kromme River Wetlands, Eastern Cape. Report. Report.

Harris, J. A. and R. van Diggelen. 2006. Ecological restoration as a project for global society. To Heleen, Arieke, Thibaud and Perrine:1.

Highway, F. L. 2005. Project development and design manual (PDDM).

Holmes, P., K. Esler, D. Richardson, and E. Witkowski. 2008. Guidelines for improved management of riparian zones invaded by alien plants in South Africa. South African Journal of Botany **74**:538-552.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos:373-386.

Kolka, R. K. and J. A. Thompson. 2006. Wetland geomorphology, soils, and formative processes. Ecology of Freshwater and Estuarine Wetlands:7-42.

Kotze, D. and W. Ellery. 2009. WET-OutcomeEvaluate. An evaluation of the rehabilitation outcomes at six wetland sites in South Africa. TT 343/09. , Water Research Commission, Pretoria.

Kotze, D., W. Ellery, D. Macfarlane, and G. Jewitt. 2012. A rapid assessment method for coupling anthropogenic stressors and wetland ecological condition. Ecological Indicators **13**:284-293.

Kotze, D. C. 2000. Wetlands and Water Quality Enhancement. School of Applied Environmental Sciences, University of Natal.

Kotze, D. C. 2004. Guidelines for managing wetlands in forestry areas. . Centre for Environment and Development University of KwaZulu-Natal.

Kotze, D. C., G. Marneweck, A. L. Batchelor, D. S. Lindley, and N. B. Collins. 2008. WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report TT 339/08, Water Research Commission, Pretoria.

Kumar, R. 2005. Research Methodology: A Step-by-step Guide for Beginners. SAGE: London.

Le Maitre, D., B. Van Wilgen, C. Gelderblom, C. Bailey, R. Chapman, and J. Nel. 2002. Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. Forest Ecology and Management **160**:143-159.

Lu, F. and Z. Li. 2003. A model of ecosystem health and its application. Ecological modelling **170**:55-59.
MA. 2003. Ecosystems and Human Well-Being: A Framework for Assessment. Island Press, Washington, D. C.
MA. 2005a. Ecosystems and human well-being. Island Press Washington, DC.
MA. 2005b. Ecosystems and Human Well-Being: Current State and Trends. Island Press, Washington, D. C.
MA. 2005c. Ecosystems and Human Well-being: Wetlands and Water Synthesis. World Resources Institute, Washington, DC.
Macfarlane, D., D. Kotze, W. Ellery, D. Walters, V. Koopman, P. Goodman, and C. Goge. 2008. WET-Health: A technique for rapidly assessing wetland health. WRC Report No. TT 340/08. Water Research Commission, Pretoria.
Mander, M., J. Blignaut, M. Van Niekerk, R. Cowling, M. Horan, D. Knoesen, A. Mills, M. Powell, and R. Schulze. 2010. Baviaanskloof-Tsitsikamma Payment for Ecosystem Services: A Feasibility Assessment. Executive Summary.
Mantel, S. K., D. A. Hughes, and N. W. Muller. 2010. Ecological impacts of small dams on South African rivers Part 1: drivers of change - water quantity and quality. Water SA **36**:351-360.
McCartney, M., M. R. McCartney, L.-M. S. Sellamuttu, S. Sonali de Silva, L. Rebelo, S. Senaratna Sellamuttu, and S. de Silva. 2011. Wetlands, agriculture and poverty reduction. Iwmi.
McConnachie, M. M., R. M. Cowling, B. W. Van Wilgen, and D. A. McConnachie. 2012. Evaluating the cost-effectiveness of invasive alien plant clearing: A case study from South Africa. Biological Conservation **155**:128-135.
Mitsch, W. J. and J. G. Gosselink. 2007. Wetlands, Fourth Edition. New York, John Wiley & Sons, Inc.
Mooney, H. A., R. N. Mack, J. A. McNeely, L. E. Neville, P. J. Schei, and J. K. Waage. 2005. Invasive alien species: The nature of the problem. Island Press.
Mucina, L. and M. C. Rutherford. 2010. (CD set). The vegetation of South Africa, Lesotho and Swaziland South African National Biodiversity Institute, Pretoria.
Murray, R., M. Goedhart, and J. Baron. 2008. High -yielding groundwater areas around the Nelson Mandela Bay Municipality. Technical TT 327/08, Water Research Commission.
Nsor, C. A. 2008. Plant community distribution and diversity, and threats to vegetation of the Kromme River peat basins, Eastern Cape Province, South Africa. Master Thesis. Rhodes University.
NWA. 1998. National Water Act.*in* D. o. W. A. a. Forestry, editor. Act No. 36 of 1998. Republic of South Africa, Cape Town.
Ong, C. and F. Orego. 2002. Links between land management, sedimentation, nutrient flows and smallholder irrigation in the Lake Victoria Basin. The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa, Columbo: Sri Lanka: International Water Management Institute:135-154.
Pugnaire, F. and F. Valladares. 2007. Functional plant ecology. CRC Press., Republic of South Africa.
Rebelo, A. J. 2012. An Ecological and Hydrological Evaluation of the Effects of Restoration on Ecosystem Services in the Kromme River System, South Africa. Master Thesis. Stellenbosch University, Stellenbosch.
Rebelo, A. J., D. le Maitre, K. J. Esler, and R. M. Cowling. 2013. Are We Destroying Our Insurance Policy? The Effects of Alien Invasion and Subsequent Restoration. Pages 335-364 Landscape Ecology for Sustainable Environment and Culture. Springer Netherlands.
Riddell, E. 2011. Characterisation of the hydrological processes and responses to rehabilitation of a headwater wetland of the Sand River, South Africa. University of KwaZulu-Natal Pietermaritzburg.
Robenson, H. A. and T. K. McGee. 2003. Applying local knowledge: the contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. Journal of Environmental Management **69**:275-287.

SANBI. 2009. Further Development of a Proposed National Wetland Classification System for South Africa., Prepared by the Freshwater Consulting Group (FCG) for the South African National Biodiversity Institute (SANBI).

Saunders, D. and J. Kalff. 2001. Nitrogen retention in wetlands, lakes and rivers. Hydrobiologia **443**:205-212.

Sieben, E., W. Ellery, D. Kotze, and M. Rountree. 2011. Hierarchical spatial organization and prioritization of wetlands: a conceptual model for wetland rehabilitation in South Africa. Wetlands Ecology and Management **19**:209-222.

Sieben, E. J. J. 2012. Plant functional composition and ecosystem properties: the case of peatlands in South Africa. Plant Ecology:1-12.

Southwold, S. 2002. Methods and techniques of field research. Methods, Techniques and Data Analysis for Field Research, Wageningen: WAU:12-15.

Toth, F. L. and E. Hizsnyik. 1998. Integrated environmental assessment methods: Evolution and applications. Environmental Modeling & Assessment **3**:193-207.

Turpie, J. K., C. Marais, and J. N. Blignaut. 2008. The working for water programme: Evaluation of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. . Ecological Economics **65**:788-798.

Van der Colf, J. 2011. The production potential of kikuyu (Pennisetum clandestinum) pastures over-sown with ryegrass (Lolium spp.). Master Thesis. University of Pretoria, South Africa.

Van der Merwe, S., V. S. Gqodwana, and M. S. Mntambo. 2011. Drought, Fire, Flood & Cold Risks in the Kou-Kamma area During December 2011. Eastern Cape Department of Rural Development & Agrarian Reform, Joubertina.

Van Ginkel, C. E., R. P. Glen, K. D. Gordon-Gray, C. J. Cilliers, M. Muasya, and P. P. v. Deventer. 2011. Easy identification of some South African Wetland Plants (Grasses, Restios, Sedges, Rushes, Bulrushes, Eriocaulons and Yellow-eyed grasses. WRC Report No. TT 479/10. Water Research Commission.

Van Oudenhoven, A. P. E., K. Petz, R. Alkemade, L. Hein, and R. S. D. Groot. 2012. Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecological Indicators **21**:110-122.

Van Wilgen, B. W., B. Reyers, D. C. Le Maitre, D. M. Richardson, and L. Schonegevel. 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. Journal of Environmental Management **89**:336-349.

Vepraskas, M. J. 1992. Redoximorphic features for identifying aquic conditions. NC Agricultural Research Service, NC State University.

Verhoeven, J. T., B. Arheimer, C. Yin, and M. M. Hefting. 2006. Regional and global concerns over wetlands and water quality. Trends in ecology & evolution **21**:96-103.

Wentzel, J. and C. E. Van Ginkel. 2012. Distribution, use and ecological roles of the medicinal plants confined to freshwater ecosystems in South Africa. Research Report, Water Research Commission.

WfWater. 2008/2009. The Kromme K90b1001 WFW Project. Gamtoos Irrigation Board, Patensie.

Wu, Y. 2005. Groundwater Recharge Estimation in Table Mountain Group Aquifer Systems with a Case Study of Kammanassie Area. Master Thesis. University of the Western Cape.

WWG. 1998. Wetland Survey, Krom River. Red Lights Flashing in the Wetlands of the Krom River Area as Observed By the WWG (1997 and 1998). Mondi Wetlands Project.

Zedler, J. B. and S. Kercher. 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annu. Rev. Environ. Resour. **30**:39-74.

Personal Communication

Buckle, J. (pers. comm., 2012). Expert. Port Elizabeth, EC.
Cowling, R. (pers. comm., 2012). Scientist. Kromme Workshop, Kareedouw, EC
Joubert, P. (pers. comm., 2012). Informant, Patensie, GIB, EC
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Appendix 1 – Biogeochemical processes; removal nitrogen and phosphorous in wetlands

The Nitrogen Cycle in wetland ecosystems

The nitrogen cycle is one of the most important chemical cycles in wetland ecosystems due its ability to remove excess amounts of nitrogen deriving from fertilizers, thereby improving water quality (Mitsch and Gosselink 2007). Nitrogen input sources can be both point pollution sources such as sewage and non-pollution sources such as agricultural runoff. Furthermore, nitrogen can be fixed from the atmosphere by activities of microorganisms. Nitrogen enters wetlands in either inorganic or organic form (Collins 2006). Nitrogen is often the most limiting nutrient in wetlands. The nitrogen cycle occurs in gaseous cycle where forms of nitrogen is altered by changes in redox potential (Collins 2006, Mitsch and Gosselink 2007). The main processes of the nitrogen cycle are illustrated in Figure 29. Nitrogen is removed by the processes of denitrification, sedimentation and uptake by aquatic plants (Saunders and Kalff 2001), of which denitrification is generally the most important one for nitrate removal (Verhoeven et al. 2006).

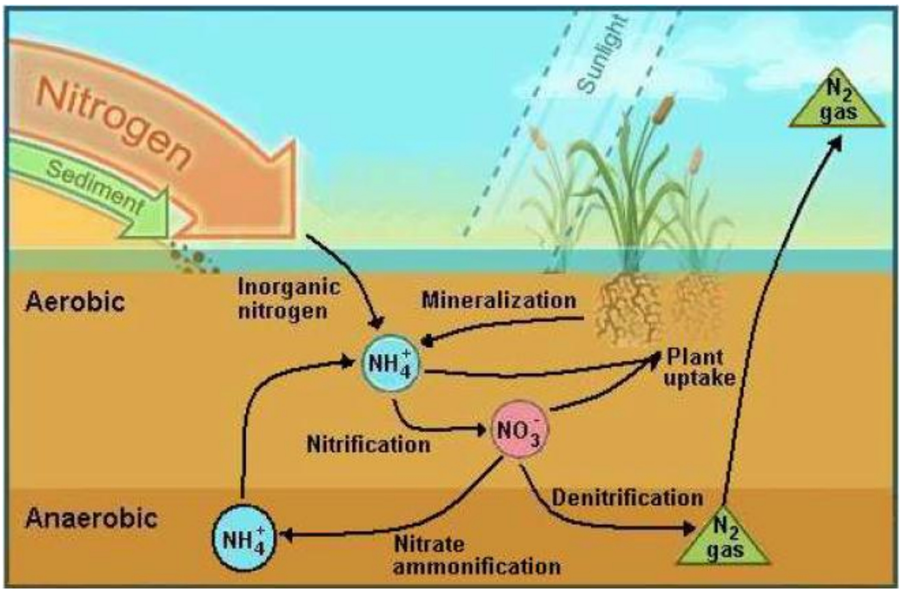

Figure 29: Simplified schematic illustration of processes related to nitrogen uptake and removal by wetlands Adapted from (Collins, 2006)

A) Mineralization, nitrification and plant uptake

Mineralization is a process when organic nitrogen is converted to inorganic ammonium ion (NH_4^+). Once ammonium ion is formed, there can be several pathways. It can be absorbed by plants through their root systems as NH_4^+ or further oxidized to nitrate (NO_3^-) through the process of nitrification and then taken up by plants (Collins 2006, Mitsch and Gosselink 2007).

B) Nitrate ammonification

Once the nitrate is formed nitrate ammonifying bacteria can reduce nitrate back to ammonium, which then can be taken up by plants or can be oxidized in nitrification (Collins 2006, Mitsch and Gosselink 2007)

C) Denitrification

Nitrates entering anaerobic soil zones are easily subject to denitrification, which is carried out by denitrifying bacteria (Verhoeven et al. 2006, Mitsch and Gosselink 2007). During the process nitrate (NO_3^-) is reduced through a series of redox reactions first to gaseous nitrous oxide (N_2O) and then further to nitrogen gas (N_2) (Verhoeven et al. 2006). Denitrification permanently removes nitrogen from the through flowing water and releases to the atmosphere (Collins 2006, Verhoeven et al. 2006). Denitrification is inhibited in acid soils and peat (Mitsch and Gosselink 2007) as well as if there is not enough nitrate present (Collins 2006) and other factors such as overload of nitrates in buffer zones can hamper the process by resulting in releasing N_2O to the atmosphere as end product, which is a strong greenhouse gas. This process highly contributes to the sink function of the wetland (Verhoeven et al. 2006).

D) Nitrogen fixation

In wetlands where oxygen level is low, nitrogenase activity can take place through the activity of certain aerobic and anaerobic bacteria and blue-green algae. During this process the conversion of N_2 gas to organic nitrogen occurs, which brings nitrogen into the wetland system. Nitrogen fixation can occur in the overlying waters, in both the aerobic and anaerobic soil layers, in the oxidized rhizosphere of the plants, an on the leaf and stem surfaces of plants (Mitsch and Gosselink 2007)

The Phosphorous Cycle in wetland ecosystems

Retention of phosphorous (P) is one of the most important attributes of both natural and constructed wetlands, particularly where phosphorus derives from non-point pollution sources such as fertilizer from agricultural fields (Mitsch and Gosselink 2007). Other potential sources of phosphorus are decaying vegetation, animal wastes, detergents and sewage treatment plants (Collins 2006).

Phosphorous occurs in wetlands as soluble and insoluble complexes in both organic and inorganic forms taking place in the sedimentary cycle in contrast to nitrogen, which occurs in gaseous cycle. At any one time, the majority of phosphorous is tied up in organic litter, and peat in organic wetland soils and in inorganic sediments in mineral wetland soils (Mitsch and Gosselink 2007). Under aerobic conditions, P is more tightly bound to soil particles than in anaerobic conditions. Figure 30 shows the main processes of phosphorous removal in wetlands.

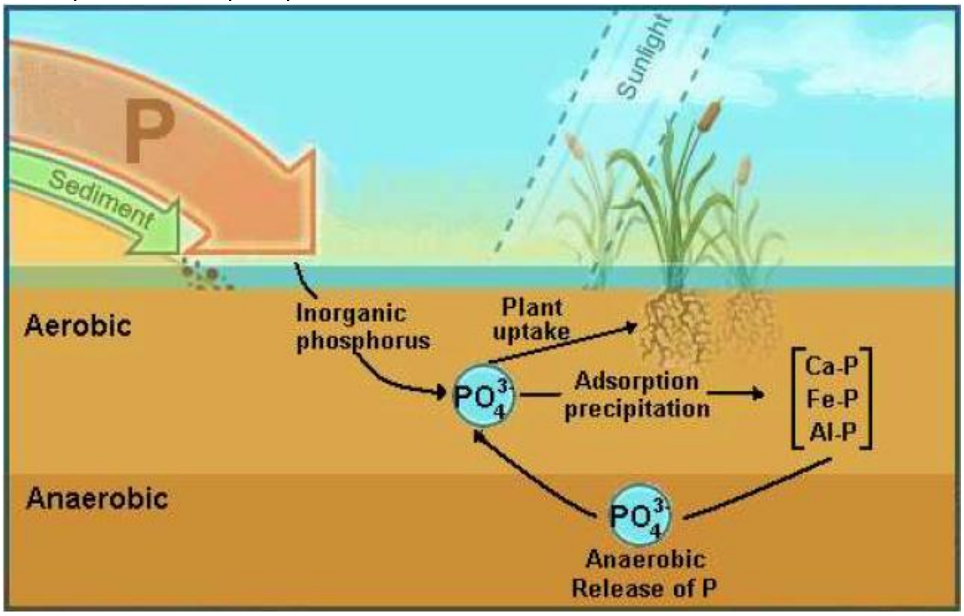

Figure 30: Simplified schematic illustration of processes related to phosphorous uptake and removal by wetlands Adapted from (Collins, 2006)

A) Precipitation and adsorption

Inorganic orthophosphates (PO_4^{3-} , HPO_4^{2-}, and H_2PO^{4-}) have the affinity to form complexes with calcium, iron, and aluminium through adsorption if they are readily available (Collins 2006, Mitsch and Gosselink 2007). The process is influenced by pH, thus in acid soils; P is fixed as aluminium and iron phosphates, while P is bound by calcium and magnesium in alkaline soils (Mitsch and Gosselink 2007). Once the suspended solids settle, the adsorbed phosphorus is removed from the water column (Collins 2006).

B) Release of phosphorous under anaerobic conditions and uptake by plants

The availability of phosphorus changes when soils are flooded and anaerobic conditions take place. As ferric (Fe^{3+}) ion is reduced to the soluble ferrous (Fe^{2+}) ion, phosphorus is released into solution, making P bioavailable for plant uptake. If vegetation is missing P diffuses back to surface waters (Collins 2006) and the wetland becomes the source of phosphorous (Ong and Orego 2002).

Phosphorous is not bioavailable for plants and microorganisms according to Mitsch and Gosselink (2007), if:

- The phosphorous is bound to organic matter as a result of building into biomass of bacteria, algae and vascular macrophytes
- The phosphate is adsorbed onto clay particles, organic peat and ferric and aluminium oxides and hydroxides
- The insoluble phosphate precipitations with ferric iron, calcium and aluminium under aerobic conditions

Appendix 2 – Delineation of wetland boundaries

In practice a land is a wetland, if it is characterized by at least one of the following attributes: (a.) wetland or hydromorphic soils; (b.) water loving plants (hydrophytes); (c.) saturated soil at or near the surface due to higher water table (DWAF 2005). These characteristics are used for the delineation procedure. In general, three different hydrological zones can be distinguished in a wetland based on the frequency of the saturation. These zones are permanently, seasonally and temporarily waterlogged zones, seen from the wettest (central) part of the wetland towards the non-wetland terrestrial areas. The objective of the delineation is to identify the outer edge of the temporary zone of the wetland.

As a first step, relevant supplementary data was collected for the delineation during the desktop analysis. Then the collected data was used for making a preliminary on-screen digitized delineation of the wetland by means of using aerial photographs (2007). Based on the preliminary delineation, six cross-sectional transects were planned perpendicular to the valley's longitudinal line to verify wetland boundaries on the field.

During both the desktop analysis and the field survey, four wetland indicators were taken into consideration; the Terrain Unit, the Soil Form, the Soil Wetness and the Vegetation Indicators. These indicators helped to identify the outer edge of the temporary zone (wetland boundary) as the different saturation frequencies of each hydrological zone also resulted in different soil and vegetation characteristics (Collins 2006)(Figure 31).

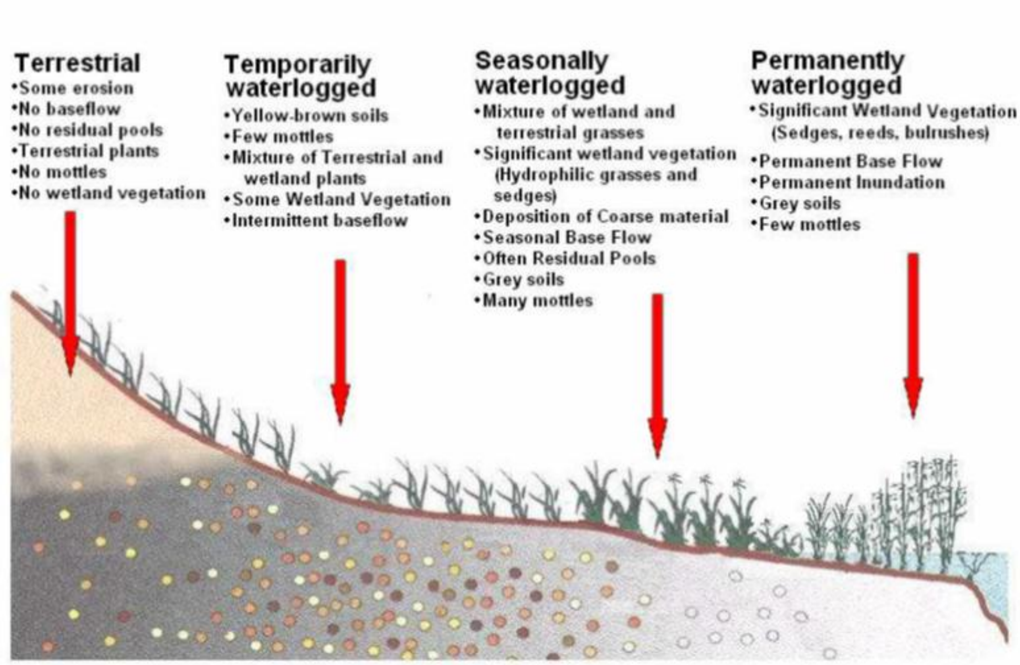

Figure 31: Different hydrological zones along a valley-bottom wetland cross-section
The different hydrological zones shows the associated soil wetness and vegetation characteristics from the permanently waterlogged zone to the non-wetland terrestrial area (Collins, 2005 as adapted from Kotze, 1996)

The wetland indicators are defined by the DWAF manual (2005). Regarding the diversity of the landscape the **Terrain Unit Indicator** is used to identify those parts where wetlands are likely to occur. In general, wetlands occur at depression areas, particularly in valley-bottoms, but they can also occur on steep to mild slopes, if there groundwater discharge takes place (DWAF 2005).

The **Soil Form Indicator** identifies the soil forms and if they are associated with prolonged and frequent saturation that would classify the soils as wetland soils. The soil forms are defined by the Soil Classification Working Group (1991). For instance, Champagne and Katspruit soil forms refer to the prolonged and frequent saturated part of the wetland which is permanently waterlogged (Collins 2006).

The **Soil Wetness Indicator** identifies those morphological "signatures" in the soil profile that developed under the conditions of prolonged and frequent saturation (DWAF 2005). These "signatures" are called redoximorphic features and they are the results of the reduction, oxidation and translocation of Fe and Mn oxides (Vepraskas 1992). They are found, for instance, as greyish reduced soil matrix; mottles (red, yellow or black). If the redoximorphic features are found within the upper 50 cm of the soil profile, the area is considered as wetland (Collins 2006).

The **Vegetation Indicator** helps to identify the presence of water-loving (hydrophilic) vegetation that is associated with wetlands. According to the wetland definition by the National Water Act the presence of hydrophilic plants should be the primary wetland indicator, however, in practice the soil wetness indicator is the most useful as the signs in the soil profile are more permanent. In the latter case , the other indicators are used to confirm the findings (DWAF 2005). Figure 32 shows the implication of Soil Wetness and Vegetation Indicators in identifying the hydrological zones of a wetland.

The topographic survey consisted of levelling operation which was used for determining elevation of points and the differences in elevations between points (Highway 2005). The elevation was measured by using equipment: a surveyor's level (dumpy level) which consisted of a telescope mounted on a tripod, a 5 m long levelling staff that was graduated in dm, flags and a compass (Photo 10).

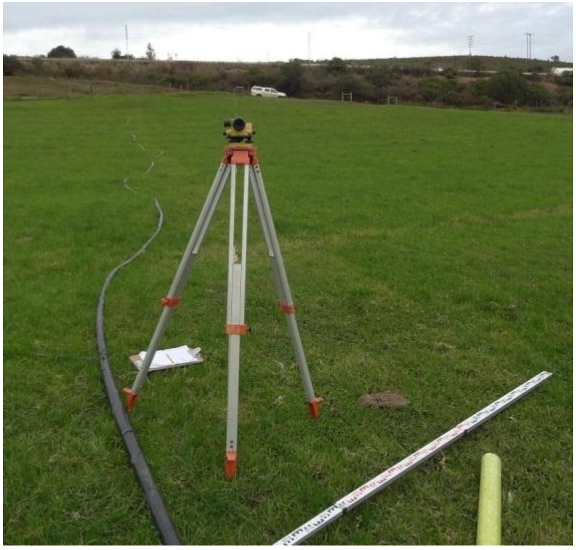

Photo 10: The surveyor's level and the leveling staff (Photo by Lieke Jager)

The soil survey was conducted along the cross-sectional transects and focused on soil characteristics that served as indicators for determining the soil wetness.

	SOIL WETNESS ZONES			
SOIL DEPTH	**Non-wetland**	**Temporary**	**Seasonal**	**Permanent / Semi-permanent**
0-10 cm	Matrix usually brown/red (chroma >1)[1] No/very few mottles Low OM[2] Nonsulphidic[3]	Matrix brown to greyish brown (chroma 0-3, usually 1 or 2)[1] Few/no mottles Low / Intermediate OM[2] Nonsulphidic[3]	Matrix brownish grey to grey (chroma 0-2)[1] Many mottles Intermediate OM[2] Sometimes sulphidic[3]	Matrix grey (chroma 0-1)[1] Few/no mottles High OM[2] Often sulphidic[3]
30-40 cm	Matrix usually brown (chroma >2) No/few mottles	Matrix greyish brown (chroma 0-2, usually 1) Few/many mottles	Matrix brownish grey to grey (chroma 0-1) Many mottles	Matrix grey (chroma 0-1) No/few mottles
VEGETATION	Dominated by plant species which occur extensively in non-wetland areas; hydrophytic species may be present in very low abundance	Predominantly grass species; mixture of species which occur extensively in non-wetland areas, and hydrophytic plant species which are restricted largely to wetland areas	Hydrophytic sedge and grass species which are restricted to wetland areas, usually <1m tall.	Dominated by: (1) emergent plants, including reeds (*Phragmites australis*), sedges and bulrushes (*Typha capensis*), usually >1 m tall (marsh); or (2) floating or submerged aquatic plants.

Key to Table

[1]Chroma refers to the relative purity of the spectral colour, which decreases with increasing greyness. To determine chroma, a Munsell colour chart is required.

[2]High OM: soil organic carbon is greater than 5% and often exceeds 10%.
Low OM: soil organic carbon is less than 2%
Intermediate OM: soil organic carbon is between 2% and 5%

[3]Sulphidic soil material has sulphides present which give it a characteristic "rotten egg" smell, and nonsulphidic material lacks sulphides.

Figure 32: Determination of wetland zonation based on soil and vegetation characteristics
Adapted from Ellery et al., (Ellery et al., 2009)

Appendix 3 – Results of delineation of the Hudsonvale wetland

The delineation procedure revealed that most of the currently visible parts of the wetland within HGMU 1 belong to the permanently waterlogged zone. That area that still was inundated seasonally or temporally was found in the perennial pastures along the surveyed transects. The delineated hydro-geomorphic units and the surveyed topographic transects are shown in Figure 33.

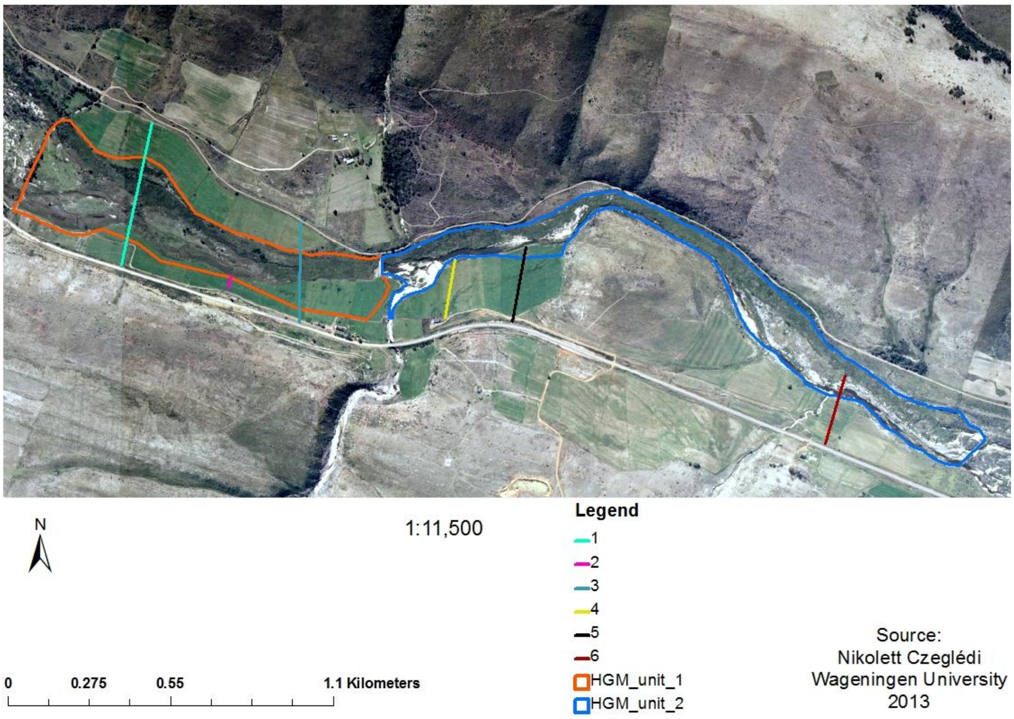

Figure 33: Location of transects along the hydro-geomorphic units

The seasonally and temporarily waterlogged areas were indicated mainly by the presence of redoximorphic features found within the upper 50 cm of the soil profile and the concave shape of slopes of the lands adjacent to the wetland. Along Transects 1 and 3, on the right side of the river the soil was characterized by the presence of soft plinthic B horizon in the depths of 50 and 20 cm, respectively. The presence of reddish, yellowish brown and black mottles as well as gley in the soft plinthic B horizon indicated that the soil periodically gets saturated caused by the fluctuating water table (Collins 2006, Kolka and Thompson 2006) (Figure 34a., 34b.).

However, finding redoximorphic features only was not enough for deciding the locations of wetland boundaries. The results of the topographic survey showed that the slope of the river's left side is convex-shaped, while the slope of the right side has a concave shape (Figure 35, 37). The concave slope makes it more likely to be inundated by water during rainy season.

Further indicators such as wetland vegetation; rushes (*Juncus)* was identified both on the left side of Transect 1 and on the right side of Transects 3 within the pastures. In the case of Transect 3, rushes were found in the shallow water that stayed behind after a recent smaller flood event (Figure 34c.). The presence of rushes, the classified wetland Westleigh soil form (seasonally wet zone) and the concave shape of the slope indicated that the area frequently and for a prolonged period is under wet conditions, thus is likely to be part of the wetland (Collins 2006).

Figure 34: Indicators of soil wetness used in wetland delineation
(a.) and (b.) showing mottling and gley of the plinthic B horizon due to the fluctuation of water table.
(c.) The red circle indicates the location of sedge vegetation within the pasture along the right side of Transect 3. (Photo by Author)

In the case of HGMU 2, the delineation procedure revealed that only a small part of the wetland is located in the perennial pasture along Transect 5. That part still was frequently inundated after floods. Although, both water –driven soil characteristics and wetland species were identified further up on the slope of the pasture, that area was considered not to be the part of the wetland. This decision was based on that the riverbed was incised at most places in HGMU 2. In general incision of the riverbed results in decreased level of water table (Ellery et al. 2009), making it less likely that the area is inundated by water from the same source. Furthermore being located on a hillslope makes it more likely that this feature is rather a seepage wetland, dominated by colluvial (gravity driven) movements of materials and fed by diffuse surface flow from the slopes and groundwater.

Transects surveyed in the hydro-geomorphic units

Six transects were surveyed, three-three in each hydro-geomorphic unit. Conducting full cross-sectional topographic survey was not possible in any of the cases due to the high water level of the main channel and the bad visibility of the levelling staff from the distance. In two cases, it was possible to connect the right and left sides of transects by means of using GPS measured absolute elevations (Transects 1 and 3). Therefore, the elevations were plotted as absolute elevation points (altitude), given in meters above sea level (m.a.s.l.). The graphs do not reflect on the actual variation in elevation in the permanently wet zones, due to aforementioned reasons. This, however, was not necessary for the delineation procedure as those parts could be clearly identified as the parts of the wetland. The graphs also show the additional information on the soil auger points and the depths of water table. These information were important to identify the actual boundaries of the wetland along the transects.

The surveyed transects are presented from upstream direction towards downstream. Therefore, it starts with transect of HGMU 1: Transects 1 to 3. Then the transects of the HGMU 2 follow with Transect 4 to 6.
starts with the transects located in HGMU 1 uppermost situated and goes towards downstream direction, staring with HGMU 1 and follows by HGMU 2. The graphs show the absolute elevations (altitude) of the area.

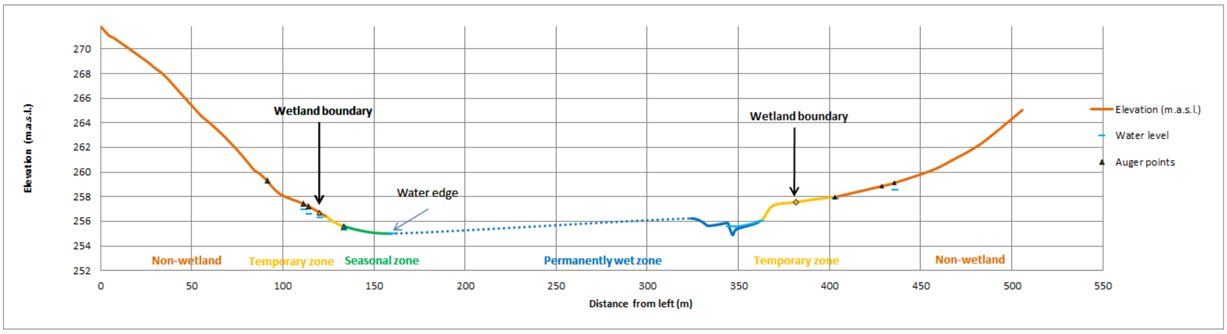

Figure 35: Changes in altitude along Transect 1

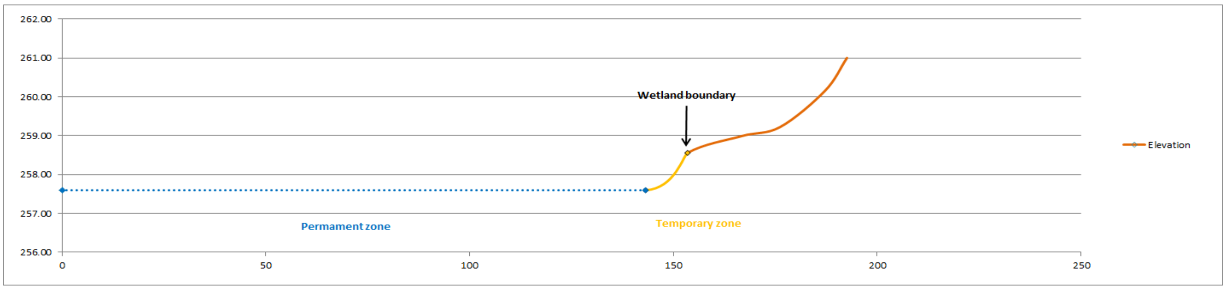

Figure 36: Changes in altitude along Transect 2
The transect only includes the right bank side of the wetland. The dotted line represents the distance between the two edges of permanently wet zones, does not show the actual elevation.

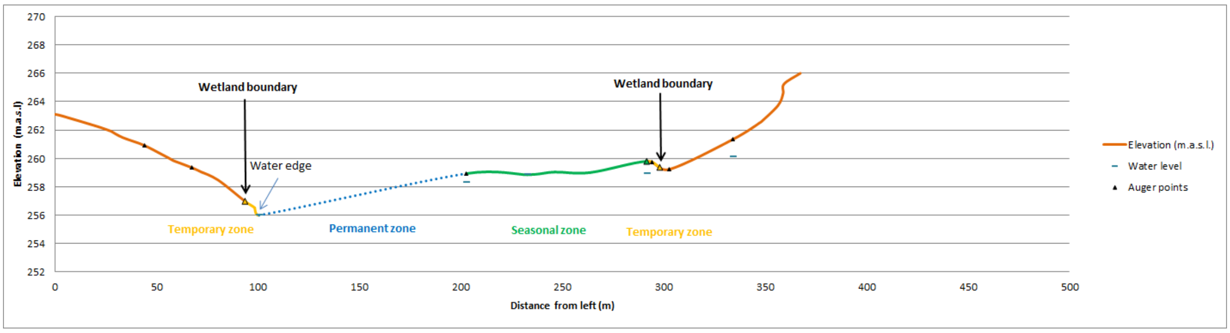

Figure 37: Changes in altitude along Transect 3
The dotted line was not possible to survey, thus it does not represent actual changes of topography in the permanently wet zone.

Transects surveyed in hydro-geomorphic unit 2

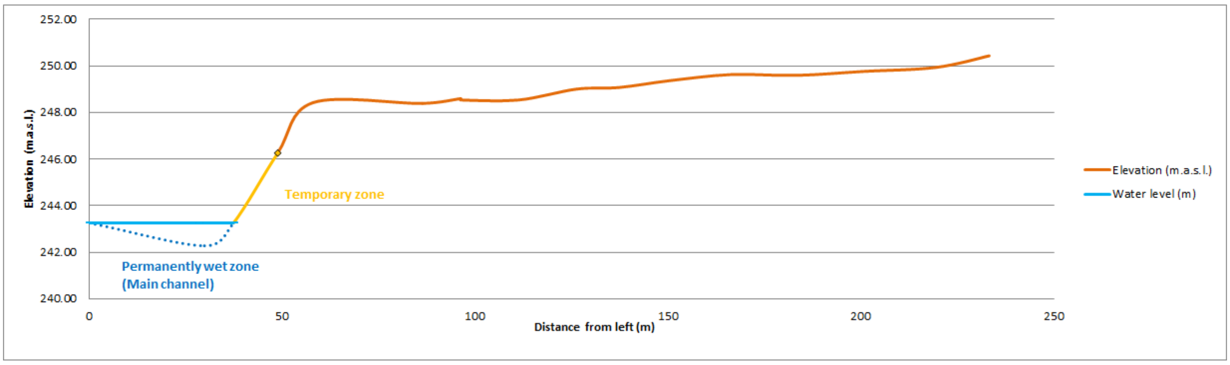

Figure 38: Changes in altitude along Transect 4
It shows only the right side of the wetland. The significant change close to the main channel of the Kromme river indicates the incision of the river and the erosion of riverbank.

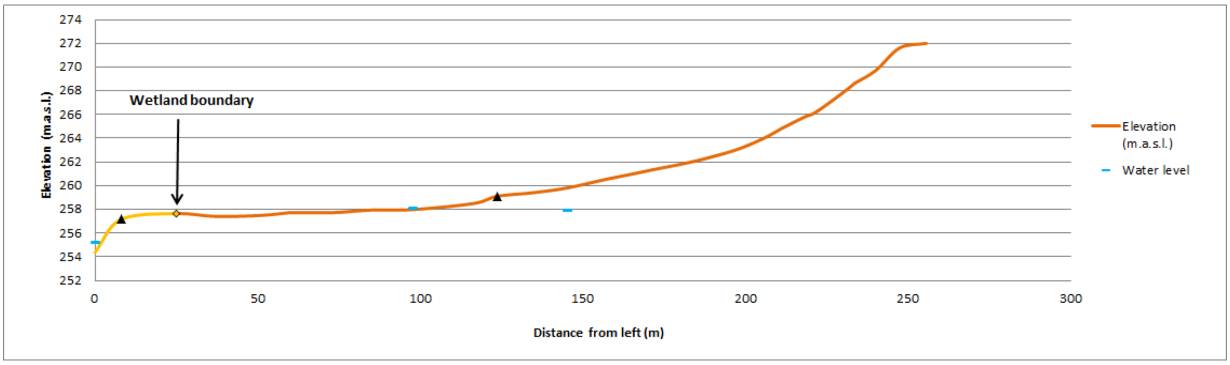

Figure 39: Changes in altitude along Transect 5

The left edge of transect is the point where the depth at the edge of the main channel was measured. Here the river bank did show signs of bank erosion as it was covered by dense mainly fynbos vegetation.

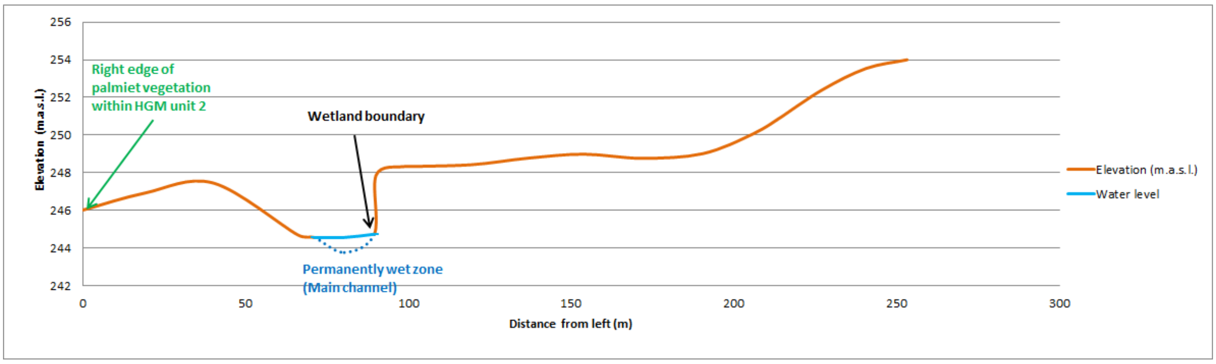

Figure 40: Changes in altitude along Transect 6

The left edge of the transect starts from the right edge of palmiet vegetation to the right side of the perennial pasture). At the confluence of the Booiskloof, the deposited clastic sediment decreased the depth and width of the channel, making it possible to cross the river.

Appendix 4 – Flood in Hudsonvale

Photo 11: The Hudsonvale wetland after flood in August 2012 (Photo by Landowner)
Large amounts of clastic sediment were deposited along hydro-geomorphic unit 1.

Appendix 5 – Current Hydrological Health (WET-Health tool)

Changes in water quantity input

Table 34: Land- use activities in the sub-catchments that potentially reducing inflow quantities and the magnitudes of their impacts

Land-use activity descriptions	Extent (%)	Intensity*	Magnitude of impact Unit 1	Extent (%)	Intensity	Magnitude of impact Unit 2
Irrigation	2.57	(-8+-8)/2*1=-8	-8*2.57/100= -0.21	2.71	(-8+-8)/2*1=-8	-8*2.71/100= -0.22
Domestic water use**			-0.01			-0.06
Alien plants	9.35	(-8+-8)/2*1=-8	-8*9.35/100= -0.75	7.67	(-8+-8)/2*1=-8	-8*7.67/100= -0.61
Plantations	-	-	-	-	-	-
Dams***	0.20	-8*1=-8	--8*0.20/100= -0.02	0.04	-8*1=-8	-8*0.04/100= -0.003
Overall magnitude of reduction in water inputs to the hydro-geomorphic unit (sum)			**-1.0**			**-0.8**

Intensity=Mean of sub-scores (e.g. duration of irrigation, prevalence of water conserving practices etc.) Vulnerability factor (defined by Mean annual precipitation/ Potential evapotranspiration ratio, in this study it was 1.0)

**Domestic water use was determined relative to irrigation, therefore the magnitude of impact score of irrigation was multiplied by the extent of domestic water use relative to the irrigation.

***Dams: specific allowance for releasing low flows within the operating rules of the dam.

c) Combined impact of altered quantity and timing of water inputs

To get the final score the magnitude of impacts of altered water quantities and flow patterns as well as the vulnerability of the HGMUs to the changes in water inputs were combined. The guideline table to combine these scores is shown in Table 38. The vulnerability factor was higher, giving higher impact score if the HGMUs' primary water inputs derived from overbank flooding and was lower, if it was mainly fed by lateral water sources. In this assessment, the higher vulnerability factors were assigned to the HGMUs based on their hydrological characteristics explained in Chapter 4.1.2.

Table 35: Guideline for assessing the magnitude of impact on the hydro-geomorphic units
Combining the altered quantity and pattern of water inputs and hydro-geomorphic type by means of the table, adapted from WET-Health assessment tool (Macfarlane et al., 2008). This table shows the scores for floodplain and channelled valley-bottoms driven primarily by over-bank flooding.

Change in quantity of water inflows	**Alteration to floodpeaks**						
	Large increase (>6)	Moderate increase (4-6)	Small increase (1.6-3.9)	No effect (-1.5 to 1.5)	Small decrease (-1.6 to-3.9)	Moderate decrease (-4 to -6)	Large decrease (<-6)
> 9	7	6	5	4	5	6	7
4 - 9	5	4	3	3	4	6	7
1-3.9 (Increase)	3	2	1	1	2.5	4.5	7
-0.9- +0.9 (Negligible)	1	1	0	0	1	5	7.5
-1- -1.9 (Decrease)	2	1.5	1	1	2.5	5	7.5
-2- -3.9	3	2.5	2	2	4	6	8
-4- -5.9	4	3.5	3	3	5	7	8.5
-6- -7.9	-**	-**	-**	4	6	8	9
-8- -9	-**	-**	-**	-**	-**	9	9.5
< -9	-**	-**	-**	-**	-**	-**	10

The magnitude of impact of altered quantity and pattern of water inputs on hydro-geomorphic unit 1

The magnitude of impact of altered quantity and pattern of water inputs on hydro-geomorphic unit 2

**Classes those are unlikely.

Changes in water distribution and retention with the hydro-geomorphic units

d) Direct water loss

Table 36: Effects of land use activities on water loss in the hydro-geomorphic units
Adapted from WET-Health (Macfarlane et al. 2008)

Land-use activity descriptors	**Low**				**High**	**Hydro-geomorphic unit 1**	**Hydro-geomorphic unit 2**
	0	2	5	8	10	**Magnitude score**	**Magnitude score**
(1) Alien woody plant type			Shrubs	Trees		0.5	0.9
(2) Plantation tree type				Wattle & pine	Eucalyptus	0.0	0.0
(3) Sugarcane Growth		Poor growth	Good growth			0.0	0.0
(4) Direct water abstractions		Low	Moderately low	Moderately high	High	4.0	1.1
Overall magnitude of increased water loss: (sum of (1), (2), (3) and (4)) x 0.8*						**3.6**	**1.5**

*Weighting factor assigned by WET-Health

e) Recent deposition, infilling and excavation

Table 37: Magnitude of impact of recent deposition, infilling or excavation
Adapted from WET-Health (Macfarlane et al. 2008)

Extent of hydro-geomorphic unit affected by deposition, infilling or excavation	Unit 1	2%
	Unit 2	7%
Descriptor	**Unit 1 Magnitude Score**	**Unit 2 Magnitude Score**
Effect on vertical drainage properties of the uppermost soil layer	0	5
Effect on the horizontal movement of water	2	2
Intensity of impact: use the highest score for the above two factors	2	5
Magnitude of impact score: extent of impact (%)/100 x intensity of impact x 1	**0.04**	**0.37**

The Present Hydrological State of the hydro-geomorphic units

Table 38: The Present Hydrological State of the hydro-geomorphic units

			Water Inputs					
			None	**Small**	**Moderate**	**Large**	**Serious**	**Critical**
			0-0.9	**1-1.9**	**2-3.9**	**4-5.9**	**6-7.9**	**8 - 10**
Water distribution & retention patterns	**None**	**0-0.9**	0	1	3	5	6.5	8.5
	Small	**1-1.9**	1	1.5	3.5	6	7	9
	Moderate	**2-3.9**	3	3.5	4	6.5	7.5	9
	Large	**4-5.9**	5	6	6.5	7	8	9.5
	Serious	**6-7.9**	6.5	7	7.5	8	9	10
	Critical	**8 - 10**	8.5	9	9	9.5	10	10

The Present Hydrological State of HGMU 1
The Present Hydrological State of HGMU 2

Appendix 6 – Current Vegetation Health (WET-Health tool)

Table 39: Description of disturbance classes commonly occurring in South Africa
Adapted from the Vegetation Module of the WET-Health assessment tool (Macfarlane et al. 2008).

Disturbance class	Description
Land uses commonly associated with complete transformation of wetland habitat	
Infrastructure	This includes houses, roads and other permanent structures that have totally replaced wetland vegetation.
Deep flooding by dams	This includes situations where flooding is too deep for emergent vegetation to grow.
Land uses commonly associated with substantial-to-complete transformation of vegetation characteristics.	
Crop lands	These lands are still in use and when active are generally characterized by almost total indigenous vegetation removal (predominance of introduced species). Examples include maize lands, tree plantations, sugarcane lands & madumbe fields etc.
Commercial plantations	Common plantations include pine, wattle, gum, poplar. Other land uses such as vineyards and orchards may have a similar impact on wetland vegetation.
Annual pastures	These areas are characterized by frequent soil disturbance with a general removal of wetland vegetation. Some ruderal wetland species may become established but are removed on a frequent basis.
Perennial pastures	Although such areas generally include a high abundance of alien terrestrial grasses or legumes, the reduced disturbance frequency may permit the establishment of some wetland species.
Dense alien vegetation patches.	Where dense patches of alien plants can be identified within a wetland system, they should be identified as a separate disturbance class and evaluated as a unit.
Shallow flooding by dams	Such areas can often be identified at the head or tail end or edges of dams.
Sports fields	These include cricket pitches, golf courses and the like, where a species such as Kikuyu have been introduced and are maintained through intensive management. These are often located within areas of temporary wetland where terrestrial species generally dominate.
Gardens	Gardens are generally associated with urban environments.
Sediment deposition/ infilling and excavation	Deposition includes sediment from excessive erosion or human disturbance (e.g. a construction site) upstream of the wetland, which is carried by water and deposited in the wetland. Infilling is the placement by humans of fill material in the wetland (e.g., for a sports field). Excavation is the direct human removal (usually with heavy machinery) of sediment from the wetland, which is commonly associated with mining and sand winning
Eroded areas	In wetlands this typically occurs as gully erosion.
Land uses commonly associated with moderate transformation of vegetation characteristics.	
Old / abandoned lands	These secondary vegetation areas have typically been altered through historic agricultural practices, but are in the process of recovering. They are generally characterized by a high relative abundance of ruderal species, but this abundance may vary greatly depending on time since cultivation ceased. In cases where this varies greatly within an HGMU, it may be worthwhile to distinguish between vegetation classes comprising recently abandoned lands and areas comprising older lands that are at a more advanced successional stage of recovery.
Land uses generally associated with low or no transformation of wetland vegetation.	
Seepage below dams	Earthen dams used for agricultural purposes often allow water to leak through the wall, creating artificial wetter areas below the dam wall. Such areas are typically characterized by an increase in hydric species.
Minimal human disturbance	These primary vegetation areas have not been significantly impacted by human activities, but may have been impacted upon by factors such as scattered alien plants. This may include wetland areas within game or extensive grazing management systems. Small pockets of untransformed vegetation may also be set aside as streamside buffers

	on commercial landholdings.

Table 40: Impact categories and associated intensity of impact scores

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

Table 41: Present Vegetation Health categories used in WET-Health
Adapted from Macfarlene et al., (2008)

Description	Overall Impact Score	Present Vegetation Health Category
Vegetation composition appears natural.	0-0.9	A
A very minor change to vegetation composition is evident at the site.	1-1.9	B
Vegetation composition has been moderately altered but introduced; alien and/or increased ruderal species are still clearly less abundant than characteristic indigenous wetland species.	2-3.9	C
Vegetation composition has been largely altered and introduced; alien and/or increased ruderal species occur in approximately equal abundance to the characteristic indigenous wetland species.	4-5.9	D
Vegetation composition has been substantially altered but some characteristic species remain, although the vegetation consists mainly of introduced, alien and/or ruderal species.	6-7.9	E
Vegetation composition has been totally or almost totally altered, and if any characteristic species still remain, their extent is very low.	8 - 10	F

Table 42: Evaluation of Trajectory of Change of vegetation within hydro-geomorphic unit 1

Disturbance class	Description	Source of change	Disturbance class extent (%) (Table 28)	Change score (Table 44, Appendix 6)	Area-weighted change score*
1	Infrastructure – gravel road	Gravel road	1.54	0	0.0
2	Perennial pastures	Perennial pastures	41.68	0	0.0
3	Dense alien vegetation patches	It is likely that the wetland vegetation will improve due to the follow – ups of IAPs clearing by WfWater both at the site and in upstream. However, it will be a slight improvement as the alien vegetation is located on places which are less accessible for clearing and will continue disperse their seeds.	6.62	1	0.1
4	Infilling (gabion weir)	No change	0.23	0	0.0
5	Eroded areas	No change	0.22	0	0.0
6	Natural	It is likely to improve substantially due to restored water retention by the gabion weir and increased base flow due to clearing of IAPs	49.73	2	1.0
				HGM change score**	**1.1**

Area weighted change score = Disturbance Class extent /100 x change score
HGM change score = sum of individual area weighted scores for each disturbance unit

Table 43: Evaluation of Trajectory of Change of vegetation within hydro-geomorphic unit 2

Disturbance class	Description	Source of change	Disturbance class extent (%) (Table 29)	Change score (Table 44, Appendix 6)	Area-weighted change score*
1	Infrastructure – cattle path	No change	0.06	0	0.0
2	Perennial pastures	No change	2.16	0	0.0
3	Dense alien vegetation patches	It is likely that the wetland vegetation will improve due to the follow – ups of IAPs clearing by WfWater both at the site and in upstream. However, it will be a slight improvement as the alien vegetation is located on places which are less accessible	8.10	1	0.1
4	Sediment deposition /infilling (gabion)	No change	7.26	0	0.0
5	Eroded areas	Vegetation is likely to deteriorate	10.73	-1	-0.1

		slightly as the erosion continues			
6	Minimal human disturbance	It is likely to deteriorate slightly due to the further desiccating impacts of the incised riverbed and increasing disturbance by cattle due to experienced droughts in the area	19.67	-1	-0.2
7	Shallow flooding by gabion weir	No change	0.47	0	0.0
8	Natural	No change	48.78	0	0.0
				HGM change score**	**-0.22**

*Area weighted change score = Disturbance Class extent /100 x change score
**HGM change score = sum of individual area weighted scores for each disturbance unit

Table 44: Trajectory classes, change scores and symbols to evaluate likely Trajectory of Change of wetland vegetation Adapted from (Macfarlane et al. 2008)

Trajectory Class	Description	Change Score	Change Class Range	Symbol
Improve markedly	Vegetation is likely to improve substantially over the next 5 years	2	1.1 to 2.0	(↑↑)
Improve slightly	Vegetation is likely to improve slightly over the next 5 years	1	0.3 to 1.0	(↑)
Remain stable	Vegetation is likely to remain stable over the next 5 years	0	-0.2 to +0.2	(→)
Deteriorate slightly	Vegetation is likely to deteriorate slightly over the next 5 years	-1	-0.3 to -1.0	(↓)
Deteriorate markedly	Vegetation is expected to deteriorate substantially	-2	-1.1 to -2.0	(↓↓)

Appendix 7 – Current Ecosystem Services (WET-EcoServices tool)

Table 45: Summary of calculated scores of ecosystem services by using the tool WET-EcoServices

Date of assessment: June, 2012 Name of assessor: Nikolett Czeglédi Details of owner/ authority: Location (Latitude/Longitude): Wetland name: Hudsonvale Size: 54 ha	Hydro-geomorphic setting of wetland F=Floodplain, VC=Valley-bottom with channel, V=Valley-bottom without channel, HW=Hillslope seepage feeding a water course, H=Hillslope seepage not feeding a watercourse, D=Depression

Ecosystem services and assessment characteristics	Scoring system					Hydro-geomorphic unit 1		Hydro-geomorphic unit 2	
	0	1	2	3	4	Score	Confidence Rating	Score	Confidence Rating
Flood attenuation									
Effectiveness of the wetland									
Size of wetland relative to catchment	<1%	1%-2%	3-5%	6-10%	>10%	0	4	0	4
Slope of wetland*	>5%	2-5%	1-1.9%	0.5-0.9%	<0.5%	4	4	4	4
Surface roughness of wetland*	Low	Mod low		Mod high	High	3	4	1	4
Depressions	None	Present but few or remain permanently filled close to capacity	Intermediate	Moderately abundant	Abundant	0	4	0	4
Frequency with which stromflows spread across the wetland	Never	Occasionally but less frequently than every 5 years		1 to 5 year frequency	More than once a year	3	4	3	3
Sinuosity of the stream channel	Low	Moderately low	Intermediate	Mod high	High	1	4	1	4

Representation of different hydrological zones*	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGMU area	2	4	1	4
Score for effectiveness:						*1.9*	*4.0*	*1.4*	*3.9*
Opportunity for attenuating floods									
Average slope of the wetland's catchment	<3%	3-5%	6-8%	9-11%	>11%	4	4	4	4
Inherent runoff potential of soils in catchment	Low	Mod low		Mod high	High	1	3	1	3
Contribution of catchment land-uses to changing runoff intensity from the natural condition	Decrease	Negligible effect	Slight increase	Moderate increase	Marked increase	0	4	1	3
Rainfall intensity	Low (Zone I)	Moderately low (Zone II)		Mod high (Zone III)	High (Zone IV)	4	4	4	4
Extent of floodable property downstream*	Low/ negligible	Moderately low		Moderately high	High	1	3	1	3
Score for opportunity:						*2.0*	*3.6*	*2.2*	*3.4*
Overall score/rating for flood attenuation						**1.9**	**3.8**	**1.8**	**3.7**
Streamflow regulation									
Link to the stream network	No link (i.e. hydrologically isolated)				Linked to the stream system	4	4	4	4
Representation of different hydrological zones*	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGMU area	2	4	3	4
Presence of fibrous peat or unconsolidated sediments below floating marsh	Absent	Present but limited in extent/depth		Moderately abundant	Extensive and relatively deep (>1.5 m)	3	4	1	3

Reduction in evapotranspiration through frosting back of the wetland vegetation	Low	Moderately low	Intermediate	Moderately high	High	0	3	0	3
HGMU occurs on underlying geology with strong surface-groundwater linkages	No		Underlying geology quartzite	Underlying geology sandstone	Underlying geology dolomite	3	4	3	4
Presence of any important wetlands or aquatic systems downstream*	None		Intermediate importance		High importance	2	3	2	3
Overall score/rating for streamflow augmentation						**2.3**	**3.7**	**2.2**	**3.5**
Sediment trapping									
Effectiveness of the wetland									
Effectiveness in attenuating floods						1.9	4.0	1.4	3.9
Direct evidence of sediment deposition	Low	Mod low	Intermediate	Mod high	High	2	3	3	3
Score for effectiveness:						*1.93*	*3.5*	*2.21*	*3.4*
Opportunity									
Extent to which dams are reducing the input of sediment	High	Mod high	Intermediate	Mod low	Low	3	3	1	4
Extent of sediment sources delivering sediment to the HGMU*	Low	Mod low	Intermediate	Mod high	High	1	4	2	3
Presence of any important wetlands or aquatic systems downstream*	None		Intermediate importance		High importance	2	3	2	3
Score for opportunity:						*2*	*3.33*	*1.67*	*3.33*
Overall score/rating for sediment trapping						**2.0**	**3.4**	**1.9**	**3.4**
Phosphate trapping									
Effectiveness of the wetland									
Effectiveness of trapping sediment						1.9	3.5	2.2	3.4
Pattern of low flows *	Strongly channelled	Moderately channelled	Intermediate	Moderately diffuse	Very diffuse	2	4	0	2
Extent of vegetation cover*	Low	Mod low	Intermediate	Mod high	High	4	4	2	3
Application of fertilizer/biocides	High	Mod high	Intermediate	Mod low	Low	0	3	0	3

directly in the HGMU*									
Score for effectiveness:						*2.0*	*3.6*	*1.1*	*2.9*
Opportunity									
Extent of sediment sources delivering sediment to the HGMU*	Low	Mod low	Intermediate	Mod high	High	1	4	2	3
Extent of other potential sources of phosphates in the HGMU's catchment	Low	Mod low	Intermediate	Mod high	High	2	3	1	3
Presence of any important wetlands or aquatic systems downstream*	None		Intermediate importance		High importance	2	3	2	3
Score for opportunity:						*1.67*	*3.33*	*1.67*	*3.0*
Overall score/rating for phosphate trapping						**1.8**	**3.5**	**1.4**	**2.9**
Nitrate removal									
Effectiveness									
Representation of different hydrological zones*	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGMU area	2	4	3	4
Pattern of low flows*	Strongly channelled	Moderately channelled	Intermediate	Moderately diffuse	Very diffuse	2	4	0	2
Extent of vegetation cover*	Low	Mod low	Intermediate	Mod high	High	4	4	2	3
Contribution of sub-surface water inputs relative to surface water inputs	Low (<10%)	Moderately low (10-20%)	Intermediate (20-35%)	Moderately high (36-50%)	High (>50%)	1	3	1	3
Application of fertilizer/biocides directly in the HGMU*	High	Mod high	Intermediate	Mod low	Low	0	3	0	3
Score for effectiveness:						*1.8*	*3.6*	*1.2*	*3.0*
Opportunity									
Extent of nitrate sources in the HGMU's catchment	Low	Mod low	Intermediate	Mod high	High	2	3	1	2
Presence of any important wetlands	None		Intermediate		High importance	2	3	2	3

or aquatic systems downstream*			importance						
Score for opportunity:						*2*	*3*	*1.5*	*2.5*
Overall score/rating for nitrate removal						**1.9**	**3.4**	**1.4**	**2.9**
Toxicant removal									
Effectiveness									
Representation of different hydrological zones*	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGMU area	2	4	3	4
Pattern of low flows*	Strongly channelled	Moderately channelled	Intermediate	Moderately diffuse	Very diffuse	2	4	0	2
Extent of vegetation cover*	Low	Mod low	Intermediate	Mod high	High	4	4	2	3
Effectiveness in trapping sediment						1.9	3.5	2.2	3.4
Application of fertilizer/biocides directly in the HGMU*	High	Mod high	Intermediate	Mod low	Low	0	3	0	3
Score for effectiveness:						*2.0*	*3.7*	*1.4*	*3.1*
Opportunity									
Extent of sediment sources delivering sediment to the HGMU*	Low	Mod low	Intermediate	Mod high	High	1	3	2	4
Extent of toxicant sources	Low	Mod low	Intermediate	Mod high	High	2	4	0	3
Presence of any important wetlands or aquatic systems downstream*	None		Intermediate importance		High importance	2	3	2	3
Score for effectiveness:						*1.67*	*3.33*	*1.33*	*3.33*
Overall score/rating for toxicant removal						**1.8**	**3.6**	**1.4**	**3.2**
Erosion control									
Effectiveness									
Direct evidence of erosion	High	Mod high	Intermediate	Mod low	Low	4	4	1	3
Extent of vegetation cover*	Low	Mod low	Intermediate	Mod high	High	4	4	2	3
Surface roughness of wetland*	Low	Mod low		Mod high	High	3	4	1	4

Level of soil disturbance in wetland*	High	Mod high	Intermediate	Mod low	Low	2	3	3	3
Score for effectiveness:						*3.3*	*3.8*	*1.8*	*3.3*
Opportunity									
Slope of wetland*	>5%	2-5%	1-1.9%	0.5-0.9%	<0.5%	4	4	4	4
Erodibility of the soil	Low	Mod low	Intermediate	Mod high	High	3	2	3	2
Runoff intensity from the wetland's catchment	This characteristic that is derived from other characteristics and therefore does not need to be entered directly					2.25	0	2.5	0
Score for opportunity:						*3.1*	*2.0*	*3.2*	*2.0*
Overall score/rating for erosion control						**3.2**	**3.0**	**2.5**	**2.7**
Carbon storage									
Representation of different hydrological zones*	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGMU area	2	4	3	4
Abundance of peat	Absent	Present but limited in extent/depth	Intermediate	Moderately abundant	Extensive and relatively deep (>0.5 m)	4	4	3	3
Level of soil disturbance in wetland*	High	Mod high	Intermediate	Mod low	Low	2	3	3	3
Overall score/rating for carbon storage						**2.7**	**3.7**	**3.0**	**3.3**
Biodiversity maintenance									
HGMU is of a rare type or is of a wetland type or vegetation type subjected to a high level of cumulative loss	No				Yes	0	2	0	2
Level of cumulative loss of wetlands in the overall catchment	Low	Mod low	Intermediate	Mod high	High	4	4	0	4
Red Data species or suitable habitat for Red Data species	No				Yes	4	2	4	2
Level of significance of other special	None	Mod low	Intermediate	Mod high	High	0	3	0	3

natural features									
Score for noteworthiness:						*2.0*	*2.8*	*1.0*	*2.8*
Extent of buffer around wetland	Low	Mod low	Intermediate	Mod high	High	0	4	0	4
Connectivity of wetland in landscape	Low	Mod low	Intermediate	Mod high	High	0	4	1	4
Alteration of hydrological regime	High	Mod high	Intermediate	Mod low	Low/negligible	1	4	0	4.0
Alteration of sediment regime	This characteristic that is derived from other characteristics and therefore does not need to be entered directly					2	3.33	1	3.33
Alteration of nutrient/toxicant regime	This characteristic that is derived from other characteristics and therefore does not need to be entered directly					0	3.33	0	3.33
Complete removal of indigenous vegetation	>50%	25-50%	5-25%	1-5%	<1%	1	4	3	4
Invasive and pioneers species encroachment	>50%	25-50%	5-25%	1-5%	<1%	1	4	1	4
Presence of hazardous/restrictive barriers	High	Mod high	Intermediate	Mod low	Low/negligible	3	4	4	4
Score for integrity:						***1.0***	***3.83***	***1.3***	***3.83***
Overall score/rating for maintenance of biodiversity						***1.5***	**3.5**	***1.1***	**3.5**
Water supply									
Representation of different hydrological zones*	Permanent & seasonal zones lacking (i.e. only the temporary zone present)	Seasonal zone present but permanent zone absent	Permanent & seasonal zones both present but collectively <30%	Seasonal & permanent zone both present & collectively 30-60%	Seasonal & permanent zone both present & collectively >60% of total HGMU area	2	4	3	4
Importance for streamflow augmentation						2.3	3.7	2.2	3.5
Current use for agricultural purposes	No use	Mod low	Intermediate	Mod high	High	4	3	4	3
Current use for domestic purposes	No use	Mod low	Intermediate	Mod high	High	0	4	0	4
Number of households	None	1-2	3-4	5-6	>6	1	4	1	4
Substitutability of wetland water source	High	Mod high	Intermediate	Mod low	Low	3	3	3	3
Overall score/rating for water supply						**2.1**	**3.6**	**2.2**	**3.6**

Provision of harvestable natural resources									
Number of different resources used	None	1		2-3	>3	0	4	1	4
Location in rural communal area*	No				Yes	0	4	0	4
Level of poverty*	Low/ negligible	Mod low	Intermediate	Mod high	High	0	4	0	4
Number of households depending on wetland	None	1	2-3	4-5	>6	0	4	0	4
Substitutability of the wetland resources	High	Mod high	Intermediate	Mod low	Low	0	3	1	3
Overall score/rating for source of goods /resources						**0.0**	**3.8**	**0.4**	**3.8**
Provision of cultivated foods									
Total number of different crops cultivated in the HGMU	None	1		2-3	>3	3	4	3	4
Location in rural communal area*	No				yes	0	4	0	4
Level of poverty*	Low/ negligible	Mod low	Intermediate	Mod high	High	0	4	0	4
Number of households who depend on the crops cultivated in the HGMU	None	1	2-3	4-6	>6	0	4	0	4
Substitutability of the crops cultivated in the wetland	High	Mod high	Intermediate	Mod low	Low	1	4	0	4
Overall score/rating for source of goods /resources						**0.8**	**4.0**	**0.6**	**4.0**
Cultural significance									
Registered SAHRA site	No				Yes	0	4	0	4
Location in rural communal area*	No				yes	0	4	0	4
Known cultural practices	None	Historically present but no longer practised		Present but practised to a limited extent	Present & still actively & widely practised	0	4	0	4
Known taboos/beliefs	None	Historically present but no longer so		Present but held to a limited extent	Present & still actively & widely held	0	4	0	4
Overall score/rating for socio-						***0.0***	**4.0**	***0.0***	**4.0**

cultural significance									
Tourism and recreation									
Scenic beauty of the HGMU	Low/negligible	Mod low	Intermediate	Mod high	High	3	4	1	3
Presence of "charismatic" species	None present	Very seldom seen	Occasionally present	Generally present	Always present	1	3	1	3
Currently used for tourism or recreation	No use	Mod low use	Intermediate use	Mod high use	High	0	4	0	4
Availability of other natural areas providing similar experiences to the HGMU	High	Mod high	Intermediate	Mod low	Low	0	4	0	4
Location within a tourism route	Low/negligible	Mod low	Intermediate	Mod high	High	2	4	2	4
Recreational hunting and fishing and birding opportunities	None	Mod low	Intermediate	Mod high	High	0	4	0	4
Extent of open water	None	Present, but very limited		Extent somewhat limited	Extensive	1	4	3	4
Overall score/rating for tourism and recreation						***1.0***	**4.0**	***1.0***	**4.0**
Education and research									
Currently used	No use	Mod low	Intermediate	Mod high	High	4	3	2	3
Reference site suitability	Low	Mod low	Intermediate	Mod high	High	1	3	0	4
Existing long term research & data collected	None	Mod low	Intermediate detail/ time period	Mod high	Comprehensive data over long period	2	4	2	4
Accessibility	Very inaccessible	Moderately inaccessible	Intermediate	Moderately accessible	Very accessible	1	4	1	4
Overall score/rating for education and research						**2.0**	**3.5**	**1.3**	**3.8**
Level of threats	Low	Moderately low	Intermediate	Moderately high	High	**2**	**3**	**3**	**4**
Level of opportunities	Low	Moderately low	Intermediate	Moderately high	High	**1**	**3**	**3**	**3**

* Characteristic used for assessing more ecosystem services