THE EFFECT OF THE LIONS RIVER FLOODPLAIN ON DOWNSTREAM WATER QUALITY

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ABSTRACT

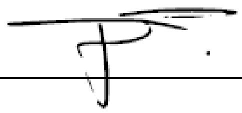
Wetlands provide important ecosystem services, including the purification of water. The uMngeni catchment is an important basin providing water to the cities of Pietermaritzburg and Durban, South Africa's second largest economic hub. However, there are rising concerns over the deterioration of water quality in Midmar Dam, a large impoundment within this basin. The Lions River, one of the main tributaries to Midmar Dam, transports pollutants from its catchment, as well as the Mooi River catchment through the recently implemented Mooi-Mgeni transfer scheme (MMTS) into the impoundment. This study aims to establish a baseline ecological integrity and effect on downstream water quality of the Lions River floodplain, an important, but degraded, wetland in the uMngeni catchment, to provide a guide for the planning and implementation of rehabilitation interventions. A comprehensive assessment of the wetland's structure was undertaken using vegetation and soil parameters, mapped and compared with an interpretation of landuse change within the wetland based on historical aerial photographs. The wetland's impact on downstream water quality was assessed by sampling water at various points in the Lions River channel through the floodplain over a period of one year. The study found that the wetland's ecological integrity has decreased due historical landuse in the floodplain. A comparison of soil wetness indicators which reflect the historic extent of the floodplain and vegetation wetness indicators which reflect the current extent of the floodplain suggest that although localised drying out of some areas has occurred, most of the historical floodplain area still supports wetland conditions. Wetness indicators of soil and vegetation indicate a transformation in the wetland's water regime. A moderate to high abundance of ruderal and alien invasive species in 61% of the floodplain, particularly the drier areas of the floodplain, further indicate a reduction in ecosystem health. Hydrological processes emerge as the key drivers of species composition and historical landuse in the floodplain. Water quality results indicate that total oxidised nitrogen decreased from upstream to downstream whilst ammonia concentrations remained stable at all the sampling points. Soluble reactive phosphorus concentrations increased, while total phosphorus concentrations decreased from upstream to downstream. This study highlighted the importance of detailed field studies and understanding for rehabilitation planning to return ecosystems to their natural function.

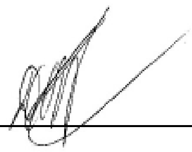
PREFACE

The research contained in this dissertation was completed by the candidate while based in the Centre for Water Resources Research, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa, under the supervision of Professor GPW Jewitt and co-supervisor Dr D Kotze. The research was financially supported by Sappi Southern Africa Limited – Forests and Water Research Commission.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Chapter 3 and Chapter 4 in this dissertation are written in the form of research papers based on research work done.





Supervisor: Prof GPW Jewitt

Date: 10 December 2015

Co-supervisor: Dr D Kotze

Date: 10 December 2015

DECLARATION 1 – PLAGIARISM

I, ______**Hlengiwe Ndlovu**______, declare that:

1. the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;
2. this dissertation has not been submitted in full or in part for any degree or examination to any other university;
3. this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;
4. this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a. their words have been re-written but the general information attributed to them has been referenced;
    b. where their exact words have been used, their writing has been placed inside quotation marks, and referenced;
5. where I have used material for which publications followed, I have indicated in detail my role in the work;
6. this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;
7. this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: Hlengiwe Ndlovu

Date: 10 December 2015

DECLARATION 2 – PUBLICATIONS

DETAILS OF CONTRIBUTION OF PUBLICATIONS that form part and/or include research presented in this dissertation (include publications in preparation, submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication).

Publication 1 – Chapter 3

Ndlovu, H, Kotze, D, Jewitt, GPW and Morris, C. in preparation. An assessment of the ecological condition based on soil and vegetation parameters of the Lions River floodplain, South Africa.

Research for this publication was conducted by H. Ndlovu with technical advice from D. Kotze and GPW. Jewitt. This publication was written in its entirety by H. Ndlovu and all data tables, graphs and maps were produced by the same, unless otherwise referenced in the text of the paper. The statistical analysis was conducted by C. Morris using data collected and prepared by H. Ndlovu. The output from the statistical analysis was used in generating the corresponding graphs in the publication. Editing and advice regarding data interpretation was provided by D. Kotze and GPW. Jewitt.

Publication 2 – Chapter 4

Ndlovu, H, Jewitt, GPW and Kotze, D. in preparation. Impact of the Lions River floodplain on downstream water quality.

Research for this publication was conducted by H. Ndlovu with technical advice from GPW. Jewitt and D. Kotze. This publication was written in its entirety by H. Ndlovu and all data tables, graphs and photos were produced by the same, unless otherwise referenced in the text of the paper. Editing and advice regarding data interpretation was provided by GPW. Jewitt and D. Kotze.

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1 INTRODUCTION

The term wetland is used worldwide to refer to ecosystems which are primarily driven by the interplay of land and water and the consequential characteristics which influence plants, animals and soils occurring in the area. In South Africa, the National Water Act (Act No 36 of 1998) defines a wetland as *“land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.”*

Wetlands are sensitive, yet important ecosystems of high value for the provision of goods and services to society, but are being rapidly and widely degraded (Walters *et al.*, 2006; Swanepoel and Barnard, 2007). Worldwide, wetlands are increasingly subjected to many human activities, including agriculture, urbanisation, extraction of biological goods and flood control practices (Sutula *et al*., 2006; Kotze *et al*., 2012), leaving them in a degraded condition. Whilst South African wetlands continue to be lost as a result of ecosystem degradation, scientific insight used to understand the impacts of landuse on these ecosystems is mainly based on Euro-American studies (Walters *et al*., 2006) and knowledge on the functioning and structure of local wetlands remains poor. It is therefore important to establish baselines against which management practices and impacts of future developments can be assessed and predicted. (Kotze and O’Connor, 2000).

In the uMngeni catchment, which drains the important economic areas around the cities of Pietermaritzburg and Durban in KwaZulu-Natal, South Africa, approximately half of the original wetland area has been lost due to human disturbance (Kotze and O’Connor, 2000; WRC, 2002; Rivers-Moore and Cowden, 2012). The remaining wetland areas continue to be threatened by cultivation, artificial drainage, alien invasive plants, too frequent burning and over grazing in the upper catchment (WRC, 2002). Furthermore, there is concern over the deterioration of water quality in Midmar Dam, the main water supply dam for the catchment (GroundTruth, 2012; Ngubane *et al*., 2015; Namugize *et al*., 2015).

In response to the water security needs on the uMngeni catchment, the uMngeni Ecological Infrastructure Partnership (UEIP) was formed. This partnership, a collaboration between stakeholders of the uMngeni catchment including private industry, government departments, local municipalities and research institutions, amongst others, has recognised the need for a coordinated effort to secure water resources within the catchment. Ecological infrastructure is defined as naturally functioning ecosystems that produce and deliver valuable services to people, such as climate change regulation, fresh water and disaster risk reduction (SANBI, 2013). These ecosystems include mountain catchments, rivers and wetlands.

The Lions River floodplain wetland lies just upstream of Midmar Dam on the Lions River and therefore presents an important opportunity for investing in ecological infrastructure for the UEIP. This study aims to establish the baseline ecological integrity of this important wetland by assessing the ecosystem's structure and functioning, as well as establish the effect of the floodplain on downstream water quality. This is to provide a guide for the planning and implementation of rehabilitation interventions on the wetland.

1.1 Research Objectives

The primary objective of the research described herein is to determine the baseline ecological condition of the Lions River floodplain, to enable recommendations on rehabilitation interventions to be made. To fulfil this, the study aims to answer the following two central research questions:

1. What is the current ecological condition and functioning of the Lions River floodplain based on vegetation composition and soil morphology as indicators of hydrological regime?
2. What effect is the floodplain having on the quality of water flowing through the main channel from upstream to downstream?

1.2 Document Structure

This dissertation is structured according the "paper format" in accordance with the regulations of the University of KwaZulu-Natal. It should be noted that using this structure means that some degree of repetition is inevitable, particularly with regards to site description and the like.

The main body comprises of three chapters which are preceded by an overall introduction and followed by a final discussion and conclusion. Although the research chapters are intended for journals, their structure is consistent with that of this dissertation.

Chapter 2 is based on the relevant literature that highlights wetland ecosystems function, their importance for water security and ecosystem service provision. This chapter also highlights the limitations that are experienced in wetland assessment, rehabilitation and monitoring. This review informed the focus and design of the two research chapters that follow. Chapter 3 describes the ecological condition of the Lions River floodplain based on soil and vegetation parameters using established methods. Whilst, Chapter 4 presents a water quality study that examined the effect of the floodplain on downstream water quality.

2 WETLAND REHABILITATION FOR IMPROVED DOWNSTREAM WATER QUALITY – A REVIEW

2.1 Introduction

Wetlands are important ecosystems which provide many ecosystem services, including the trapping of sediment, nutrients and toxic compounds. In South Africa, which is a water-scarce country, wetlands can play an important role in managing the limited water resource by storing and purifying water, recharging groundwater and regulating stream flow (Swanepoel and Barnard, 2007). However, wetlands are subjected to many human activities, including agriculture, urbanisation, extraction of biological goods and flood control practices that are increasing worldwide (Sutula *et al*., 2006; Kotze *et al*., 2012). Consequently, many wetlands are left in a degraded condition both ecologically and hydrologically with a diminished capacity to provide important ecosystem services.

Wetlands have been reported to assimilate non-point source pollution along river channels, improving water quality and controlling the transportation of pollutants downstream (Llorens *et al*., 2009; Fan *et al*., 2012). Wetlands are transitional ecosystems occurring between the upslope drainage areas and the stream channel. Consistent with their position in the landscape, wetlands display a zonation of edaphic and floristic characteristics which is primarily driven by variations in hydro-period, the frequency and duration of saturation (Grenfell *et al*., 2005). The hydro-period, combined with depth, drainage and water source are some of the main factors that influence the provision of ecosystem services such as water quality improvement (Malan and Day, 2012). The excessive alteration of the wetland's hydrological regime by human activities, such as the diversion of water for agricultural use, is likely to lead to the severe degradation of a wetland. In South Africa, wetland degradation has resulted in the need for the assessment of wetlands for a variety of purposes, including wetland management, rehabilitation planning and policy development (Kotze *et al*., 2012).

The processes of wetland degradation and rehabilitation have classically been depicted as occurring on straight parallel paths, but in opposite directions. However, in reality these are complex, involving dynamic changes in biodiversity and ecosystem function (Zedler, 1999). Rehabilitation interventions typically involve efforts to reintroduce plant and animal species and recover ecosystem functions that have been lost through degradation. Unfortunately wetland protection and rehabilitation typically follow belatedly after the loss of many wetlands or after the complete degradation of wetland ecosystems. Little evidence of rehabilitation success exists from long-term monitoring studies of restored wetlands (Zedler, 2000). It is important to develop inclusive monitoring techniques to improve our understanding of the impact of wetland rehabilitation.

This paper provides a review of the effect of wetland rehabilitation on downstream water quality improvement. The importance of rehabilitating wetlands as an aspect of water resources management is also highlighted. In addition, considerations for the necessity of long-term monitoring of rehabilitation interventions are made.

2.2 Wetland Functional Assessments

With growing pollution levels and deteriorating water quality of the world's water resources, it has become important to analyse and understand the effectiveness of wetlands in improving water quality (Fan *et al*., 2012). Wetland ecosystems are acknowledged for performing invaluable functions in the management of water quality and are consequently recognised as an integral component of catchment systems (Grenfell *et al*., 2005). These functions are generally linked to the wetlands' ecological integrity, which drive processes that allow for the provision of these ecosystem functions (Figure 2.1). This has prompted an interest and need for the development of wetland assessment methods that can;

1. assess the condition of wetlands and the levels of stress on ecosystem integrity caused by the degradation of the ecosystem
2. provide a measure for the effectiveness of management and rehabilitation activities, and
3. monitor wetland condition (Fennessy *et al*., 2007).

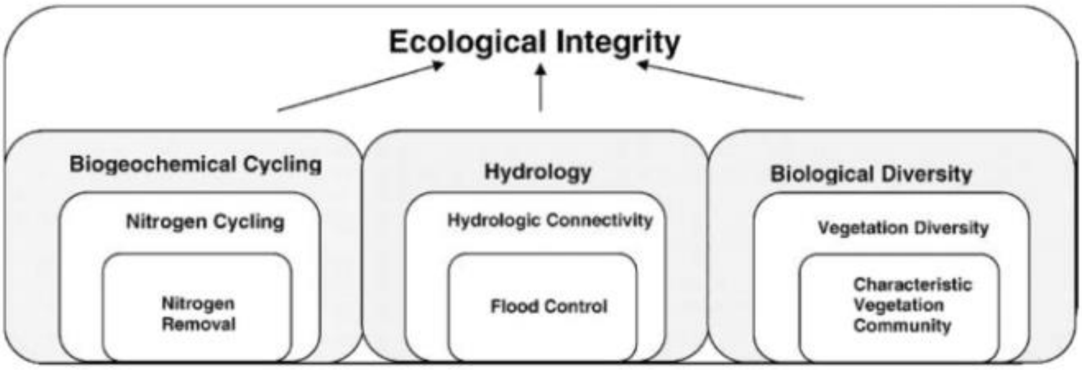


Figure 2.1. Illustration of the ecological integrity concept as the integrating function of wetlands including both ecosystem structure and function (Fennessy *et al.,* 2007)

2.2.1 A hydrogeomorphic approach to wetland functional assessments

The hydrogeomorphic (HGM) method originally developed by Brinson (1993) as a classification method for wetlands and later developed as an assessment tool (Smith *et al*., 1995), assesses wetlands based on hydrological and geomorphological controls. These controls are largely responsible for maintaining the functional aspects of wetland ecosystems. The HGM method places emphasis on the abiotic components of a wetland for functions such as the chemistry of water, habitat maintenance and water storage and transport. This method produces scores for wetland functions such as biogeochemistry, hydrology, plant community and habitat (Jordan *et al*., 2007). The HGM method requires a characterisation of the wetland, which involves describing the wetland ecosystem and its surrounding landscape, the proposed development or rehabilitation project and its potential impacts on the wetland (Smith *et al*., 1995). The assessment models of the HGM method define the relationship between the wetlands ecosystem, the landscape and the capacity of the wetland to perform a function (such as nutrient removal) by considering the;

1. geomorphic setting, which is the wetland's topographic location within the landscape,
2. water source and its transport, including precipitation, groundwater and surface flow, and
3. hydrodynamics, which is the rate at which water moves in the wetland and the direction of flow (Brinson, 1993; Smith *et al*., 1995).

The assessment models result in a functional index score based on several variable scores, which provide a means of estimating the capacity of a wetland to perform a function in relation to a reference wetland. The variable scores are derived from field observation in a one hectare area around an assessment point in a wetland. The HGM method provides a tool to rapidly and systematically assess the functional capacity of a wetland (Shafer, 2005). The study of the Lions River floodplain uses the HGM approach to wetland functional assessments as the underlying framework over which the hydrology, geomorphology, vegetation and soil characteristics were assessed. The use of the HGM method in wetland functional assessment has both benefit and limitations (Table 2.1).

Table 2.1. The benefits and limitations of using the HGM approach for wetland functional assessments (Source: based on Shafer, 2005)

Benefits	**Limitations**
It is based on the comparison with a reference wetland's data	It does not explicitly assess offsite impacts
It incorporates a classification system as part of the wetland assessment process	Does not assess cumulative impacts at a landscape scale
Provides a rapid assessment procedure	Cannot compare different wetland types
Determines the wetland functional capacity which can be used in determining mitigation and rehabilitation interventions	Does not assign a value to wetland functions

Goodall and Naudé (1998), Fisher and Acreman (2004), Sutula *et al.* (2006) and Fan *et al*. (2012) have stressed the importance of also considering wetland characteristics, such as size, location, vegetation and climate when conducting wetland assessments, as these influence the wetlands' ability to perform functions such as denitrification and sedimentation. However, such detailed studies require ample time in the field and taxonomic expertise to complete, which are often not available and not cost-effective (Fennessy *et al*., 2007).

2.2.2 Rapid assessment methods

Rapid assessment methods (RAMs) aim to evaluate natural ecosystems and their complex ecological conditions, using a limited set of indicators or stressors in field (Sutula *et al.,* 2006). These stressors are assessed and used to deduce conclusions about the ecological integrity of a wetland ecosystem. RAMs are increasingly being viewed as integral to the implementation of wetland assessment, rehabilitation and monitoring programmes (Fennessy *et al*., 2007). However, RAMs are still best used as a part of more comprehensive wetland assessment programs, supporting resource inventories and qualitative monitoring.

A review of RAMs was undertaken by Fennessy *et al*. (2007), using four criteria, namely, the method's ability to measure the current condition of the wetland, the necessity for conducting site visits, the efficiency of the method (requiring little taxonomic expertise and time in field) and the ability to verify the assumptions underlying the method. The evaluation was initially of 40 methods, from which 16 were selected for further analysis and then a further six for in-depth evaluation. The review revealed that the evaluated RAMs had multiple applications, including being applied for ecological condition monitoring, mitigation and rehabilitation planning, establishment of wetland performance criterion and regulatory decision-making.

Additionally, Fennessy *et al.* (2007) highlighted the importance of having a clear definition of the study area, as this will influence data collection as well as the analysis and the results of the study. Different wetland types must also be considered, as different wetlands are subject to different stressors and have varying susceptibilities to particular stressors. There may also be issues with scoring, as the results of the assessment are ultimately the "best professional judgement" of the user. Therefore, it is important to clearly document the process for arriving at the result. Finally, it is important to establish the link between a RAM study and comprehensive data, to enable the extrapolation of more detailed results through probability-based sample design for the entire resource base.

In South Africa, Macfarlane *et al*. (2009) developed the tool WET-Health, which is a RAM as a response to decision makers needing to have an easy, user-friendly and cost-effective tool to enhance their ability to make ecologically sound decisions. The WET-Health tool provides a means to carry out a study that covers a broad landscape, based on available data, as well as rapid field assessment method for a wetland (Kotze *et al*., 2012). WET-Health assesses the condition of the wetland using stress indicators based on geomorphology, hydrology and vegetation, for the purpose of rehabilitation planning and assessment (Macfarlane *et al*., 2009). Whilst the tool does assess ecosystem function, it primarily focuses on ecological integrity expressed in terms of deviation from a natural reference state and to a limited extent, water quality. The assessment is based on the key assumptions that a wetland will respond predictably to a stressor. Although geomorphology, hydrology and vegetation indicators are assessed separately in the tool, it is recognised that they are closely linked and may have feedback effects on each other.

2.2.3 The role of wetland functions in the provision of ecosystem services

The review of wetland functional assessment makes a case for the importance of ecosystem functions that occur in wetlands for the provision of services such as water quality improvement, pollution control and flood attenuation (Grenfell *et al*., 2005; Jordan *et al*., 2007; Acreman and Holden, 2013). A wetland's ability to improve water quality is largely dependent on factors such as the water source, hydro-period, drainage pattern and inundation depth. Wetlands which are fed by groundwater, river or over-land run-off will have varying water quality as this is influenced by the type and concentration of chemical constituent which are present in the incoming water (Malan and Day, 2012). Additionally, the duration of saturation as well as drainage pattern will influence water quality as this will have an influence on the contact time between water, soil and vegetation, while also influencing evaporation and the ability of chemicals to concentrate (Jordan *et al*., 2007; Malan and Day, 2012). It is therefore important to assess the wetland's functioning to understand these processes and better inform rehabilitation planning and monitoring. Table 2.2 below highlights some of the important ecosystem services provided by wetlands and the underlying ecosystem functions to which they are linked.

Table 2.2. Wetland ecosystem services with examples of underlying ecosystem functions (Source: based on Grossman, 2010)

Services	**Ecosystems function (structure and process) maintaining the service**
Hydrological services	
Flood water detention	Storage of overbank water, reduction of flow velocity
Groundwater recharge / discharge	Infiltration / seepage of water to / from groundwater
Sediment retention	Sediment deposition
Biogeochemical services	
Nutrient retention	Uptake of nutrients by plants, storage in soil, transformation and gaseous export (denitrification)
Carbon sequestration	Organic matter accumulation
Ecological services	
Food web support	Biomass production
Habitat provision / landscape structural diversity	Habitat (permanent, nursery, migratory resting, etc.) for plants and animals

Riparian habitats and wetlands with fluvial connections are used around the world to improve the quality of water flowing through them in agricultural catchments (Verhoeven *et al*., 2006). Wetland biogeochemical functions enable wetlands to achieve this through nutrient removal and sediment trapping. A collective study of data from 57 natural wetlands around the world by Fisher and Acreman (2004) showed that wetlands reduced nitrogen (N) and phosphorus (P) loading. However this primarily depended on the degree of waterlogging and the duration and rate of nutrient loading. The review suggested that N and P removal required differing wetland types, where P removal was maximised under aerobic conditions which allowed P to bind to iron and aluminium and minimised sediment P-release. In contrast, N removal is maximised by a fluctuating water table where anaerobic and aerobic conditions are juxtaposed within the sediment. Moreover, the review revealed that wetlands that were sampled more frequently and during high flow events were more likely to display increased nutrient loss. This indicates that wetlands can be a source of nutrient loading during high flow events as the sediment to which N and P are bounded is flushed out of the system. This occurs when wetland soils in a nonsaturated aerobic state are flooded and easily extractable soil P is flushed out. However, this only happens in the first few days following the development of anaerobic conditions caused by waterlogging. Soon thereafter, the easily extractable P becomes immobilized again as it is bounded to iron in a solid phase (Kirk *et al*., 1998). Figure 2.2 below illustrates this process graphically.

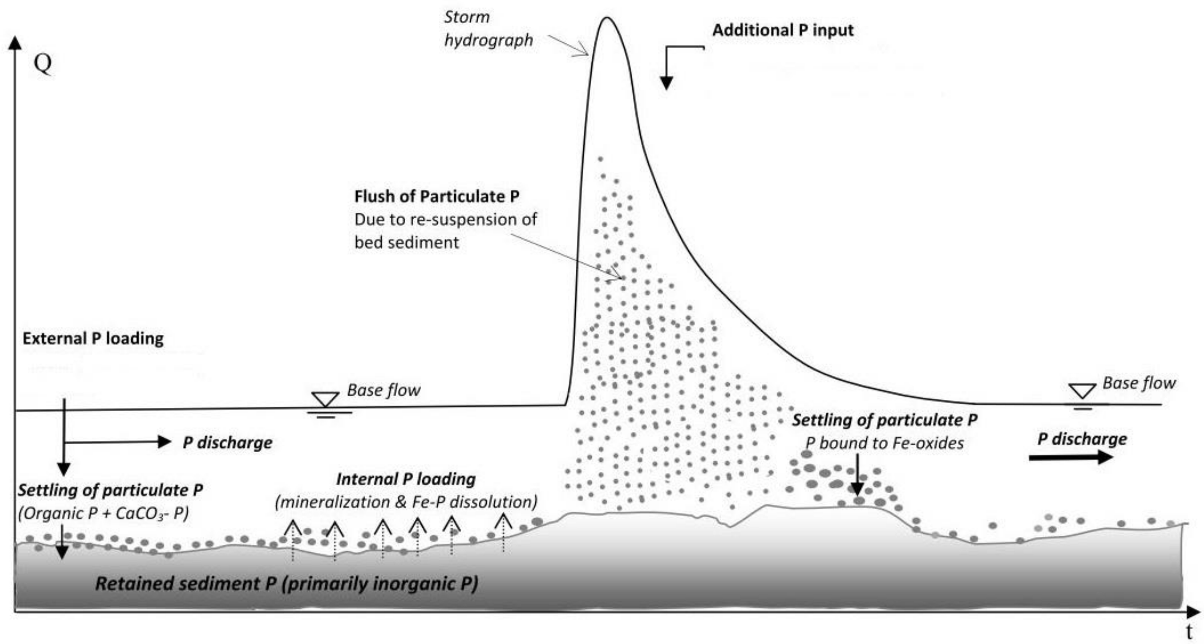


Figure 2.2. Schematic of the possible phosphorus transport processes during low flow and high flood events. The grey oval shapes of different sizes illustrate settling and re-suspension of particulate P (Nyenje *et al*., 2014)

Wetlands have also been known to perform hydrological functions such as flood attenuation and groundwater recharge and discharge (Bullock and Acreman, 2003; Acreman and Holden, 2013). A review of 169 wetland functional studies around the world by Bullock and Acreman (2003) confirmed that wetlands have a strong influence on the hydrological cycle, strengthening the view that wetlands are an integral component of water resources management. In addition, the review found that approximately 80% of the studies suggested that floodplains reduced flooding, while approximately 41% of the headwater studies suggested enhanced flooding. It is therefore, important to consider wetland type when assessing hydrological functions. Wetlands can alter floods in many ways including;

1. changing peak flow which determines the maximum flood level and inundation,
2. rise-time which has an influence on how fast the water rises and how quickly it reaches its peak,
3. the lag-time between precipitation and reaching the flood peak,
4. the duration of the flood, and
5. the flood volume (Acreman and Holden, 2013).

Acreman and Holden (2003) conclude that when assessing wetland hydrological functions, it is important to consider the wetland's location and configuration in the landscape, as in the broad sense upland wetlands tend to enhance flooding, whilst floodplains generally reduce flooding. Topography is also important as it influences the wetland's ability to store surface water. Finally, soil characteristics such as moisture content, grain size, hydraulic conductivity and organic matter content, all have an impact on the wetland's ability to absorb water and the movement of water through the soil.

Wetlands are a reflection of the presence of water in a landscape (Grenfell *et al*., 2005). Their interaction with the environment and the resultant soil and vegetation characteristics can only be understood through their ecosystem functions. HGM functional assessment and RAM's, can provide a basis from which these functions can be understood. However, the understanding of wetland functions can still be significantly improved (Acreman and Holden, 2003; Jordan *et al*., 2007) by incorporating soil properties such as water table depth, percentage water filled pore space, alkalinity, hydraulic conductivity and soil organic matter content, as well as vegetation characteristics. Denitrification which is the most important wetland biogeochemical function contributing to N retention requires an absence of oxygen and a supply of organic carbon and nitrate. Denitrification can be correlated with the availability of organic carbon, water table depth and the percentage of water filled pores (Jordan *et al*., 2007).

Hefting *et al*. (2013) and Verhoeven *et al.* (2006) note that wetlands worldwide are being used to reduce nutrient concentrations in through-flow water and have a significant role to play in improving water quality in agricultural catchments. A ten-year record of water quality data was studied by De Klerk (1997) of two degraded wetlands (wetland 1 and wetland 2, Figure 2.3) in areas dominated by agriculture in the uMngeni River catchment showed that both wetlands improved the quality of water passing through them.

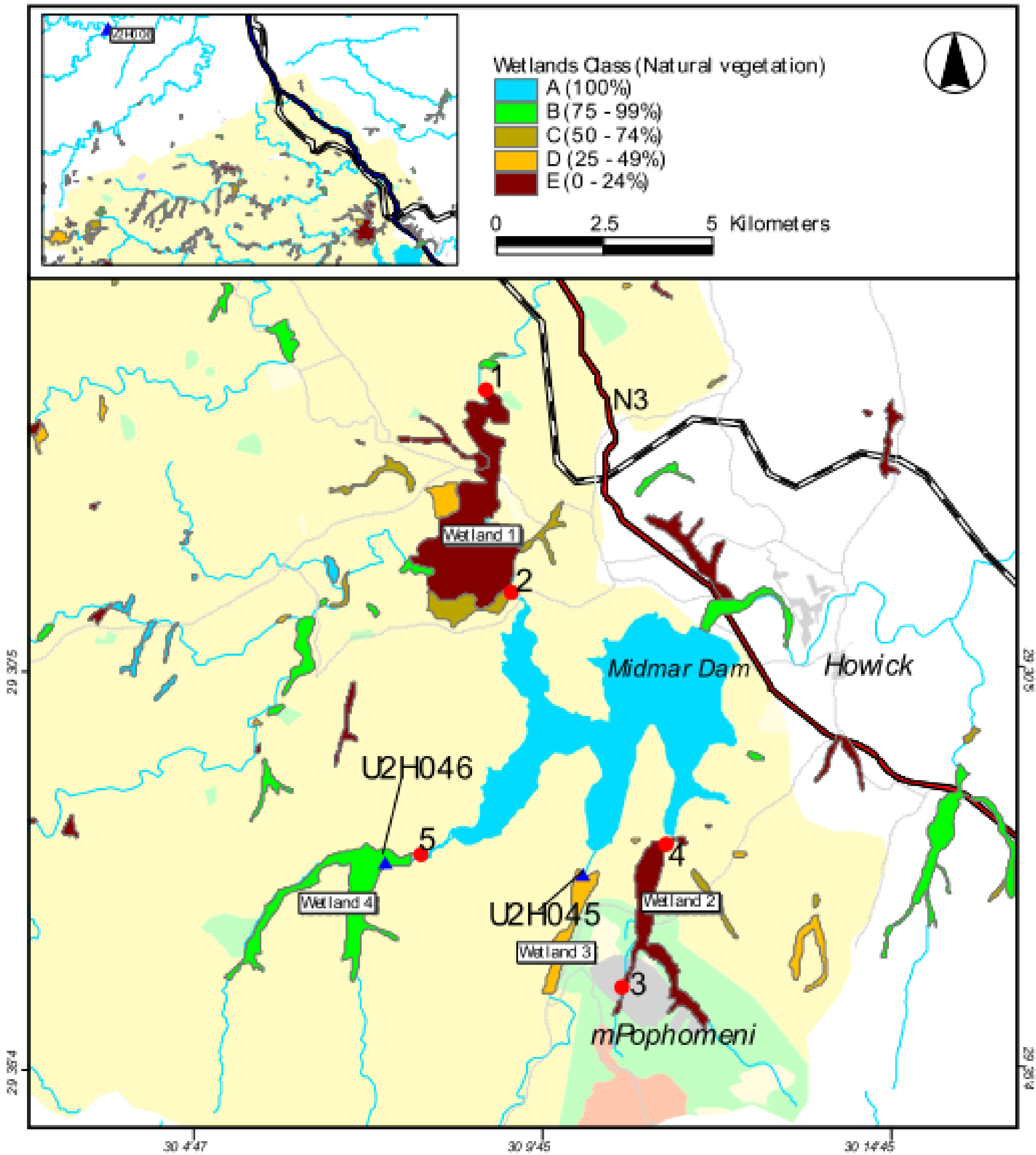


Figure 2.3. Two study wetlands in the uMngeni River catchment (De Klerk, 1997)

While most of the constituents showed improvement, in both wetlands there was no improvement in nitrates. Wetland 2 also showed no improvement in total phosphates. Wetland 2 is located within a township and subjected to high phosphate loading from the township's sewage systems, thus indicating that landuse plays a significant role in the quality of water in wetlands. Although it is important to sample water quality throughout the wetland and not just at the inflow and outflow to account for additional water inputs between upstream and downstream measuring points which may bias the results positively or negatively, this study by De Klerk (1997) is an indication of the potential of wetlands for improving water quality even in a degraded condition. The study site for this study, the Lions River floodplain, comprises of the upper portion of Wetland 1 (Figure 2.3).

2.3 Rehabilitation of Wetland Ecosystems

In view of the increasing loss of natural ecosystems, the field of rehabilitation is a growing area of scientific endeavour, especially concerned with wetland rehabilitation (Whigham, 1999; Llorens *et al*., 2008). The rehabilitation of a wetland's hydrological regime must begin with an understanding of the regime, how it has been altered and how much of it must be restored for the system to function optimally. The hydrological regime can be altered by flood control practices, drainage, in-filling, dams, water diversions and groundwater extraction, which all result in changes to flood peaks, frequency and the duration of flooding (Zedler, 2000; Martinez-Martinez *et al*. 2014).

Rehabilitation interventions are normally aimed at restoring wetland function and enhancing the provision of services such as flood attenuation and water quality improvement. However, the success of these interventions is debatable, as project promoters generally claim success to justify the high costs of rehabilitation (Zedler, 2000; Kolka *et al*., 2000). Whigham (1999) concurred and further stated that with the continued failure of rehabilitation projects, wetland biodiversity continues to decline, although, it is also important to recognise that wetland protection and rehabilitation is only a part of a larger effort to conserve biodiversity.

Wetland rehabilitation and construction projects often fail because of the lack of consideration for the fact that a wetland is part of the larger landscape (Whigham, 1999). This is further exacerbated in non-tidal wetland habitats, where it is considerably harder to restore hydrological conditions. Rehabilitation intervention in non-tidal floodplains must be considered within the context of natural processes such as sedimentation (Ellery *et al*., 2003).

It is also suggested that the rehabilitation of soil conditions forms a vital part in restoring a non-tidal wetland (Whigham, 1999).

The use of reference wetlands in rehabilitation efforts is highly desired for gaining information, which can be used in preparation for rehabilitation interventions to reduce the probability of failure and partial successes (Whigham, 1999; Sutula *et al*., 2006). Rehabilitated wetlands can also be compared to natural reference wetlands, to determine the extent to which rehabilitation interventions were successful in restoring ecosystem function and biodiversity. Moreover, reference wetlands can be used to guide efforts to ensure that wetland rehabilitation is successful. However, Kotze *et al.* (2012) notes that there is lack of data for reference wetlands in South Africa and this is echoed by Li *et al.* (2012) in China and Sutula *et al*. (2006) in the United States.

Wetlands are a cost-effective method for improving water quality, while yielding added benefits such as flood attenuation, contributing to biodiversity conservation and providing for human recreational and cultural needs (Natho and Venohr, 2014). Rehabilitation interventions are important for reclaiming degraded landscapes and mitigating the impacts of human developments especially in agricultural and industrialised catchments.

2.4 Monitoring the Outcomes of Wetland Rehabilitation

Little evidence of rehabilitation success exists from long-term monitoring studies of restored wetlands (Zedler, 2000). Although the investment of public funds into the protection and rehabilitation of wetlands has occurred, wetland loss continues as wetland conditions are not monitored routinely. Additionally, monitoring efforts across projects are not consistent, thus making it difficult to conduct analyses and draw conclusions to inform decision making (Sutula *et al.*, 2006).

Zedler (2000) and Kolka *et al.* (2000) argue that monitoring techniques used to monitor the impacts of rehabilitation interventions are biased towards predicting success, by considering changes to single wetland components, such as the rehabilitation of hydrological condition in isolation of the how that change will impact other components, such as vegetation and biodiversity. Therefore, it is important to develop inclusive monitoring techniques to improve our understanding of the impact of wetland rehabilitation. Braack *et al*. (n.d) notes that it is important to initiate monitoring programmes before or early in the process of wetland rehabilitation to establish a baseline upon which the effectiveness of rehabilitation interventions can be measured against. Also, the monitoring programme is often the only tangible feedback available to managers.

In developing monitoring programmes for wetland rehabilitation projects, it's important to consider all aspect of the project, including social and ecosystem benefits. This will determine the approach (Table 2.3), intensity and frequency of monitoring. Other important considerations include:

1. What level of monitoring provides answers to the key question being asked by the project (e.g. did the project improve the wetland's ability to enhance water quality?)?
2. Does the monitoring answer the question at an appropriate level for the stakeholders involved in the project?
3. Does the monitoring programme match the resources available to the project in terms of funding, time and skills (Water and Rivers Commission, 2002)?

Table 2.3. Qualitative and quantitative approaches for monitoring the wetland rehabilitation outcomes (based on NOAA, n.d)

Qualitative	**Quantitative**
• Aerial photographs of the wetland area showing the wetlands general hydrology and vegetation cover • Ground-level photographs for identification of some plant species, general level of plant growth, and general water levels • General site observations such as turbidity, presence of solid waste, evidence of human use, vegetation condition, presence of invasive plants and evidence of erosion	• Measurement of water level changes with an automatic water level gauge • Sampling water periodically to assess changes in water quality • Collecting of soil samples to test for organic matter and other soil characteristics • Surveying surface elevations at permanent transects once a year • Recording plant species and cover by species along randomly established transects across the site

It is important develop monitoring programmes which are appropriate for the project and are within the available budget (Figure 2.4). Monitoring the effects of rehabilitation interventions forms an important component of wetland rehabilitation project and facilitates a learning and continual improvement process for rehabilitation projects.

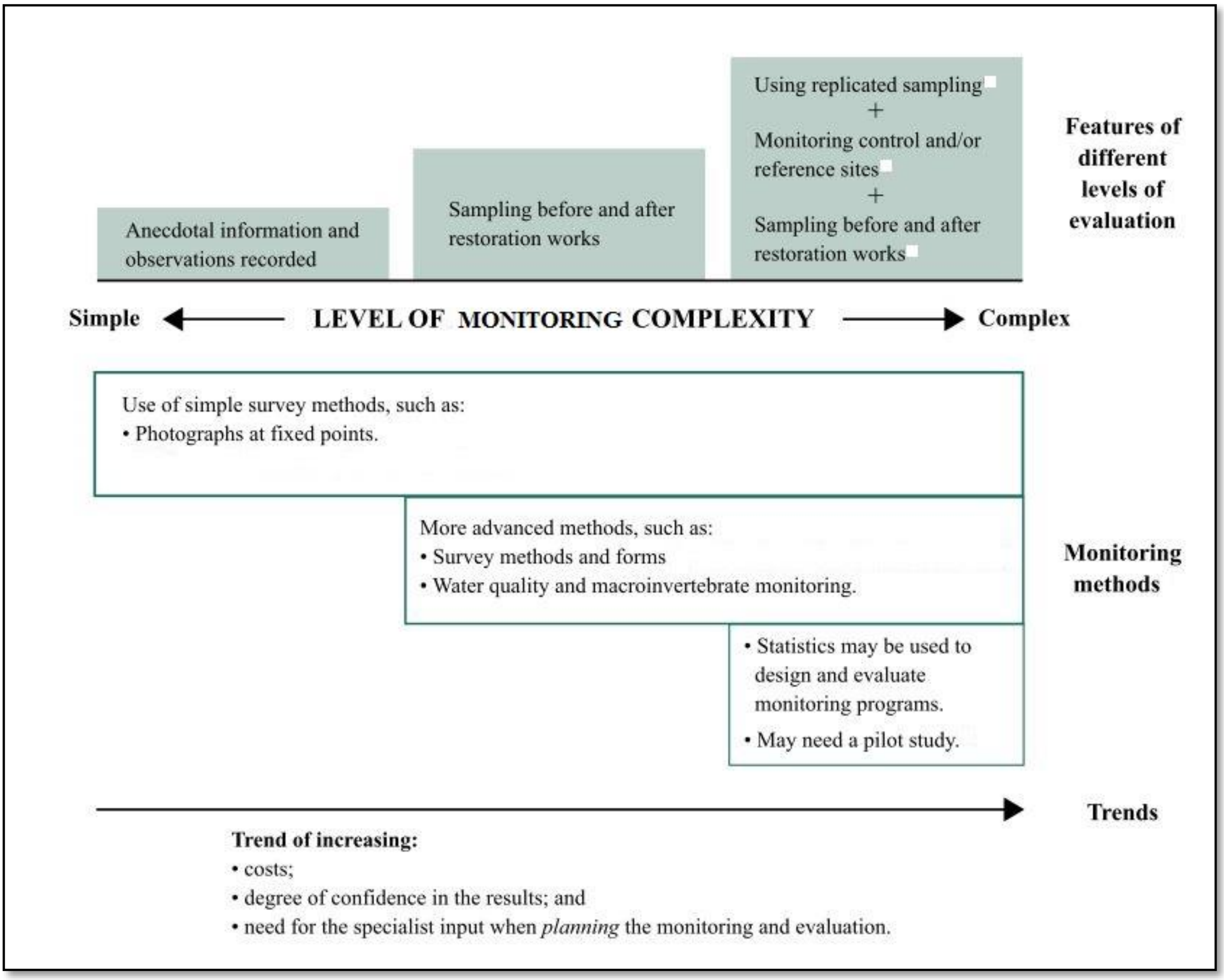


Figure 2.4. The features of different levels of evaluation (based on Water and Rivers Commission, 2002)

2.5 Conclusion

Wetlands worldwide have been reported to assimilate pollution along river channels, providing ecosystem services, such as nutrient and sediment trapping, controlling the transportation of pollutants downstream and improving water quality. This review has highlighted the importance of conducting wetland functional assessments, implementing rehabilitation interventions and the need for long term monitoring of the effects of wetland rehabilitation.

The HGM approach to wetland functional assessment and the RAMs which have been developed from its adaptation, provide a good basis from which wetland ecosystem functions can be understood. By using a limited set of field observation of stressors on the wetland’s hydrological and biogeochemical functions, an indication of the wetland’s capacity to perform ecosystem services such as flood attenuation, nutrient removal and sediment trapping can be estimated.

Wetland rehabilitation must begin with an understanding of the prevailing hydrological regime and how it has been altered, as wetland functioning is highly dependent on the wetland’s hydrological condition. Likewise, understanding of the soil and vegetation characteristics is important for the development of rehabilitation programmes in wetlands. The use of reference wetlands for the planning, implementation and monitoring of rehabilitated wetlands would be ideal for providing a comparative basis to refer to. However, such wetlands are scarce and there is a lack of data for such wetlands worldwide. It is therefore important to comprehensively assess different wetland HGM types to build our knowledge basis and understanding of these ecosystems, also enabling the implementation of efficient rehabilitation interventions that work.

The literature emphasises the importance of wetlands for improving water quality both at individual wetland scale and at a catchment scale. However, it is also important to note that although it has been demonstrated that wetlands are effective in improving water quality, their effectiveness may vary considerably depending on the particular pollutant and features of the wetland. Therefore, it is important to monitor wetlands over the long term to further build the understanding of how this function can be enhanced in light of the continued deterioration of water resources worldwide. Tangible monitoring programmes must be developed to assess the impacts of rehabilitation interventions on the whole wetland ecosystem, to foster understanding and improvement in rehabilitation for enhancing ecosystem services.

* * *

As highlighted in this review, wetlands are important ecosystems worldwide that are integral to water resource management. However, our understanding of these ecosystems is limited, especially in the Southern African perspective. Chapter 3 presents a methodology for assessing wetland ecological condition on the Lions River floodplain based soil and vegetation parameters and historical landuse. This is useful for understanding ecosystem structure and function and assists in the planning and implementation of rehabilitation. Chapter 4 investigates the impact of the floodplain on downstream water quality.

3 AN ASSESSMENT OF THE ECOLOGICAL CONDITION BASED ON SOIL AND VEGETATION PARAMETERS OF THE LIONS RIVER FLOODPLAIN, SOUTH AFRICA

Abstract

Wetlands are exposed to many human activities, including agriculture and urbanisation that are increasing worldwide, resulting in wetland degradation. In South Africa, a water-scarce country, wetlands can play an important water regulating role. This study aims to establish a baseline ecological integrity of the Lions River floodplain, an important, but degraded, wetland in the uMngeni catchment, to provide a guide for the planning and implementation of rehabilitation interventions. A comprehensive assessment of the wetland's structure was undertaken using vegetation and soil parameters, mapped and compared with an interpretation of landuse change within the wetland based on historical aerial photographs. The study concluded that the wetland's ecological integrity has decreased due to historical landuse in the floodplain. Wetness indicators of soil and vegetation can be used to indicate a transformation in the wetland's water regime, where the soil reflects the historic water regime and vegetation reflects the current water regime. A moderate to high abundance of ruderal and alien invasive species in 61% of the floodplain, particularly the drier areas of the floodplain, further indicate a reduction in ecosystem health. Soil degree of wetness emerged as the key drivers of species composition and historical landuse in the floodplain. The drier areas in the floodplain are most disturbed. This study highlighted the importance of detailed field studies and understanding for rehabilitation planning to return ecosystems to their natural function, thereby forming important ecological infrastructure for sustained water provision.

3.1 Introduction

Wetlands are sensitive and important ecosystems of high value for the provision of goods and services to society, but are being rapidly and widely degraded (Walters *et al.*, 2006; Swanepoel and Barnard, 2007). The term wetland is used worldwide to refer to ecosystems which are primarily driven by the interplay of land and water and the consequential characteristics which influence plants, animals and soils occurring in the area. Wetland hydrological processes result in three key elements, namely fluctuating water table, hydromorphic soils and hydrophilic plant communities (Mitsch and Gosselink, 2007; Xialong *et al.,* 2014). Wetland ecosystems are driven by hydrogeomorphic variables and hydrological processes which establish a physical template for chemical and biological processes and alter the wetland's physiochemical properties (Cabezas *et al.,* 2007; Xialong *et al.,* 2014). In South Africa, the National Water Act (Act No 36 of 1998) defines a wetland as *"land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil."*

Wetlands occur in the transitional area between terrestrial and aquatic systems and will therefore have varying hydroperiods and water regimes (Kotze *et al.,* 1996; Walters *et al.,* 2006; Mitsch and Gosselink, 2007; Cabezas *et al.,* 2007). In South Africa, very few long term wetland water table measurements exist, therefore water regime is often determined using soil morphological and vegetation features (Kotze *et al.,* 1996). The system developed by Kotze *et al.* (1994, 1996) for wetland water regime has proven useful for describing the degree of wetness for wetland soils using soil morphological features, particularly the chroma of the soil matrix and intensity and depth of soil mottling (Kotze and O'Connor, 2000; Vepraskas and Cadwell, 2008).

Hydrological functioning of the upstream catchment is recognised as the driving determinant for the formation and maintenance of specific wetland types (such as floodplains, depressions and valley-bottom wetlands) and wetland processes (Thompson and Polet, 2000; Tockner and Stanford, 2002; Mitsch and Gosselink, 2007). Located in the low-gradient alluvial 'shelves', floodplain wetlands can be defined as low lying areas of land, formed under the present climate and sediment load and are periodically inundated by lateral overflow water from their associated rivers (Ollis *et al*., 2013). Although, the primary source of inundation in floodplains is often lateral overflow from the main stream channel, other contributing water sources are recognised including groundwater, direct precipitation, inputs from tributaries and surface runoff. (Cole *et al.,* 1997; Tockner and Stanford, 2002). Fluvial dynamics, including flood and flow pulses, is the key driver of hydrological connectivity within floodplains, a key process for the water-mediated transfer of energy, matter and organisms within the system (Tockner and Stanford, 2002). Thus, the disturbance of a wetland's hydrological functioning by human intervention within and outside the wetland, such as inter-basin water transfers alters the natural distribution patterns of aquatic biota, presents problems of water quality in the system and disrupts ecological processes in the wetland (Bunn and Arthington, 2002).

Being the physical foundation of wetlands, soil is the key medium for the conversion of substances and a reservoir for chemical substances supporting wetland plants (Cabezas *et al*., 2007). Hydric soils are defined as soils which are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part (Soil Survey Division Staff, 1993; Kotze *et al.*, 1996). The prolonged saturation of mineral soil results in anaerobic condition which cause gleying, whilst periodic saturation results in alternate anaerobic and aerobic condition, which generally cause the formation of yellow, orange and red or black mottles in a grey to brownish-grey matrix (Kotze *et al*., 1996). Therefore, soil morphology can be used as an indicator of the long term soil water regime even in systems with altered hydrological conditions.

Hydrophilic wetland plants are the major biological group driving ecological processes in the wetland system. Due to their adaptation to the anaerobic conditions of wetland sediments, hydrophilic plants play an important role in nutrients accumulating in wetland systems. (Xialong *et al.*, 2014). Environmental pressures such as level of inundation, soil water regime, pH and degree of water table fluctuation act as drivers of wetland plant assemblage and structure and can be defined using sampled vegetation (Kennedy *et al.,* 2006). Wetland vegetation forms functional groups according to their level of confinement to wetland condition ranging from obligate wetland species, which are strongly confined to wetland environments, to non-wetland species which occur in terrestrial areas (Marneweck and Kotze, 1999). Therefore wetland indicator status of vegetation can be recorded to provide an indication of wetness in a wetland, with the wettest areas being dominated by obligate wetland species (Cowden *et al*., 2013).

Worldwide, wetlands are increasingly subjected to many human activities, including agriculture, urbanisation, extraction of biological goods and flood control practices (Sutula *et al*., 2006; Kotze *et al*., 2012). Often, wetlands are left in a degraded condition both ecologically and hydrologically, with a diminished capacity to provide important ecosystem services.

Whilst South African wetlands continue to be lost as a result of ecosystem degradation, scientific insight used to understand the impacts of landuse on these ecosystems is mainly based on Euro-American studies (Walters *et al*., 2006) and knowledge on the functioning and structure of local wetlands remains poor. It is therefore important to increase the knowledge base of local wetland functioning and establish baselines against which management practices and impacts of future developments can be assessed and predicted (Kotze and O'Connor, 2000).

In the uMngeni catchment, which drains the important economic areas around the cities of Pietermaritzburg and Durban in KwaZulu-Natal, South Africa, approximately half of the original wetland area has been lost due to human disturbance (Kotze and O'Connor, 2000; WRC, 2002; Rivers-Moore and Cowden, 2012) whilst cultivation, artificial drainage, alien invasive plants, too frequent burning and over grazing continue to be a significant threat to wetlands in the upper catchment (WRC, 2002). Furthermore, there is concern over the deterioration of water quality in Midmar Dam, the main water supply dam for the catchment (Ngubane *et al*., 2015; Namugize *et al*., 2015). In response to this, stakeholders of the uMngeni catchment have collaborated in investing in ecological infrastructure, forming the uMngeni Ecological Infrastructure Partnership (UEIP). Ecological infrastructure is defined as naturally functioning ecosystems that produce and deliver valuable services to people, such as climate change regulation, fresh water and disaster risk reduction (SANBI, 2013). These ecosystems include rangelands, wetlands, rivers and mountain catchments. The Lions River floodplain which lies just upstream of Midmar Dam, therefore presents an important opportunity for investing in ecological infrastructure for the UEIP. Thus, this study aims to establish the baseline ecological functioning of this important floodplain wetland by assessing the ecosystem's structure, to provide a guide for the planning and implementation of rehabilitation interventions on the wetland. To achieve this, a comprehensive assessment of the wetland's soil and vegetation is undertaken, as well as an analysis of landuse change in the wetland. In this chapter, three fundamental questions are addressed:

- What landuse changes have occurred within the wetland and how has this impacted the ecosystem's structure and functioning?
- What is the historic and current representation of wetness zones on the floodplain, as inferred from soil morphology and vegetation characteristics respectively?
- What are the key drivers of the ecosystem structure in the floodplain?

3.2 Methods

3.2.1 Study Area

The study was conducted in the Lions River floodplain (S29°27'14.8638"; E30°9'2.256") in the KwaZulu-Natal (Figure 3.1). Located in the upper uMngeni catchment above Midmar Dam, the Lions River has a catchment area of 362.01 km^2. Mean annual precipitation (MAP) in the upper uMngeni catchment is generally more than 700 mm per annum (Warburton *et al*., 2012), with most of the rainfall falling in the summer months (October – March). The catchment's mean annual run-off ranges from 200-500 mm per annum (Midgley *et al*., 1994), whilst average annual minimum and maximum temperatures are 19°C to 25°C respectively. Landuse in the Lions River catchment is predominantly commercial agriculture and forestry, which is also found in the immediate surrounds of the study site.

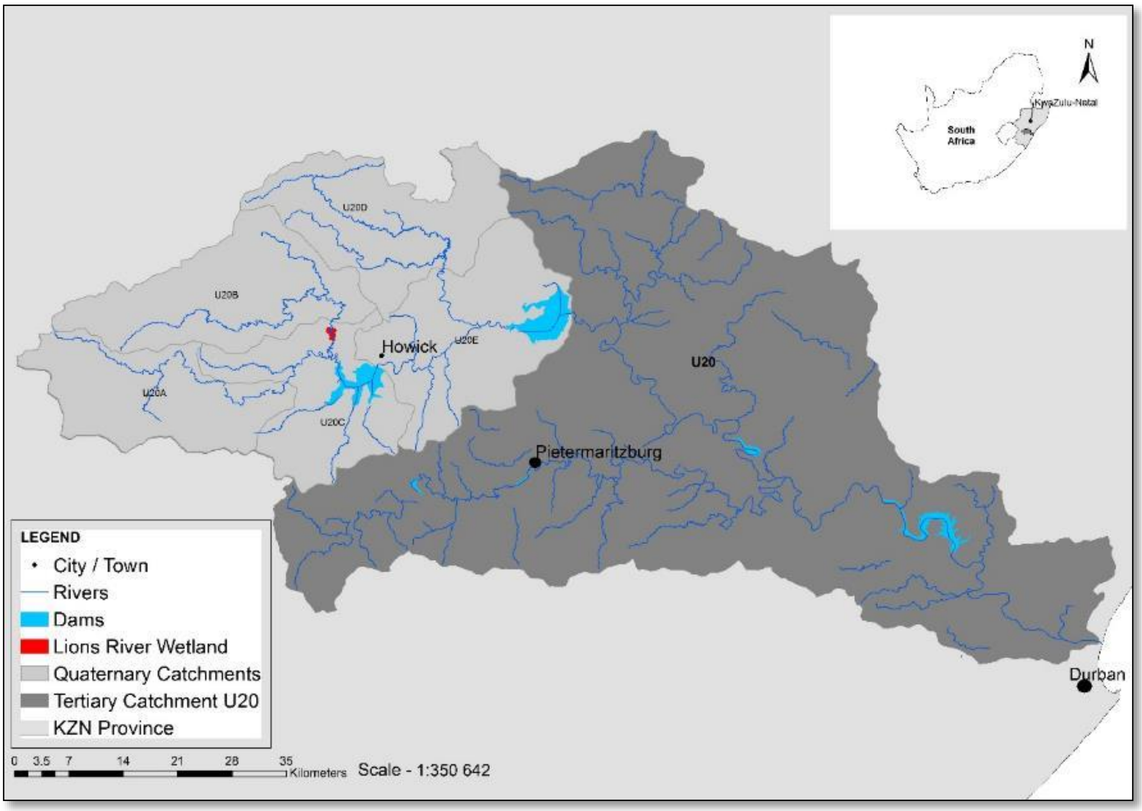


Figure 3.1. Location of study site in the upper uMngeni catchment, KwaZulu-Natal.

The Lions River floodplain lies on land that is owned and managed by Sappi Southern Africa – Forests and the boundary of the floodplain has been mapped using the company's internal resources for management purposes.

3.2.2 Sampling strategy

The sampling procedure commenced with the selection of five transect lines, over which survey plots at 50 metre interval would be located (Figure 3.2). Using a recent aerial image of the floodplain as a guide, the transect lines were spatially distributed across the wetland to be inclusive of oxbows, artificial drainage channels and areas of varying degrees of wetness. This was to ensure that the wetland was sampled to provide a representative baseline condition of the entire wetland. Three of the transect lines fell on the western side of the main channel only due the occurrence of a hill (elevated ground) on the eastern side.

A total of 61, 2m by 2m survey plots were sampled during late spring (November) of 2014 to ensure easy identification of the plant species when they were in full bloom. November also falls within the site's rainy season which is when the wetland is most 'active'.

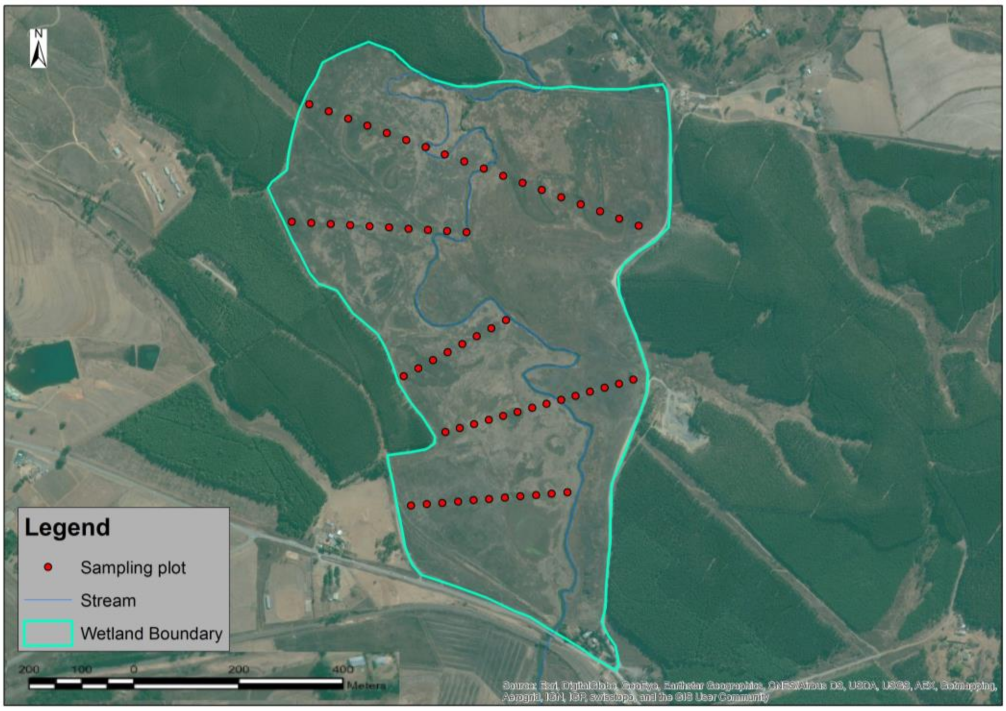


Figure 3.2. Map of survey plots on five transect lines at Lions River wetland (Source: Esri, Digital Global).

At each of the survey plots, vegetation and soil characteristics were described as outlined in sections 3.2.3 and 3.2.4.

3.2.3 Plant community composition and richness

Botanical composition. Within the 2m by 2m plots, all the species present were identified and recorded. Where a species was unknown to the survey team, a sample was collected, allocated a nickname and labelled for later identification. A visual estimation was then made of each species' aerial coverage within the plot using vegetation cover classes based on Londo (1976). Using an *a priori* classification, each of the species identified within the floodplain were assigned a wetland indicator status based on the classes outlined in Table 3.1 (Ervin *et al*., 2006; Van Ginkel *et al*. 2011; Lichvar *et al*., 2012).

Table 3.1. Wetland indicator classes (Van Ginkel *et al*., 2011) and abundant species at the Lions River floodplain for each class

Indicator Status	**Ecological Index**	**Abundant species at Lions River floodplain** (*Asterisk denotes alien invasive species)
Obligate	1	*Hemarthria altissima, Juncus effusus, Leersia hexandra, Phragmites australis*
Facultative positive	2	*Agrotis cf. eriantha, Paspalum dilatatum**
Facultative	3	*Eragrostis plana, Trifolium repens**
Facultative negative	4	*Hypericum forrestii*, Rubus cuneifolius**
Non-wetland / terrestrial	5	*Conyza albida*, Verbena bonariensis*, Richardia brasiliensis**

With the species identified, a Wetland Index Value (WIV) (Wentworth and Johnston, 1986; Carter *et al*., 1988; Cowden *et al*., 2013) was determined (Table 3.2). Using the approach defined by Carter *et al*. (1988), WIV was calculated using the ecological index for the assigned wetland indicator status of each species ranging from 1 (obligate) to 5 (non-wetland) and the proportional abundance recorded for each indicator class at each plot.

Table 3.2. Wetland Indicator Value thresholds (Wentworth and Johnston, 1986)

	Wetland Indicator Value
Wetland	< 2.5
Transitional	2.5 – 3.5
Non-wetland	> 3.5

Furthermore, the proportion of ruderal (weedy) and exotic species abundance relative to indigenous non-ruderal species abundance was determined for each sampled plot. From the plot data, wetness zones were extrapolated and mapped using ArcGIS drawing tool. In addition to the plot data, *in situ*, but *ad hoc* observation as necessary, field experience and Google Earth images of the study site, were used to determine the wetness zones as indicated by WIV. Similarly, the proportion of ruderal and exotic species abundance were extrapolated and mapped for the whole wetland.

3.2.4 Soil physical and chemical properties

Degree of soil wetness. Soil morphological features (matrix chroma, and intensity and depth of mottling) following Kotze *et al.* (1994, 1996) were used to describe the wetland's soil water regime. A core was sampled at each plot to a depth of 1.2 metre using a Dutch screw or bucket auger. The matrix colours for the different horizons were determined using the Munsell Soil Colour Chart and the depth and intensity of mottling were estimated in order to categorize the site as one of the four wetness classes: non-wetland, temporarily wet, seasonally wet and permanently/semi-permanently wet (Kotze *et al.*, 1996). Using the South African soil classification system (SCWG and MacVicar, 1991), the soil form of each soil core was identified. The approach used for mapping vegetation characteristics was used to extrapolate soil degree of wetness and soil forms in the Lions River wetland.

Soil texture. Soil texture was estimated in field using the 'finger test' method. All samples were manipulated with water to reach a state of maximum plasticity to determine the soil texture. This was done by the same field technician for all samples to minimise error.

3.2.5 Historical Image Analysis

Historical aerial photographs of the site from the years 1944, 1959, 1967, 1978, 1989 and 2010 were obtained and digitised using ArcGIS^{TM} 10.2. Landuse was visually determined and mapped on each image using six categories, namely: commercial forestry, cultivated land, channel straightening, artificial drainage channels, man-made structures and other disturbance (Table 3.3).

Table 3.3. Description of the six categories used to map landuse

Category	**Description**
Commercial forestry	Commercial forestry includes area planted with mainly *Populus sp.* for timber production purposes.
Cultivation	Cultivation is considered to be areas cultivated with agricultural crops mainly for food production.
Channel straightening	Channel straightening is considered to be the modification of the stream with the wetland resulting in a new shorter course of the stream.
Artificial channels	Artificial channels includes created artificial drains, which have the potential of having a high impact on water retention within the wetland (Macfarlane *et al*., 2009).
Man-made structures	Man-made structures include all buildings found with the wetland area.
Other disturbance	Other disturbance includes all observed disturbance within the wetland that could not be categorised into the other five categories, example, grass mowing and channel impeding structures.

3.2.6 Statistical analysis

Statistical analysis was undertaken to describe the correlation between vegetation species composition and the prevailing environmental variables namely; soil water regime, soil texture, historical disturbance and artificial drainage of the wetland. A constrained conical correspondence analysis was used to ascertain the optimal dispersion of species scores and the environmental variable that is most strongly related to species composition. This method highlights the environmental variables driving species composition on the floodplain. Table 3.4 below gives a description of the plot data used in the CCA. Furthermore, an analysis of variance was conducted to compare the means of the Wetland Index Value (derived from the vegetation composition data) and the soil water regime groups (identified based on soil morphology).

Table 3.4. A description of all variables used in the statistical analysis

Variable	**Description**
Species composition	All vegetation species identified during the vegetation surveys per plot and their abundance.
Disturbance	Plot location was overlaid with the historical images (Section 3.3.1) to determine if the plot had been historically disturbed or remained undisturbed.
Drainage	Plots located within or outside artificial drainage channels within the floodplain.
Soil forms	Prevailing soil form at the plot as identified during the soil survey (Section 3.2.4).
Soil texture	Texture of the soil as estimated in field (Section 3.2.4).
Soil water regime (hydregime)	Plot location on the wetness gradient from wet (permanently wet = 1) to dry (non-wetland = 4) as indicated by soil morphological features.

3.3 Results

3.3.1 Historical landuse and land cover

Historical landuse and land cover change was mapped for Lions River floodplain using aerial photographs from the years 1944 to 2010 (Figure 3.4). Figure 3.4a shows an aerial photograph of the Lions River floodplain from 1944, the earliest image that could be found of the site. Landuse within the floodplain was mainly cultivation with evidence of artificial channels constructed to drain water off these areas. Man-made structures and 'other disturbance' were also observed. Up-to 1959 (Figure 3.4b), cultivation persisted in the floodplain, although reduced from 1944 and was restricted to the north-east and south-west corners of the floodplain. The artificial drainage channels were still present in 1959.

In 1967 (Figure 3.4c), a further transition in landuse had occurred, and cultivation was replaced by commercial forestry within the floodplain. The wetland is also surrounded by commercial forestry. The number of structures in the floodplain had also increased and were concentrated in the same area. Forestry activities had expanded by 1978 (Figure 3.4d) to include the areas where previously man-made structures had been located. Artificial channels remained clearly visible and were likely to be active. Although reduced, commercial forestry was still present in the wetland in 1989 (Figure 3.4a).

Currently (2010), all commercial forestry and agriculture has been removed and is now excluded from the floodplain. However, the floodplain remains in an altered hydrological condition due to the network of artificial drains which are still actively draining the western portion of the floodplain (Figure 3.4b). Also, most parts of the floodplain continue to be disturbed by intensive cattle grazing. Moreover, the wetland's upper catchment is extensively used for agriculture, whilst in its immediate surrounding areas, commercial forestry remains the dominant landuse. This is continuing to have an impact on water inputs to the floodplain and the quality of the water in the main channel.

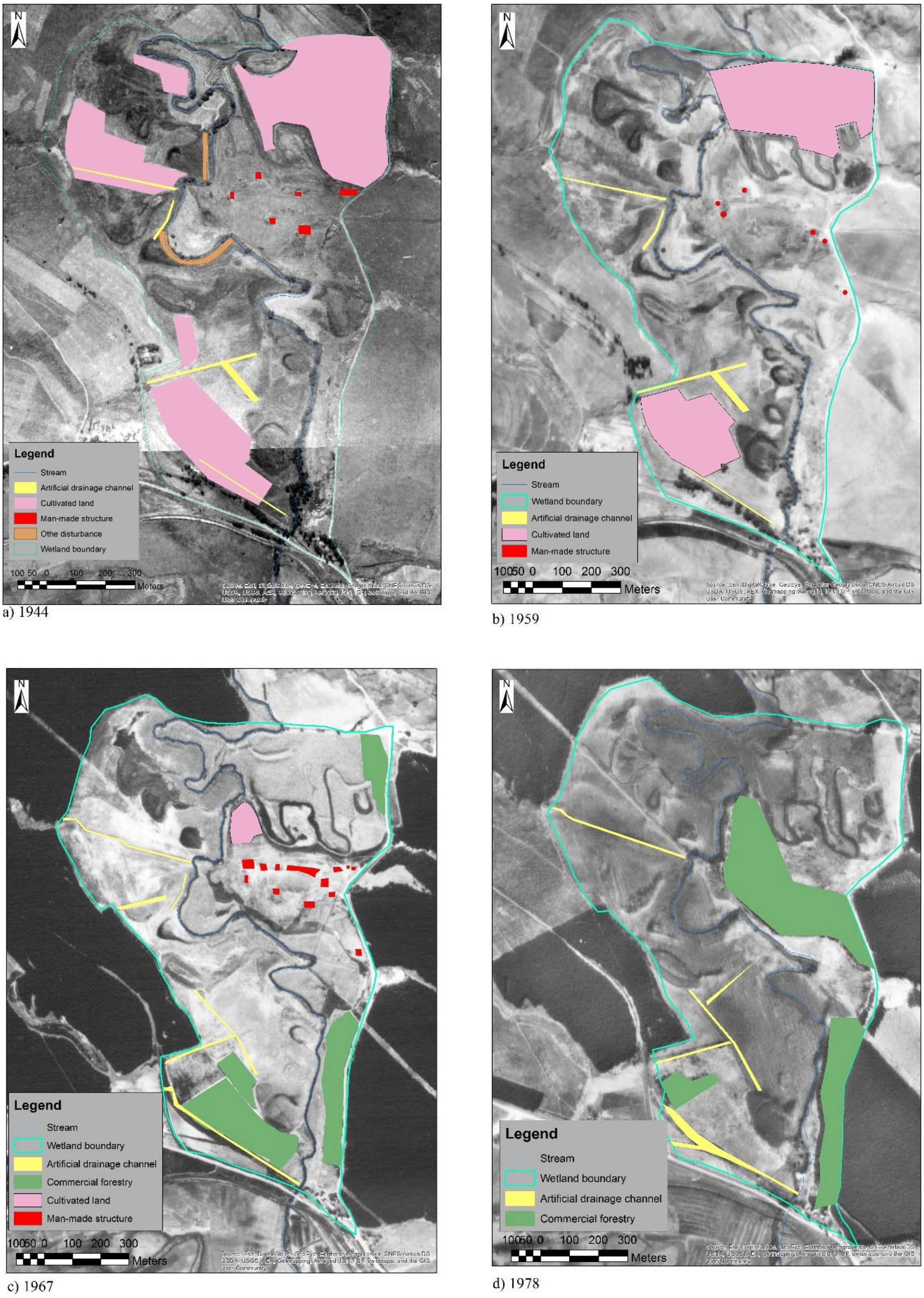
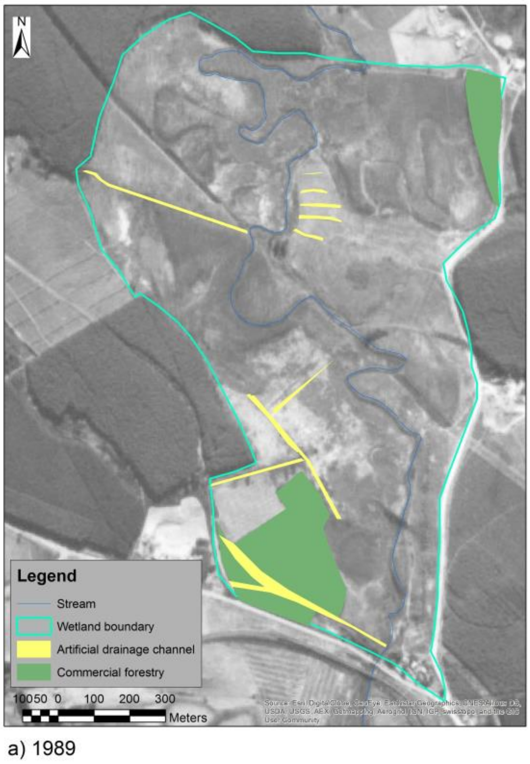


Figure 3.3. Landuse change at Lions River floodplain over time, a) 1944, b) 1959, c) 1967 and d) 1978, from aerial photos (Source: Esri, Digital Globe)



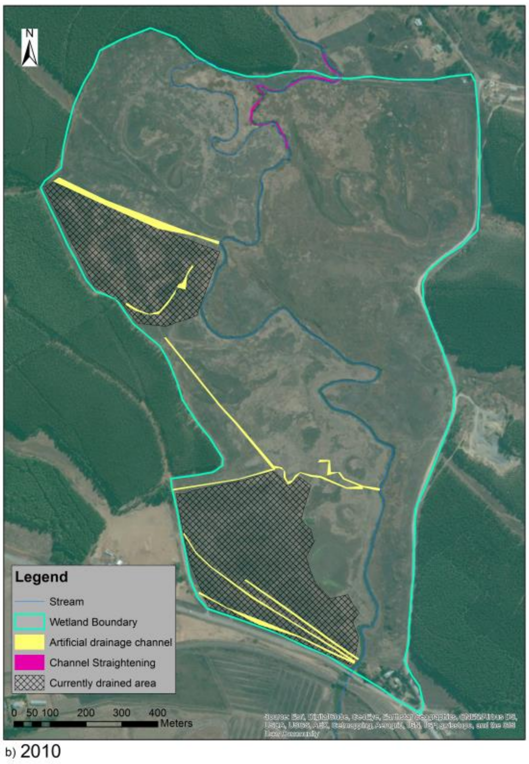


Figure 3.4. Landuse change at Lions River floodplain over time, a) 1989 and b) 2010, from aerial photos (Source: Esri, Digital Globe)

Over time (Figure 3.5) landuse in the Lions River floodplain transitioned from being predominantly cultivation in the 1940's and 1950's to commercial forestry 1970's. In the 1980's 'use' of the floodplain had been significantly reduced, whilst currently, all cultivation and commercial forestry have been excluded from the floodplain. To date, 'use' of the floodplain is limited to cattle grazing. Remnant effects of previous landuse in the form of artificial drainage channel to drain water for cultivation and forestry purposes are still evident on the floodplain.

Figure 3.5. Proportion of different landuse at Lions River floodplain (1944 - 2010)

3.3.2 Physical and Chemical Characteristics of the Soil

Following the system for describing wetland regime by Kotze *et al.* (1994, 1996) using soil morphological characteristics, of the sampled plots, 46% were considered permanently or seasonally saturated, 21% temporarily saturated and 33% were non-wetland.

Figure 3.6a and Figure 3.6b show the soil forms found in the floodplain and a representation of the soil's degree of wetness respectively, extrapolated from the sampling plot data for the whole floodplain. The Katspruit soil form covers the majority of the floodplain, followed by the Clovelly, Hutton, Westleigh then the Bloemdal soil forms. Permanently and seasonally wet areas lie predominantly on the northern and western reaches of the floodplain, whilst temporarily wet and non-wetland areas lie on the eastern and southern margins.

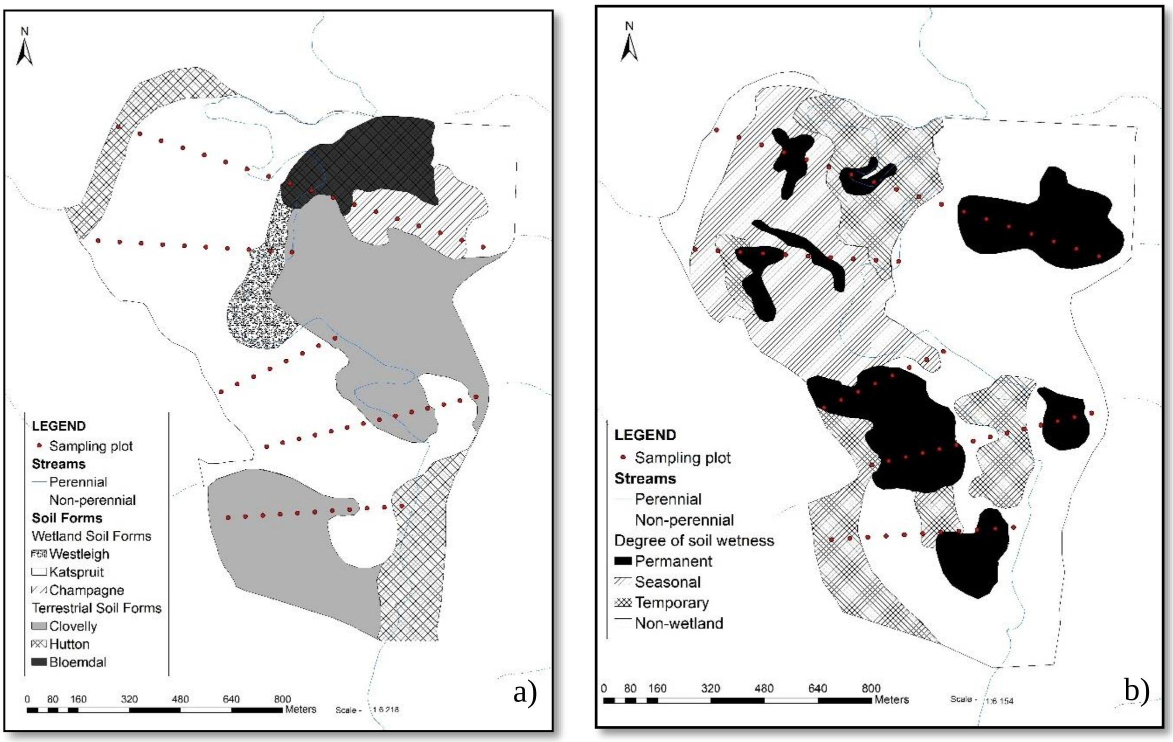


Figure 3.6. (a) Map of soil forms within the floodplain (b) Map of degree of soil wetness zones as indicated by soil morphology

The soil forms were strongly related to the degree of soil wetness found in the wetland. The Champagne soil form was confined to the permanently wet area on the north-eastern side of the wetland, whilst the Katspruit soil form occurred across the permanently, seasonally and temporarily wet areas. The Clovelly soil form, a typical upland soil, was found in the temporarily wet and non-wetland areas. The Hutton and Bloemdal soil forms which are similar in characteristics, differing in signs of wetness in the deep horizons occurred in the non-wetland areas.

The results of the soil analysis showed that extensive areas on the floodplain are naturally not wetland, being characterised by the Hutton and Clovelly soil forms which are typically upland soil forms. These areas are naturally not subjected to the prolonged saturated conditions which would be characteristic of wetlands.

3.3.3 Vegetation Characteristics

Wetland wetness zones derived from vegetation WIV in the sampled plots, indicated that 43% of the plots could be classified as wetland, 44% transitional and 13% non-wetland. An extrapolation of the vegetation plot data is shown in Figure 3.7 and indicates that wet and transitional areas lie on the western and northern reaches of the wetland, whilst non-wetland areas are found on the eastern and southern areas of the wetland.

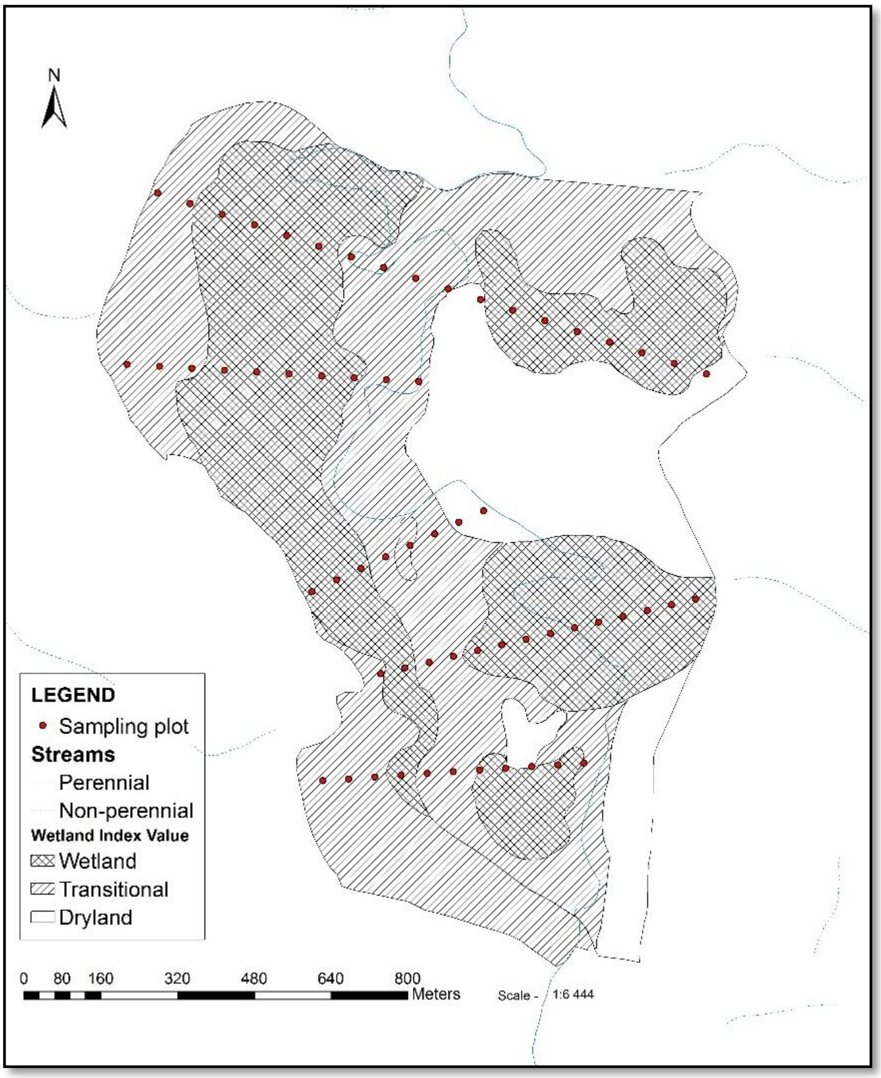


Figure 3.7. Map of WIV as an indicator of wetness in the floodplain

The proportional abundance of ruderal and exotic species (Figure 3.8) was used as an indication of the ecological condition of the wetland vegetation. A very high abundance (>75%) of ruderal/exotic species is found in the transitional area lying central in the wetland whilst a low abundance of these species is observed in most of the areas categorised as wetland according to WIV. Non-wetland areas in the eastern and southern areas of the floodplain were observed to have a medium abundance of ruderal/exotic species, ranging from 25-50% abundance, whilst those lying in the central and northern areas had a high abundance ranging from 51-75 %.

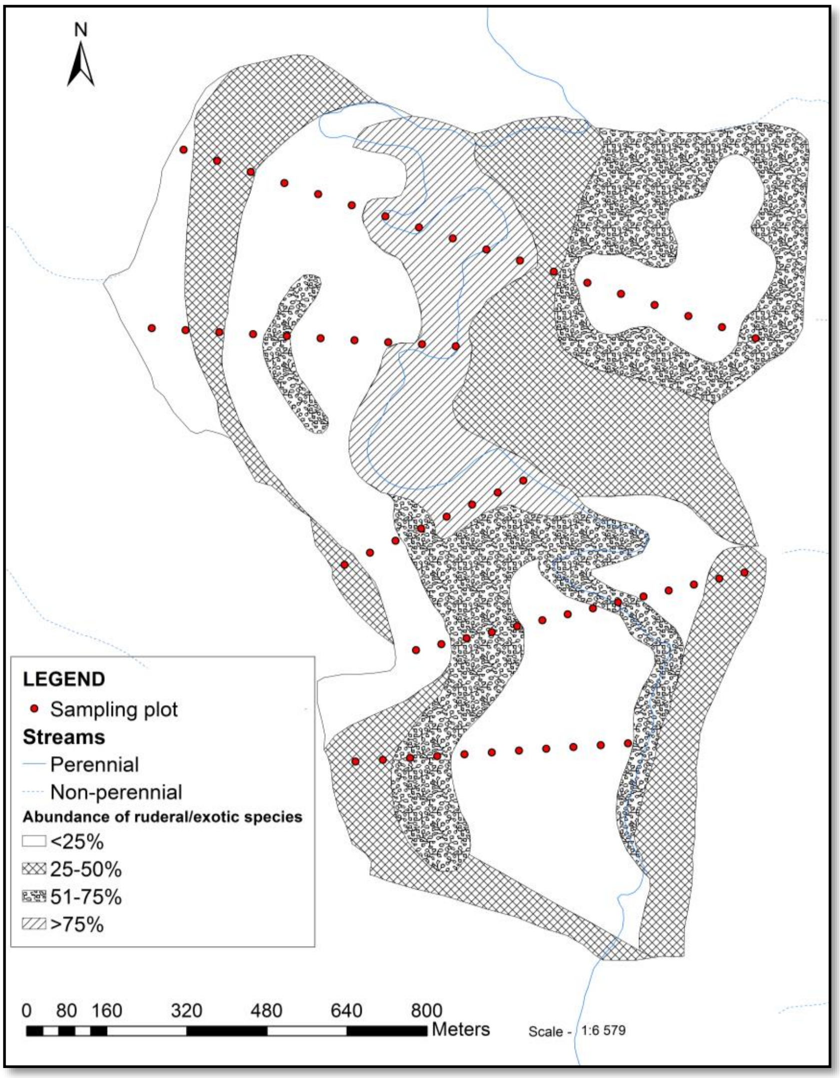


Figure 3.8. Illustration of proportional abundance of ruderal and exotic species at Lions River floodplain

Based on the map in Figure 3.8, it was determined that overall, 39% of the floodplain had a low (<25%) abundance of ruderal and exotic species, whilst 40% of the floodplain area had medium to high (25 – 75%) abundance. Areas with a very high (>75%) abundance of ruderal and exotic species covered 21% of the total floodplain area.

3.3.4 Relationship between Soil and Vegetation Properties

The canonical correspondence analysis (CCA) (Figure 3.9) of plant species composition against the prevailing environmental variables highlights the wetland's soil water/hydrological regime is a key driver of species composition. This is indicated by the close alignment of the gradient of hydrological regime and axis one of the CCA. Moreover, the length of the arrows representing environmental variables is proportional to the rate of change, therefore the long hydrological regime arrow indicates a large change and indicates that change in soil water regime is strongly correlated with the ordination axes and thus with the variation in species composition. This is further illustrated by a high turnover of species along the soil hydrological regime gradient from wet to dry areas in floodplain. The species located on the wettest (right) end of the axis are obligate wetland species (e.g. *Juncus effusus, Leersia hexandra* and *Schoenoplectus sp.*) with WIV value of less than 2.5, whilst those on the drier (left) end of the axis are terrestrial non-wetland species (e.g. *Richardia brasiliensis, Solanum sp.* and *Eragrostis curvula*) with a WIV of more than 3.5. Secondary to soil water regime, soil texture also drives species composition in the wetland. Although the results of the CCA show historical disturbance by cultivation and forestry as having an insignificant effect on species composition, this is probably more indicative of the floodplain being generally disturbed. Areas which have historically not been disturbed have subsequently been disturbed by intensive cattle grazing, the currently dominant landuse in the wetland. Moreover, there are potentially more areas which were historically disturbed, however these were not detected due to their occurrence outside of the specific years of the examined aerial images.

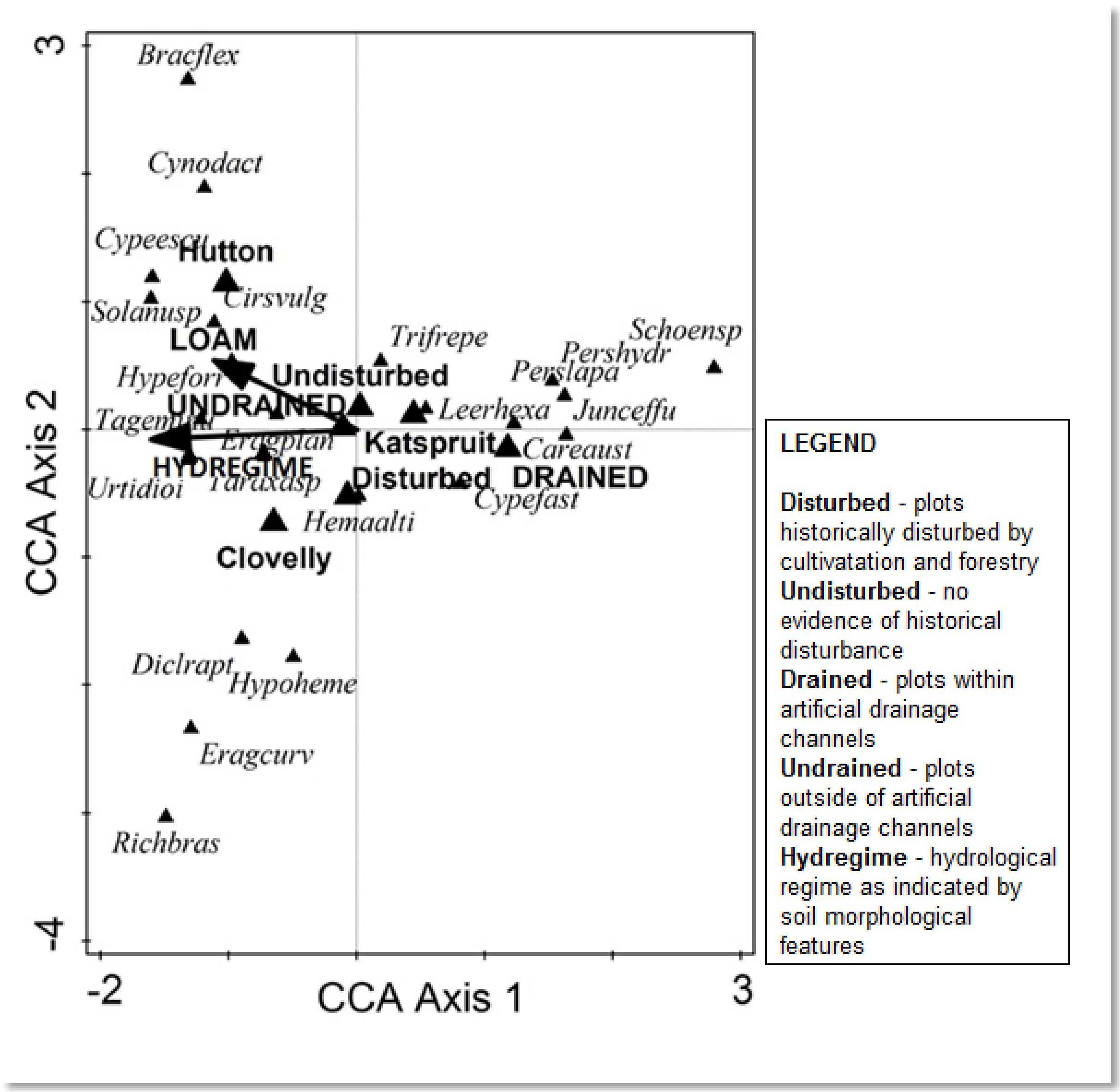


Figure 3.9. Plot of environmental variables and species (with at least 5% of their variance accounted for) along the first two axes of a canonical correspondence analysis (CCA) of plant species composition (log-transformed % abundance, singletons excluded, rare species down-weighted) in the Lion's River wetland. Species names appear in Annexure 1

An analysis of variance (ANOVA) was conducted to compare the effect of soil water regime on the wetland index value (WIV). This showed that the effect of soil water regime on WIV was significant, (F (3, 57) = 6.86, p = <.001) with a generally increasing mean average value of WIV with increasing dryness in the soil (Table 3.5).

Table 3.5. Descriptive information summary for WIV: soil water regime ANOVA

	N	Mean	Std. Dev	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Permanently wet	22	1.767	0.877	0.187	1	2.55	1	3.656
Seasonally wet	11	2.417	0.938	0.283	1.638	3.015	1	3.952
Temporarily wet	11	2.823	0.591	0.178	2.571	3.340	1.54	3.610
Non-wetland	17	2.861	0.844	0.205	2.506	3.520	1.059	3.846

A number of outlying points in the permanently wet (WIV>2.5) and non-wetland (WIV<3.5) areas (Figure 3.10) were observed. Outlying points in the permanently wet areas were generally associated with medium-high disturbance, where the abundance of ruderal/exotic species ranges from 50-75%. Whereas, outlying points in the non-wetland area with an uncharacteristically low value for WIV were generally associated with points lying on the stream banks, within artificial drains and the area affected by lateral runoff from the roads. All these factors would contribute to water availability in the area thus allowing the establishment of wetland plant species.

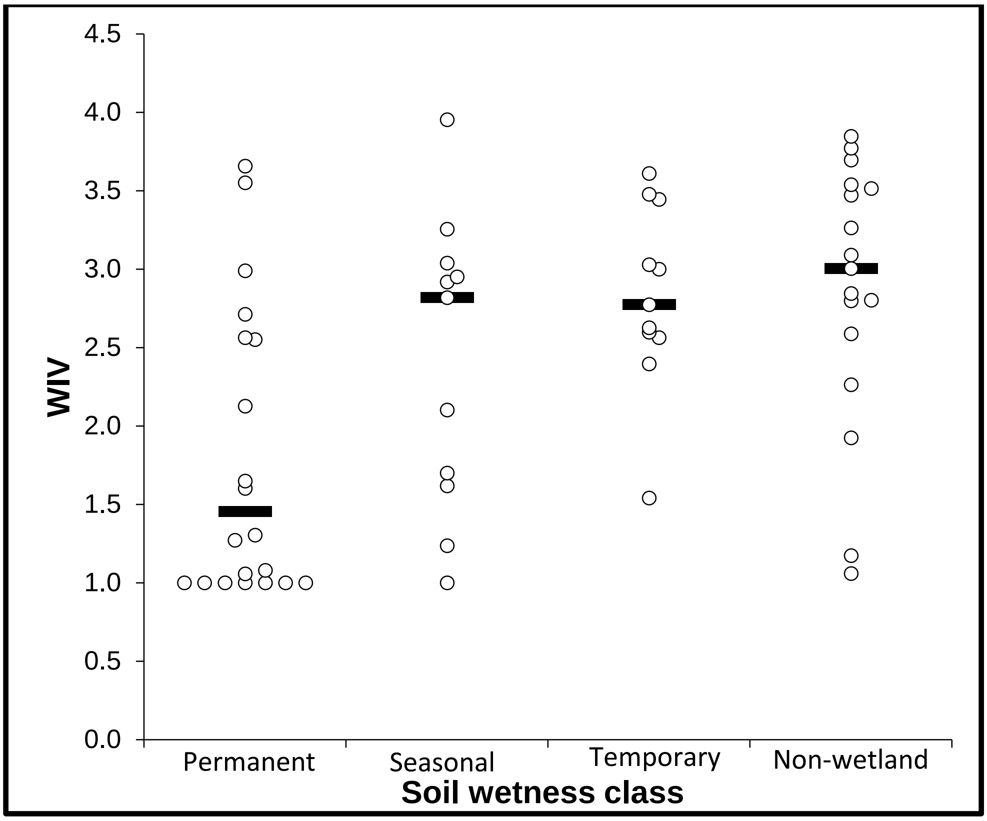


Figure 3.10. Averages of WIV in the four soil wetness groups. Points of similar value have been jittered to prevent overlap

The proportion of sites which had non-wetland soil but wetland vegetation was higher than those with wetland soils but non-wetland vegetation, suggesting that the sites had been artificially wetted (Table 3.6). Although the WIV thresholds have not been tested for South African wetland conditions, it is argued that these preliminary results are an indication of the impact of the artificial drains on the study site which have artificially wetted some areas, whilst having a drying effect on others. Concentrated flow in the artificial drainage channels which redirected flow from some areas to others was observed in field during the study period.

Table 3.6. Correspondence of wetland indicators of the soil and vegetation and Lions River floodplain

	"Wetland vegetation"	**"Non-wetland vegetation"**
"Wetland soil"	39 (matches)	4 (mismatches)
Non-wetland soil	13 (mismatches)	4 (matches)

3.4 Discussion

Hydrological processes are recognised as the ultimate drivers of ecosystem function in wetlands (Hoffman *et al*., 2009), influencing the interaction between water and soil and vegetation composition. At the Lions River floodplain, hydrological processes were assessed based on soil hydromorphological features and a wetland index value determined using vegetation. The water regime as indicated by WIV (Figure 3.7) in the wet areas were causally related to the soil's degree of wetness as indicated by soil morphology (Figure 3.6b). The wet areas classified as wetland according to WIV matched areas classified as permanently and seasonally wet according to soil morphology. However, there was a mismatch in the transitional and non-wetland areas as indicated by WIV and soil morphology. Even though the WIV thresholds have not been tested for South African wetland conditions, it is noteworthy that the mismatch predominantly shows a level of wetness based on vegetation being higher than that showed by the soil (Table 3.6).

In artificially drained wetlands, although sometimes with a lag period, the vegetation tends to change to reflect the current hydrological regime of the wetland. The soils tend to retain morphological indicators (e.g. a low chroma matrix and mottles), even through dry years, reflecting the historical hydrological regime of the wetland (Tiner, 1993; Vepraskas and Caldwell, 2008). At the Lions River floodplain, artificial drainage channels have caused the artificial wetting and drying of portions of the floodplain leading to changes in the plant community. Hydric soils, which have developed over long periods of saturation, remain visible in the floodplain's soils, even after being artificially drained and through dry years. Thus, vegetation tends to reflect the current hydrological regime of the floodplain and soils reflect the floodplain's long term water regime. This comparison of soil wetness indicators and vegetation wetness indicators suggest that although localised drying out of some areas has occurred, most of the historical floodplain area still supports wetland conditions.

Wetland rehabilitation projects aim to imitate natural processes and reinstate natural ecological driving forces (Russell, 2009) to aid in the recovery of a dynamic system. These projects are often targeted at rewetting wetlands which have been dried out, making the naturally dry areas at the Lions River floodplain an important consideration and limitation for rehabilitation. Extensive areas within the floodplain are characterised by typically terrestrial soils, indicating that these areas are naturally not wetland which has implications for the rehabilitation of this floodplain, which will be discussed in chapter five.

Research has clearly documented that different wetland vegetation species require different combinations of water availability, water chemistry and soil type (Kopeć *et al*., 2013), making wetlands with altered hydrological regimes vulnerable to the encroachment of terrestrial alien invasive species when exposed to prolonged dryness. Similar to the findings of Walters *et al*. (2006) in the wetlands of the southern Drakensberg, KwaZulu-Natal, that the wettest areas of the wetlands had the lowest occurrence of exotic species, in this study it was found that, the proportional abundance of alien and ruderal species (Figure 3.8) was higher in the transitional and non-wetland (Figure 3.7) areas. These areas were also associated with the historical landuse in the study site, where areas were drained for cultivation and commercial forestry. A large proportion of the alien and ruderal species found on this floodplain are not adapted to growing under high levels of soil wetness. The abundant non-wetland species which are also alien invasive species were found on the driest end of the soil water regime (Figure 3.9) including, *Rubus cuneifolius, Hypericum forrestii, Tagetes minuta* and *Richardia brasiliensis* further illustrating that soil wetness as a key driver of species composition in the wetland.

Also identified in this study was that soil water regime had a significant influence on landuse in the floodplain. Commercial forestry was historically restricted to areas indicated by soil as being temporarily wet or non-wetland areas, whereas, agricultural crops were established in seasonally and temporarily wet and non-wetland areas, supported by the creation of artificial drainage channels designed to divert water off seasonally and semi-permanently wet areas of the floodplain. Moreover, both agricultural crop and commercial forestry have historically been excluded from the permanently wet areas of the wetland. Other forms of disturbance such as man-made structures were also restricted to areas outside permanently wet areas. Similar to Walters *et al*, (2006), landuse in Lions River floodplain has been historically constrained by the wetland's abiotic regime, particularly the soil's degree of wetness. Furthermore, landuse on the study site was concentrated in the easily accessible portions of the wetland, possibly due to convenience of transportation and irrigation matching results from similar studies elsewhere in the world, for example Xu *et al*. (2012).

Artificial drainage of wetlands is common in wetlands which have been used for agricultural purposes, diverting water from lateral run-off. And has a high impact on the retention and distribution of water (Macfarlane *et al*., 2009), resulting in a concentrated flow in localised areas and the transfer of run-off from the surrounding catchment into the wetland's main channel. This is evident at the Lions River floodplain, where presently, the floodplain is drained by artificial drainage channels confined to the western side (Figure 3.4f). However, because the artificial drainage channels have not been maintained for a very long time, their condition has deteriorated and they are less functional. They may be having a lesser influence than compared to the past.

3.5 Conclusion

This study has shown that there is value in comprehensive field studies of wetland ecosystems to build an understanding of system processes and structure. The methodology used in the study to draw a link between vegetation and soil characteristics is novel to African wetland studies and has a broader application. The study shows the importance of considering both vegetation and soil characteristics as indicators of wetland conditions, as the use of only one variable may lead to under or over estimation of wetland boundaries during delineation, monitoring and rehabilitation planning of these ecosystems.

The vegetation species composition on the floodplain shows that the structure of the floodplain has been transformed, resulting in transitional wetland species occurring on non-wetland soils. The high abundance of ruderal/exotic species indicates a reduction in ecosystem health. Wetland ecosystem processes have also been transformed by the artificial drainage channels as evidenced by wetness indicators of soil and vegetation, further reducing the health of the system. The ecological integrity of the wetland has been reduced however, portions of the floodplain which show a mismatch in the indicators of wetness by soil and vegetation may be candidates for rehabilitation.

Historical disturbance in the floodplain indicates that landuse in a wetland is limited by abiotic components of the ecosystem, confirming that wetland ecosystem function and use is primarily driven by hydrological function. The impact of the historical landuse within the floodplain is evident in the high abundance of exotic/ruderal species and altered hydrological process resulting from the artificial drainage channels which have changed the species composition.

It is important to comprehensively assess different wetlands types to build our knowledge basis and understanding of these ecosystems, also enabling the implementation of efficient rehabilitation interventions that work. Soil water regime emerges as the main driver of ecosystems processes at the Lions River floodplain, influencing both plant species composition and landuse within the floodplain. This is an important element for rehabilitation planning and implementation as the soil characteristics reflect the historic natural conditions of this floodplain.

Having lost half of the original wetland area due to human disturbance in the uMngeni catchment, the Lions River wetland presents an opportunity for investing in ecological infrastructure for the UEIP. The results of this study indicate a potential for the rehabilitation of this wetland’s ecological condition, enabling it to form part of a network of healthy ecosystems supporting the inflow to Midmar Dam.

4 IMPACT OF THE LIONS RIVER FLOODPLAIN ON DOWNSTREAM WATER QUALITY

Abstract

The uMngeni catchment is an important basin providing water to the cities of Pietermaritzburg and Durban, South Africa's second largest economic hub. However, there are rising concerns over the deterioration of water quality in Midmar Dam, a large impoundment within this important catchment. The Lions River, one of the main tributaries to Midmar Dam, transports pollutants from its catchment, as well as the Mooi River catchment through the recently implemented Mooi-Mgeni transfer scheme into the impoundment. This study therefore aims to determine what effect the Lions River Wetland, a degraded floodplain system, has on downstream water quality. An assessment of the wetland's impact on water quality was conducted by sampling water at various points through the floodplain over a period of one year. Water quality results indicate that total oxidised nitrogen decreased from upstream to downstream whilst ammonia concentrations remained stable at all the sampling points. Soluble reactive phosphorus concentrations increased, while total phosphorus concentrations decreased from upstream to downstream. It is concluded that the lack of bank overspill and low rainfall during the study period reduced the effectiveness of this floodplain to retain nutrients. Also, a deeply incised main channel with limited riparian vegetation and reduced water retention time and increased flow velocity due to the Mooi-Mgeni Transfer Scheme have also probably impacted the floodplain's ability to retain nutrients. Ongoing degradation of the wetland by overgrazing and artificial drainage is also having an impact.

4.1 Introduction

Worldwide, the term wetland refers to ecosystems which are driven by the interplay of land and water and the consequential characteristics which influence plants, animals and soils occurring in the area (Mitsch and Gosselink, 2007). The interaction between vegetation, soil and water is important for the provision of ecosystem services such as the trapping of sediment, nutrients and toxic compounds (Dosskey *et al*., 2010). Floodplain wetlands are important ecosystems known to retain nutrients such as nitrogen (N) and phosphorus (P) (Verhoeven *et* *al*., 2006; Natho and Venohr, 2014). However, these sensitive ecosystems are being rapidly degraded (Swanepoel and Barnard, 2007; Filoso and Palmer, 2011). Although subject to increasing pressure by human activities such as agriculture (Verhoeven *et al*., 2006; Sutula *et al*., 2006; Kotze *et al*., 2012), wetlands play an important water resource role by storing and purifying water, recharging groundwater and regulating stream flow (Swanepoel and Barnard, 2007). Alteration to a wetland's structure and hydrological processes diminish its ability to regulate water quality by controlling the transportation of pollutants downstream (Llorens *et al*., 2009; Filoso and Palmer, 2011; Fan *et al*., 2012).

Floodplain wetlands in their natural state retain water, nutrients and sediments, thus making their management a cost effective alternative for flood attenuation and water quality improvement along river corridors (Natho and Venohr, 2014). In floodplains, nutrient retention occurs either when nutrient-rich river water inundates the floodplain through bank overspill or when the floodplain acts as a buffer for diffuse lateral nutrient inputs from upland areas (Filoso and Palmer, 2011; Natho and Venohr, 2014). The effectiveness of floodplain wetlands in retaining nutrients is largely controlled by inundation area and duration, water retention time (Filoso and Palmer, 2011), flow velocity, soil characteristics, hydraulic load (Natho and Venohr, 2014) and water temperature (Mitsch *et al*., 2000). During inundation, nitrate removal occurs through denitrification, whilst sedimentation is the driving process for P retention. The strength of each process for removing nutrient varies with pollutant type and site condition (Dosskey *et al*., 2010).

The uMngeni catchment, although not the largest basin, is KwaZulu Natal's most heavily utilised water source, currently providing water to the Greater Durban and Pietermaritzburg Metropolitan areas (Hemens *et al*., 1977; Hodgson *et al*., 2000; Hart and Wragg, 2009). In response to a prolonged drought period in 1983, the Mearns Emergency Transfer Scheme was constructed to transfer water from the Mooi River to Midmar Dam in the uMngeni catchment. In 2003, the yield of the emergency transfer scheme was increased as part of the first phase of the Mooi-Mgeni Transfer Scheme (MMTS), whilst in 2013 the second phase was commissioned (Umgeni Water, 2014). With a maximum delivery capacity of 4.5 m^3/s, the MMTS pumps water and gravity feeds it into Midmar via the Mpofana, Lions and uMngeni

Rivers (Rolwston and Crous, 2012) resulting in a highly regulated system with above normal flow for most of the year.

Water quality assessments in the upper Mooi and uMngeni River catchments indicate both rivers have generally acceptable quality water (Hodgson *et al*., 2000). However, results from recent studies i.e. GroundTruth (2012) and Ngubane *et al*. (2015) show an increase in nutrient loads in the Lions River, implying a general increase in N and P concentrations in the catchment. Moreover, with the increasing population and concentration of economic activities in the uMngeni catchment, water quality monitoring remains important for detecting any decline in water quality into the future (Hart and Wragg, 2009). Intensive agriculture in the upper catchment is a major source of nutrients, resulting in elevated levels of N and P entering groundwater and streams (Hoffman *et al*., 2009; Ngubane *et al*., 2015; Namugize *et al*., 2015).

The uMngeni Ecological Infrastructure Partnership (UEIP), a collaboration between stakeholders of the uMngeni catchment including private industry, government departments, local municipalities and research institutions, amongst others, have recognised the need for a coordinated effort to secure water resources within the catchment. Ecological infrastructure is defined as naturally functioning ecosystems that deliver valuable services to people, such as climate change regulation, fresh water and disaster risk reduction (SANBI, 2013). These ecosystems include rivers and wetlands.

The Lions River Wetland is a large but degraded floodplain lying just upstream of Midmar Dam in the upper uMngeni catchment. It has been historically disturbed by artificial drainage channels, cultivation and commercial forestry in most parts (Section 3.3.1). The floodplain is still actively drained by the artificial drainage channels on its eastern and southern boundaries (Figure 3.4). Furthermore, the floodplain is heavily grazed by a large number of cattle which have also caused the formation of a network of pathways within the wetland.

Ecological infrastructure, such as wetlands is perceived to play an important role in mitigating the deterioration of water resources. Thus, with increasing nutrient concentrations in the Lions River catchment and the deterioration in water quality in the larger uMngeni catchment

(Ngubane *et al*., 2015), the Lions River floodplain presents an important opportunity for investing in ecological infrastructure for the UEIP to improve water quality in Midmar Dam.

This study of the Lions River Wetland therefore aims to establish what effect, if any, this degraded floodplain is having on downstream water quality. This is done by analysing water samples taken at various points along the river channel which runs through the wetland.

4.2 Methods

4.2.1 Study Area

This study was conducted in the Lions River Wetland (S29°27'14.8638"; E30°9'2.256") in the Lions River District, KwaZulu Natal (KZN). Located in the upper uMngeni catchment on the Lions River, the floodplain is approximately 2 km upstream of Midmar Dam and downstream of the MMTS transfer site, with a catchment area of 362.01 km^2.

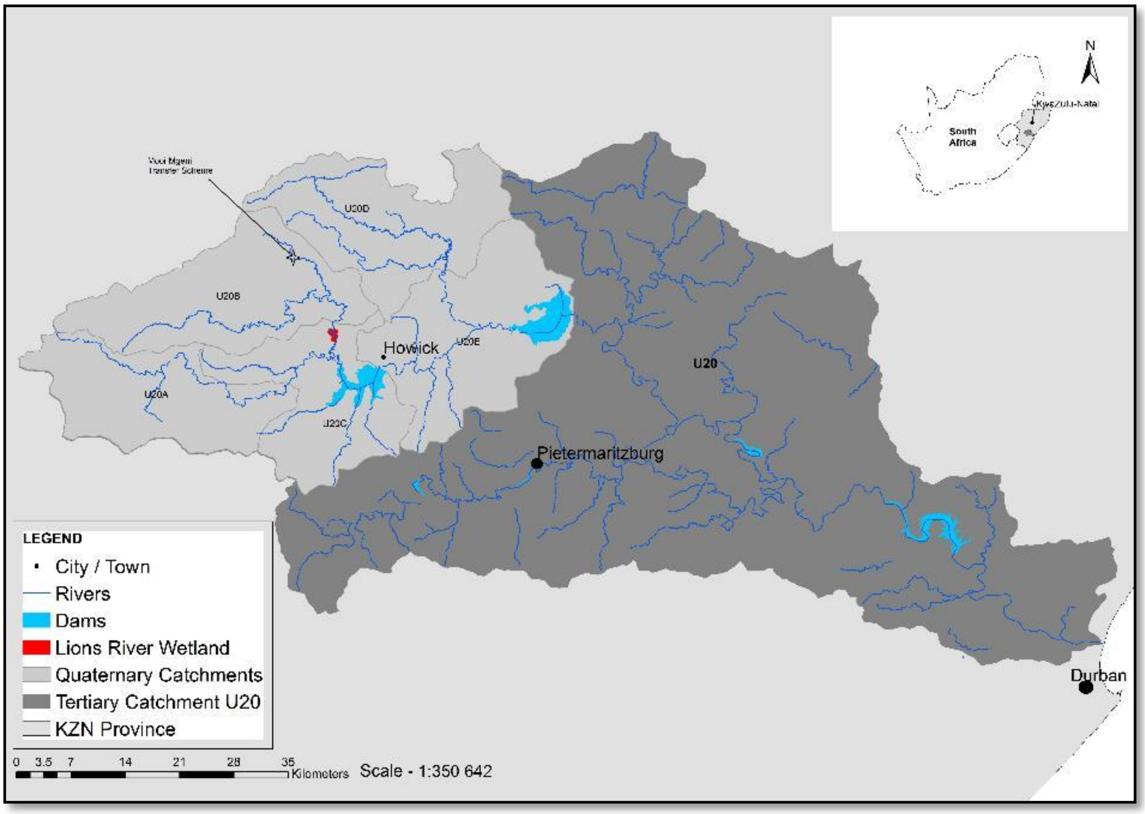


Figure 4.1. Location of study site in the upper uMngeni catchment, KwaZulu Natal.

Mean annual precipitation (MAP) in the upper uMngeni catchment is generally more than 700 mm per annum (Warburton *et al*., 2012), with most of the rainfall falling in the summer months (October – March). However, during the 2014/2015 hydrological year, rainfall in KZN has been consistently below normal, with a total below 500 mm for the year (Figure 4.2). The catchment's mean annual run-off ranges from 200-500 mm per annum (Midgley *et al*., 1994), whilst average minimum and maximum temperatures are 19°C to 25°C respectively. Land-use in the Lions River catchment is predominantly commercial agriculture and forestry.

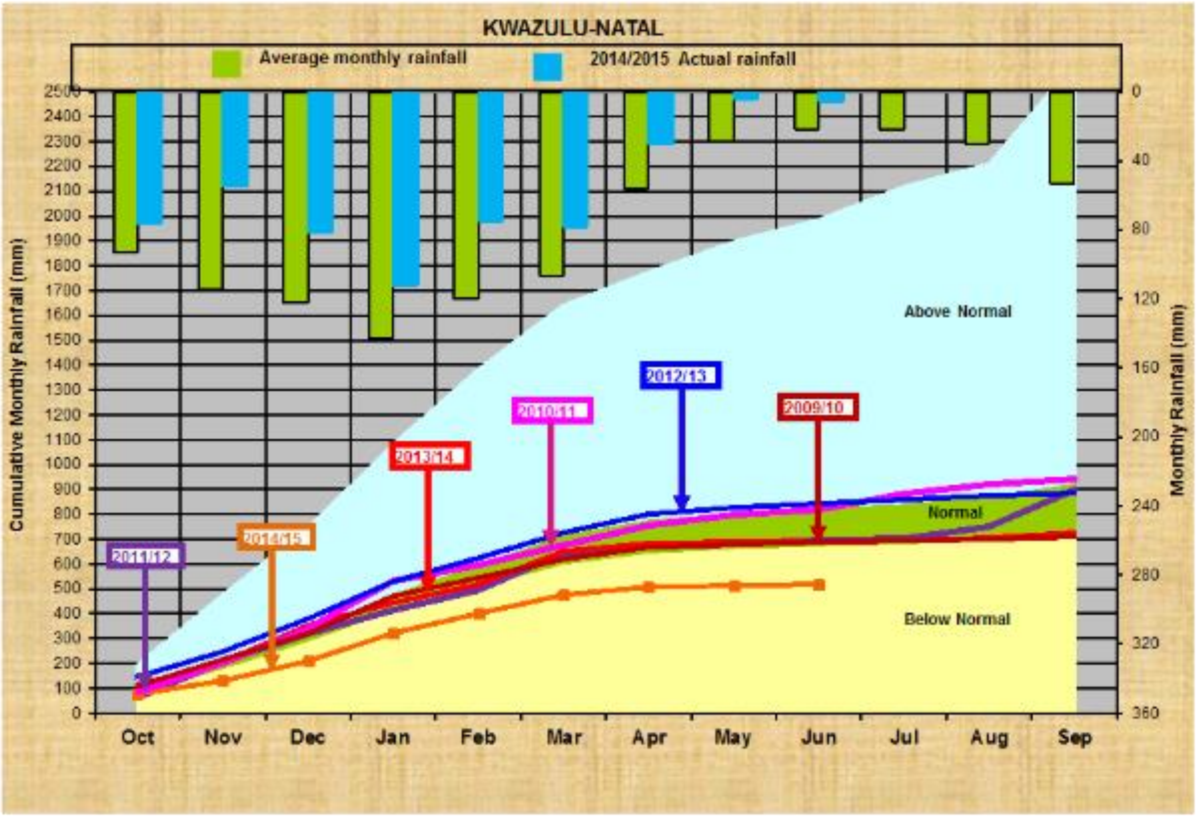


Figure 4.2. KZN provincial rainfall trends (DWS, n.d)

The Lions River floodplain is highly degraded, having been disturbed historically by commercial forestry, agriculture and artificial drainage (Figure 3.4). The four wetness classes (Figure 3.6b), non-wetland, temporarily wet, seasonally wet and permanently/semi-permanently wet (Kotze *et al.*, 1996) are well represented within the floodplain. Alien invasive species (Figure 3.8) have encroached onto large areas of the floodplain.

The Lions River is one of the receiving streams of the MMTS scheme which was constructed to augment water supply to Midmar Dam. The Lions River floodplain lies downstream of the MMTS, receiving water from the transfer scheme before it reaches Midmar Dam two kilometres downstream. The floodplain has had its flow regime altered by the inter-basin transfer scheme from the Mooi to the uMngeni River catchment, resulting in a deeply incised channel that is largely disconnected from the larger floodplain areas. Since 1983, the deeply incised channel in the floodplain can be attributed to the increased discharge rate due to the MMTS. During a geomorphological study, Hunter (2009) found that erosion generally occurred throughout the length of the MMTS receiving stream and limited deposition had occurred in the Lions River. Furthermore, it was found that the level of stream erosion could be linked to the water release duration of the MMTS. Although, the water level rises during water release from the transfer scheme, no bank overspill occurred during the study period.

4.2.2 Water samples

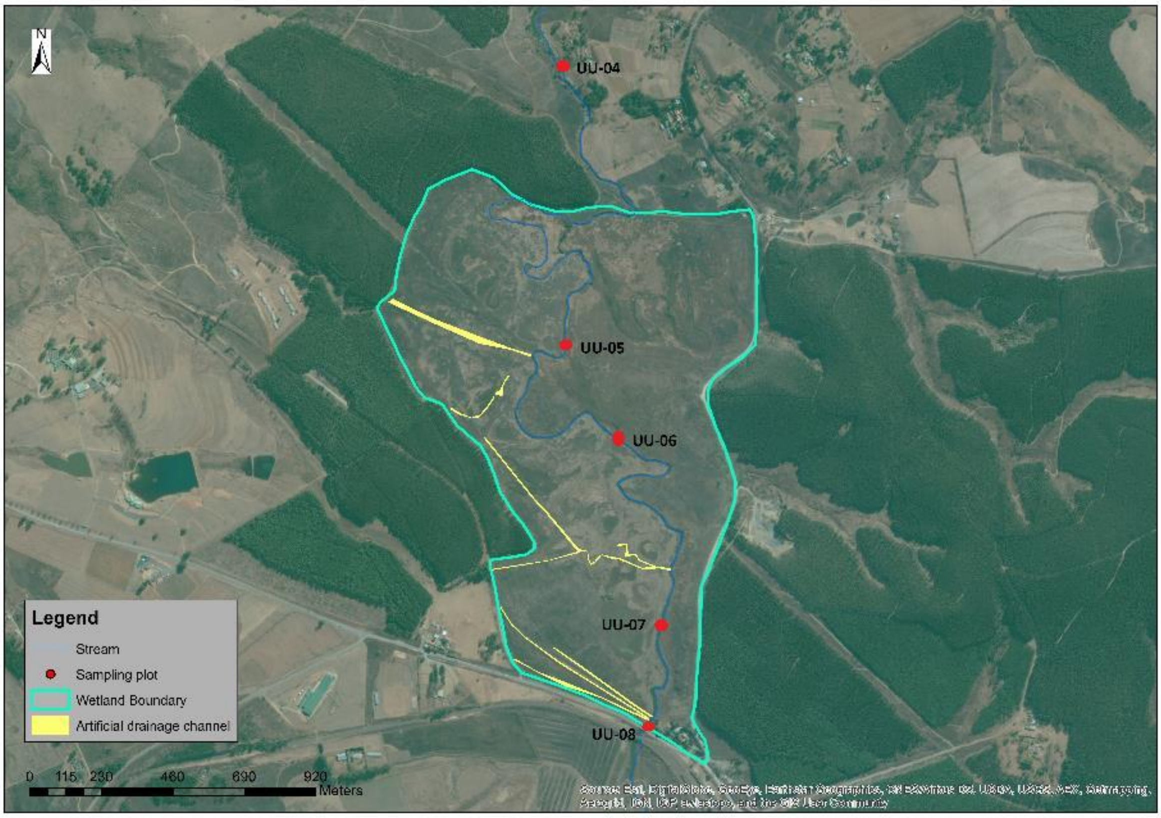


Figure 4.3. Location of water quality sampling points at Lions River floodplain

Water quality samples were collected biweekly, i.e. every two weeks, for a period of one year (July 2014 – June 2015) from 5 sampling points in the Lions River Wetland (Figure 4.3). A brief description of each site is given in Table 2.1 below.

Table 4.1. Description of each water quality sampling site

Site no.	Description	Photo of site
UU-04	Inlet site at Department of Water Affairs and Sanitation gauging weir U2H011, upstream of floodplain	
UU-05	Site within floodplain. Water level averaged at 1.5m below bankfull level during the study period. Channel deeply incised, no vegetation on the bank. Area is grazed by cattle during the wet season.	
UU-06	Site within floodplain. Water level averaged at 0.8m below bankfull level during the study period. Channel banks have collapsed in the vicinity of this sampling and vegetation debris has collected around collapsed banks. Area is grazed by cattle throughout the year.	

Site no.	Description	Photo of site
UU-07	Site within the floodplain. Water level averaged at 0.5m below bankfull level during the study period. Channel widens here, with grass and American bramble especially on the banks. Area is grazed by cattle throughout the year and a network of paths has formed along the channel bank. Sites UU-07 and UU-08 have potential for bank overspill to occur and to greatly influence water quality if better vegetated with riparian vegetation.	 
UU-08	Outlet site beneath R102 bridge. Channel is wide and deep with grass. Water level frequently near bankfull level. Site often used as drinking site by cattle grazing on the floodplain.	

A grab sample was collected at each sampling point using a new polyethylene bottle and a sterile sample collection bottle for coliform bacteria. Samples were kept in a cooler box during transportation to the ISO 17025 accredited Umgeni Water Amanzi laboratory where they were analysed following standard laboratory procedures (Umgeni Water, n.d) for the constituents outlined in Table 4.2. Although water quality sampling was undertaken for a period of one year, bacteria samples could only be collected for the latter seven months due to logistical and technical difficulties experienced during the beginning of the sample period.

Table 4.2. Constituents analysed in collected water quality samples

Constituents	Sampling frequency	No. of samples collected
Ammonium (NH_4)	Biweekly	23
Total oxidised nitrogen (TON)	Biweekly	23
Soluble reactive phosphorus (SRP)	Biweekly	23
Total phosphorus (TP)	Biweekly	18
Escherichia coli (*E. coli*)	Monthly	7

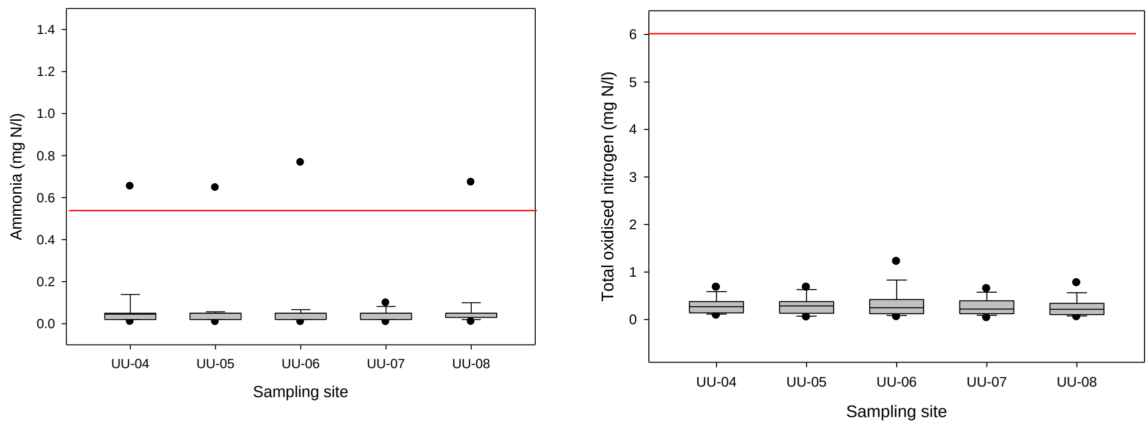
4.2.3 Statistical Analysis

An analysis of the effect of the floodplain on water quality based on the upstream and downstream concentrations on pollutants collected during the study period of one year. Pollutant concentrations measured upstream (UU-04) and those measured downstream (UU-08) were grouped using box and whisker plots and compared using a “student” t-test (Sherman, 1954). The question of interest for the analysis was whether, on average, the quality of water flowing through the floodplain changes from upstream to downstream. If the floodplain is having no effect on downstream water quality, the two sets of data can be regarded as having come from the same population. To study seasonal variations in average mean pollutant concentrations, a “student” t-test was used to compare the means for each sampling site during the wet (October – March) and dry (April – September) seasons.

4.3 Results

Water quality results from the sampled sites show that NH_4 concentrations (Figure 4.4a) remained stable from upstream (sampling site UU-04) to downstream (sampling site UU-08) with no significant changes ($p = 0.9$). However, results for the middle sampling site (UU-06) showed elevated concentrations on a number of sampling occasions. NH_4 concentrations were consistently below the target concentration of 0.58 mg N/l for aquatic ecosystems as set out in the South African national guideline for raw water quality (DWAF, 1994; 1996a).

Concentrations of TON (Figure 4.4b) also showed no significant changes ($p = 0.6$) moving from upstream to downstream. Concentrations remained consistently higher at sampling site UU-06, although they were still below the 6 mg N/l target set for TON in the DWAF (1994; 1996b) guideline.



a) NH_4 b) TON

Figure 4.4. Box plot indicating the range of concentrations of NH_4 and TON measured at each sampling site for the entire year (bars indicate the 10^{th}, 25^{th}, median, 75^{th} and 90^{th} percentiles, red line representing the DWAF (1994) water quality standard, dots represent 5^{th} and 95^{th} percentile outliers), n = 23

Wet (October – March) and dry (April – September) seasonal mean concentrations for NH_4 were also calculated (Figure 4.5). NH_4 average mean concentrations were significantly ($p = 0.008$) lower during the wet season than in the dry season. Also, dry season mean concentrations were more variable ranging between 0.052 and 0.129 mg N/l. Sampling site UU-07 had the lowest mean concentration whilst the inlet and outlet had similar means. The average mean concentrations were generally higher in the dry season compared to the wet season. No patterns were observed with the outlying points.

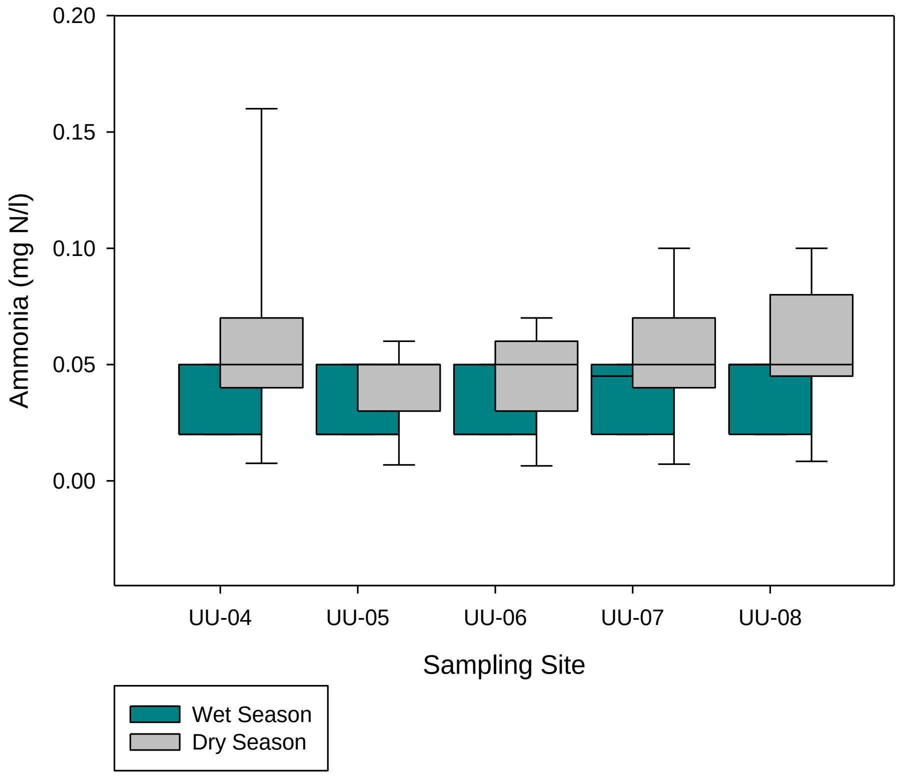


Figure 4.5. Box plot indicating the range of wet (n = 12) and dry (n = 11) seasonal concentrations of NH_4 measured at each sampling site (bars indicate the 10^{th}, 25^{th}, median, 75^{th} and 90^{th} percentiles

Average mean seasonal concentrations for TON showed more variation from upstream to downstream during the wet season than in the dry season, although the means were generally higher during the dry season (Figure 4.6). There was not a statistically significant ($p = 0.176$) difference between wet and dry season average mean concentrations of TON.

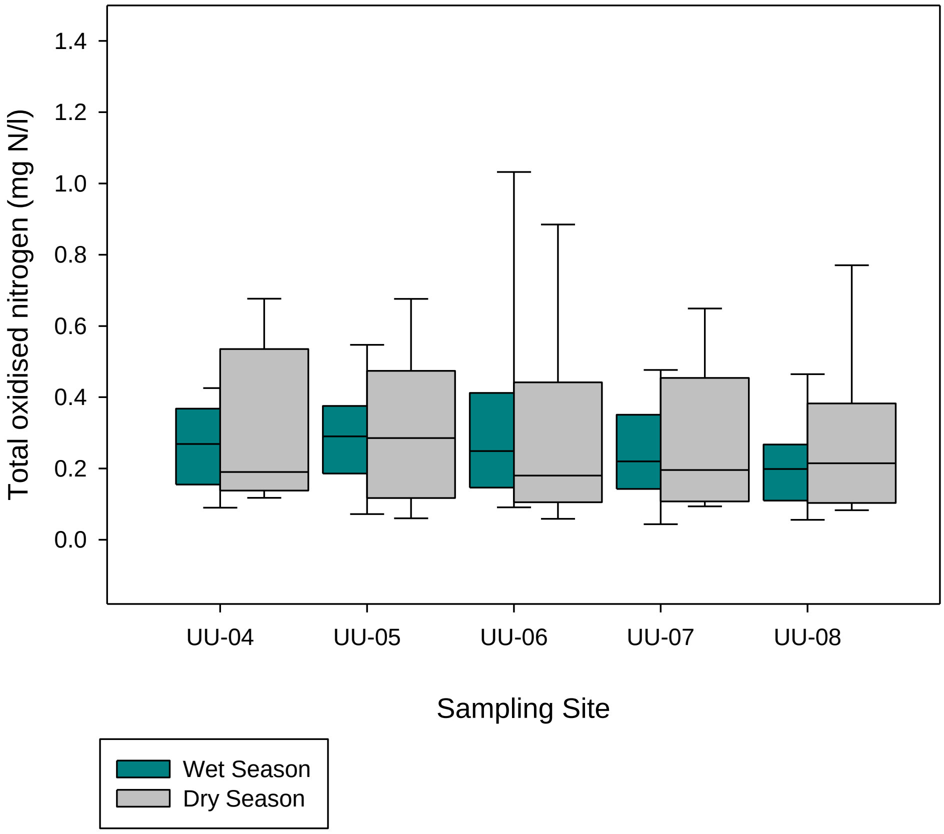
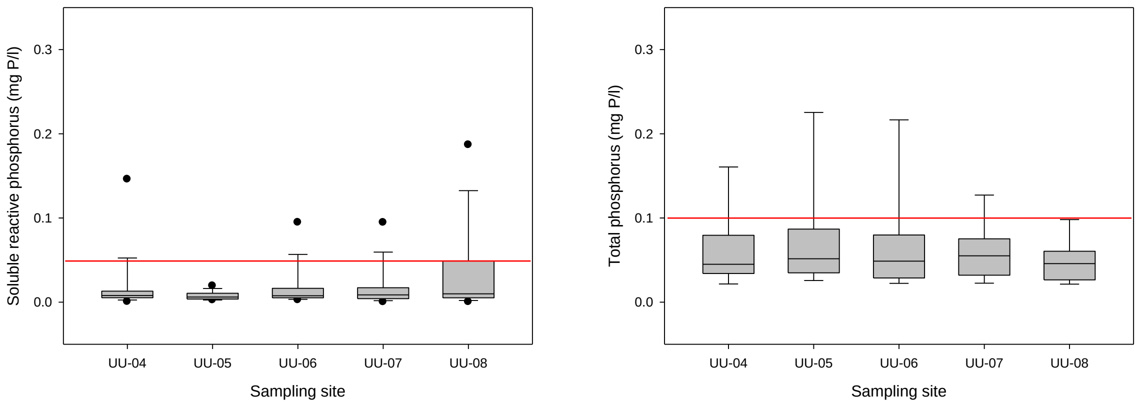


Figure 4.6. Box plot indicating the range of wet (n = 12) and dry (n = 11) seasonal concentrations of TON measured at each sampling site (bars indicate the 10^{th}, 25^{th}, median, 75^{th} and 90^{th} percentiles

Phosphorus levels were measured in the water quality samples as concentrations of SRP and TP. SRP concentrations increased from upstream to downstream, whilst concentration at UU-05 remained generally lower than other sample sites on all sampling occasions and was the only site that never exceeded the DWAF (1994; 1996a) limit of 0.05 mg/L (Figure 4.7a). At UU-08 concentration of SRP exceeded the limit of 0.05 mg/L for eutrophication of rivers (DWAF, 1994; 1996a) on at least five sampling occasions.

TP concentrations showed an insignificant (p = 0.3) decrease from upstream to downstream (Figure 4.7b). Concentrations were below the limit quoted by DWAF (1994; 1996a) for river eutrophication of 0.10 mg/L.



a) SRP

b) TP

Figure 4.7. Box plot indicating the range of concentrations of SRP and P measured at each sampling site for the entire year (bars indicate the 10th, 25th, median, 75th and 90th percentiles, red line representing the DWAF (1994) water quality standard, dots represent 5th and 95th percentile outliers), n = 23

A significant (p = 0.05) seasonal variation in average mean concentrations was also observed for SRP (Figure 4.8). Wet season mean concentrations remained below 0.020 mg P/l, whilst dry season mean concentrations ranged between 0.009 – 0.056 mg P/l. Both wet and dry mean concentrations were higher at the outlet than at the inlet.

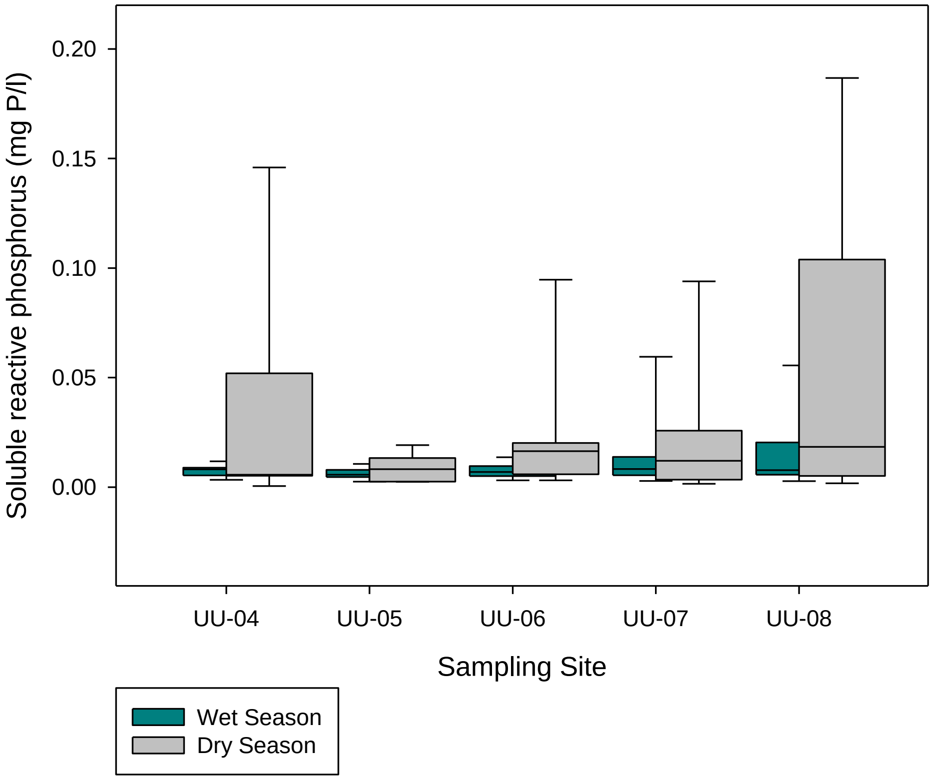


Figure 4.8. Box plot indicating the range of wet (n = 12) and dry (n = 11) seasonal concentrations of SRP measured at each sampling site (bars indicate the 10^{th}, 25^{th}, median, 75^{th} and 90^{th} percentiles

Mean TP concentrations were more variable during the dry season, however during both wet and dry season outlet mean concentrations were lower than at the inlet (Figure 4.9). There was not a statistically significant (p = 0.160) difference between wet and dry season average mean concentrations of TP.

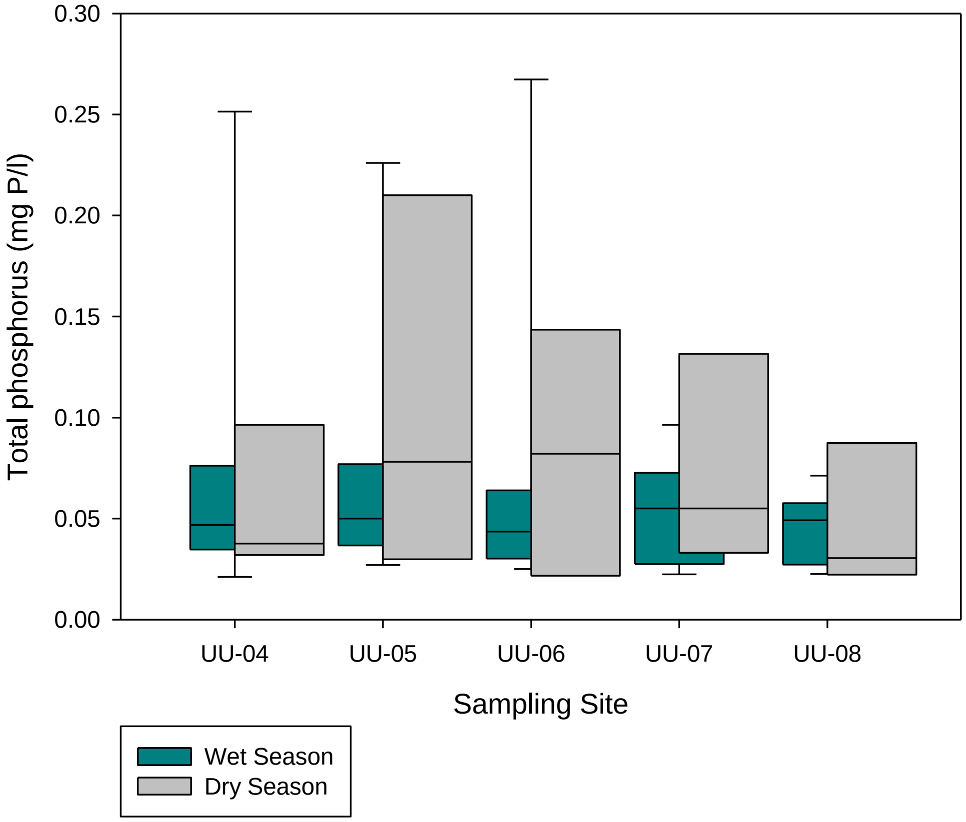
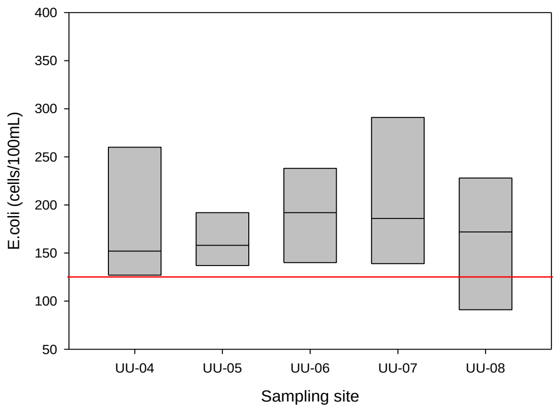
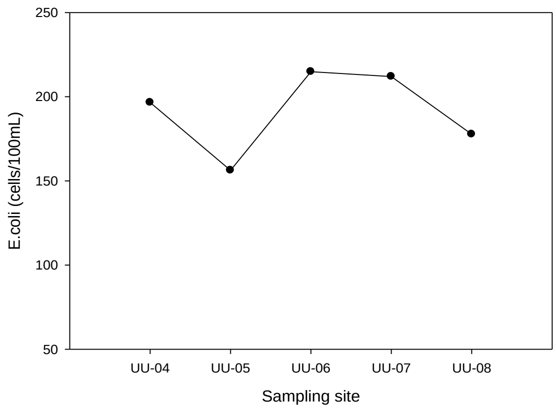


Figure 4.9. Box plot indicating the range of wet (n = 11) and dry (n = 7) seasonal concentrations of SRP measured at each sampling site (bars indicate the 10th, 25th, median, 75th and 90th percentiles

Concentrations of *E. coli* were measured from samples taken at the five sampling sites on a monthly basis. Concentrations were consistently higher than the South African 130 cells/100mL standard (DWAF, 1996c) for full human contact (Figure 4.10a). *E. coli* counts generally increased from UU-04 to UU-06, then decreased at UU-07 and UU-08. Although there was a decrease in count at the last two sampling sites, the count at the outlet (UU-08) was often higher than at the inlet (UU-04). Annual mean count showed the lowest concentration of *E. coli* was at UU-05 (Figure 4.10b), whilst UU-04 and UU-08 had counts of 197 and 178 cells/100mL per annum respectively.



a)



b)

Figure 4.10. a) *E. coli* count and annual mean at each sampling site (bars indicate the 25th, median and 75th percentiles, red line representing the DWAF (1996c) water quality standard). b) Annual average mean count of *E. coli* at each sampling site (n = 7)

4.4 Discussion

Protection of clean water supplies and improving the chemical quality in water resources in degraded areas is important for sustained human consumption and ecosystem health worldwide (Dosskey *et al*., 2010). Many studies at site scale have demonstrated that wetlands have the capacity to improve water quality over the long term (Verhoeven *et al*., 2006) by retaining nutrients and transforming them to less harmful substances (Hoffman *et al*., 2009). However nutrient cycling in floodplains is dependent on factors including; inundation area and duration, water retention time (Filoso and Palmer, 2011), flow velocity, soil characteristics, hydraulic load (Natho and Venohr, 2014), water temperature (Mitsch *et al*., 2000), soil characteristics and microbial groupings present (Baldwin and Mitchell, 2000). Therefore, it is important to understand the dynamics that drive water quality improvement, how they have been impacted by degradation and their causal effect on processes linked to nutrient cycling.

Nutrient uptake by the root zone of vegetation directly influences nutrient concentration in water flowing through floodplains (Dosskey *et al*., 2010). Riparian vegetation has a relatively large demand for N. However, at the study site little to no change in N was observed in the water quality samples through the floodplain. This was attributed to the channel being deeply incised with limited riparian vegetation on the banks (Table 4.1). The deeply incised channel at the Lions River floodplain merely transmits water through the floodplain greatly restricting its interaction with riparian vegetation and the larger floodplain area. It can therefore be expected that with no bank overspill occurring on this floodplain, N retention is probably restricted. It is well documented that vegetation in the riparian zone strongly influences chemical content of water in the adjacent stream (Baldwin and Mitchell, 2000; Hefting *et al*., 2005; Dosskey *et al*., 2010), particularly by nutrient removal and the lack thereof has had a detrimental effect on the study site's ability to reduce N levels. Also, N accumulation in wetlands is strongly correlated with organic matter deposition (Noe and Hupp, 2005), making riparian vegetation an important factor for N cycling.

Phosphorus retention in floodplains is driven by a range of physical, biological and geochemical processes (Noe and Hupp, 2005; Hoffman *et al*., 2009) which include sediment deposition, plant uptake, microbial activity (Brinson *et al*., 1981) and reduction and oxidation processes. The effectiveness of floodplains in retaining P is also strongly influenced by the form in which P enters the system (Hoffman *et al*., 2009). At the Lions River floodplain, SRP increases through the system whilst TP decreases. The increase in SRP from upstream to downstream in the floodplain indicates that SRP is being lost in this system, possibly through the conversion of insoluble P into a soluble form. Hoffman (1991) and Hoffman *et al*. (2009) reported losses of SRP in riparian and floodplain wetlands respectively and attributed their results to SRP loss from the root zone and lateral inputs from upland agricultural fields. At the Lions River floodplain, observations made in field during the study period note polluted water being transported into the main channel by an artificial drainage channel below sampling point UU-07. Thus, elevated downstream SRP levels may be linked to the run-off transported through the floodplain from the surrounding agricultural and commercial forestry land by artificial drainage channels into the main channel (Figure 3.3f), but further investigation is required to confirm this. Fisher and Acreman (2004) also reported SRP losses in other wetland types. Additionally, sedimentation is recognised as the major process driving the removal of P during floodplain inundation, overland flow (Tockner *et al*., 2002) and surface runoff (Noe and Hupp, 2005; Hofman *et al*., 2009). Noe and Hupp (2005) note that alterations to floodplain hydrological conditions effectively reduce sediment deposition. The MMTS has altered the hydrological conditions of the Lions River floodplain by increasing the velocity and quantity of water flowing through the floodplain resulting in a reduced water residence time and reduced sediment deposition in the floodplain (Hunter, 2009). This has probably led to increased losses of SRP as residence time is recognised as the most critical factor affecting the retention of SRP (Hoffman *et al*., 2009).

Local hydrological processes are recognised as the ultimate drivers of nutrient retention in floodplains (Hoffman *et al*., 2009). Being the decisive factor influencing contact between water and soil, it is fundamentally important to understand hydrological and biogeochemical processes governing nutrient dynamics in riparian areas (Baldwin and Mitchell, 2000; Noe and Hupp, 2005; Hofman *et al*., 2009; Dosskey *et al*., 2010). Noe and Hupp (2005) found that reduced hydraulic connectivity between floodplains and rivers was a limiting factor for sediment and nutrient retention in floodplains. Similar to these findings, the decreased hydraulic connectivity between the river channel and floodplain at the study site is likely to limit nutrient and sediment accumulation in the floodplain.

Nutrient retention in floodplains mainly occurs, either when water inundates the floodplain through bank overspill or when the floodplain acts as a buffer for diffused lateral nutrient inputs from upland areas (Filoso and Palmer, 2011; Natho and Venohr, 2014). The lack of bank overspill and low rainfall during the study period may have reduced the effectiveness of this floodplain to retain nutrients. Reduced water retention time (Filoso and Palmer, 2011) and increased flow velocity (Natho and Venohr, 2014) due to the MMTS have also probably impacted the floodplain's ability to retain nutrients.

Finally, faecal coliforms, including *E. coli* are common water quality indicators used to determine the presence of pathogenic microorganism that pose a health risk for humans. A number of mechanisms, such as inactivation, exposure to radiant energy, adsorption and sedimentation have been identified as responsible for *E. coli* removal in wetlands (Boutilier *et al*., 2009). At the study site, *E. coli* counts showed a net reduction from the inlet to outlet, however, peak counts were observed at sampling point UU-06 within the floodplain. This was attributed to the high cattle numbers grazing on the floodplain which may be a source for *E. coli*.

4.5 Conclusion

In this study the effect of the Lions River Wetland on downstream water quality has been investigated. Particularly the quality of water in the main channel flowing through the floodplain was analysed using water quality samples collected in the floodplain and related to the prevailing environmental variables in this degraded wetland. In the one year period, July 2014 to June 2015, ammonia and SRP concentrations consistently showed an increase from upstream to downstream. Total oxidised nitrogen and TP decreased from upstream to downstream through the floodplain. Overall, faecal coliform counts in the form of *E. coli* decreased from upstream to downstream.

Increased water demand within the uMngeni catchment and low rainfall during the study period resulted in the need for prolonged water release from the MMTS inter-basin transfer scheme. This increased flow velocity within the channel and effectively reduced water resident time in the floodplain. This, coupled with a deeply incised channel with little riparian vegetation is identified as a key contributor to low nutrient retention in the floodplain. A deeply incised channel with little riparian vegetation has a limited capacity to drive denitrification, a key process for the retention on N in floodplains. Furthermore, the increased flow velocity due to additional water inputs from the MMTS, limits sedimentation which drives P retention in floodplains.

Lastly, this study of the Lions River floodplain suggests that portions of the floodplain are acting as a source of nutrient and *E. coli* transported into the main channel. Due to degradation of the floodplain, artificial drainage channels are potentially transmitting nutrient from surrounding agricultural land through the floodplain and into the main channel, whilst the cattle grazing on the floodplain are a source for *E. coli*.

* * *

Chapter two of this dissertation highlighted the importance of comprehensively assessing different wetlands types to build our knowledge basis and understanding of these ecosystems, also enabling the planning and implementation of efficient rehabilitation interventions. The final chapter (i.e. Chapter 5) outlines the limitations of this study's comprehensive assessment of the ecological condition and impact of on downstream water quality of the Lions River floodplain. Furthermore, based on the outcomes of the study, the implications of the knowledge gained on the rehabilitation of the floodplain are discussed, as well opportunities for further research.

5 FINAL DISCUSSION AND CONCLUSION

In many parts of South Africa, wetland loss is estimated to be more than 50% of the original wetland area (Kotze and O'Connor, 2000; WRC, 2002; Driver *et al*., 2011; Rivers-Moore and Cowden, 2012) and this is the case for the upper uMngeni catchment. The main pressures faced by wetland ecosystems, and floodplains in particular (which have the highest proportion of critically endangered ecosystem types), include cultivation, poor grazing management, catchment-wide impacts such as inter-basin transfer schemes and pollutants and sediment (Driver *et al*., 2011). Fortunately, degraded wetlands can be rehabilitated to achieve at least a basic level of ecological and hydrological functioning forming healthy ecological infrastructure that provides and delivers important ecosystem services (Driver *et al*., 2011; SANBI, 2013). The primary objective of the research described in this dissertation was to determine the baseline ecological condition of the Lions River floodplain, to enable recommendations on rehabilitation interventions to be made. To fulfil this, the following two central research questions were addressed:

1. What is the current ecological condition and functioning of the Lions River floodplain based on vegetation composition and soil morphology as indicators of hydrological regime?
2. What effect is the floodplain having on the quality of water flowing through the main channel from upstream to downstream?

Changes in landuse often result in alterations to floodplain hydrology, leading to changes in vegetation composition (Owen, 1999). Often, floodplains become dominated by ruderal and invasive alien species (Zedler and Kercher, 2004). At the Lions River floodplain, approximately 40% of the floodplain area had medium to high (25 – 75%) abundance of redural and exotic species, whilst 21% of the total floodplain area had a very high (>75%) abundance (Section 3.3.3). The proportional abundance of alien and ruderal species, which were mostly non-wetland species, was higher in the drier areas i.e. transitional and non-wetland areas of the floodplain as illustrated in Figure 3.8. Alien invasive species have detrimental impacts on biodiversity and ecosystem function and their control is now a priority for Africa (Boy and Witt, 2013). The results of this study show a high proportional abundance of ruderal and alien invasive species on the floodplain, making their eradication an essential component of rehabilitating this floodplain to re-instate its natural vegetation composition. Moreover, overgrazing on floodplains can reduce biodiversity and increase alien invasive species (NSWDPI, 2008), therefore establishing a controlled grazing programme for the Lions River floodplain is important for its rehabilitation.

Hydric soils develop over long periods of saturation and remain visible in wetland soils which have been artificially drained and through drought years (Vepraskas and Caldwell, 2008), thus reflecting a wetland's long term water regime. Extensive areas within the Lions River floodplain are characterised by typically terrestrial soils (Hutton and Clovelly soil forms, Figure 3.6), indicating that these areas are naturally not wetland. These results are discussed in detail in chapter three which delves into question one of the two central questions for this dissertation, pertaining to the ecological condition and functioning of the Lions River floodplain.

It's been well documented that nutrient uptake by the root zone of vegetation directly influences nutrient concentration in water flowing through floodplains (Dosskey, 2001; Hefting *et al*., 2005; Baker *et al*., 2006). Riparian vegetation has a relatively large demand for N (Dosskey *et al*., 2010), however, at the study site little to no change in N was observed in the water quality samples through the floodplain. This was attributed to the channel being deeply incised with limited riparian vegetation on the banks. Furthermore, elevated downstream SRP levels may be linked to the run-off transported through the floodplain from the surrounding agricultural and commercial forestry land by artificial drainage channels into the main channel. Additionally, the MMTS has altered the hydrological conditions of the Lions River floodplain by increasing the velocity and quantity of water flowing through the floodplain, resulting in a reduced water residence time and limited sediment deposition (Hunter, 2009). Sedimentation is recognised as the major process driving the removal of P in floodplains (Tockner *et al*., 2002; Noe and Hupp, 2005; Hofman *et al*., 2009). Exploring question two of the central research questions for this dissertation, pertaining to the floodplain's effect on downstream water quality, chapter four concludes that the floodplain's contribution to improving downstream water quality is limited, and an important factor contributing to this is probably the degraded nature of the Lions River floodplain.

Wetlands are managed around the world to improve water resource management in agricultural catchments (Verhoeven *et al*., 2006). Thus, it is conclude from this study that rehabilitation interventions on this floodplain must be guided by soil characteristics which are a closer reflection of the floodplain's natural hydrological regime rather than vegetation, which generally reflect more recent hydrological conditions. Results from the showed that a fairly limited area of the floodplain that was historically wetland, as reflected in the soil morphology, now no longer support wetland conditions, as reflected in the vegetation. Thus opportunities for rehabilitation through re-wetting historical wetland areas are limited on the Lions River floodplain. However, soil hydromorphological features do show extensive areas of naturally non-wetland areas in the floodplain which could be investigated for constructing artificial wetlands to expand the floodplain enhancing the provision of ecosystem services. A number of studies have shown success in agricultural catchments using constructed wetland (Llorens *et al.*, 2009; Moreno-Mateos *et al*., 2010).

The results of this study suggest that nutrient retention at the Lions River floodplains mainly occurs either when water inundates the floodplain through bank overspill or when the floodplain acts as a buffer for diffused lateral nutrient inputs from upland areas (Filoso and Palmer, 2011; Natho and Venohr, 2014). Rehabilitation of the main channel to promote better riparian vegetation cover and the artificial drainage channels for improved retention of lateral run-off from surrounding agriculture and commercial forestry areas is likely to be important for promoting water and nutrient retention at the Lions River floodplain.

On-site assessments of individual wetlands typically require a considerable amount of time, resources and personnel with highly specialised training for completion (Maltby and Barker, 2009). This was an obvious limitation for the MSc level Lions River floodplain study. Due to the restricted scope of the study, key limitations included a lack of direct investigation of the impacts related to the degradation of the main channel by the MMTS and limited riparian vegetation on the banks of the main channel in relation to the floodplains' effect on downstream water quality. The impact of the construction of the artificial drainage channels in the main floodplain area in relation to ecological condition and functioning was also not thoroughly investigated. Moreover, the extent to which the floodplain has an influence on water quality of lateral inputs from the surrounding catchment was not examined. Also, the role of soil hydraulic connectivity as a driver of the ecosystems' structure and function was not fully explored but only inferred from soil hydromorphological features. Nevertheless, the results of the study provide a valuable knowledge base for the planning and implementation of rehabilitation and future monitoring at the Lions River floodplain.

Although, this study of the Lions River floodplains had its limitations, it is believed that it has nonetheless made some key scientific contributions to the understanding of wetland ecosystems in Southern Africa. The systematic approach used to survey historical water regime of the floodplain as reflected in soil morphology and the more current water regime as reflected in vegetation composition is a novel approach in the Southern African context of wetland assessments. The use of a combination of well-established tools i.e. WIV, soil morphological characteristics and soil classification enables this enables the approach taken for this study to be transferrable for application to other wetlands in the region for informing wetland rehabilitation planning, implementation and monitoring. Comprehensive wetland assessments are important for building our knowledge base and understanding of these ecosystems, also enabling the implementation of efficient rehabilitation interventions. Therefore, it is recommend that the wider application of this approach be explored.

Further research and monitoring of the hydrological and geomorphological processes driving ecosystem structure and function at the Lions River floodplain has the potential to enhance the usefulness of the findings of this dissertation. Also, further research into the impact of the MMTS on the floodplain by conducting a geomorphology study of the floodplain to establish if the river channel is still adjusting to the higher discharge through increased erosion or the system has reached a state of equilibrium is important going forward. This is a key determinate for the success of rehabilitating the main channel by establishing and promoting better riparian vegetation growth.

Additionally, the sampling plots established for the vegetation survey undertaken in chapter 3 present an opportunity for the establishment of permanent vegetation monitoring plots for monitoring at an intermediate level of complexity, as described in Figure 2.4. The species composition established by this study can be used as a baseline to assess the success of rehabilitation interventions during future monitoring of the site. There is also an opportunity for the continuation of water quality monitoring at the established sampling sites of the study, with the possibility of additional monitoring of the quality of water transmitted by the artificial drainage channels from the surrounding areas into the main channel.

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7 ANNEXURE 1

7.1 Lions River Wetland Vegetation Species List

Scientific Name	8 letter Acronym	Classification	Indicator status	Wetland Index Value
*Agrimonia procera**	Agriproc	Exotic	Non-wetland	5
Agrostis continuata	Agrocont	Indigenous	Obligate	1
Agrostis lachnantha	Agrolach	Indigenous	Obligate	1
Agrotis cf. eriantha	Agroeria	Indigenous	Facultative pos	2
*Alternanthera sessilis**	Altesess	Exotic	Facultative pos	2
Amaranthus sp.	Amarspec	Ruderal indigenous	Non-wetland	5
Aristida junciformis	Arisjunc	Indigenous	Facultative	3
*Brachypodium flexum**	Bracflex	Exotic	Facultative	3
*Bromus catharticus**	Bromcath	Exotic	Facultative neg	4
Carex austro-africana	Careaust	Indigenous	Obligate	1
Carex acutiformis	Careacut	Indigenous	Obligate	1
Centella asiatica	Centasia	Indigenous	Facultative pos	2
cf. Conyza scabrida	Conyscab	Indigenous	Facultative pos	2
*Conyza albida**	Conyalbi	Exotic	Non-wetland	5
Conyza pinnata	Conypinn	Indigenous	Facultative pos	2
Cotula nigellifolia	Cotunige	Indigenous	Obligate	1
Crinum sp.	Crinumsp	Indigenous	Obligate	1
Cymbopogon sp.	Cymbopsp	Indigenous	Non-wetland	5
Cynodon dactylon	Cynodact	Indigenous	Facultative neg	4
Cyperus esculentus	Cypeescu	Indigenous	Facultative	3
Cyperus latifolius	Cypelati	Indigenous	Obligate	1
Cyperus fastigiatus	Cypefast	Indigenous	Obligate	1
*Dactylis glomerata**	Dactglom	Exotic	Facultative	3
Diclis raptans	Diclrapt	Indigenous	Facultative	3
Eleocharis dregeana	Eleodreg	Indigenous	Obligate	1
Eragrostis curvula	Eragcurv	Indigenous	Facultative neg	4
Eragrostis plana	Eragplan	Indigenous	Facultative	3
Eragrostis planiculmis	Eragrpla	Indigenous	Obligate	1
*Ciclospermum leptophyllum**	Cicllept	Exotic	Facultative	3
*Fragaria vesca**	Fragvesc	Exotic	Facultative neg	4

Scientific Name	8 letter Acronym	Classification	Indicator status	Wetland Index Value
Hemarthria altissima	Hemaalti	Indigenous	Obligate	1
*Hypericum forrestii**	Hypeforr	Exotic	Facultative neg	4
Hypoxis hemerocallidea	Hypoheme	Indigenous	Non-wetland	5
Juncus effusus	Junceffu	Indigenous	Obligate	1
Juncus exsetrus	Juncexse	Indigenous	Obligate	1
Kyllinga melanosperma	Kyllmela	Indigenous	Obligate	1
Leersia hexandra	Leerhexa	Indigenous	Obligate	1
*Lilium formosanum**	Liliform	Exotic	Facultative neg	4
Mimulus gracilis	Mimugrac	Indigenous	Obligate	1
*Oenothera rosea**	Oenorose	Exotic	Facultative neg	4
*Cirsium vulgare**	Cirsvulg	Exotic	Non-wetland	5
Oxalis cf. corniculata	Oxalcorn	Ruderal indigenous	Non-wetland	5
*Paspalum dilatatum**	Paspdila	Exotic	Facultative pos	2
*Paspalum urvillei**	Paspurvi	Exotic	Facultative pos	2
*Pennisetum clandesinum**	Pennclan	Exotic	Facultative neg	4
*Persicaria hydropiper**	Pershydr	Exotic	Obligate	1
*Persicaria lapathifolia**	Perslapa	Exotic	Obligate	1
*Phalaris arundinacea**	Phalarun	Exotic	Obligate	1
Phragmites australis	Phraaust	Indigenous	Obligate	1
*Plantago lanceolata**	Planlanc	Exotic	Facultative neg	4
Pseudognaphalium luteo-album	Pseulute	Indigenous	Facultative pos	2
Ranunculus multifidus	Ranumult	Indigenous	Facultative neg	4
*Richardia brasiliensis**	Richbras	Exotic	Non-wetland	5
*Rubus cuneifolius**	Rubucune	Exotic	Facultative neg	4
Schoenoplectus sp.	Schoensp	Exotic	Obligate	1
Senecio polyodon	Senepoly	Ruderal indigenous	Facultative pos	2
*Solanum sp.**	Solanusp	Exotic	Non-wetland	5
Sporobolus africanus	Sporafri	Ruderal indigenous	Non-wetland	5
*Tagetes minuta**	Tageminu	Exotic	Facultative neg	4
*Taraxacum sp.**	Taraxasp	Exotic	Facultative pos	2
*Trifolium repens**	Trifrepe	Exotic	Facultative	3
Typha capensis	Typhcape	Indigenous	Obligate	1

Scientific Name	8 letter Acronym	Classification	Indicator status	Wetland Index Value
*Urtica dioica**	Urtidioi	Exotic	Facultative	3
*Verbena bonariensis**	Verbbona	Exotic	Facultative neg	4