ASSESSMENT OF THE FUNCTIONAL HEALTH STATUS OF THE MELVILLE WETLAND SYSTEM, KWADUKUZA, SOUTH AFRICA

By

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PREFACE

The experimental work described in this dissertation was carried out in the School of Geography and Environmental Sciences, University of KwaZulu-Natal, Westville campus, from March 2015 to December 2016, under the supervision of Dr.. Srinivasan Pillay.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

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DECLARATION- Plagarism

I, Ms. Salicia Gounden declare that;

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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ABSTRACT

Internationally, wetlands are recognised as being valuable, natural ecosystems that provide a spectrum of functions, goods and services. Wetlands are also known to be extensively prone to pollutants. KwaDukuza, which forms a part of the ILembe Municipality district, is located along the North coast of the KwaZulu-Natal province of South Africa, has recently experienced rapid economic development.

The main land use activities occurring in this area are equally divided between subsistence agriculture and industries. These activities have inadvertently resulted in the drastic degradation of wetlands, rivers and other coastal bodies located in this area. Depending on how negatively affected, this could have a significant impact on the economic development of the region (KwaDukuza Municipality, 2012). Furthermore, the current water crisis occurring in South Africa could be further compounded by the degradation of these water sources (Kotze et al, 2004) and have given rise to a substantial need to carry out objective assessments of the condition of wetland environments (Day and Malan, 2010).

Wetland assessments include step-by-step methodology whereby the reference or the pre-impact condition, present ecological state, ecological importance and sensitivity are all established (DWAF, 2004). In this study, from conducting such assessments it was found that the Melville wetland system, located in a rapidly developing suburb of the KwaDukuza Municipality, comprised of four hydrogeomorphic units and one river riparian unit. Results conclusively indicate that three out of the four HGM units were in a largely modified state with the remaining HGM unit in a moderately modified state, along with the river riparian area. Overall it was established that out of a total area of 6.79Ha, only 3.17Ha of healthy wetland remains.

Therefore it is essential that the relevant recommendations and mitigation measures such as the installation of gabion weirs, re-vegetation programmes, correct storm water management and most significantly, the minimising of human disturbances, be implemented and enforced to the fullest extent. Relevant implementable measures are presented in the concluding chapter.

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LIST OF ABBREVEATIONS

- APHA – American Public Health Association
- CC – Calcium Carbonate
- CMAs – Catchment Management Areas
- D.O – Dissolved Oxygen
- DWA – Department of Water Affairs
- DWS – Department of Water and Sanitation
- DWAF – Department of Water Affairs and Forestry
- EPA – Environmental Protection Agency
- FE - Iron
- GPS – Global Positioning System
- HGM Classification – Hydrogeomorphic Classification
- ICP OES - Inductively Coupled Plasma-Optical Emission Spectroscopy
- Mn – Manganese
- NEPA – National Environmental Policy Act
- NWA – National Water Act
- O.M – Organic Matter
- PES – Present Ecological State
- TDS – Total Dissolved Solids
- USEPA – United States Environmental Protection Agency

CHAPTER ONE

1. INTRODUCTION

1.1 WETLANDS

The term 'wetland' is generally used to describe a multitude of habitats where land becomes periodically saturated. Precipitation such as snow or rain, that is not lost to atmospheric processes such as transpiration or evaporation, enters a catchment and travels through the catchment until it reaches the sea (Collins, 2005). The formation of a wetland occurs when the topography or geology hinders the movement of water travelling through the catchment. This is usually where the topography is very gentle sloping or flat, or where groundwater seeps to the surface resulting in the soil layers at the surface to become permanently or seasonally saturated (DWAF 2004).

Such an environment thus provides a suitable habitat for plants known as hydrophytes, which thrive in such conditions These hydrophytes further play a role in changing the soil composition and hydrology by slowing down the water travelling through the catchment, as well as producing organic matter which ultimately accumulates in the soil (DWAF 2005).
Wetlands are therefore predominantly found in locations where surface water accumulates, and/or where groundwater seeps to the surface, which causes an area to become saturated for extended periods of time (Kotze, et al, 2004).

Thus, the phrase 'wetland' refers to aquatic ecosystems that may be permanently saturated, or areas that are not commonly saturated. Due to wetlands occurring between such extremes, they are regarded as transitional ecosystems, which encompass characteristics of both non-wetland and wetland environments (Collins, 2005).

Internationally, wetlands are recognised as being valuable, natural ecosystems and are known to carry out important functions (Davies and Day, 1998). Some of these functions include; providing a habitat for certain organisms which are exclusively reliant on wetland environments as areas for feeding, breeding, or as a nursery area for their young (Cowan, 1995). Furthermore wetlands also act as a 'sponge' during periods of flooding (flood attenuation), whereby wetlands are able to retain flood waters in the soil and thereafter gradually release the water. Additionally wetlands also act as water purifiers, as wetlands are able to absorb the nutrients and contaminants contained in the surface runoff (Davies and Day, 1998).

As a result of identifying the significance of wetlands, the Ramsar Convention was formed, which is a global treaty that aims to conserve wetland environments (Cowan, 1995). The treaty - of which South Africa was the fifth signatory member - binds its members to a set standard which promotes the conservation of wetland environments (Day and Malan, 2010). However, despite the development of such treaties, and the known ecological value of wetland ecosystems, they are still under significant threat (Cowan, 1995). It is estimated, by the Ramsar Convention on Wetlands, that the total loss of wetlands globally is 50% (Dini, 2004). It has been furthermore estimated from numerous studies that there has been a 35%-50% decrease in South African wetlands and the benefits that they offer (Dini, 2004).

In rural or agriculture dominated areas, the diminishing of wetland environments are related to activities such as poor drainage, ploughing, groundwater abstraction, and the construction of roads or bridges, over or too near wetlands, thus resulting in erosion and shrinkage of the wetland area along with marginalisation of remnant habitats. Wetlands can also become degraded due to nutrient enrichment which is caused by return flows containing livestock waste, as well as fertiliser from frequently fertilised lands. Furthermore, wetlands can become polluted due to the use of herbicides and pesticides, and effluent from mining (usually peat mining) activities, which similarly run off into the surrounding wetland environment (Ollis et al, 2013).

In urban areas, the loss of wetlands results from activities such as; the infilling of wetlands, drainage and diversion of flows, all of which are done in order to accommodate expanding infrastructure, such as houses and roads. The hydro-period of wetlands located in urban areas can also be subjected to great change as they can be completely drained or else receive increased flows due to an increase in groundwater levels, and/or increased run off from hardened surfaces. Nutrient enrichment in wetlands is also evident in urban areas as untreated sewage is dumped in these wetland environments increasing the degradation of wetlands (Macfarlane et al, 2014 a).

1.2 MOTIVATION FOR STUDY

KwaDukuza, located on the KwaZulu-Natal north coast approximately 60km from Durban, is a local municipality within the ILembe District Municipality, is located along the North coast of the KwaZulu Natal province of South Africa. The main land use activities occurring in this area are equally divided between agriculture and industries. Wetlands located in the iLembe District and KwaDukuza in particular, are thought to be extensively prone to degradation due to the rapid pace of development. Various land use related activities have resulted in the drastic degradation of wetlands, rivers and other coastal bodies located in this area.

Depending on how negatively affected, this could have a significant impact on the economic development of KwaDukuza (KwaDukuza Municipality, 2012). Furthermore, the current water crisis occurring in the region could be further compounded by the degradation of these water sources (Kotze et al, 2004). Due to such threats, there is a substantial need to carry out objective assessments of the condition of wetland environments (Day and Malan, 2010).

The uncontrolled expansion of a number of residential areas such as Ethafeni, Groutville, and Melville has compromised numerous wetlands. One example of a wetland at risk is the Melville wetland located adjacent to the main road (R102) connecting Stanger with Tongaat to the south. Since the Melville wetland is located in the midst of a fast developing area, and since it is seen as an obstruction to development, local residents see no value in it and are actively encroaching into wetland zones.

It is therefore critical to study the health status of the Melville Wetlands, assess the value of this feature in terms of the goods and services it provides and evaluate its ecological sensitivity and vulnerability. This would provide the basis for recommendations to mitigate impacts and for the rehabilitation and protection of this valuable ecosystem.

1.3 AIM AND OBJECTIVES

The aim of this study is to evaluate the ecological status of the Melville Wetlands using the tools for wetland assessment developed and used in South Africa

The objectives of the study with reference to the Melville Wetlands are as follows:

- Map, delineate and classify the wetlands;

- Determine the Present Ecological State (PES) of the hydrogeomorphic units making up the wetland environment;
- Conduct a functional assessment;
- Establish the ecological sensitivity and vulnerability.

1.4 STUDY REGION

Below, Table 1.1 outlines a brief description of the study site.

Table 1.1. Summary of the Physiographic Characteristics of KwaDukuza

(KwaDukuza Municipality, 2012)

Geographic Location	29^0 22' 40" S 31^0 15' 17" E
Rainfall Range (mm/yr; minimum-maximum)	650 – 1200 mm/yr
Temperature Range	Average Minimum: 16^0C Average Maximum: 21^0C
Vegetation Unit	KwaZulu Natal Coastal Belt (CB3)
Population	300 000

1.5 REGIONAL LOCATION

The area in which this study is based on falls within the KwaDukuza municipality which is one of the four local municipalities that comprise of the ILembe district municipality (ILembe District Municipality, 2013). KwaDukuza is centred on 29^0 22' 40" S and 31^0 15' 17" E, along the north coast of the KwaZulu Natal province in South Africa, and has an inland and coastal expanse of approximately 1200 km^2 in which the current population is estimated to be 300 000 (KwaDukuza Municipality, 2012).

The KwaDukuza Municipal region extends from the uThongathi River in the south, to the Zinkwazi River in the north and borders four other Municipalities, namely; Mandeni, eThekwini, Maphumulo and Ndwedwe. It is one of the four municipalities that comprise of the ILembe District Municipality (KwaDukuza Municipality, 2012).

1.6 REGIONAL CLIMATE AND ENVIRONMENTAL CONTEXT

The KwaZulu Natal province in which KwaDukuza is located in is known for its sub-tropical climate, with little to no variation in seasons. KwaDukuza has a mean temperature range of 5^0C, with minimum temperatures averaging around 16^0C and mean maximum temperature of around 21^0C. Average rainfall in this region ranges from an average of 650mm/year to 1200mm/year (KwaDukuza Municipality, 2012).

Much of the land in KwaDukuza has been significantly transformed over the years. Multiple rivers meander through this region in a west to east direction which eventually reaches the Indian Ocean. These rivers include; the uThukela River (the largest river in KwaZulu Natal), Zinkwazi, uMvoti, uMhlali, and the uThongathi River.

Various land use related activities, especially those concerning the cultivation of sugar cane, has resulted in significant degradation of the wetlands and rivers located in KwaDukuza. This has, as a result caused negative impacts on the functioning of these ecosystems (KwaDukuza Municipality, 2012).

1.7 LAND USE ACTIVITIES WITHIN THE KWA DUKUZA REGION

KwaDukuza serves as the main commercial centre of the ILembe District with various activities occurring in this district. Agriculture being the most significant of these activities, contributes 23% of the total gross domestic product (ILembe District Municipality, 2013).

The most predominant type of agricultural product produced in this region is sugar cane, however there are various other products produced such as flowers (for retail purposes) and vegetables which thrive in the sub-tropical climate of KwaDukuza. As a result of the large scale agricultural activities this area is also known for the multiple industries located here, such as the sugar cane mills (SIVEST, 2007).

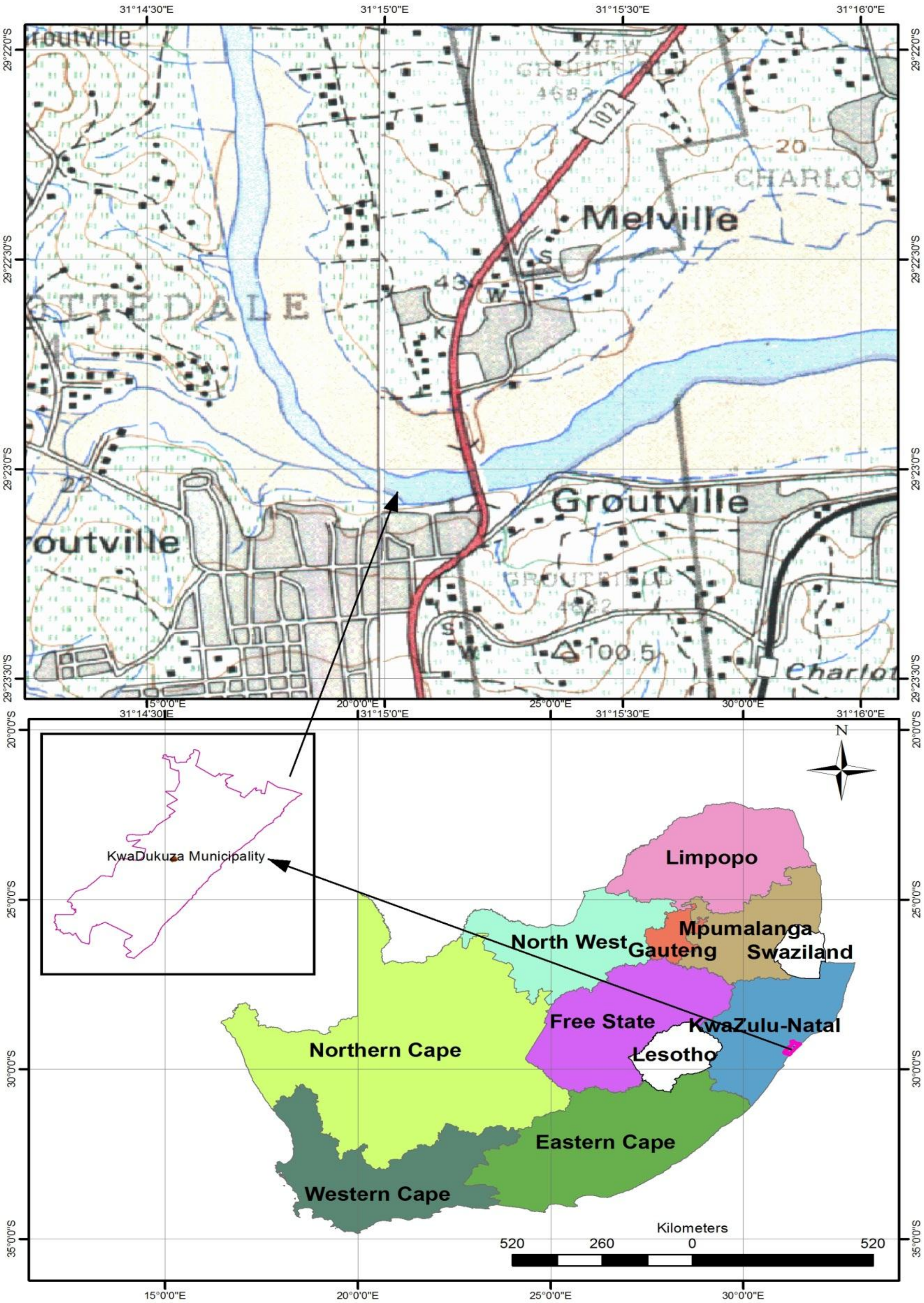


Figure 1.1. Regional Setting of KwaDukuza and the Melville Study Site

1.8 STUDY SITE: MELVILLE

The wetlands that are the focus of this study are located in the residential suburb area of Melville, which is town situated within the KwaDukuza municipality region, KwaZulu-Natal. Melville is centred on the co-ordinates of 29°22'40"S and 31°15'17"E and is located approximately 1.5km away from neighbouring town of Groutville, and 5km south of KwaDukuza town, along the main road, the R102.

1.8.1 Melville Wetland System

The total area of the study site was determined to be 6.79Ha with a catchment area of 712m^2. The Mvoti River is situated to the west and south of the study site, and travels eastwards, dissipating into the Indian Ocean. The site is bordered by residential infrastructure and the R102 (main road) running along the left of the site. To the right of the R102, adjacent to the wetland, is Melville Primary School.

For a short distance of an estimated 1200m, the Johambini Stream extends upstream. Along the eastern boundary of Melville Primary School there is a short stream which flows for about 200m and drains a narrow catchment that contributes to the overall catchment area of the wetlands. Within the catchment area there are regions which are partly inhabited with vacant areas that are covered with grasses, but are becoming increasingly utilised for residential purposes.

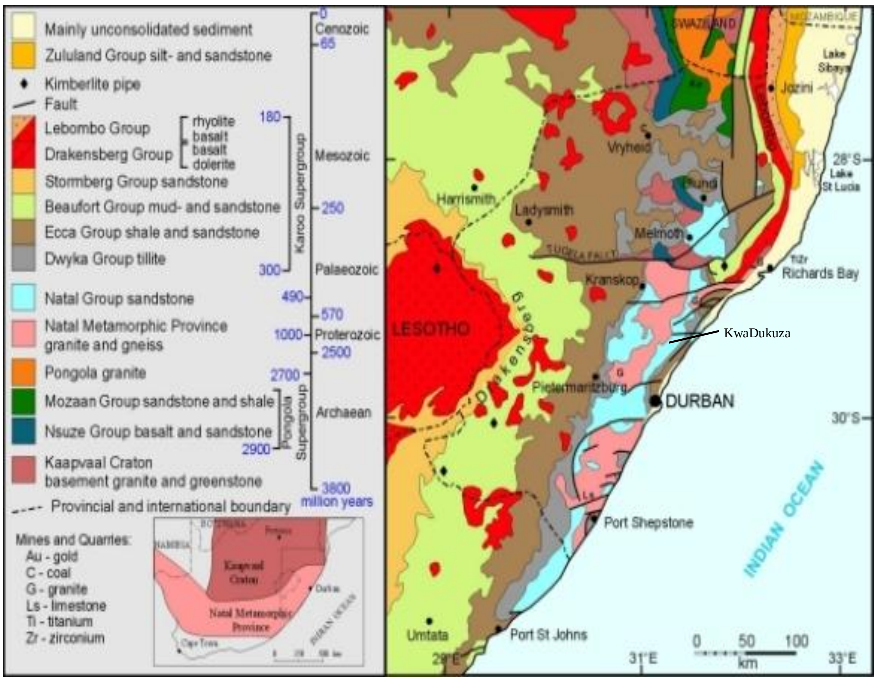
As a result of such developments there is a potential for high solid waste pollution within this site which poses a great threat to health of the wetlands.

1.8.2 Land Uses occurring in Melville

The most predominant land use occurring within Melville, and more specifically within the study site, is residential use. Due to the significantly rural communities encompassing this area a large portion of the population are reliant on agricultural practices for their livelihoods, thereby a large portion of the land is utilised for the cultivation of crops such as lettuce and cabbage. In addition to subsistence farming taking place, this region is rapidly developing with the building of infrastructure such as roads and houses taking place in close proximity to the wetlands.

1.8.3 Soils and Geology

The regional geology underlying the study site is characterized by Quaternary aged semi-consolidated and mostly arenaceous rock (sandstone, feldspathic-sandstone and arkose). This is underlain by sedimentary rocks of the Pietermaritzburg Formation of the Ecca Group of the Karoo Sequence (Johnson et al, 2006). The Pietermaritzburg formation, in turn, is underlain by Dwyka and Natal Groups formations (Durban Geological Map – 2930 Durban, 1988). Within the study area wetlands, sediment and organic matter accumulated over several decades have led to the formation of well-developed, organic rich horizons.



<u>Figure 1.2. Underlying Geology of the KZN Coastal Belt</u>

(University of KwaZulu Natal, Department of Geology map)

1.8.4 Vegetation

Indigenous vegetation was found to be largely removed within the study site, due to the encroachment of agricultural activities and the development of housing. Some of the dominant obligate wetland vegetation identified included Phragmites capensis, Pennisetum purpurem and Cyperus papyrus. There was however a large presence of alien invasive species such as Helianthus, Solanum mauritianum and Ricinus communis.

1.9 SUMMARY AND CHAPTER SEQUENCE

As defined by The National Water Act (NWA), wetlands are; "land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life in saturated soils." Their enormous significance is recognised both internationally and nationally.

KwaDukuza is an area which is situated in an area which is heavily affected by the current water shortages in South Africa. Therefore, as a result of such situations being prevalent, it is now, more so than ever, essential to measure and monitor the health status of wetlands, by means of a wetland assessment, which is what this study aims at accomplishing.

Chapter two, following on, identifies the literature used to substantiate the study in which wetland classification, hydrological zones, factors used in a wetland assessment, as well as other topics, are researched. Chapter three is the methodology which extensively explains the methods by which results were obtained. Chapter 4 examines the results found throughout the study and are discussed further in Chapter 5. And finally, Chapter 6 comprises of recommendations and mitigations as well as brief concluding remarks summing up the entire study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 WETLANDS: Definition and General Characteristics

As per the National Water Act No. 36, a wetland can be defined 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.'

This definition was initially formulated by Cowardin et al (1979) in aid of the wetland classification system. According to this definition, for an area to be categorised as a wetland, it must conform to a minimum of one of the following criteria:

- Saturated hydric soil must predominantly constitute of the substrate.
- Hydrophytes must, at least temporarily, be supported by the land.
- The substrate, must be periodically submerged under shallow water or appear saturated.

The definition provided by the NWA appears significantly different from the definition offered by Ramsar in 1971, which states, 'for the purpose of this Convention, wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres' (Ramsar COP 7, 1999).

The NWA definition clearly does not include rivers and estuaries, unlike the Ramsar definition. However, the wetland classification system which is used to categorise South Africa's wetlands, is inclusive of the Reserve Determination Method (DWAF, 1999), which thus promotes compatibility with the definition put forward by Ramsar by including what Cowardin et al, (1979) referred to as 'deep water habitats' into the original definition. These deep water habitats are defined as 'permanently flooded lands lying below the deep water boundary of wetlands. They include environments where surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are attached to the substrate.'

According to the Dini, Cowan and Goodman (1998) classification protocol, the wetland Reserve Determination method (DWAF, 1999) describes the following types of South African wetlands:

- Lacustrine – fresh water lakes.
- Palustrine – fresh water peatlands, marshes, swamp forests, springs and flood plains.
- Endorheic – seasonal and permanent pans.

2.2 WETLAND DISTRIBUTION IN SOUTH AFRICA

Wetlands are generally most common in areas that have a high mean annual rainfall such that the amount of water received through precipitation exceeds the amount of water lost through surface runoff and evapotranspiration (Botes, 2009).

Past studies, concerning national wetland environments, reveals that in South Africa the number of wetlands within are low, and their extent is limited as a result of the physiographic and climatic regimes predominant in the landscape (Begg, 1986). The majority of steep topography, coupled with the low annual rainfall experienced in the coastal belt zones and the inland margins of South Africa has rendered these regions unsuitable for the formation of wetlands (Begg, 1986).

The existence of wetlands are therefore more commonly experienced within the interior plateau zone of South Africa as a result of its flat topography, despite this region receiving less than 500mm of mean annual rainfall (Barnes et al, 2001). However, alternatively riverine wetlands are found occurring in regions along drainage lines and river banks within the inland margin zone of South Africa, and more limitedly within the coastal belt zone (Barnes et al, 2001). For instance, the floodplain wetlands existing along the lower uMgeni River are amongst the few wetland areas occurring within the coastal bet of the country.

Due to such findings it is realised that a greater value needs to be attached to all types of wetlands in South Africa despite their size, location or their classification.

2.3 WETLAND CLASSIFICATION

The concept of classifying wetland systems is to categorise similar types of wetlands into groups and subgroups, usually for the purpose of inventorying wetlands. In each classification system, every wetland type is representative of a general set of characteristics, be it ecological, geomorphological or hydrological. The main purpose of classifying wetlands is to aid in understanding and identifying the predominant wetland types present in a specific area, and to offer a broad-level categorisation of the system (Cowardin et al, 1979).

In South Africa, the system of classification of Dini, Cowan and Goodman (1998) is utilised, which is based on the system developed by Cowardin. This classification system recognises six types of wetland groups which are namely, estuarine, marine, lacustrine, riverine, endorheic and palustrine. This method of classification was utilised as the early basis of inventorying and mapping South African wetlands. Furthermore it is the system utilised in the Wetland Reserve Determination Process (DWAF, 1999).

Hydrogeomorphic Classification (HGM) was formulated by Brinson (1993) for the US Army Corps of Engineers, which is now the most commonly utilised system in America. This system of classification is based on the idea that despite the uniqueness of each wetland, they can still be placed in groups depending on the similar functional properties they share. HGM Classification concentrates mainly on geomorphic and hydrological characteristic which maintains many of the functional aspects of wetland systems (Kotze et al, 2004).

The HGM system has been modified by Marneweck and Batchelor (2002) for conditions experienced in South Africa, and furthermore modified by Kotze, Lindley and Collins (Kotze et al, 2004). This system has been adapted for utilisation in wetland inventory and wetland assessment, and is accepted for use in the Wetland Reserve Determination method. The HGM system is concerned with the hydrogeomorphic determinants of wetlands, as well as the topographic setting (DWAF, 2006).

The HGM classification system categorises wetlands according to the manner in which water moves in, through and out of a wetland system, as well as the position of the wetland on the crest, slope or in the valley bottom (DWAF, 2006). There are five palustrine wetland types categorised according to the HGM classification system which are, floodplains, channel valley bottoms, unchannelled valley bottoms, pans and depressions (including lakes) and seepage wetlands (Kotze et al, 2004).

2.4 TYPES OF WETLANDS

As per the National Wetland Classification System developed by Macfarlane et al (2007), there are multiple types of wetlands in South Africa. Each of these wetland types are described further according to the findings of Macfarlane et al (2007).

2.4.1 Floodplains

Floodplains commonly receive majority of their water in times of increased flow events when the waters breach the adjacent stream banks. These types of wetlands are believed to be significant in the attenuation of floods due to their topographic location that they occupy and the nature of the vegetation which they consist of (Macfarlane et al, 2007).

The occurrence of flood attenuation by floodplains is generally increased early in the rainy seasons to the point where saturation of the soil occurs and all depressions, such as oxbows, are filled. Conversely, in the late season, the capacity of the floodplains to attenuate flooding events is usually diminished. However, even during periods of flooding in the late season, floodplains are, to some extent, still efficient in reducing flooding events, especially in the more arid periods (Macfarlane et al, 2007).

With regards to stream flow, floodplains are known to have little to no impact on the regulation of stream flows. Floodplains consist of soils which are predominantly constituted of clays, these clay rich soils retain water which is commonly lost through the process of evapotranspiration. As a result, this reduces the contribution of water to stream flows as well as to the replenishment of groundwater sources (Macfarlane, 2007).

Floodplains are generally regions rich in phosphorous as they contribute immensely to the trapping of phosphorous. This occurs when waters breach onto the banks of the river, thus causing a decrease in the flow velocity laterally, which therefore allows sediment to be deposited across the floodplain landscape. As a result, due the strong bounding characteristic of phosphorous, it is retained throughout the floodplain (Macfarlane et al, 2007).

Conversely, the removal of nitrogen (through nitrification or denitrification), is likely to take place within floodplains, but however it is limited as a result of decreased residence times occurring during flooding events and limited movement of the sub surface waters within a wetland. Additionally, the nutrient concentration found in flood waters breaching the floodplain is generally low due to the process of dilution (Macfarlane et al, 2007).

2.4.2 Channelled Valley Bottom

Channelled valley bottom wetlands have many similarities to floodplains, however some significant differences exists between floodplains and channelled valley bottom wetlands, such differences include; a decreased amount of sediment deposition occurring in channelled valley bottom wetlands and the absence of floodplain features such as oxbows, meander scrolls and levees in channelled valley bottom wetlands. These wetlands also tend to have steeper slopes and are much narrower (Macfarlane et al, 2007).

From a functional perspective, channelled valley bottom wetlands are less prone to aid in the attenuation of floods and the trapping of sediments, however, they can provide such benefits to a certain extent. Nitrate as well as toxicant removal will take place, mainly from the water received from the surrounding hillslopes (Macfarlane et al, 2007).

2.4.3 Non- Channelled Valley Bottom

Floodplains and non- channelled valley wetland types resemble each other in the gradient of their slopes (which are generally gentle in slope), high amounts of sediment deposition, as well as in the location which they tend to exist in. Unalike features between these two types of wetlands include the input from the stream channel of non- channelled valley bottom wetlands, which is diffused through the wetland even during periods of low flow, as a result this forms an extensive area of organic matter rich soils and a wetland region that remains permanently saturated (Macfarlane et al, 2007).

Consequently, the removal of nitrates and toxicants is predicted to be lower in non-channelled valley bottoms, as in floodplains there is a greater amount of contact between the wetland and runoff waters, especially when there is a considerable groundwater contribution received by the wetland. Toxicants are removed via photo degradation due to the shallow waters promoting the penetration of sunlight thus allowing photo degradation of toxicants to occur (Macfarlane et al, 2007). Similarly, the amount of phosphate retained within non-channelled valley bottom wetlands tends to be lower than that retained in floodplains. This is caused due to extended periods of anaerobic conditions which allows for a certain level of phosphate to be remobilised (Cronk and Fennessy, 2001).

In seepage slopes however, the removal potential of nitrates would further be decreased as a consequent of the subsurface water movement through a wetland (generally where significant amounts of nitrate removal occurs, associated with increased levels of organic matter and decreased levels of oxygen) occurring at a lesser extent due to the less permeable, finer soils as well as the lower gradients.

Conversely, where there is an increase in subsurface water inputs, the level of nitrate removal in non- channelled valley bottom wetlands is largely resembled to that of hillslope seepage wetlands (Macfarlane et al, 2007). Regulation of the stream flow may occur to a certain extent, however this is likely to be strongly dependant on aspects such as; loss due to transpiration from vegetation and the soil characteristics (Macfarlane et al, 2007).

2.4.4 Hillslope Seepage Wetlands

These types of wetlands are usually associated with water discharged from groundwater sources, however contributions from surface water may supplement flows through the wetland. Hillslope seepage wetlands are thought to contribute to a portion of attennation of surface flows during the early parts of the season until soil saturation occurs, while thereafter their ability to attenuate floods becomes limited (McCartney 2000; McCartney et al, 1998).

Evapotranspiration occurring within hillslope seepage wetlands is recognised to cause a significant decrease in the total quantity of water, which otherwise would reach the stream system potentially (Macfarlane et al, 2007). Nevertheless, the build-up of fine sediments and organic matter within wetland soils causes the diminishing speed of subsurface water flows through the wetland and down the slopes. Hence, a 'plugging' effect is created which results in an increase in the storage capacity of slopes above the wetland, as well as a prolonging of the supplementation of the water to the stream body during periods of low flows. For the majority of hillslope seepage wetlands this contribution is strictly confined to the wet season, however for a few of these wetlands this contribution may extend into the dry seasons (Macfarlane et al, 2007).

Seepage wetlands are largely recognised for the multiple benefits that they are known to provide to enhance the quality of water. Such benefits include the removal of inorganic pollutants and an excess of nutrients which are produced by domestic, industrial and agricultural wastes (Rogers et al, 1985; Gren et al, 1994; Ewel, 1997; Postel and Carpenter 1997).

Furthermore, these wetlands would be considered to have an increased removal potential for nitrogen. Nitrogen and specifically nitrate removal is likely to be experienced due to the groundwater emerging through areas within the wetland of low redox potential, with wetland vegetation promoting the supply of organic carbon which is imperative to the process of denitrification (Muscutt et al, 1993).

With regards to the erosional characteristics of hillslope seepage wetlands, despite their steep slopes (which increases the risk of erosional activities occurring), these types of wetlands are not considered to be significant from an erosional aspect, considering that the vegetation on the slopes remain intact (Macfarlane et al, 2007).

2.4.5 Isolated Hillslope Seepage Wetlands

Isolated hillslope seepage wetlands closely resembles' hillslope seepage wetlands as they both have similar sources of functioning and water. However, a significant difference between these two types of wetlands is the degree of wetness, as isolated hillslope wetlands generally have a lower level of wetness in comparison to hillslope seepage wetlands and furthermore have minimal direct contribution to the regulation of the stream flow as a consequent of them not directly being connected to a stream channel (Macfarlane et al, 2007). A number of these settings do however, provide waters through subsurface water flows, as experienced on slopes covered in sand (Macfarlane et al, 2007).

2.4.6 Depressions

Depressions are able to receive both groundwater and surface flows, which in turn builds up within the depression due to a characteristic underlying impervious layer which prevents the drainage of the accumulated water (Goudies and Thomas, 1985; Marshal and Harmse, 1992). The relevant contributions from each of the water sources may differ greatly amongst the various depressions. The ability for flood attenuation is diminished due to the position of the depressions within landscapes, which are usually situated in locations where they are isolated from stream channels (Macfarlane et al, 2007). Nonetheless, these features do receive runoff from the surrounding landscape, due to their inward draining characteristics. As a result, depressions are able to decrease the quantity of surface water which would alternatively reach the stream body during periods of storm flow (Macfarlane et al, 2007).

Depressions are therefore considered not to be significant in stream flow regulation due to their inward drainage characteristic and their underlying impermeable layer. Additionally, depressions are also considered insignificant in the trapping of sediments, with a number of depressions originating due to the removal of sediments from wind activity (Goudie and Thomas, 1985; Marshal and Harmse, 1992).

Temporary depressions contribute to the precipitation of minerals, such as phosphate, as a result of the concentrating effects of evaporation. The cycling of nitrogen is major within depressions, however some losses occur due to the processes of volatilisation (when concerning high pH) and denitrification. The quality of water found in depressions is influenced by the geology, pedology as well as the local climate (Allan et al, 1995). Consequentially, these factors affect the ability of the system to deal with the nutrient inputs. In depressions that dry out completely during the dry periods, some of the built up nutrients and salts are transported out of the depression by wind activities and are in turn deposited in the surrounding slopes. Furthermore, when the depression becomes refilled with rain water, the remaining salts and nutrients dissolve (Macfarlane et al, 2007).

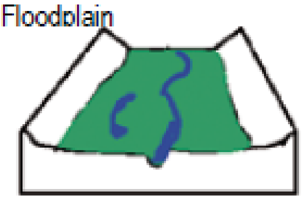
Hydrogeomorphic types	**Description**
Floodplain 	Valley-bottom areas with a well defined stream channel, gently sloped and characterized by floodplain features such as oxbow depressions and natural levees and the alluvial (by water) transport and deposition of sediment, usually leading to a net accumulation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

Figure 2.1. Wetland Classification

(Macfarlane et al, 2007)

2.5 HYDROLOGICAL ZONES

The hydrological regime within wetlands does not remain constant throughout the entire wetland due to the nature of the landscape in which wetlands are usually formed.

There are areas within wetlands or entire wetland systems that range from being permanently saturated throughout the year; to areas that are seasonally saturated for 5-11 months of the year. Such wetlands are dependent on the rainfall and climate patterns as well as those wetlands which are temporarily saturated for 1-5 months of the year but still long enough to develop anaerobic soil conditions. Wetlands may exhibit all of the hydrological zones (permanent, seasonal and temporary), any two of them, or only one - depending on the hydrology (DWAF, 2003).

The redoximorphic properties present within the soil matrix in wetlands aids in determining the hydrological zones (DWAF, 2006). In seasonal and temporary wet zones of a wetland the mottles redox concentration are near the soil surface, whereas in non-wetland zones the mottle redox concentrations are located much deeper in the soil profile.

In permanently saturated wet zones of the wetland the mottle redox concentration are usually low or absent as a consequence of the anaerobic conditions (DWAF, 2003). The oxidation of the colourless Fe^{2+} to $Fe^{3+}$is not as readily present as in the seasonally and temporarily wet soils. The reduction and the subsequent redox concentrations and redox depletions in the soil is significant in defining the parameters of a wetland. Wetlands are only classified as such once the soil displays these redoximorphic characteristics within the upper 500mm of the soil profile (DWAF, 2006).

2.5.1 Temporary Wet Zones

The temporarily saturated zone of the wetland is characterized by a minimal grey matrix of less than ten percent of the soil volume, the occurrence of chroma mottles and minimal periods of saturation (typically not more than three months per annum). The temporary wet zone is the area between the wetland and surrounding dry land (DWAF, 2006). The hydrological functions associated with the temporary wet zones are not significant due to the limited surface area of the temporary wet zone, the lack of water they receive, lack of the significant aerobic and anaerobic conditions, limited organic matter due to the short time span of anaerobic conditions and the mediocre plant productivity. The capability of the temporary wet zones to perform hydrological functions are higher than the adjacent dry lands and may be significant sites for these functions, if the other, more capable hydrological units, do not exist (DWAF, 2006).

2.5.2 Seasonal Wet Zone

Seasonally saturated wet zones are characterised by a grey soil matrix of more than ten percent of the soil volume, the high occurrence of chroma mottles and extended periods of wetness (a minimum of three months of saturation per annum). Episodic flooding results in aerobic and anaerobic conditions in seasonal wet zones which are more favourable than permanent zones for performing water purification functions. The seasonally saturated zone is the most important zone for the water purifying process dependant on the aerobic/anaerobic environment. The frictional value of the seasonal zones are not as high as that of permanently saturated zones; it is in most cases still sufficient (DWAF, 2006). The frictional value is dependent on the ratio of inflow and surface area and the flat nature of the palustrine wetland type, to diminish the velocity of flows enough in order for the purifying of water to take place. Seasonally wet zones usually have a lower organic content than permanently wet zones as a result of the prevalence of aerobic conditions, which promotes the decay of organic matter. Efficiency of seasonally wet zones with regards to organic matter is therefore lower than in permanent wet zones, but still contributes significantly to towards water purification with using these processes (DWAF, 2006).

2.5.3 Permanent Wet Zone

Permanent wet zones are characterised by a prominent grey (gleyed) matrix, absence or few high chroma mottles, saturation throughout the year and a sulfuric odour (DWAF, 2006). From all the zones, the permanently wet zones have the most significant potential to reduce the velocity of water due to the high frictional value of the hydrophytes and the flatness of palustrine type wetlands; they naturally diminish the velocity of flow, even when vegetation is not present. The permanent saturation of the soils results in anaerobic conditions. High organic content is associated with the permanent wetlands due to the prevalence of hydrophytes and the anaerobic conditions the decomposition process is slowed down. The water purification functions, flood attenuation and regulation associated with organic matter are most efficient in this zone than compared to the other zones (DWAF, 2006).

2.6 THE PHYSIOCHEMICAL ENVIRONMENT OF WETLANDS

2.6.1 Interstitial Water

There are multiple major inflows and outflows occurring within wetland systems, these include; precipitation, evapotranspiration, surface water inflows and outflows, tidal inflows and outflows, groundwater to and from rivers, groundwater inflows, and groundwater flows received from upland regions (van der Valk, 2012). For the formation of a wetland to occur in a particular region, it is imperative that the total amount of input components must exceed the total amount of output components (Schwirzer, 2006).

Relative to this, it must be noted that water flows, as well as surface and sub-surface water levels are dynamic, as they are subjected to the consequences of seasonal change, and thus the changes in geomorphology and climate (Schwirzer, 2006). This is clearly recognised in the presence of floodplain wetlands, as these types of wetlands, during periods of droughts or dry seasons (when the water table drops), alternatively receives their water from adjacent river systems (Nyarko, 2007).

Nyarko (2007), highlighted the existence of a relationship between surface and wetland interstitial water quality. This relationship notes that alterations in the wetland environment, caused due to the influence of external factors, such as seasonal and climatic changes, are accompanied by alterations in the river system and vice versa. Especially significant in these scenarios are the resultant effects on the chemical and physical properties of river and wetland interstitial waters (Kingsford, 2000).

2.6.2 Water Quality

The phrase ‘water quality’ is utilised to describe the aesthetic, biological, chemical and physical characteristics of water which determines its suitability for various uses as well as for the conservation and protection of aquatic (including semi aquatic) environments (DWAF, 1996). The health of wetland ecosystems are greatly dependant of the quality of water, as the water quality partially determines the health and integrity of wetland systems (Reddy and

Gale, 1994). The use of water quality in determining ecosystem health has become mandatory for several Catchment Management Areas in South Africa, to the extent that water quality testing and monitoring form a vital component of Catchment Management Plans (Dickens et al, 2003).

2.6.3 Water Quality Management

Increasing levels of focus have been placed on monitoring the level of water quality in aquatic and semi aquatic environments in South Africa, due to growing concerns regarding the depleting water sources, in an already water scarce country. Additionally, the high expense associated with the complete degradation of wetland ecosystems has brought about the imperativeness of monitoring and measuring the quality of water and variables associated with water quality, in order to discover trends, early detection of problems and for the application of suitable limits (Sukdeo, 2010).

The standards of water quality in South Africa are maintained by the water quality guidelines developed by the Department of Water Affairs (DWA), formerly known as the Department of Water and Sanitation (DWS). The aim of these guidelines is to bring about acceptable standards of water quality variables pertaining to the particular activity for which the resource will be utilised for (DWAF, 1996). These guidelines relate to the management of water resources which are used for recreational, domestic, agricultural and industrial purposes as well as for the conservation of aquatic and semi aquatic environments (DWAF, 1996).

2.6.4 Physical Properties of Sediments

Sediments can be generally categorized as cohesive or non-cohesive. Cohesive sediments resistance to erosion are dependent on the strength of the cohesive bond which holds together the particles. Cohesion of sediments takes precedence over the influence of the physical properties of individual particles (Simons and Senturk, 1992). However, due to erosion, cohesive particles may become non-cohesive with regard to the transportation process. Chemical and physical reactions can also influence alteration of sediment properties (Morgan, 1995). Alternatively, non-cohesive sediments typically compromise of larger, detachable particles, in comparison to the cohesive sediments. Non-cohesive sediment particles respond to fluid influences and their physical characteristics such as sediment size is influenced by movement (Simons and Senturk, 1992).

Sediment size is one of the most important properties of sediments. This is due to the fact that size is an important parameter when working with sediment particles, as well as the fact that other parameters such as specific gravity and shape tend to be in correlation with, and influenced by sediment particle size (Beuselinck et al, 1998). Sediment size can also be defined by factors such as fall velocity, sieve size, volume and weight diameter. Apart from volume, the definitions are typically affected by the density and shape of the sediment particle (Schnurrenberger et al, 2003).

Furthermore, other parameters which affects grain size distribution is influenced by numerous factors which include; weathering history, parent material, transport processes and as well as the environment in which the sediment is deposited occurs (high or low energy) (Tucker, 1998).

Sizes of grains are measured in mm or phi of which there are specific classifications shown in Figure 2.1. The four broad classifications are divided into gravel, sand, silt and mud. Gravel is classified as grains which are >2mm, sand comprises of sediment which falls between the range of 0.063-2mm in size, silt which is between the range of 0.0039-0.063mm and clay which are made up of sediments falling between the range of 0.00006-0.0039mm (Mitsch and Gosselink,2000).

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	
	64		-6.0	Pebble	
	4		-2.0	Granule	
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	
1/2	0.50	500	1.0	Medium sand	
1/4	0.25	250	2.0	Fine sand	
1/8	0.125	125	3.0	Very fine sand	
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	
1/64	0.0156	15.6	6.0	Fine silt	
1/128	0.0078	7.8	7.0	Very fine silt	
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

Figure 2.2. Sediment Size Classification

(Wentworth, 1922)

Measures of dispersion such as; sorting, skewness and kurtosis, are commonly used when determining sediment distribution within fluvial systems (Morgan, 1995).

Sorting refers to the spread of grain size distribution, in other words it is the measure of standard deviation of sediments and is related to the depositional mechanism. Sorting increases with the sediment transport distance (Morgan, 1995). Sorting is measured in phi usually but in this study mm was used instead. The values obtained for sorting represent different sorting class. This can be further viewed in figure 2.2 where sorting class and standard deviation in mm and phi are represented (Tucker, 1998). Well sorted sediment will therefore have a standard deviation ranging from 0.35-0.71, moderately sorted sediments have a range of 0.71-1.0 and poorly sorted sediments have range falling between 1.0 - 2.0. Any sediments having a standard deviation of that greater than 2.0 will therefore be classed under very poorly sorted sediments (Morgan, 1995).

2.6.5 Wetland Sediment

Wetland sediment, otherwise referred to as hydric soils, is a type of soil which has undergone prolonged periods of flooding or saturation, which in turn results in the dominance of anaerobic conditions (Maltby and Barker, 2009). Hydric soils play a vital role in the functioning of wetland systems (Environmental Law Institute, 2002). They have a significant effect on the availability of nutrients, groundwater, hydraulic conductivity, the rooting and growth of wetland plants, and the ability of wetlands to provide a suitable habitat for multiple organisms (Environmental Law Institute, 2002).

2.7 Types of Wetland Sediment

There are two predominant categories of wetland soils which are organic and mineral soils (Sprecher, 2001). These two categories differ mainly on their source material constituents, and by the difference in organic carbon levels (Sprecher, 2001).

Organic soils originate from plant debris and are most predominant in wetland regions where the decomposition rate is slower as a result of a high moisture content (Aber et al, 2012). These soils usually appear black in colour, light weight, porous, and are more commonly known as ‘mucks’ or ‘peat’ (Sprecher, 2001). In order for a soil deposit to be classified as organic they have to meet multiple criteria which includes organic carbon component equivalent to 10% and 200mm of organic material within the upper 800mm of the soil layer, or that of any thickness rising from the solid surface to gravel or rock (Mitsch and Gosselink, 2000).

Mineral soils are constituted from weathering rocks or from material transported to the wetland site by wind, ice, water or landslides. As a result these soils have varying percentage constituents of sand, silt and clay (Weaver, 1976). Unlike organic soils, mineral soils are known to be made up of less than 10% of organic carbon. Mineral soils comprise the largest percentage of soils globally and are not only found in wetlands, but in a multitude of other environments (Sprecher, 2001).

2.7.1 Delivery of Sediment to Wetlands

As per the findings of Maltby and Barker (2009), it is recognised that sediments located in a wetland area that are derived from external sources, otherwise known as allochthonous sediment, are predominantly mineral in nature. Conversely, sediment that are found in wetlands which are derived from internal sources, otherwise known as autochthonous sediment, are found to be predominantly organic sediments of a chemical or biogenic source, and are created by means of decomposition of animal and plant material through processes occurring *in situ* (Maltby and Barker, 2009).

In wetland regions, allochthonous sediments are constituted of fluvial sediment which were originally transported from adjacent catchments and rivers. These sediments in particular are reflective of the catchment parent material and the physiographic properties (Abed, 2009).

Multiple, varying modes of transportation are subjected to facilitate the movement of river and catchment derived sediment, which includes the suspended load, wash load, and the bed load (Sukdeo, 2010). Separate from sediment already residing within wetlands themselves, sediments are constantly being transported in and out of wetland bodies via marine and fluvial sources (Abed, 2009; Sukdeo, 2010).

2.7.2 Hydric Soil Chemistry

The chemical properties of hydric soils are governed by oxidation- reduction reactions which influences the functions and properties of hydric soils, and as a resulting factor often supports the identification of hydric soils (Vepraskas and Faulkner, 2001). As sediments are dispersed from one region to another, alteration of their chemical properties occur in an aim to establish a state of equilibrium within the receiving environment (Sukdeo, 2010).

The dominant chemical processes taking place in hydric soils, such as denitrification, methane gases, the production of mottled soil colours, and hydrogen sulphide, are formed due to reducing reactions (Chapin III et al, 2011). Reducing reactions are commonly known for having an effect on soil colour as well as water quality (Vepraskas and Faulkner, 2001).

According to Burich (2008), the physical characteristics of individual sediment grains have a significant effect on transport, deposition, desorption, absorption and ion exchange. In particular, the grain sizes of sediments are most responsible for metal interactions as it has a direct effect on surface area, surface charge of a sediment particle, and cation exchange capacity (Horowitz, 1985). Additional sediment characteristics that affect the chemistry of soil, and therefore sediment quality, include both calcium carbonate and organic matter content (Sukdeo, 2010).

2.7.3 Organic Matter

Organic matter (O.M) within the soil is the sum of all animal and plant material at their various stages of decomposition, along with other extensively decomposed substances and the tissues and cells from soil organisms (Brady and Weil, 1999). Despite living organisms not being included in the definition of O.M, their roles played are vital for the formation of O.M, as the flora and fauna (such as rodents and earthworms), contribute to the breaking down and movement of organic material within the soil (McCauley et al, 2009).

Organic matter tends to accumulate within wetland ecosystems as the rate of photosynthesis tends to be higher than in other environments, and furthermore the rate of decomposition tends to be lower due to anaerobic conditions commonly experienced in wetlands (USEPA, 2008).

Furthermore, fine textured soils, such as silts and clays are sometimes known to have higher volumes of O.M as compared to coarser textured soils due to the strong cohesion properties of these particles, and thus may have a strong association between O.M and silt and clay (Hassink, 1997). The strong cohesion of these particles reduces the wettability and the permeability of the soil thereby allowing for the accumulation and slow decomposition of O.M within the soil profile (Chenu et al, 2000).

2.7.4 Calcium Carbonate

The crust of the Earth comprises of more than 4% of calcium carbonate ($CaCO_3$), therefore the three calcium carbonate minerals, known as vaterite, aragonite and calcite, are some of the most significant rock forming minerals (Hoque et al, 2013). Rocks however, are not the only deposits of calcium carbonate existing in nature as numerous plants and animals, as well as many bodies of water contain significant amounts of calcium carbonate. The correlation between these naturally occurring resources exists in the form of the carbonate cycle (Bowen, 1979).

Animals and plants absorb calcium carbonate from water where it typically occurs in its dissolved form known as calcium hydrogen carbonate ($Ca[HCO_3]^{2-}$). Animals, for example, are therefore able to absorb this form of calcium carbonate and use it to build up their shells and skeletons. Subsequently, when these animals, such as crustaceans and coccoliths die, they form part of sedimentary deposits on the bed of the water body, such as wetlands (Hoque et al, 2013).

2.8 WETLAND INVENTORY, ASSESSMENT AND MONITORING

Recent Australian literature pertaining to wetland assessments reveals that there may be some significance in differentiating between the terms inventory, assessment and monitoring, especially when formulating data gathering exercises of wetlands (Finlayson and Davidson, 2001), as each of these three activities require collection activities and information types that is different from each other (Butcher, 2003).

2.8.1 Wetland Inventory

Wetland Inventory can be described as the collation and/or the collection of core data pertaining to the management of wetlands, as well as the provision of a database for particular monitoring and assessment activities (Finlayson and Davidson, 2001). Included under this definition of Wetland Inventory is wetland mapping and delineation.

South African wetland delineation aims to establish the outermost region of the wetland which demarcates the area between terrestrial regions and the wetland areas. This activity of wetland delineation utilises four specific indicators (DWAF, 2003):

- Soil formation indicator: establishes the different soil forms which are subjected to frequent and prolonged saturation periods.
- Soil wetness indicator: establishes signature morphological features which form in the soil profile due to frequent and prolonged saturation.
- Terrain unit indicator: aids in identifying regions in the landscape where wetlands are likely to be present.
- Vegetation indicator: establishes hydrophytes which are correlated to commonly saturated soils.

2.8.2 Wetland Assessment

Wetland assessments can be described as a collection of actions associated to the establishment of the health status of wetlands, the rehabilitation of wetlands, the formulation of license or permit decisions regarding wetlands, development of wetland classifications, as well as various other actions concerning wetlands (DWAF, 2004).

According to the Australian literature, wetland assessments can be defined as the following; "Assessment is the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities" (Finlayson and Davidson, 2001). As per this definition, wetland assessments are to follow a particular set of steps, generate information, and in turn result in various outputs which offer data pertaining to the present state of the wetland and a reference condition (DWAF, 2004).

2.8.3 Wetland Monitoring

According to DWAF (2004), wetland monitoring serves to provide information for water resource planners, managers and other stakeholders involved in the management of water. An activity may qualify as a form of wetland monitoring if it encompasses of three main, connected functions, namely, data storage, data management and data acquisition.

Furthermore, wetland monitoring can be described as a determination of how, and to what level a wetlands ecological status has altered (Butcher, 2003). Thus if this approach is chosen wetland monitoring can be defined as the following; “wetland monitoring is the collection if specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management” (Finlayson et al, 2002).

2.8.4 The Relationship between Inventory, Assessment and Monitoring

Wetland inventory, assessment and monitoring are all regarded as separate entities, however they are all strongly correlated with each other (Finlayson et al, 2002). Each of the three activities requires a type of data which is different, yet supports each other in different aspects (Butcher, 2003).

Wetland inventory gathers the data to describe the ecological status of wetlands, and offers the foundation for aiding the formulation of appropriate monitoring and assessment. Wetland assessments establish the threats and value of wetlands, as well as any alterations in ecological character, thus providing the relevant data from which a hypothesis can be determined for monitoring purposes. Finally, wetland monitoring offers data pertaining to the extent of change of a wetland system from a natural reference condition (Finlayson et al, 2002).

A reference condition refers to the properties of wetlands which are least affected by anthropogenic activities. This condition can be determined from data obtained from locations which represent those with the least affected condition for specific wetland types within a catchment, landscape or ecoregion (Butcher, 2003).

2.9 ASSESSMENT OF WETLANDS

In order to determine the health of wetlands, various methodologies have been developed both nationally and internationally (Uys, 2004). In the U.S for instance, the United States Environmental Protection Agency (USEPA) established an assessment that aids in determining the health status of wetlands by means of bio-assessments (Uys, 2004).

This assessment relies on the assumption that organisms living in wetland environments have lived within these environments for thousands of years, and are therefore resilient to any modifications caused by external factors. As a result of such an assumption, it is anticipated that alterations of the communities inhabiting wetland environments due to varying intensities of human interference can be foreseen (Botes, 2009). However, utilising this assessment has a disadvantage as it was developed specifically for application in the North American context and thus its application in other parts of the world may yield results which are regarded questionable (Botes, 2009).

Another approach established to assess the health of wetlands is the hydrogeomorphic approach developed by Brinson and Rheinhardt (1996). The hydrogeomorphic approach utilises reference wetland conditions to outline goals and standards necessary for the creation and restoration of wetlands (USEPA, 2002). Despite this approach being widely applied, its relevance within South Africa may be hindered due to the lack of information available on wetland reference sites (Botes, 2009). However, there is a probability of this changing in the future due to multiple detailed studies regarding the evolution and origin of South African wetlands being recently undertaken (Botes, 2009).

Even though several systems have been established within national bounds for assessing the health of wetlands, the WET-Health tool is the most widely accepted and comprehensive assessment (Botes, 2009). The triumph of this tool is due to its intensive focus on the underlying biological, geomorphological and hydrological processes that aids wetland ecosystems as well as the constituent species, as opposed to identification of indicator communities in isolation (Macfarlane et al, 2007).

The WET-Health tool therefore allows for the assessment of these three factors in separate modules and calculated the deviation of the conditions occurring currently from the reference condition which represents the pristine state (Macfarlane, 2008). Due to the high relevance of this tool in South African wetlands, this tool was utilised in this study of the Melville wetland and is described further in the methodology chapter.

2.9.1 Wetland Assessments in South Africa

Wetland assessments in South Africa follow a step-by-step method whereby the reference or the pre-impact conditions; the present ecological state and, the ecological importance and sensitivity of a wetland are established (DWAF, 2004). A wetland assessment requires a collaboration of both desktop and field surveys.

Desktop surveys allow for an in depth understanding of the area to be obtained before going out into the field. This is done through the utilisation of aerial and satellite imagery of the study site, which can highlight areas of interest from where samples should be taken. Once in the field, delineation of the wetland can occur, as well as obtaining multiple samples of soil and water from specific sites, which will be further analysed in a lab. Additionally, an ecological survey of surrounding vegetation should be documented whilst out in the field. All data gathered out in the field must thereafter be analysed through the use of GIS software, laboratory analyses and the use of methods developed by wetland organizations in the country (SANBI, Working for Wetlands, Water Research Commission, etc.) (DWAF, 2004).

A level one or level two wetland assessment can be undertaken. A level one wetland assessment comprises of a study which is predominantly desktop based, with little field verification. Conversely, a level two wetland assessment requires systematic data collection from the wetland as well as the catchment area. A level one assessment is primarily utilised where there are a number of wetlands that needs to be assessed over an extensive area whereas a level two assessment is utilised when there is only a single wetland unit needed to be assessed (Macfarlane et al, 2007). For the purpose of this particular study a level two wetland assessment will be undertaken.

2.10 FACTORS USED IN ASSESSING THE CONDITION OF A WETLAND

The physical, functional and biotic factors are the three most typically used variables when determining the environmental condition of a wetland. Each of these variables can be used individually or in conjunction with each other depending on the priority of the assessment, as well as the application to which the outcome data will be put (DWAF, 2003).

Usually, functional assessments, like that carried out in this study, determine the extent to which different wetland systems carry out different functions with regards to a pre-established 'type specific' reference condition (USDA, 2008).

In order to establish the ecological character of a wetland, physical variables such as, water source, water regime, geomorphic setting, length, area, bathymetry, and soil composition are utilised (Butcher, 2003). The latter of these variables are significant for giving an understanding of the previous wetting regime of a wetland, as well as how it differs from present conditions. This is a crucial aspect of wetland classification and delineation (Adamus et al, 2001).

Soil, hydrology and vegetation are the most significant and most commonly utilised physical variables. Soil is particularly used to determine the type of wetland as well as regime, and is crucial for providing an understanding of physical and biological conditions (DWAF, 2004). Vegetation, as it is also an important component of wetlands, are also one of the variables utilised to provide information pertaining to wetting regimes and wetland condition (Glen et al, 1999).

The definition of a wetland developed by Cowardin et al (1979), which is probably the most commonly accepted definition, describes wetlands as, "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water." These same authors further establish three key properties of wetlands which are, hydric soils, hydrophytes being present and hydrology.

Another commonly viewed definition, developed by the National Research Council (1995), states that, "a wetland is an ecosystem that depends on constant or recurrent, shallow inundation, or saturation at or near the surface of the substrate. The minimal essential characteristics of a wetland are recurrent, sustained inundation, or saturation at or near the surface and the presence of physical, chemical and biological features reflective or recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic or anthropogenic factors have removed them or prevented their development."

Within both of the above definitions a commonality exists, as each of the definitions make key references to soil, hydrology and vegetation (hydrophytes) thus, highlighting the importance of both soil and vegetation as variables in a wetland assessment.

Furthermore, a significant connection is recognised between the three components mentioned above. Essentially, a decline in the integrity of the hydrological condition would in turn lead to a decline in the vegetation integrity, even though the vegetation may not be rapid in response, especially where the MAP:PET ratio is high or where a certain species dominates the vegetal cover. Additionally, a diminishing hydrological integrity can also lead to a decline in the geomorphological integrity, pertaining to the characteristics of the hydrological change as well as the local conditions including, soil type and wetland slope.

Similarly, a decline in the integrity of the geomorphology will most certainly cause a decline in hydrological integrity, however the extent of the effect will be dependent on local features such as, texture of the soils and slope of the wetland. The consequence of a decline in the geomorphological integrity on vegetation may be indirect, for example through desiccation as a result of the drainage effect formed by erosion gullies, or direct, such as the deposition of sediment on existing vegetation.

The consequence of a decrease in vegetation integrity on hydrology will be significantly dependant on the compositional and structural changes that occur, as a major result of the effect vegetation on transpiration rates and surface roughness. Vegetation cover, however, is the most significant factor affecting geomorphological integrity. If vegetation cover is removed, the rate of erosion within a wetland, is increased, mainly where the geomorphological and geological settings encourage erosion activities, making a wetland more susceptible.

2.10.1 Hydrology

Hydrology is referred to as the flow of subsurface and surface water into, through and out of a wetland (Macfarlane et al, 2007). Hydrology forms a major component of wetland health assessments as they are a defining characteristic of wetlands. The hydrological conditions experienced within wetlands are contribute to various major processes such as the sediment fluxes, the production of anaerobic conditions within soil and the availability of solutes and nutrients. In turn, these factors determine which flora and fauna shall make the wetland a habitat, which will consequently have a feedback effect on the hydrological environment (Mitsch and Gosselink, 2000). Therefore, the result of modifying the hydrological environment within a wetland may be major, in terms of the entire structure of the wetland and the biophysical processes which take place.

2.10.2 Geomorphology

The saturation of soil, particularly in wetlands where this saturation is prolonged, has an identifiable impact on the soils morphology, thus affecting mottling, the soils matrix and chroma (Natural Resources Conservation Service, 1995).

Mottling of the soil refers to the segregated colour sequences viewed in the saturated layers of the soil profile due to the solution and precipitation of predominantly manganese and iron as a result of differences between the oxidised and anaerobic states (Kotze and Marneweck, 1999). The matrix of the soil refers to the ‘background colour’ whereas the chroma is described with regards to the spectral colour and its purity, which as the greyness of the soil increases, the chroma decreases (DWAF 2003).

Each of these factors are affected by the duration and extent of soil saturation, differences in wetness within the soil profile, and the type or nature of the substrate or soil present, creating characteristic features, staining, distinctive colouring, and sometimes odours in the soil profile (Kotze and Marneweck, 1999). Where in depth information about the hydrology is unavailable for a particular location, hydric indicators from the soil profile are the most relied upon indicators of the wetting regime over an extensive period of time (DWAF, 2004).

2.10.3 Vegetation

Plants which are found in wetland regions are termed hydrophytes and are generally categorised into two types, submerged and emergent hydrophytes. Submerged hydrophytes are those where all photosynthetic components are submerged by water, whereas the emergent hydrophytes are those where some of the photosynthetic components are not submerged and are in direct contact with the atmosphere (Glen et al, 1999). Those plants however which do not require being submerged for a part of their life cycle, but can handle being submerged, are referred to as semi-aquatic plants or helophytes (DeKyser et al, 2003).

Furthermore, hydrophytes can be separated into another two categories depending on what type of environment they can thrive in, which are obligate hydrophytes and facultative hydrophytes. Obligate hydrophytes are only able to live in wetland areas whereas facultative hydrophytes are able to occur not only in wetland areas, but also in areas which are not considered to be wetlands (DWAF, 2003). Species of hydrophytes have acquired multiple reproductive, physiological and morphological adaptions which allows them to reproduce, grow and thrive in any soil condition, whether it be dry or saturated (DWAF, 2003).

Due to the significant sensitivity of wetland vegetation to hydrology, they are commonly utilised for the delineation of wetland boundaries. In order to use the wetland vegetation for wetland delineation purposes the predominant categories of hydrophilic plant species present must be identified, as it is not a sufficient indicator to identify individual wetland plants for delineation. Where there are only a few wetland plants occurring in a region dominated by terrestrial plants, that area cannot be deemed a wetland (Adamus et al, 2001).

Distinctive vegetation types thrive in each of the three transitional areas of a wetland (temporary, seasonal and permanent) (DWAF, 2003). The establishment of the wetland plant community groupings, along with the composition of these species are generally influenced by variables such as, the salinity of the water, water regime and most importantly, anthropogenic disturbances (DeKeyser et al, 2003).

As per the US EPA, wetland vegetation provides the following vital attributes for good functioning of wetland ecosystems (Mitsch and Gosselink, 2000):

The vegetation in wetlands are at the base of the food pyramid and is therefore the ‘primary pathway’ for the flow of energy through the system, primary productivity in wetlands may vary, but some vegetation abundant wetlands have levels of productivity which are extremely high, almost as high as some tropical rainforests. The vegetation in wetlands also provide a critical habitat for specific groups of organisms such as phytoplankton and epiphytic bacteria, as well as periphyton, algae, and some species of amphibians, fish and macroinvertabrates.

There also exists a strong link between wetland vegetation and the water chemistry in wetlands. Hydrophytes are able to remove nutrients, contaminants and metals through the uptake and accumulation in their tissues. Furthermore wetland vegetation is able to influence the sediment regime and hydrology of wetlands through processes like modifying currents as well as shoreline and sediment stabilisation.

Alterations in water quality and quantity and to the composition of species (due to invasions and change of habitat) are the predominant factors causing changes to wetland vegetation. Wetland vegetation inevitably responds to any changes in the biotic, spatial, temporal or structural attributes of wetland environments by disappearing, altering their growth form, or moving to a more suitable location (Brock, 2003).

2.10.4 Wetland Vegetation as an Indicator of Wetland Condition

Vegetation in wetland areas are known to be the single best indicator for monitoring the variables that mould wetlands in a particular region (Butcher, 2003). There are numerous reasons why wetland vegetation act as such efficient indicators, some of these reasons include their rapid growth rate, their high amounts of species richness, and their immediate response to environmental alterations (USEPA, 2001).

Wetland plants are abundantly utilised as wetland condition indicators, and are presumed to be specifically useful for this as they can further be utilised to represent both the functional and structural attributes of ecological properties (Butcher, 2003). The structural aspect, including the composition of plant species, can be influenced by factors such as eutrophication and other forms of nutrient enrichment, whereas the functional aspect includes vegetation that are involved in nutrient cycling and energy flow (Butcher, 2003).

Wetland vegetation has also been revealed to be an excellent indicator of anthropogenically induced alterations within wetland environments. Individually, each plant type shows a different levels of sensitivity to the various stressors which they are exposed to. As the conditions within the environment alter, the composition of the vegetation communities alters accordingly (DWAF, 2004).

The USEPA (2001) have identified a compilation of references which highlights the correlation between alteration in the composition of plant communities within wetlands and various stressors such as, metals, turbidity, sediment loading, nutrient enrichment, hydrological alterations and other contaminants.

The water regime in wetlands is believed to be a predominant factor regarding the function (e.g. primary production) and the structure (e.g. species richness) of the vegetation community (DWAF, 2004). Wetland plants are affected by numerous factors within the water regime such as, flow rate, water chemistry, and water depth (USEPA, 2001). Each of these factors are all influenced by human disturbances and natural occurrences (encompassing of successional alterations in composition), thus the cause-effect relationship is not easily determined (Adamus et al, 2001). As a result, Wilcox et al (2002), suggested the use of plant indices for wetlands which acquire a stable hydrology and are not custom to natural disturbances.

However, plant indices are commonly utilised throughout all conditions. For example, in wetlands which experience periods where they completely dry out (seasonal wetlands), which makes them increasingly susceptible to human interference, plant indices are utilised to determine wetland condition due to the lack of phytoplankton and macroinvertabrates present for sampling, thus making wetland vegetation the only viable option for sampling (DeKyser et al, 2003).

Even though wetland vegetation is the most recognised biota utilised for assessing the condition of wetlands, there are a number of disadvantages which need to be realised. Butcher (2003), has recognised that, in Australia the quantity of trained professional plant ecologists, who solely specialise in wetland environments is miniscule in comparison to the number of trained professional macroinvertabrates taxonomists. This statistic is believed to be mirrored in South Africa, where the utilisation of wetland vegetation as a primary indicator in determining the condition of wetlands, requires professional knowledge of which in South Africa there are only a small number of trained plant taxonomists that specialise in wetland environments (DWAF, 2003).

Furthermore, for the purpose of determining the Ecological Reserve, where it is crucial to acknowledge the correlation between hydrology and biota, further studies pertaining to the correlation between the response of various species of plants and environmental conditions (particularly hydrology), would be advised (USEPA, 2001).

2.10.5 Soils and Wetland Vegetation as Indicators of the Wetting Regime in Wetlands

Areas within wetlands and wetlands themselves can be seasonally, temporarily or permanently wet. This therefore means that the different areas within a wetland or the entire wetland itself can vary from being saturated or flooded every few years, to being saturated or flooded for only a few days in a year, to being saturated or flooded permanently throughout the entire year (Tiner, 1999). A characteristic property of zones within a wetland or an entire wetland is that if they are wet for a temporary period, they must have a period of saturation or flooding long enough to allow for anaerobic conditions to develop (DWAF, 2004).

The wetland regime within wetlands can be established by analysing the soil and wetland vegetation criteria together. A set of criteria was developed which included a set of criteria for soils and wetland vegetation in order to aid in establishing the degree of wetness occurring within wetlands (Kotze et al, 1994).

SOIL	DEGREE OF WETNESS		
	Temporary	Seasonal	Permanent / Semi-Permanent
Soil depth 0-10 cm	Matrix brown to greyish brown (chroma 0-3, usually 1 or 2) Few/no mottles Nonsulphidic	Matrix brownish grey to grey (chroma 0-2) Many mottles Sometimes sulphidic	Matrix grey (chroma 0-1) Few/no mottles Often sulphidic
Soil depth 30-40 cm	Matrix greyish brown (chroma 0-2, usually 1) Few/many mottles	Matrix brownish grey to grey (chroma 0-1) Many mottles	Matrix grey (chroma 0-1) No/few mottles Matrix chroma: 0-1
VEGETATION	**DEGREE OF WETNESS**		
	Temporary	Seasonal	Permanent / Semi-Permanent
If herbaceous:	Predominantly grass species; mixture of species which occur extensively in non-wetland areas, and hydrophytic plant species which are restricted largely to wetland areas	Hydrophytic sedge and grass species which are restricted to wetland areas, usually <1m tall.	Dominated by: (1) emergent plants, including reeds, sedges and bulrushes, usually >1 m tall; or (2) floating or submerged aquatic plants.

Figure 2.3. Identification of Different Wetting Regimes

(Kotze et al, 1994)

The broad categories of wetland vegetation displayed at the bottom of the above table can be further separated into functional categories consisting of species with the same kind of characteristics and life history. The particular life history methodology may vary within and between the functional groups, however the properties related to the methodology can be similar (Kotze and Marneweck, 1999). For instance, floating or submerged aquatic plants found in permanent and temporary regions within a wetland, can sometimes survive periods of drought by means of propagules which are resistant to desiccation such as turions, similarly, wetland grasses found in seasonal zones can also survive by means of rhizomes which are desiccation resistant (Kotze et al, 1994).

Developing an understanding of these strategies as well as the associated characteristics will aid in establishing the frequency of wetting which could be required for sustaining certain populations. Furthermore, developing an appreciation of the growth rate responses of certain vegetation species to inundation will aid in establishing duration and depth requirements for the vegetation to thrive (DWAF, 2004).

By establishing an indicator species and/or functional groups, as well as their spatial arrangement, a professional can thereafter utilise the soil indicators along with the life history properties to determine an almost exact flow regime, including depth, timing and duration of inundation, for any region within a wetland or entire wetlands themselves (Adamus and Brandt, 1998).

2.11 WETLAND HEALTH

The ratification of environmental policies and legislation concerning the conservation and protection of wetlands located in South Africa initially prompted a significant interest in ensuring that the areal extent of wetlands are less diminished or otherwise completely undisturbed (Cronk and Fennessy, 2001).

The quantified impacts experienced in wetland areas were documented in reports monitoring wetland health, and were solely based on the acreage of wetland loss (Cronk and Fennessy, 2001). However, the accelerated rate at which wetlands were being degraded was recognised and therefore highlighted the significance of preserving the functionality and health of wetland systems (Horwitz et al, 2012). As a result, this brought about an increase in the attention of assessing the condition or quality of wetlands as opposed to only monitoring alterations in their shape and size (Horwitz et al, 2012).

As recorded by Macfarlane et al (2008), the term ‘wetland health’ can be defined as; “a measure of the deviation of wetland structure and function from the wetland’s natural reference condition.” The term ‘reference condition’ of wetlands refers to the health status of a wetland prior to any human influences which may in turn cause a transformation in the system to a point where it no longer functions at its optimum potential (Uys, 2004).

Taking into account the above terminology, a healthy wetland environment is thus a system which is entirely capable of carrying out its ecological functions due to the relations between its biological, chemical and physical parameters and the wellbeing of each (Mitsch and Gosselink, 2000). A wetland of optimum health status is characterised by the chemical and physical properties mirroring those of the naturally occurring habitats which are located within the same region and thus are full equipped to sustain multiple biological communities (Mitsch and Gosselink, 2000).

2.12 CHEMICAL INDICATORS OF WETLAND HEALTH

Research conducted by Wray and Bayley (2006), shows that water and sediment chemistry parameters are useful as indicators of wetland health. Indicators idealistically represent a cause and effect relationship and portray a general idea of wetland health (Mitsch and Gosselink, 2000).

Utilising such indicators for the evaluating the extent of wetland degradation and the ecological well-being of wetlands proves to be both cost- and time- effective as they are able to provide a diagnosis on the health status of a wetland without the aid of numerous parameters and measurement of processes (Mitsch and Gosselink, 2000).

2.12.1 Chemical and Physical Parameters

The other sources of elements which will be presented in this study are; Ammonium (NH_4), Calcium (Ca), Potassium (Na), Sodium (Na) and Sulfur (S) Magnesium (Mg), Nitrogen (N), Phosphorus (P) and Carbon (C), as well as parameters such as pH, Dissolved Oxygen (D.O) and Total Dissolved Solids (TDS). These will be discussed below.

- Ammonium (NH_4)

Ammonium is a nutrient that contains hydrogen and nitrogen as seen in its chemical form. In its ionized state, ammonium is known as ammonia (NH_3). Ammonia is known to be much more toxic than ammonium, as it is dependent on pH and temperature, therefore if there is an increase in those two factors, ammonia levels will increase and in turn make the water environment in which this element consist in extremely unstable (APHA, 1989).

Ammonia also is known to be an important source for plant growth in aquatic systems. The conversion of ammonia to nitrate and nitrate is done by bacteria, and thereafter plants use these broken down elements. If an aquatic system is predominantly nitrate concentrated, these waters are known to be unpolluted. The method of how ammonia comes into an aquatic system is by excretion from animals, and also when animals and plants decompose. Concentrations of ammonia in water are common, however, too high concentration can be detrimental with regards to reproduction and growth rates, and can even cause deaths (Mckee and Wolf, 1963).

Ammonium on the other hand can also be dangerous, as high concentration can be highly toxic to fish and other species that live in water. It is also important to note that ammonia does not only come from natural sources into aquatic systems today, as this element can be found in domestic, agricultural pollution and also industrial pollution, primarily from fertilizers. As ammonia and ammonium are both dependent on temperature and pH, those factors are the only way to measure their toxicity ((Mckee and Wolf, 1963).

- Calcium (Ca)

Calcium is known to occur naturally in water due to the fact that it is part of the earth's crust. Seawater is known to contain a high concentration of calcium which is approximately 400 parts per million (ppm), whereas rivers contain only 1-2 ppm of calcium, with the exception of rivers near limestone's or lime producing areas which have a calcium concentration of 100 ppm (Bowen, 1979).

Calcium in water is mostly found in a Ca^+ (aqueous) manner, however it can be found in other forms. Calcium is an important element in water as it acts as determinant of water hardness, pH stabilizer, in turn showing its buffer qualities. Calcium can therefore be found also in many construction materials such as brick lime, cement and concrete. Calcium can also remove sulfur dioxide from industrial emissions, and sulfuric acid can be neutralized before a discharge can occur. Calcium can also be increase turbidity in waters and impacts soil quality in the form of fertilizers in a positive manner (Bowen, 1979).

Calcium is known to have many positively qualities to aquatic systems such as a dietary requirement for most aquatic species besides insects and bacteria, calcium carbonate is known to be a building of skeleton for aquatic species, and even eye lenses and also plants require calcium oxalate as it is an important constituent. In addition, the hard water that calcium creates protects fish from direct metal intake, and if calcium levels are too low and pH are known to be between 4.5-4.9, this can have detrimental impacts on grown salmon and their eggs respectively. However, calcium also tends to have negative impacts due to them interacting with the detergents and cleansing agents, which in turn can cause an increase in domestic waste in aquatic systems (World Health Organisation, 1993).

- Potassium (K)

Potassium is known to contain 400 ppm in seawater and around 2-3 ppm in rivers. The large difference in is due to the oceanic basalt which has a large concentration of potassium. Potassium tends to have a characteristic of settling and likely to end up in sediment, and also be found in a naturally abundant radioactive isotope which is ^{40}K (Bowen, 1979).

Potassium also occurs in various minerals and can be dissolved through weathering processes. Examples of minerals that they occur in are feldspar which is not good for potassium production compounds as compared to chlorine minerals, carnalite and sylvite. Even some clay minerals contain potassium which occur due to naturally processes and settle in sediment as mentioned above. Potassium is known to be a dietary requirement for most species but also bacteria, due to the important role it plays in the functioning of nerves (McKee and Wolf, 1963).

It is a limiter and promoter for plant growth. In coastal aquatic systems dead animals and plants that contain potassium often bind with clay minerals in the soil before dissolving away with water. Furthermore, the potassium is then taken up by plants as it is readily available. However, due to ploughing activities disturbing this process, fertilizers which in most instances contain potassium are added to agricultural soil instead. Furthermore, potassium is extremely weak hazardously to water; however it does tend to spread quite fast, due to its low transformation potential and high mobility rate. Potassium toxicity is only from other components that are joined with the compound such as potassium cyanide. In addition, one of the only impacts of potassium is its salts that may kill plants cell due to the high osmotic activity (Bowen, 1979).

- Sodium (Na)

Sodium is a compound that has been on the earth for billions of years due to it being washed out of rocks and soil into seawater and further remaining there for millions of years. Rivers usually contain 9 ppm of sodium, seawater has approximately 11000 ppm of sodium and the water we drink contains a low 50mg/L of sodium (McKee and Wolf, 1963).

The concentration of sodium is solely dependent on two factors which are geological conditions and wastewater contamination. Sodium is known several industrial purposes and one of them being acting as a heat reducing medium in nuclear reactors. The compound is also useful as a synthetic fertilizer in the form of sodium nitrate (Bowen, 1979).

Sodium converted into these different states are useful in many ways such as sodium carbonate being applied in water purification in order to neutralize acids and also used as a cleansing product. ^{24}Na which is the radioactive isotope for sodium is known to be used in medical research. However, sodium is known to be a hazardous compound and is a risk factor when found in water, but at the same time if can exist in water in the form of sodium chloride. The compound is known to be a dietary mineral for animals, however, plants hardly contain any sodium and it can also greatly charge wastewater in different forms (Wintrobe et al, 1970).

- Sulfur (S)

Sulfur is an element that usually has a rotten egg odour when in the form of hydrogen sulphide. Its ability to transform into hydrogen sulphide is when sulfur gets into groundwater, and thereafter naturally occurring bacteria can decrease the organic sulphite ores and create hydrogen sulphide. Sulfur cycling in fresh water wetland systems was though to play a small role in the regulation of decomposition and the release of nutrients; however its role in coastal wetlands is well recognised.

The input of SO_4^{2-} from surrounding watersheds into freshwater wetland systems however, can cause an increase the role of the Sulfur cycle. Similarly, an increase input of SO_4^{2-} into salt water systems can cause a gain in momentum of the Sulfur cycle, particularly sulfate reduction and the corresponding microbial processes (USEPA, 2008).

Sulfur is not known to be found in municipal waters and is more likely to be found in well and groundwater (Clarke, 1980). Sulfur can enter water supplies most commonly when sulphite ores are oxidized. Rocks and soil are also known to contain sulfur minerals, and therefore, the sulfur compound can dissolve in groundwater as a result due to water being a strong natural solvent. Rainwater can also be another source of sulfur (Clarke, 1980).

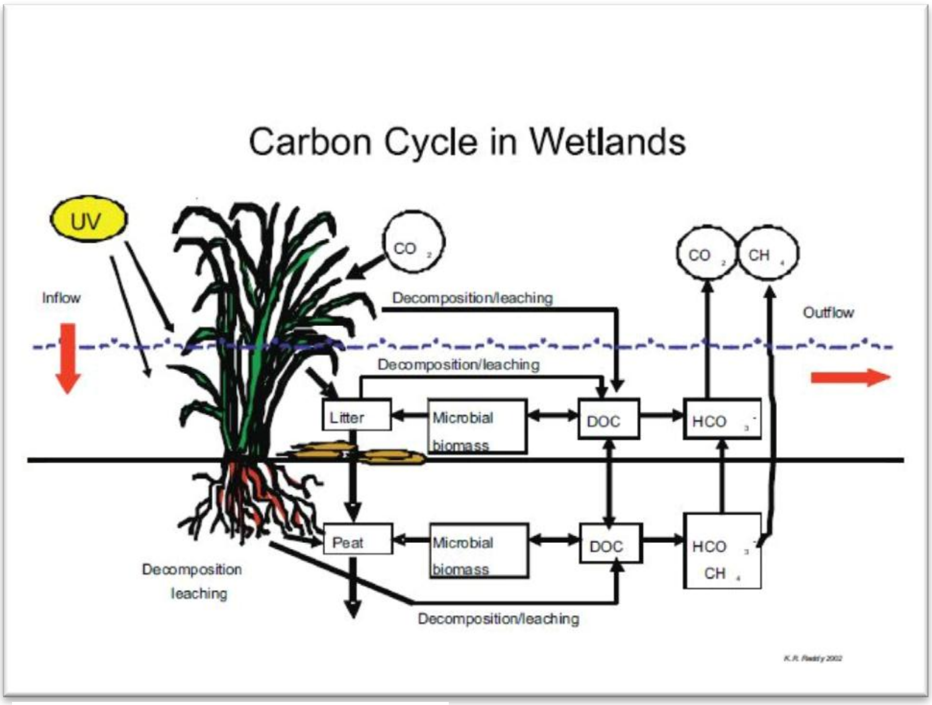
Sulfur in soil can be a food or energy source for bacteria, and in turn, bacteria creates hydrogen sulphide, which is recognisable in water due to its unappetizing taste, however it is not known to be an extreme health risks. Furthermore, the main problem that sulfur poses is that the odour it gives off is unpleasant, but it can however cause other problems such as stains on clothes, merge with bacteria to cause slimes which can lead to clogs and corrosion in pipelines and also, high levels of sulphate in water can cause diarrhoea, especially in infants (Water Treatment Fundamentals, 1983).

- Magnesium (Mg)

Magnesium is regarded as an important macronutrient which is utilised by animals and plants in a wetland system (Sukdeo, 2010). The use of fertilisers and chemical industries all aid in the increase of magnesium in wetlands, which have adverse effects on the organisms within such as disturbances to the central nervous system and the metabolism (U.S EPA, 2008). However, decreased amounts of magnesium in these environments also have negative effects on wetland organisms such as, reduced reproductive capabilities and skeletal deformities (DWAF, 1996).

- Carbon (C)

In comparison to upland systems, many wetland systems accumulate organic matter (O.M) and as a result serve as global carbon sinks. The build-up of organic Carbon within wetlands is majorly due to the balancing of two processes; Carbon Losses through decomposition and Carbon Fixation through photosynthesis (U.S. EPA, 2008). Large pools of Carbon storage include detrital O.M, soil O.M, plant biomass, microbial biomass and dissolved organic carbon (Kotze et al. 2007). Carbon compounds resistant to anaerobic and aerobic decomposition are inclined to build-up in wetland ecosystems as peat or humic substances. In cases lacking oxygen, humic substances become recalcitrant to decomposition and provide major storage for carbon and other nutrients within wetlands. Humic substances however, become more readily degraded under drained conditions, which in turn release nutrients and thus affecting the water quality downstream (USEPA, 2008).



*DOC – DISSOLVED ORGANIC CARBON

Figure 2.4. Carbon Cycle

(USEPA, 2008)

- Nitrogen (N)

Nitrogen is able to enter a wetland in both inorganic and organic forms. The amount of inorganic and organic Nitrogen received by a wetland is dependent on the origin and the type of water entering the system. The removal of particulate Nitrogen quantities is achieved by the settling and burial of these particulates, whereas the expulsion of dissolved Nitrogen quantities is governed by numerous biogeochemical reactions occurring in the water column and soil. The rates at which these processes occur are relative to the biological and physio-chemical properties of the water column, soil and organic substrates (Kotze et al, 2007).

Nitrogen reactions occurring within wetlands efficiently process inorganic Nitrogen through denitrification and nitrification, ammonia volatilization and plant uptake aiding in decreasing amounts of inorganic Nitrogen in water sources. Conversely, a significant quantity of dissolved organic Nitrogen acquired by in-situ plants goes back into the water column due to the breakdown of organic matter or detrital tissue in the soil of which the majority is resistant to decomposition. Under such conditions, water exiting a wetland may exhibit elevated amounts of Nitrogen in its organic form. However, rates of these reactions will ultimately be governed by the optimal environmental conditions represented in the wetlands water column and soil (Kotze et al, 2007).

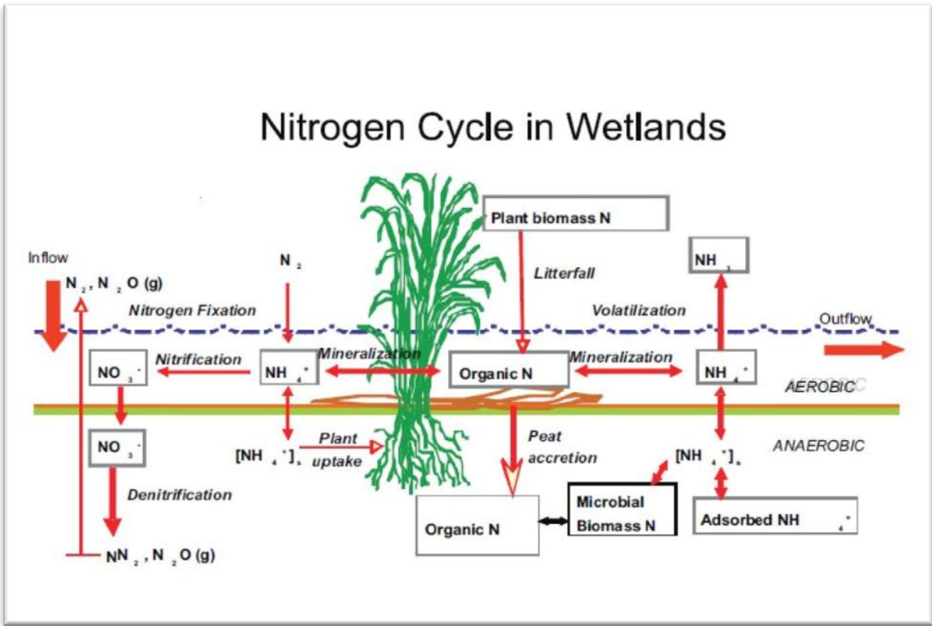
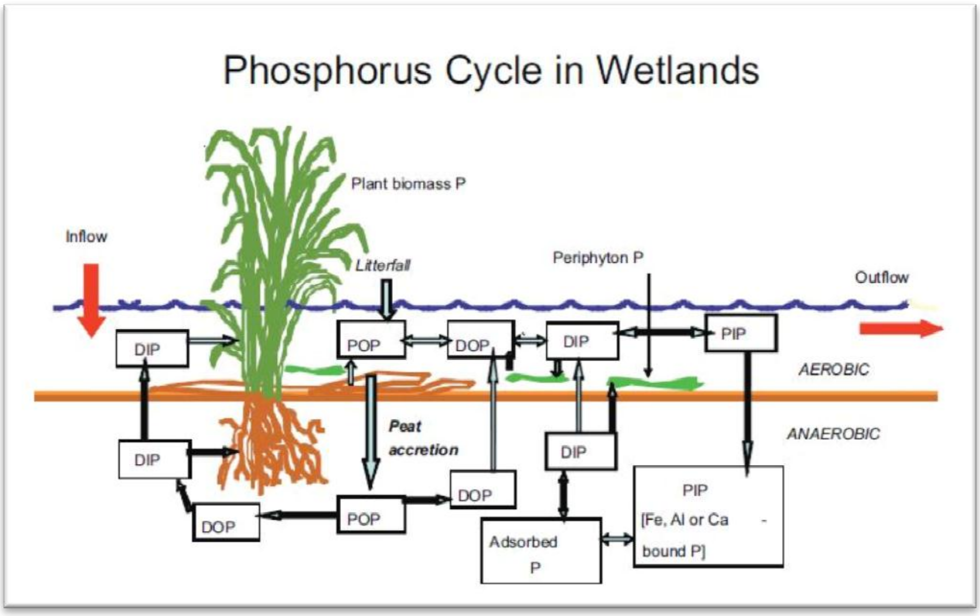


Figure 2.5. Nitrogen Cycle (USEPA, 2008)

- Phosphorus (P)

Wetland systems have the ability to regulate the retention of Phosphorus by means of physical mechanisms such as sedimentation and entrainment, as well as biological mechanisms such as release and uptake by plants and microorganisms (USEPA, 2008). Within the water column, Phosphorus usually occurs in the form of particulate and dissolved quantities, with both of these forms encompassing a certain amount of organic and inorganic pools. The proportions of these pools are dependent on the type and source of water flowing into the system (Kotze et al, 2007).



*DIP – Dissolved Inorganic Phosphorus

*DOP – Dissolved Organic Phosphorus

Figure 2.6. Phosphorus Cycle (USEPA, 2008)

- pH

pH is a measure of the hydrogen ion conductivity of a water sample (DWAF, 1996). As the concentration of hydrogen ions in a water sample increases, the pH decreases, and the sample becomes more acidic (DWAF, 1996). Conversely, as the concentration of hydrogen ions decreases, the pH increases, and the sample becomes more alkaline or basic (DWAF 1996). pH concentrations in wetland waters may be altered by anthropogenic activities such as pollution emitting activities, industries, and mining, which can in turn lead to the phenomenon 'acid rain' (DWAF, 1996). Altering pH levels have drastic effects on aquatic organisms as it modifies the osmotic and ionic balances of individual organisms, slows down growth rates and reduces fecundity (DWAF, 1996).

- Dissolved Oxygen (D.O)

It is imperative that there exists an adequate amount of D.O in aquatic and semi-aquatic ecosystems, as aerobic aquatic organisms rely on it for a variety of functions such as breathing (DWAF, 1996). A decrease in oxygen levels in aquatic and semi aquatic systems can be attributed to the presence of increased quantities of organic matter, the re-suspension of anoxic sediments, the release of anoxic bottom water and high turbidity levels (DWAF, 1996). As a result of reduced D.O in such ecosystems there becomes changes in feeding and breeding patterns, reduced growth and physiological stress (DWAF, 1996).

- Total Dissolved Solids (TDS)

TDS measure the total inorganic salts, organic compounds, and other dissolved solids in water (DWAF, 1996). Water quality in wetlands is deteriorated when TDS or salts appear in excess of the 'normal' amount (DWAF, 1996). When alterations in the amount of TDS occur, it affects different organisms to varying degrees, as it depends on their ability to withstand such alterations by maintaining a balance between the dissolved ions in their cells and tissues and water (DWAF, 1996).

2.13 THE VALUE OF WETLANDS

The significant level of importance placed on wetland ecosystems is as a result of recent recognition of the numerous present and possible future values and functions which proves to be immensely beneficial to society (Scodari, 1997). Recorded by Howe et al (1991), the benefits provided by wetlands refers to; "those functions, products, attributes, and services provided by the ecosystem that have values to humans in terms of worth, merit, quality or importance" (Collins, 2005: 41). The benefits provided by wetlands can be obtained directly, by means of consumption of wetland resources, or indirectly, by utilising the ecosystem services provided by wetland landscapes (Georgiou and Turner, 2012).

2.13.1 Direct Benefits

Wetlands are commonly utilised as a source of water for agricultural, domestic and industrial purposes. Water is extracted from wetlands for the above purposes by means of direct abstraction or via shallow wells (Dickens et al, 2003). Furthermore, water from wetlands may travel distances and move into underlying aquifers which can also serve as a source of water, or alternatively it may move deeper into a groundwater source and thus serve as a long term water source for communities situated further away from wetlands (Dickens et al, 2003).

Wetlands provide an abundance of plant and animal products which are harvested and utilised throughout the world. Once harvested, these products are utilised for the purpose of food, fuel, craft making, animal fodder, and medicine (Day, 2009). Wetland systems are furthermore known to provide harvestable products that can be obtained beyond the system; such are birds and fish which migrate. When these species venture out of the wetland system they benefit those communities which are 'off-site' as well as carrying out functions vital to other ecosystems (Scodari, 1997).

Additionally, wetlands are known for their socio-cultural value which is intrinsically correlated to the benefits provided through the utilisation of the wetland resources (Maltby and Barker, 2009). Rural communities in particular, which are located along the periphery of wetland systems, largely rely on the wetland environment for water, in areas where there is no or a lack of potable water, for subsistence farming, and as a source of income such as those relying on craft making as an occupation (Maltby and Barker, 2009). These areas also provide a location where religious and cultural ceremonies are conducted, and increases the aesthetic appeal of landscapes from which many receive spiritual upliftment (Dickens et al, 2003). Furthermore, wetland systems may also be regarded as areas of historical significance and thus constitute a significant part of a country's cultural heritage (Dickens et al, 2003).

South African wetlands are recognised worldwide for increasing the beauty of landscapes and for housing rare fauna and flora communities (Alexander et al, 2000). As a result, regions adjacent to, or consisting of wetland systems, such as the Isimangaliso Wetland Park and the Greater Saint Lucia Wetland Park, are renowned for being popular tourist sites, thus significantly contributing to the growth of the South African economy (Dickens et al, 2003).

Wetlands are also widely utilised for recreational activities such as, canoeing, fishing and angling (Day, 2009). Many wetland sites are also now being identified for their scientific significance, and are therefore being used in multiple studies for monitoring, experimentation and determining long term environmental trends (Day, 2009). Furthermore, wetlands can be utilised as a major educational tool, as the comprise of evidence relating to present and past conditions, which in turn could establish a better understanding of wetland habitats and species within (Dickens et al, 2003).

2.13.2 Indirect Benefits

As proclaimed by the North Atlantic Treaty Organisation (2006), wetlands are considered to be 'the kidneys of the landscape,' as a result of their vital role in hydrological and chemical cycles, as well as 'biological supermarkets,' given the array of biota and extensive food chains that they are known to support.

Wetland systems serve as sediment traps, and are therefore more commonly recognised as regions of sediment deposition as opposed to sediment sources (Mullins, 2012). Majority of sediment (80-90%) in waters flowing through wetlands are removed due to the vegetation within wetlands slowing down the flow of water comprising of sediment. This process is commonly referred to as sedimentation (Schiwirzer, 2006).

Wetlands are known to provide refuge and food to an abundance of animal and plant species, including mammals, reptiles, birds, fish, amphibians, invertebrates and micro-organisms (Aber et al, 2012). Wetlands serve as conservancy areas as the house numerous endemic and rare species (Brijlal, 2005). Therefore interference, of any sort, in wetland systems endangers the biota, compromises habitat integrity, and may lead to irreplaceable loss of related ecosystems, if not carefully managed (Schwirzer, 2006).

Wetland systems are mostly recognised for the role they carry out in the hydrological cycle (Begg, 1986; Bullock and Acreman, 2003). These systems act in a manner which dampens the intensity of destruction that comes with events such as flooding as they act as a storage area for increased volumes of water and sediment (Renwick and Eden, 1999). Consequently, wetlands are able to control and reduce the amount of water that reaches the downstream areas of the river during flooding events and thus prevents severe damage to the adjacent areas (Dickens et al, 2003). Wetlands are additionally able to store large volumes of runoff water generated by rainfall and the melting of snow, and as a result they function to sustain stream and river flow, and decrease the peak flow occurring during floods (USEPA, 1995).

Furthermore, wetland systems play a significant role in maintaining the soil water equilibrium due to their intricate relationship with groundwater (USEPA, 1995). The wetlands association with groundwater is such that when weather conditions favouring an increase in the water table occur, aquifers below the surface, contribute water to the wetlands; whereas when weather conditions that favour a decrease in the water table occur, the reverse occurs where the aquifers receive water from the contributing wetlands (Dickens et al, 2003). This process is recognised as 'groundwater discharge' and 'groundwater recharge,' respectively (Dickens et al, 2003).

The most revered function of wetlands however, is its function of water purification. Wetland systems are able to serve as natural filters as they enhance the water quality of water from inland regions through various processes (Begg, 1986; Collins, 2005). Such processes include; decomposition, aerobic and anaerobic processes, the accumulation of organic matter, and the uptake of minerals by the wetland plants, which all aid in the eradication of chemicals and minerals from wetland waters, effectively reducing any possible hazards to surrounding ecosystems (Dickens et al, 2003).

2.14 THREATS TO WETLAND HEALTH

As indicated by scientific studies, natural phenomenon's such as climate change and sea level rise are generally going to have an effect on wetland ecosystem functioning and thus the health of wetland systems. However, it is recognised that anthropogenic factors undoubtedly have the most significant influence on the health of wetland environments (Dickens et al, 2003).

Growing pressure is placed on wetland systems by anthropogenic factors which in turn results in their degradation and eventually their destruction (Horwitz et al, 2012). A lack of education and awareness pertaining to the multiple services and benefits provided by wetlands encourages indifferent human behaviour and attitudes towards wetland resources, and therefore the ongoing of unsustainable practices (Dickens et al, 2003).

In the current age of industrialisation, immediate economic benefits are prioritised, and the effect such activities have on the environment is often overlooked (Uys, 2004). This, compounded by the poor enforcement of legislation, the lack of local institutional capacity, and the lack of implementation and development of initiatives aimed at assisting existing policies, has collectively highlighted the dire need for effective wetland protection and conservation programmes in South Africa (Dickens et al, 2003).

Apart from the above, collective increases in human population along with industrialisation, urbanisation and the continuation of unsustainable agricultural practices, has resulted in increasing pressure being placed on wetland systems, diminishing their longevity and health (Sahu and Choudhury, 2005). This is further recognised by Kotze et al (1994), who records that the most predominant direct influence of wetland destruction is the depletion of wetland area due to filling or draining for the purpose of human habitation, silviculture and agriculture.

The dominant causes leading to wetland degradation includes; mining, afforestation, the construction of dams and roads, erosional degradation, toxic and solid waste disposal and water abstraction (Kotze et al, 1994). Conversely, the most dominant indirect causes leading to wetland degradation consists of the anthropogenic input of nutrients and other contaminants into wetland systems, as well as the introduction of alien invasive species (Zedler, 2004). Of all the above mentioned factors, the most influential factor leading to the diminishing of wetland health is those factors occurring off-site due to the extensive area of these catchment areas in relation to area occupied by identified wetland regions (Dickens et al, 2003).

Disturbances may be quantified directly by calculating the wetlands response to alterations caused by anthropogenic influences (Mitsch and Gosselink, 2000). Taking into consideration the multiple pathways of wetland disturbance, it is recognised that it is not feasible or convenient to quantify all potential hazards to the wetland environment and their possible effect on the functioning of such systems (Mitsch and Gosselink, 2000). Alternatively, wetland specialists and fresh water ecologists make use of standard parameters as indicators when assessing the health status of wetlands (Uys, 2004).

2.15 WETLAND LOSS

Globally, according to Fraser and Keddy (2005), the spatial extent of wetland landscapes has been reduced by approximately 50% in the last century. According to research conducted within several major South African catchments, it has been found that between 35% and 50% of national wetlands have already been severely degraded or lost (Dini, 2004).

The loss or degradation of wetlands can be attributed to direct and indirect anthropogenic activities (McInnes, 2010). It is argued however, that even though the rate at which wetlands are destructed has increased over the years, the constructing of man-made wetlands in turn mitigates, and in some cases totally negates, the loss of natural wetland systems (Fraser and Keddy, 2005). This particular ideology, at a conceptual level, comes across as fairly logical, however the practicality of this and its rate of success has been subjected to a great deal of speculation (Fraser and Keddy, 2005). Research has shown that attempts by humans to form fully functional wetland environments have often failed as a result of insufficient information relating to the sustaining of plant and animal communities vital for the existence of wetland ecosystems (Fraser and Keddy, 2005).

South Africa has been recognised as being not conductive for the formation of wetlands, and as a result has magnified the seriousness of wetland loss related issues on a national scale and hence the imperative need to encourage the implementation of better management strategies, as well as rehabilitation and conservation programmes (Kotze et al, 1995). It can therefore be deduced that wetland destruction and wetland loss in South Africa is comparatively more significant than that of other countries due to the lack of prominence of wetlands within national bounds and the sporadic location of these systems (Begg, 1986; Kotze, 1995).

Immense attention must be placed on the detrimental consequences related to wetland loss and degradation in a developing, semi-arid country such as South Africa (Turner, 1991). The inevitable consequences of continued or accelerated wetland degradation includes; increase in species extinction, threatened wildlife resources, increased occurrence and intensity of flooding downstream, a decrease in reliable water supplies and water quality, and lower agricultural productivity of the land (Millennium Ecosystem Assessment, 2005).

These resultant outcomes act to degrade the facets upon which well-being and efficient ecosystem functioning (including mankind) relies on (Kotze et al, 1995). Losing wetlands in turn results in ecosystems to disintegrate and furthermore the loss of biodiversity and an increase in the unattended needs of the dependant poor and rural communities (Kotze et al, 1995). Additionally, the loss of wetlands has a crippling effect on the South African economy by creating the need for manmade wetlands and rehabilitation programmes, which can be equivalent to billions of rands (Kotze et al, 1995).

Thus, policies, conventions and legislation aimed mainly at encouraging the sustainable use, management, conservation, and protection of wetland ecosystems in South Africa should be a main priority of all tiers of government (Dickens et al, 2003).

2.16 WETLAND OFFSETS

Wetland offsets include the implementation of conservation methods which are formulated to offset foreseen detrimental negative impacts on wetlands. These methods are applied to address any major residual effects developing from development activities (SANBI and DWS, 2016).

The aim of wetland offsets include achieving ‘No Net Loss’ and ideally a gain in the values and functions gained by wetlands which encompass ecosystem services and water resources, conservation of ecosystems, and conservation of species of concern (SANBI and DWS, 2016).

Wetland offsets are implemented within a mitigation hierarchy and are solely aimed at atoning for immense negative impacts created due to development projects and is only executed consequent to all feasible procedures been taken into account to minimise, prevent and rehabilitate these impacts (SANBI and DWS, 2016). Once all attainable measures have been taken into consideration, every effort must be made to reduce the remaining adverse impacts and thereafter remediate or rehabilitate the affected area (Kotze et al, 2007).

2.16.1 Attaining a Wetland Offset

In cases where a wetland offset is suitable, numerous methods may be implemented in order to deliver the desired outcome. The methods are explained in the following broad categories: (SANBI and DWS, 2016).

- Protection: this encompasses the utilisation of legal mechanisms. This may involve the particularising of relevant legislation and acts, as well as ensuring that the offset locations are included in a suitable land use zone, ensuring that conservation outcomes are preserved in the long term.

- Rehabilitation: the outcome of rehabilitation fortifies the overall improvement of the wetland condition. The process of rehabilitation includes the alteration of the chemical, biological or physical properties of a degraded wetland in the aim of improving the integrity of the wetland. Actions such as removing water flow obstructions, the removal of alien species, and the blocking drainage canals, all assist in the rehabilitation programme.

- Averted Loss: this refers to the prevention of the degradation or loss of an existing wetland system and the provision of its ecological services by various physical activities. This would be applicable in cases where active erosion occurring in a wetland is stabilised in order to prevent the spreading of an erosion gully further into a wetland.

- Establishment: this encompasses the creation of a wetland system where none occurred before. This is done by altering the chemical, biological, or physical properties of particular site. A successful creation of such a wetland system will result in the gain of wetland services and values.

- Direct Compensation: this involves reimbursing communities affected by the loss of a wetland and the subsequent services they provide. This is primarily done by supplying a substitute of the service lost which may be in the form of a similar asset or monetary compensation.

CHAPTER 3

3. METHODOLOGY

3.1 INTRODUCTION

Chapter three encompasses a detailed explanation of the various methods utilised in conducting this study.

The initial step of this study was to carry out delineation at both a desktop level and out in the field. Thereafter, a wetland assessment was conducted, post identification of the different HGM units making up the wetland system. The tools utilised in conducting the wetland assessment included Wet-Health, Wet-Ecoservices, Google Earth, and Arc GIS. Furthermore, a granularmetric analysis was done in order to display the different sediment size profiles of the different hydrological zones.

In addition to conducting a wetland assessment, an analysis of a river riparian area comprising the study site was carried out using the Integrity of Habitat Index tool.
Water samples were also taken at locations where sources of open water was observed in close proximity to where sediment samples were taken. This was carried out in order to assess the quality of the water at these regions, providing a holistic diagnosis of the health status of the Melville wetland system.

3.2 DELINEATION OF THE MELVILLE WETLANDS

3.2.1 Desktop Delineation

A desktop study was initially completed in order to obtain a broad understanding of the general study site. The desktop delineation can only assist with the fieldwork to identify where possible wetland areas could be located and is not entirely accurate. Once wetland boundaries were delineated at a desktop level, a field survey was conducted to verify if these areas are correct and to identify and delineate areas that were not seen at a desktop level.

Desktop delineation was conducted on Google Earth®. The polygon tool was used and boundaries were drawn around each HGM unit identified at a desktop level by identification of characteristic vegetation, and topography.

3.2.2 Field Delineation

A comprehensive wetland delineation survey was completed in June 2016. A field survey was conducted in order to ensure boundaries were accurately delineated at a desktop level. In order to map out the different boundaries of the wetland study site, soil cores were obtained by using a Dutch soil auger which was compressed into the soil bed to a depth of approximately 50cm. The location of each soil core obtained was thereafter logged and recorded by a Global Positioning System.

In order to identify wetland areas within the study site, four specific wetland indicators were used:

- Vegetation
- Topography of the landscape
- Soil wetness
- Soil form

When a wetland area is verified by the above indicators, wetland delineation proceeded. The procedure of the wetland delineation involved identifying the different hydrological zones of the wetland, namely, the permanent, seasonal and temporary zones. The verification of these different zones start at the most outer edge of the temporary zone in order to find the boundary between the aquatic and neighboring terrestrial area. Once this zone was found, the seasonal and permanent zones were easier to find as these areas are generally within the boundary of the temporary zone.

A Dutch soil auger was used to obtain sediment cores. The sediment cores were evaluated on-site for redoxymorphic soil features such as gleying, mottling, soil wetness and soil chroma; and thereafter the sample was discarded. In addition to the soil cores, GPS coordinates of the location of soil cores were captured and mapped using Google Earth® for further analysis and processing. All information such as aerial photography, field notes and coordinates of sampling sites were used in combination to identify and delineate the extent of the wetlands.

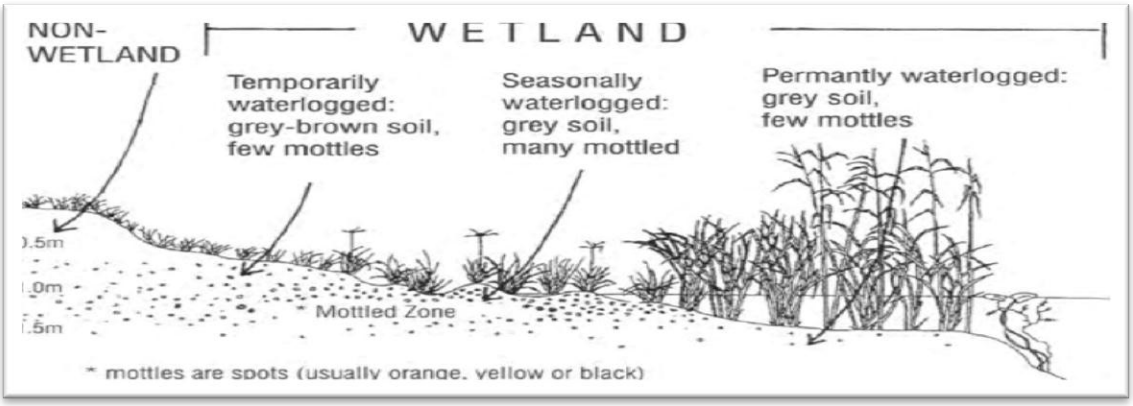


Figure 3.1. Representation of Wetland and Non Wetland Zones

(DWAF, 2004)

Table 3.1. Classification of Vegetation Occurring in Wetlands

(DWAF, 2008)

Type	Description
Obligate wetland species	Mostly grows in wetlands (> 99% presence in wetlands).
Facultative wetland species	Generally grows in wetlands (67-99% presence in wetlands), are occasionally found in non-wetland.
Facultative species	Likely to grow in wetland and non-wetland areas (34-66% occurrences in both non-wetland regions wetland).
Facultative dry-land species	Predominantly grow in non-wetland conditions but sometimes in wetland conditions (1-34% occurrence in wetlands).

3.3 WETLAND CLASSIFICATION

Wetland areas may encompass more than one hydrogeomorphic units. Once delineation was completed HGM units were identified and were classified according to the National Wetland Classification System developed by the SANBI (Ollis *et al*., 2013; DWAF, 2004). The HGM classification system uses the hydrological and geomorphological features of the delineated wetland unit to determine its classification.

3.4 WETLAND FUNCTIONAL ASSESSMENT

In addition to the above mentioned, functional assessments were conducted on all HGM units comprising the Melville wetland system. The functional assessment tools utilised in this study were: WET-EcoServices Level 2 assessment, and WET-Health Level 2 assessment.

3.4.1 Determination of Wetland Health using the WET-Health Tool

The Wet-Health tool has been developed to monitor wetlands nationally in South Africa which will be used in a range of contexts such as wetland management and rehabilitation. (Macfarlane et al, 2007).

The tool has recognized different requirements for users, therefore creating two levels of assessment which are Level 1 and 2. For the purpose of this study a Level 2 assessment was conducted. A level 2 assessment involves more structured data collection from the wetland and catchment areas (Macfarlane et al, 2007) and incorporates all aspects of the Level 1 assessment.

WET-Health takes into consideration three important components of wetland systems which are geomorphology, hydrology and vegetation. These components are assessed and any deviations from the natural environmental conditions are noted. The overall health of each component is assessed within a three step process (Macfarlane et al, 2007).

<u>Step 1:</u> PES Determination for each Hydrological, Geomorphological and Vegetation Components

The first step was based on human and natural impacts in the wetland and catchment areas, and each HGM unit was assessed on "Present Ecological State" so that ultimately the wetland could be scored from 0 (wetland being identical to natural environmental conditions) to 10 (wetland significantly changed) for hydrology, geomorphology and vegetation seperately. Due to the score of 0-10 not being entirely easy to work with when doing a wetland assessment, this will be translated into one of six health classes, A-F.

<u>Step 2:</u> Wetland Vulnerability determination

The second step was completed by determining the threat and/or vulnerability, and an evaluation was also completed for each HGM of the likely "Trajectory of Change" within the wetland (Lackey, 2001; Davis and Slobotkin, 2004). This was broken up into five categories of likely alteration depending on the direction and/or degree of probable change. These categories are:

↑↑ = large improvement

↑ = slight improvement

→ = remain the same

↓ = slight decline

↓↓ = rapid decline

<u>Step 3:</u> Determination of the Overall PES

The third and final step was completed by establishing the overall health of each HGM by jointly representing the overall "Present Ecological State" (a combination of the hydrological, geomorphological and vegetation heath) and likely Trajectory of Change (Macfarlane *et al*., 2007). The overall health of a HGM unit was calculated using the following equation:

<u>Equation 1</u> (Macfarlane et al, 2007).

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

Table 3.2. PES Categories and the Relevant Level of Modification Experienced

Impact Category	Health Category	Description	Range
None	A	Unmodified/natural	0 – 0.9
Small	B	Mostly Natural with a few modifications. A slight change in ecosystem processes is discernable and a small loss of natural habitats and biota may have taken place.	1 – 1.9
Moderate	C	Moderately modified. A moderate change in the ecosystem processes and the loss of natural habitats has taken place but the natural habitat remains predominantly intact	2 – 3.9
Large	D	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred.	4 – 5.9
Serious	E	A very large change in ecosystem processes and loss of natural habitat and biota but some of the remaining natural habitat features are still recognizable.	6 – 7.9
Critical	F	The modification has reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota	8 – 10

3.4.2 Assessing wetland Goods and services using the WET-EcoServices Tool

The WET-EcoServices Level 2 assessment establishes the goods and services provided by the HGM units potentially affected by development. The tool is extremely important as it provides the different ecosystem services delivered by the wetland and this is categorized into a number of different factors.

The WET-EcoServices assessment tool focuses on assessing the extent to which a benefit is being supplied by the wetland habitat, based on both the opportunity for the wetland to provide the benefits; and the effectiveness of the particular wetland in providing the benefit. The direct and indirect benefits provided by wetlands to surrounding landscape and society were assessed by a rating score for different characteristics of each wetland and their surrounding catchments, which were based on a scale provided by WET-EcoServices. This scale includes: **low (0), moderately low (1), intermediate (2), moderately high (3) and high (4).**

These scores were thereafter obtained for each ecological service and the extent to which each service is provided can be assessed based on the score.

3.4.3 Hectare Equivalence

Hectare equivalence was established in order to determine the amount of remaining healthy wetland in a wetland system that has suffered some level of degradation as identified by the WetHealth assessment. Additionally, the amount of degraded wetland was also be calculated by the subtraction of the amount of healthy wetland from the total area of the wetland (Kotze et al, 2007).

This methodology therefore aids in the decision making process when it comes to rehabilitation programs. By determining hectare equivalence, it can be determined the feasibility of rehabilitation plans. This is better known as wetland offsets.
Hectare equivalence was calculated using the following equation:

Equation 2 (Macfarlane et al, 2007)

$$\frac{10 - \text{Overall PES}}{10} \times \text{Area of Wetland}$$

3.4.4. Longitudinal Profile and Vulnerability

The longitudinal profile of each individual HGM unit was determined by calculating the slope and plotting this against the elevation.

The vulnerability of each HGM unit was determined by utilizing a graph derived from the Wet-Health series (depicted below). The vulnerability diagram represents a HGM units inherent vulnerability to changes in the geomorphology. The rate at which headcut erosion occurs is dependent on multiple factors, however the most predominant factor is recognized as being the slope of a HGM unit. The steeper the slope, the greater the rate of headcut erosion for any given discharge will be. It is thus this relationship between discharge and longitudinal slope of a wetland that is utilised to assess its vulnerability (Kotze et al, 2007).

The vulnerability factor for the Melville HGM units was therefore established by plotting the longitudinal slope of the unit against the area of the unit (which is an equivalent to mean annual discharge). Once plotted on the graph, it was investigated whether the HGM unit fell above or below the thick black line (in between scores 2 and 5). If the HGM units vulnerability factor was found to exist above the line the system was deemed as degradational, whereas if it was found below the line it was determined as aggregational.

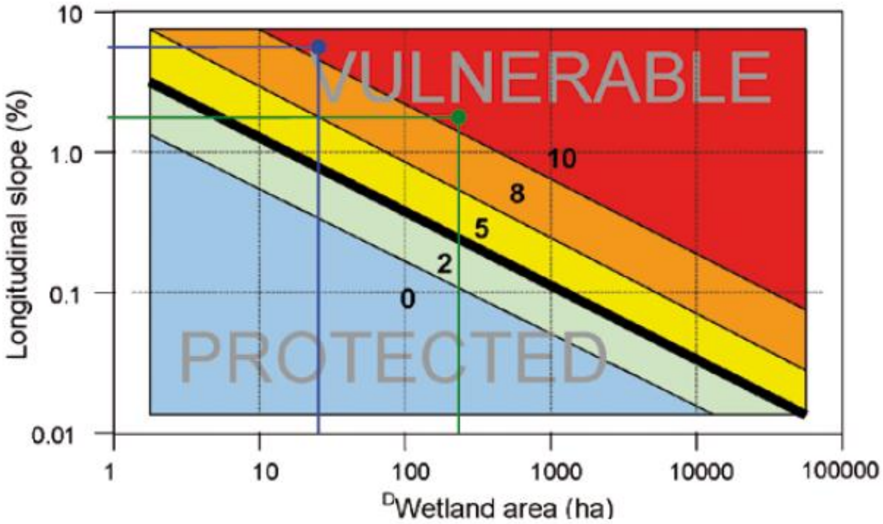


Figure 3.2. Vulnerability Diagram

(Macfarlane et al, 2007)

3.5 INDEX OF HABITAT INTEGRITY (IHI)

The Index of Habitat Integrity was utilised in this study in order to evaluate the health of units classified as river riparian. The IHI was utilised instead of the Wet-Health tool for river riparian areas as the Wet-Health tool is strictly reserved for use in areas classified as a wetland HGM unit. River riparian units are classified separate to wetlands and are therefore assessed using the IHI tool (Ollis et al, 2013). The IHI tool encompasses the following steps:

Step 1: Desktop Delineate

The first step was to desktop delineate the study area, which was done on Google Earth® utilising the polygon tool to outline the boundaries of the river riparian regions.

Step 2: Conduct a Field Survey

Thereafter, a field survey was commenced. All impacts on the hydrological, geomorphological, and vegetation regimes were noted in the field.

Step 3: Score IHI Datasheets

The IHI datasheets comprised of vegetation, hydrology, geomorphology and water quality modules, in which impact factors were listed which were weighted in terms of their prominence (out of a maximum of 100%) and were scored from 0 (negligible impact) to 5 (significant impact).

Step 4: Determine Vegetation, Hydrology, Geomorphology and Water Quality PES

Upon the completion of scoring the datasheets, PES scores were automatically obtained for each of the components contributing to the health of the system the IHI datasheets. PES categories ranged from a category A to category F depending on the score obtained (as seen in Table 3.2 above).

Step 5: Determine Overall PES

Once individual PES scores were acquired for vegetation, hydrology, geomorphology and water quality, the overall PES score and category could be determined, which was calculated automatically on the IHI datasheet.

3.6 LABORATORY ANALYSES

The following analyses were conducted at the University of KwaZulu Natal in the Geology Soils Laboratory for soil samples and in the Chemistry Laboratory for water samples, subsequent to the completion of the field work.

3.6.1 Granulometric Analysis

The textural analysis of the sediment was carried out via the dry sieving method using a Retch sieve shaker. Sediment was dried in the low-temperature oven at 110°C for 48 hours. Thereafter, sediment sub-samples were disaggregated by using a pestle and mortar in order to separate the larger grain sizes from the smaller grain sizes (Morgan, 1995). The samples were then placed on the uppermost member of the column of metal sieves, and passed through sieves of aperture sizes 2 mm, 1 mm, 0.5 mm, 0.25mm, 0.125 mm, 0.053 mm and tray from top to bottom respectively (Morgan, 1995). These sieves were shaken for 8-10 minutes. After sieving, the quantity of sediment retained on each sieve were emptied into their respective plastic boats which were labelled 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, 0.053mm and tray, and thereafter weighed and recorded (Mitsch and Gosselink,2000).

Particle size distribution and its analysis require the determining of size parameters and constitute of measures of central tendency, such as the mean (Selly 2000). As recognised by Tucker (1998), determining the mean is regarded as the most favoured measure for average particle sizes, and a much grander measure of the whole distribution when compared to its counterpart parameters such as the median or mode (Selly, 2000).

3.6.2 Organic Matter

Loss on ignition is a commonly utilised procedure which can be used to determine organic matter content of sediment core sub-samples (Heiri et al., 2001). In order to prepare for the loss of ignition process the sediment sub-samples from the 50ml beakers were transferred into clean ceramic crucibles and thereafter pre-dried in the low temperature oven at 60^{o}C for a period of 4 hours (Beaudoin, 2003).

Thereafter, the samples in the crucible were transferred to a muffle furnace and the samples were ignited at a temperature of 550^{o}C in order to facilitate the oxidization of organic matter to carbon dioxide and ash (Battarbee et al., 2002). In addition, once samples were ignited, they were taken to a low temperature oven and were put through a cooling period of 60^{o}C for 2 hours. Weights of the dried crucibles, post-60^{o}C dried sediment and post-550^{o}C sediment were all recorded.

Organic matter content was therefore calculated as the mass difference between the sediment dried at 60°C and the ash produced following ignition at 550°C (Beaudoin, 2003).
The following method was used to establish the percentage of total organic matter content in sediment sub-samples:

Equation 3 (Beaudoin, 2003)

$$\% \text{ OM} = (\text{Weight of post } 550^{o}\text{C ash}) / (\text{Weight post } 60^{o}\text{C dry}) \times 100$$

3.6.3 Calcium Carbonate

The method utilised to determine the calcium carbonate content was also the loss on ignition analysis. Following the 2 hour cooling period in a low temperature oven at 60°C for organic matter content, the sediment sub-samples within the crucibles were further ignited at a 1000°C for a period of 2 hours to determine the respective calcium carbonate within that exist within the sub-samples (Heriri et al, 2001; Battarbee et al., 2002). In addition, once the 2 hour ignition process was completed, samples were transferred to a low temperature oven which was set at 60°C for a 2 hour cooling period (Heriri et al, 2001). Once the process was completed, the post-1000°C dried sediment was weighed and recorded (Beaudoin, 2003).

The calcium carbonate content of sub-samples were calculated by using the following equation:

Equation 4 (Heriri et al, 2001)

$$\%\text{CCC} = \frac{(\text{Weight of post-}550^{o}\text{C ash} - \text{Weight of post-}1000^{o}\text{C ash}) \times 2\ 274 \times 100}{(\text{Weight post-}60^{o}\text{C dry sample})}$$

3.6.4 Water Chemistry

Water samples were obtained at various points in close proximity to the soil samples during the filed delineation process. The water samples were securely contained in clear bottles which were labelled and taken back to the University of KwaZulu Natal lab for further analysis. Parameters analysed included D.O, pH, salinity, phosphorus, nitrates, TDS, and electrical conductivity. These parameters were analysed by utilising the various methodologies listed below:

- **<u>Yellow Springs Instrument (YSI)</u>**

Parameters such as D.O, TDS, electrical conductivity, pH and salinity were measured in the laboratory using the YSI 6920 Multi-parameter Sonde (Sukdeo, 2010).
Water samples were poured into the cup holders of the YSI machine, which were rinsed out with deionized water before each sample was analysed. The cup holders were subsequently filled up to a particular point until probes entered the water. Thereafter, the samples were left in the cup of the YSI machine for a period of five minutes in order for the machine to stabilise and to ensure accuracy of the D.O, TDS, electrical conductivity, pH and salinity readings which were taken from the YSI hand-held device (Sukdeo, 2010).

- **<u>Ion Chromatography</u>**

The procedure of ion chromatography was utilised in order to measure phosphates and nitrates. This method involves the insertion of a water based sample into a carbonate or bicarbonate eluent, which is a fluid substance used to remove/ wash away particles (Haddad, 1994). The eluent was pumped through the ion-exchanger, which was a resin-packed column for which ions within a sample have different affinities (Haddad, 1994). The different ions are separated during this process and as the eluent and separated ions pass through the ion-exchanger. The eluent conductivity was reduced such that the detection and conductivity of the ions are enhanced (Haddad, 1994). The enhanced conductivities are measured and are then identified using respective retention times, and were quantified by comparison between the calibration standards and their peak areas (Haddad, 1994).

3.7 CONCLUSION

The methods mentioned above were utilised in order to determine the health status of the hydrological, geomorphological, and vegetation regimes of the Melville wetlands and surrounding river riparian regions. In addition to determining the health status of the hydrological, geomorphological, and vegetation regimes, the water quality within this area was also analysed, in order for an overall PES of the Melville wetland area to be established.

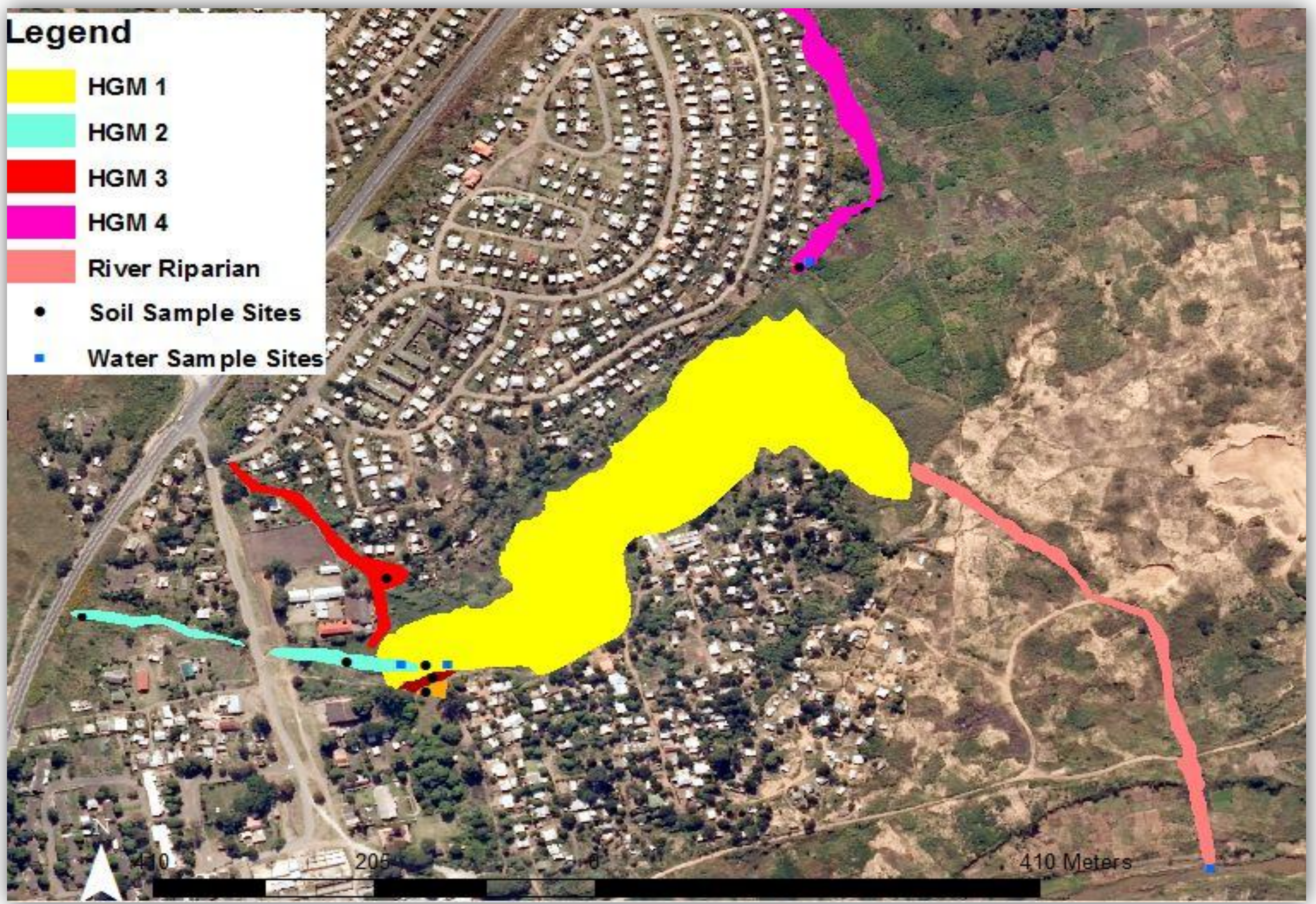


Figure 3.3. Soil and Water Sample Points

CHAPTER 4

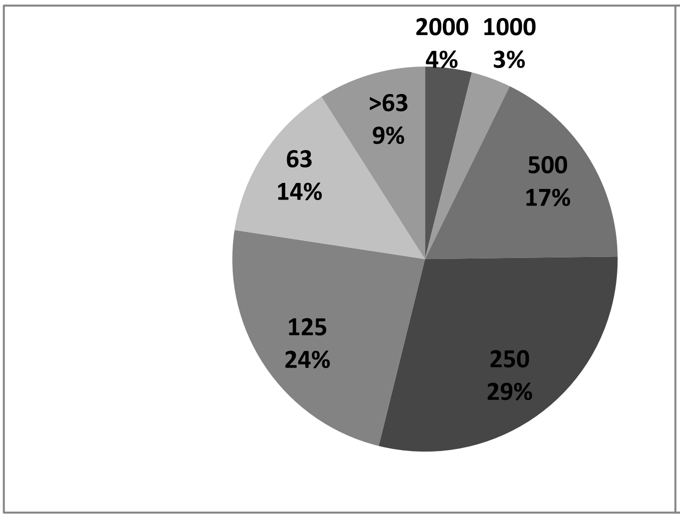
4. RESULTS

4.1 INTRODUCTION

Chapter four is a condensation of all the data obtained through desktop and field surveys. Data concerning sediment distribution, organic matter, delineation, longitudinal and vulnerability profiles, ecological services and functional health of the Melville wetland system have been assessed and are displayed below. In addition to the wetland assessment data, this section contains the results pertaining to the health of the river riparian area comprising the Melville wetland system, as well as the results of the water quality in this area.

4.2 SEDIMENT DISTRIBUTION

The distribution of sediment refers to the size class of sediments found in a particular environment. From these size classes, sediments can be categorised as gravel, sand, silt or clay. This data provides one with a general outlook on what kind of sediments are occurring in a particular region, thus providing information such as what type of environment these sediments are occurring in.



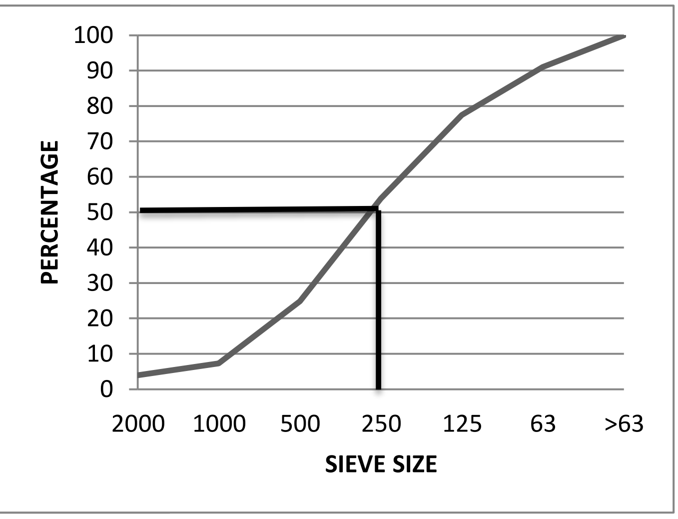


Figure 4.1. Sediment Size Distribution and Distribution Curve for Site A

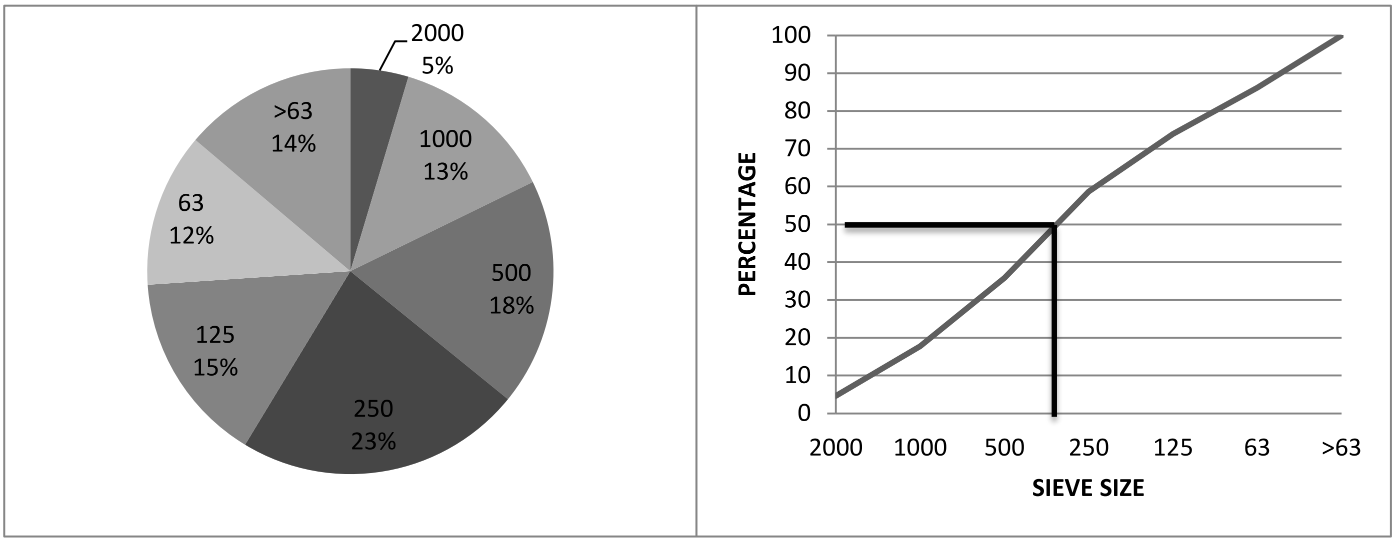


Figure 4.2. Sediment Size Distribution and Distribution Curve for Site B

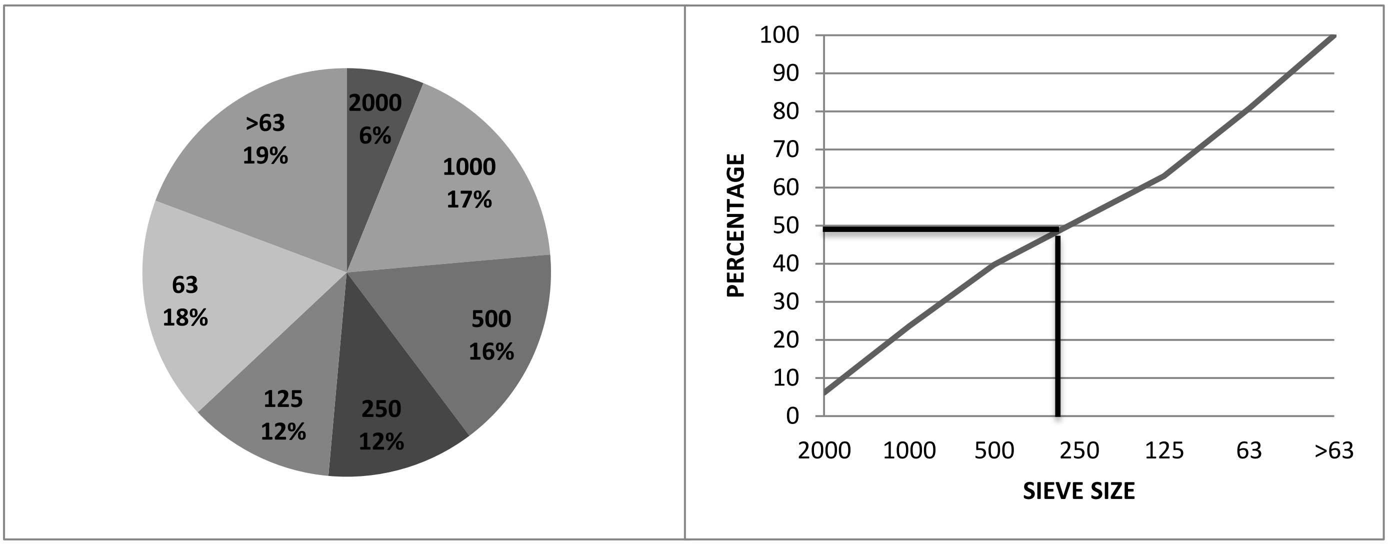


Figure 4.3. Sediment Size Distribution and Distribution Curve

The pie charts displayed above depict the distribution of different grain sizes found within the sediment samples taken from points A, B and C. Each pie chart shows the different size categories of sediment grains, as per the sieve measured in millimetres, and the percentage retained within each size class.

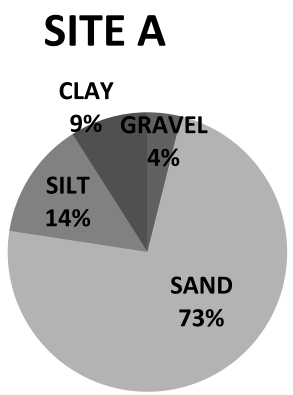
In site A it can be seen that this region has a large percentage of sediment grains in the size classes of 125mm and 250mm with 53% of the total sediments falling within these size classes. It can therefore be established that this region is dominated by medium sized sediment grains with a low concentration of coarse sediment. From Figure 4.4 below it can further be established that this region has a mean sediment size of approximately 240mm.

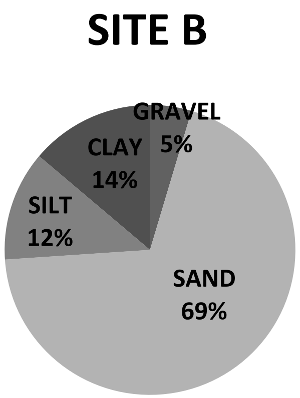
In site B the 250mm size class is the most predominant with 23% of total sediments falling within this range. Having similar percentages, the size classes 125mm, 63mm and >63mm make up 41% collectively. It can thereby be deduced that this location is dominated by medium sized sediment grains, with an increasing amount of fine sediments as compared to site A. This is further compounded by the mean sediment value of this site, seen in Figure 4.2, of approximately 380mm.

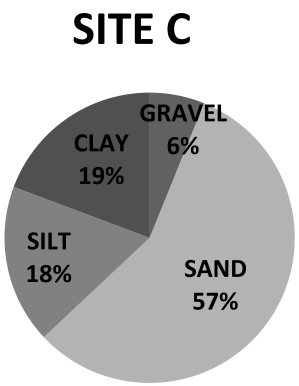
Site C has a dominant concentration of sediment within the 125mm, 63mm and >63mm size class which make up 49% of total sediments. From the depiction it can therefore be ascertained that this region is dominated by fine grain sediments and has a lesser amount of medium sized sediments as compared to sites A and B. However, there is an increase in coarse grain sediments in this. The mean sediment size can be seen to be much finer than in Sites A and B with a mean sediment value of approximately 250.

Using the different size classes, the sediments were able to be classed as either gravel, sand, silt or clay. In Figure 4.4 it can be seen how much of gravel, sand, silt and clay was found at the different sites A, B and C. Throughout all three sites there seems to be a trend of increasing silt and mud quantities moving from site A through to site C, and a similar trend is experienced with gravel. However, an opposite trend is experienced with sand as there is a decrease in the amount of sand moving from site A to C.

Site A is dominated by sand sized sediment grains, with 73% of all sediment falling within the sand category. In site B sand sized sediment still dominate the region, however there is a slight decrease of 4% from site A to site B. In site C silt and mud constitute 37% of the total sediments, which is a significant increase of 14% and 11% from sites A and B.







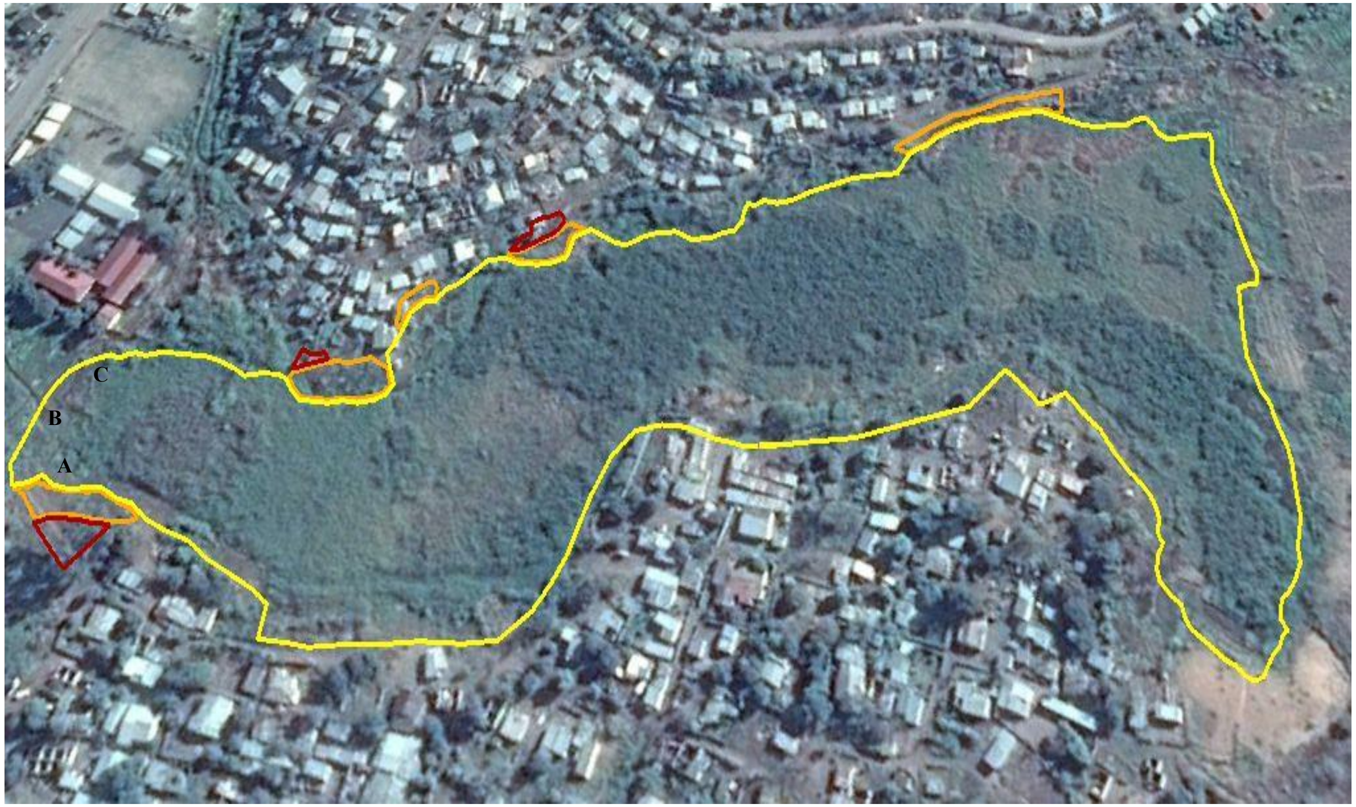


Figure 4.4. Gravel, Sand, Silt and Clay Distribution in Site A, B and C

4.3 ORGANIC MATTER and CALCIUM CARBONATE CONTENT

Figure 4.5 is a depiction of the organic matter (O.M) and Calcium Carbonate (C.C) content occurring in each site within the top (0-10cm) and bottom (40-50cm) layers. From the above figure, it can be observed that there is an increase in both O.M and C.C from site A to site B and a further increase in site C, with the top layers having larger quantities of O.M and C.C in each site.

In site A, it can be established that the amount of O.M and C.C is increased from A bottom to A top. From Figure 4.5, the C.C content for this site can be seen as 0.52g for the bottom layer and 0.63 for the top layer, giving a collective C.C content value of .15g for site A. As a result, it can be established that site A has a greater C.C content than O.M.

As per Figure 4.5, it can be seen that there is an increase in O.M and C.C, in both layers, from site A to site B. In site B there is a collective value of 1.91g for O.M. Collectively, site B has a C.C content of 2.08, which is evidentially an increase from the O.M content in this site.

Similarly, there is a further increase in O.M and C.C content in site C. As depicted in the above figure, there is the highest concentration of O.M at 2.35g. C.C content within this site is also the highest.

In conclusion, it can be summarised that there is a general increase of both O.M and C.C content throughout each site. There are also increases of O.M and C.C from bottom to top layers within each site. Furthermore, it is noted that there is a greater C.C content that O.M throughout each site.

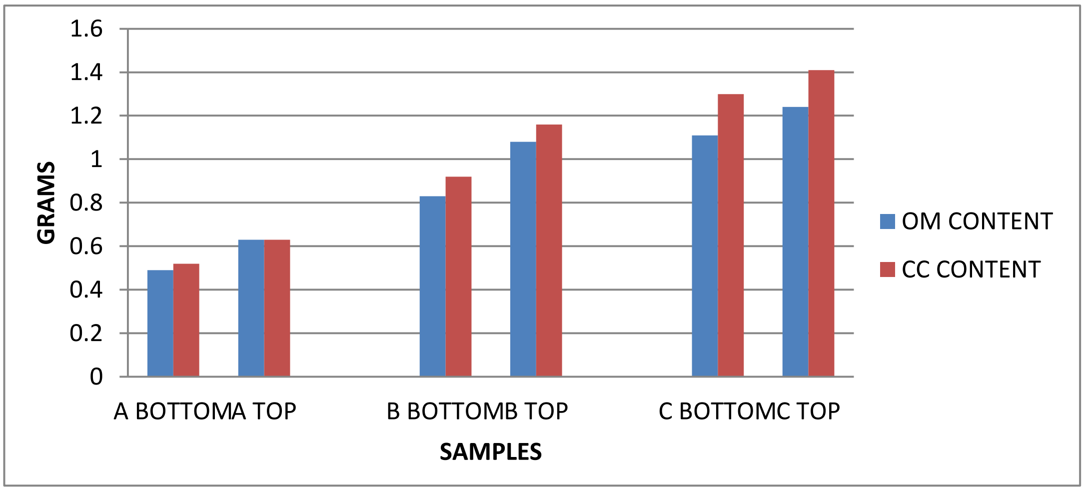


Figure 4.5. O.M and C.C Content

4.4 DELINEATION

The different hydrogeomorphic units within the wetland system were identified according to the characteristics displayed by each unit (these characteristics are explained in Figure 2.1 of Chapter 2). The different HGM units are displayed below in Figure 4.6. It was established that HGM 1 was an unchannelled valley bottom wetland, with HGM 2, 3, and 4 classified as channelled valley bottom wetlands. HGM 5 was identified as a river riparian area, and thus a separate analysis was acquired for that unit.

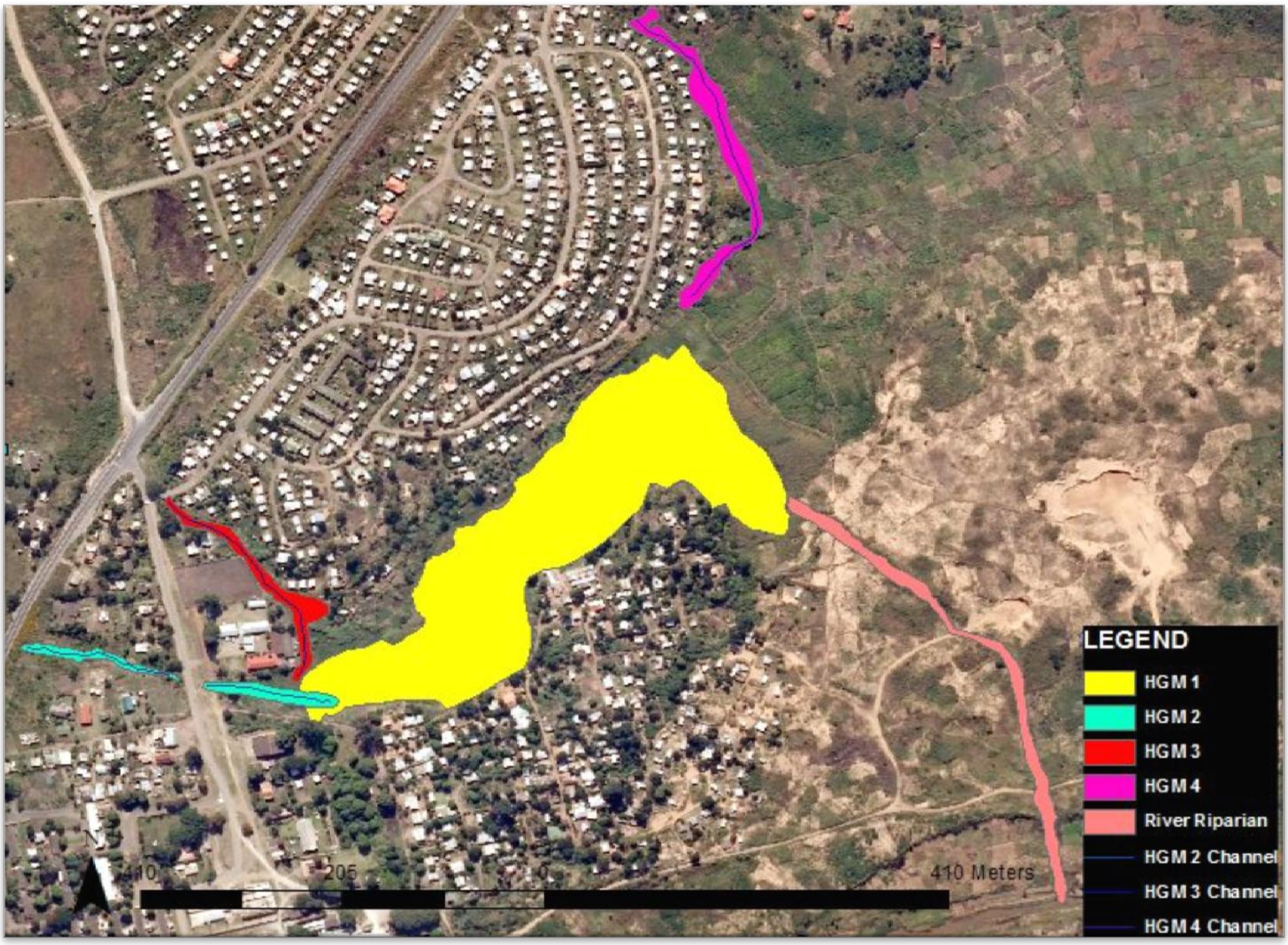


Figure 4.6. HGM Units

Furthermore, the permanent, seasonal, and temporary zones were delineated by evidence gathered from soil and vegetation profiles taken from the various predetermined points, displayed in Chapter 3.

These zones are depicted in Figure 4.7.

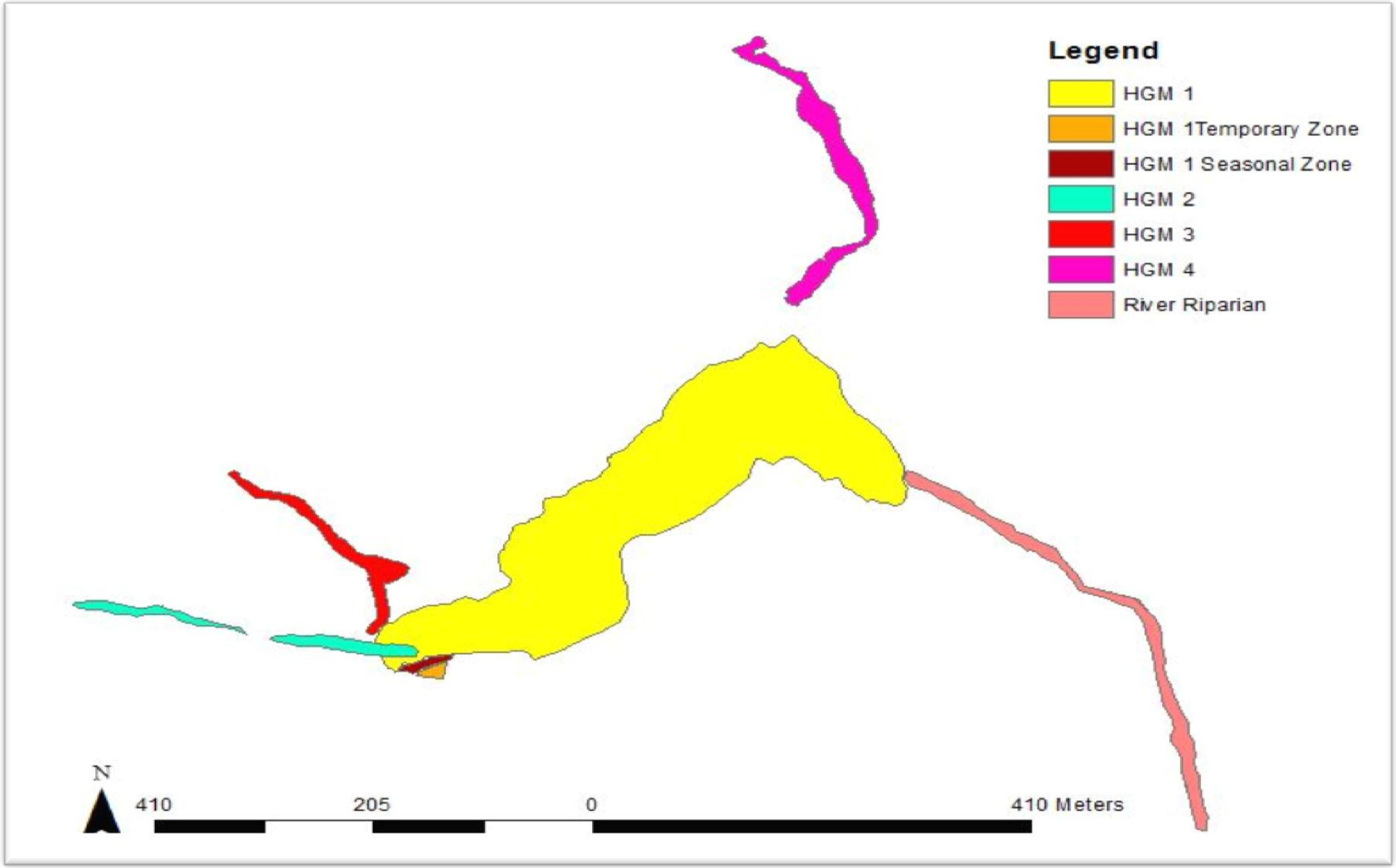


Figure 4.7. Delineation of the Melville Wetland System

The above zones were identified by a desktop delineation, and thereafter confirmed by sediment cores and vegetation profiles observed in the field. Below are the sediment cores taken at the sample points demarcated in Figure 3.3, and a brief description of each. Tables filled out in the field, with a description of soil and vegetation profiles at each of the sampling sites can be found in the appendix section.

Figure 4.8 displays three examples of the soil profiles observed at the different sampling locations.

The first depiction represents a soil profile in the permanent zone of HGM 1. This was deduced due to the presence of orange coloured and the intermediate contrast of mottles within the soil profile in the 0-10cm and 30-40cm layer. Furthermore, the matrix value and chroma was established to be 4 and 1 respectively in the 0-10cm layer and 3 and 1 in the 30-40cm layer.

The second picture shows evidence of high abundance of mottling present with an overall intermediate contrast and orange colour in the 0-10cm and 30-40cm layers. The matrix value and chroma was concluded to be 4 and 2 within the 0-10 cm layer and 4 and 1 within the 30-40 cm layer. This soil profile was therefore indicative of a seasonal zone.

The soil profile displayed in the third picture represents a temporary zone as this layer provides evidence of no mottling in both soil profile layers. Additionally, the 30-40cm layer has a matrix value and chroma of 5 and 2 in the 0-10 cm layer and 5 and 1 in the 30-40 cm layer, confirming its temporary zone characteristics.

1. Permanent Zone

2. Seasonal Zone

3. Temporary Zone

Figure 4.8. Soil Profile of the Permanent, Seasonal and Temporary Zones in HGM 1

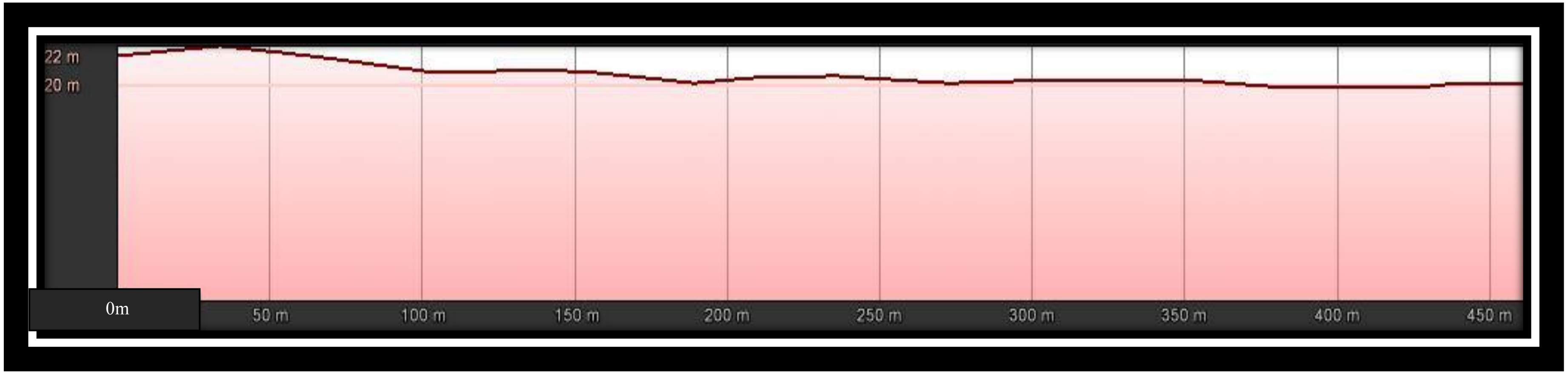
4.5 LONGITUDINAL PROFILE and VULNERABILITY

The longitudinal profile for each HGM was established in order to obtain the slope. The slope and the area of each HGM (Table 4.1) were thereafter plotted on a vulnerability graph in order to view the level of threat to the different HGM's as well as to determine whether the HGM units are aggregational or degradational.

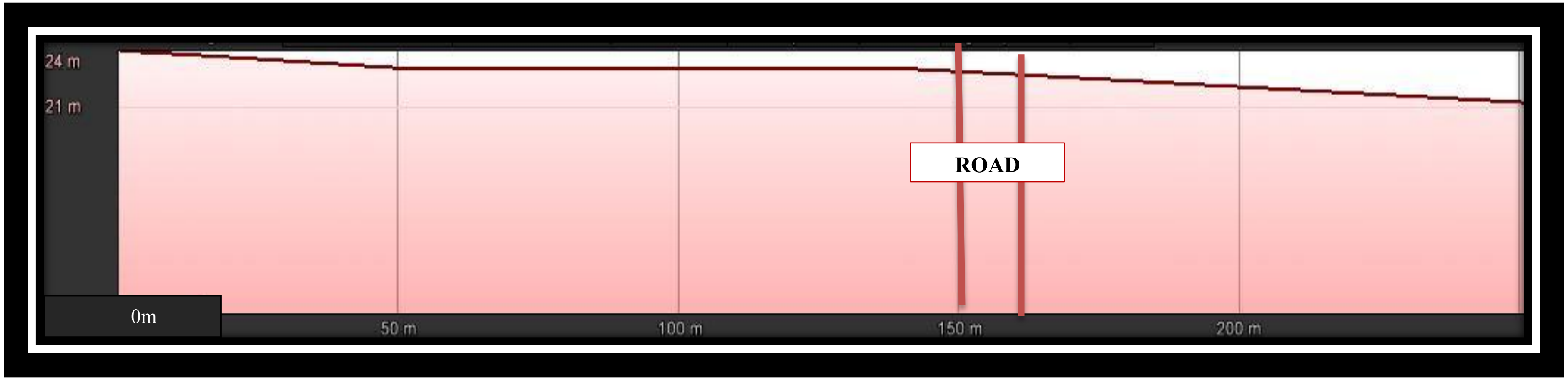
Table 4.1. HGM Unit Area and Slope

HGM UNIT	HGM TYPE	HGM AREA (Ha)	HGM SLOPE
1	Unchannelled valley bottom	5.63	0.6
2	Channelled valley bottom	0.3	1.1
3	Channelled valley bottom	0.3	2.1
4	Channelled valley bottom	0.56	5.2

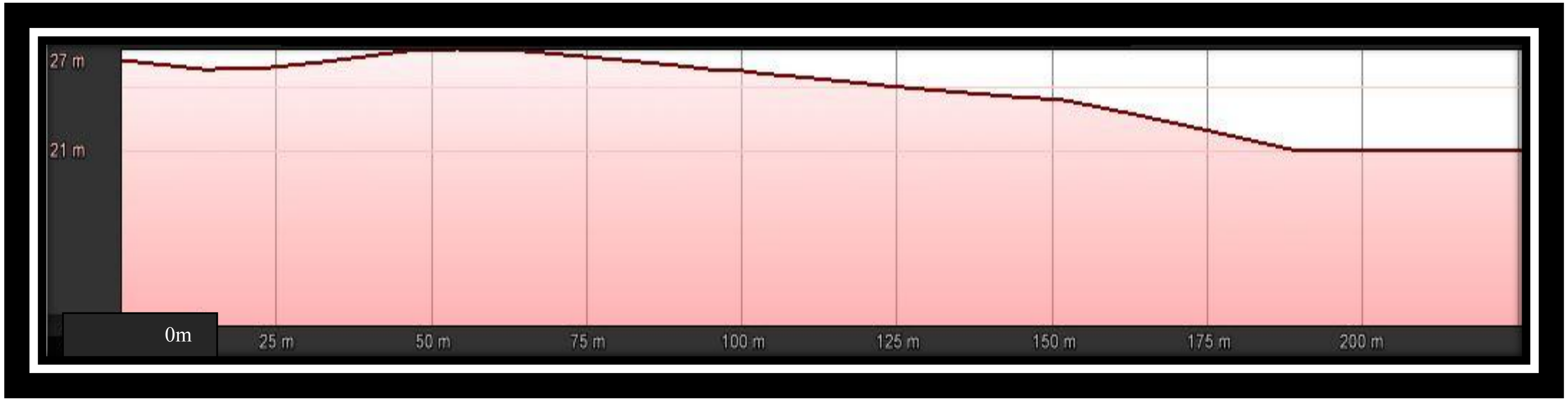
HGM 1


22 m
20 m
0m
50 m
100 m
150 m
200 m
250 m
300 m
350 m
400 m
450 m

HGM 2


24 m
21 m
ROAD
0m
50 m
100 m
150 m
200 m

HGM 3



HGM 4

Figure 4.9. Longitudinal Profiles of HGM Units 1, 2, 3 and 4

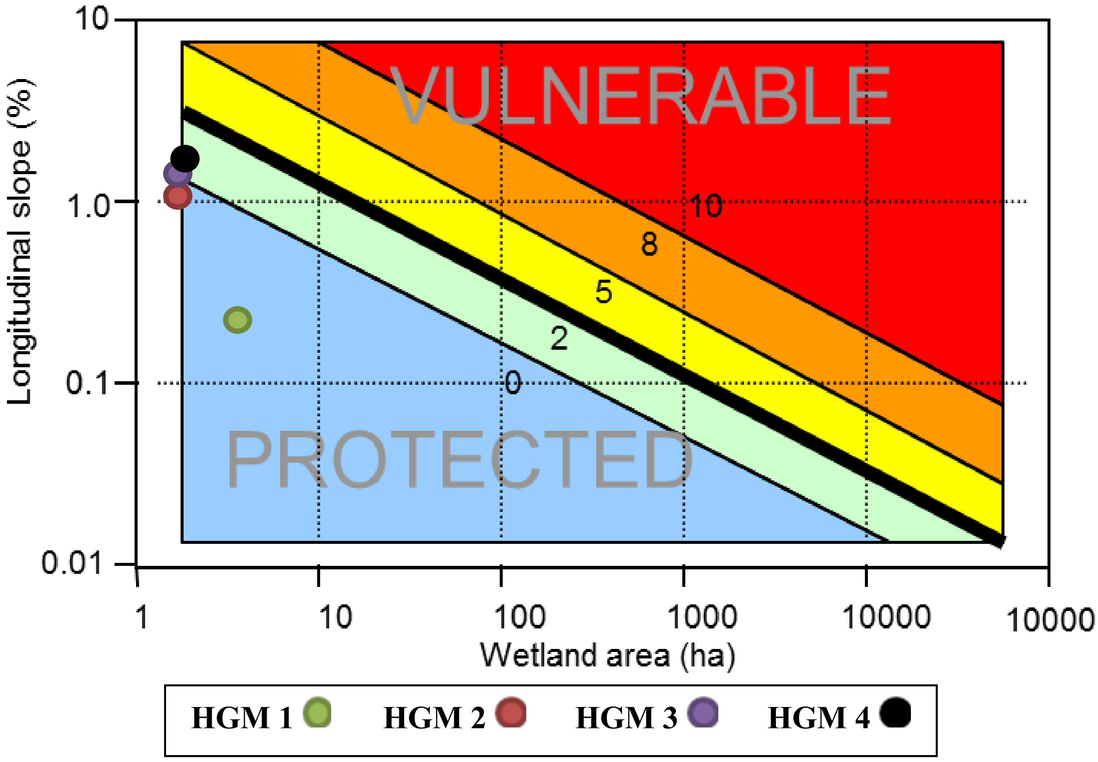


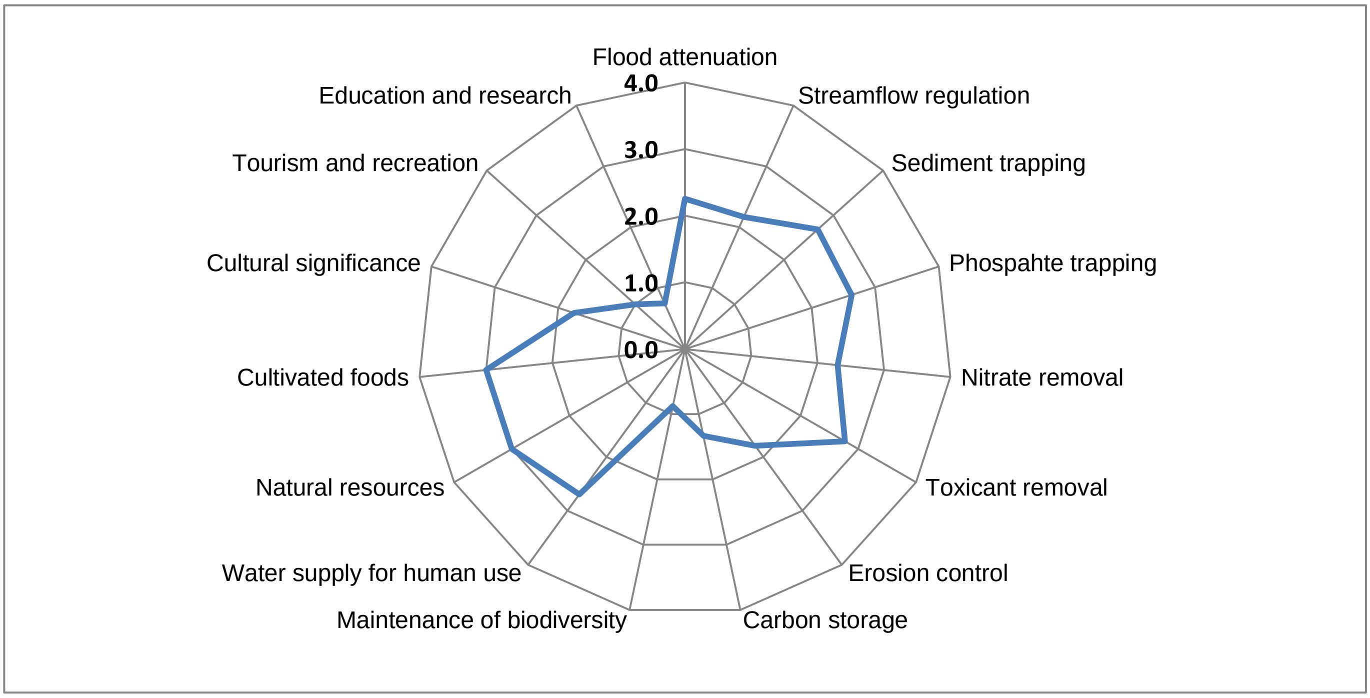
Figure 4.10. Vulnerability Factor of HGM Units

Figure 4.10 above is a depiction of the vulnerability of each HGM. From the longitudinal profiles of each HGM, displayed in Figure 4.9, the slope of individual HGM's were deduced (Table 4.1). The wetland area was plotted against the slope of each HGM, and the vulnerability was subsequently obtained.
All four HGM's fall within the 'protected' range as they all fall below the threshold line.

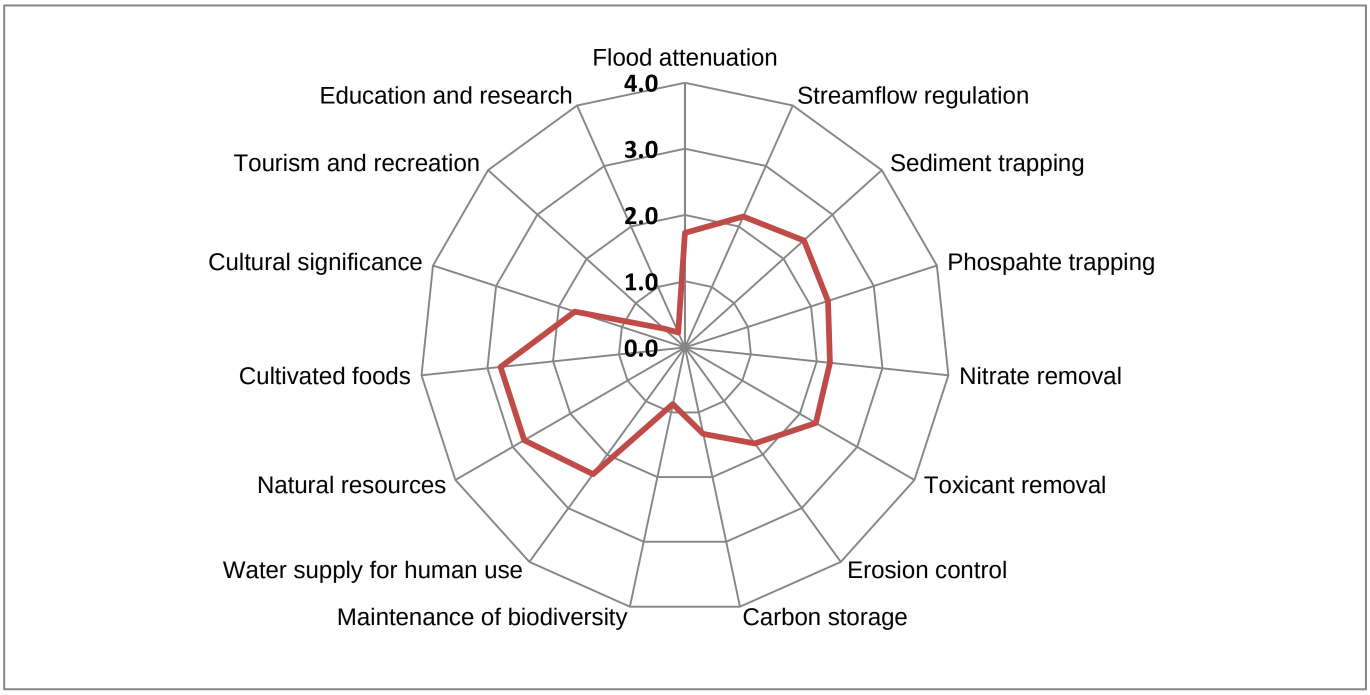
HGM 1, with a slope of 0.4 and an area of 5.63Ha, has a vulnerability score of 0. HGM 2 and HGM 3 have areas of 0.3Ha and slopes of 1.1 and 2.6, respectively, thus scoring a vulnerability score of 0. HGM 4 has a slope of 3 and an area of 0.56Ha, with the steepest slope HGM 4 has a vulnerability score of 2.

Due to all the HGM's falling within the 'protected' zone and below the threshold line, they are all considered to be aggregational units.

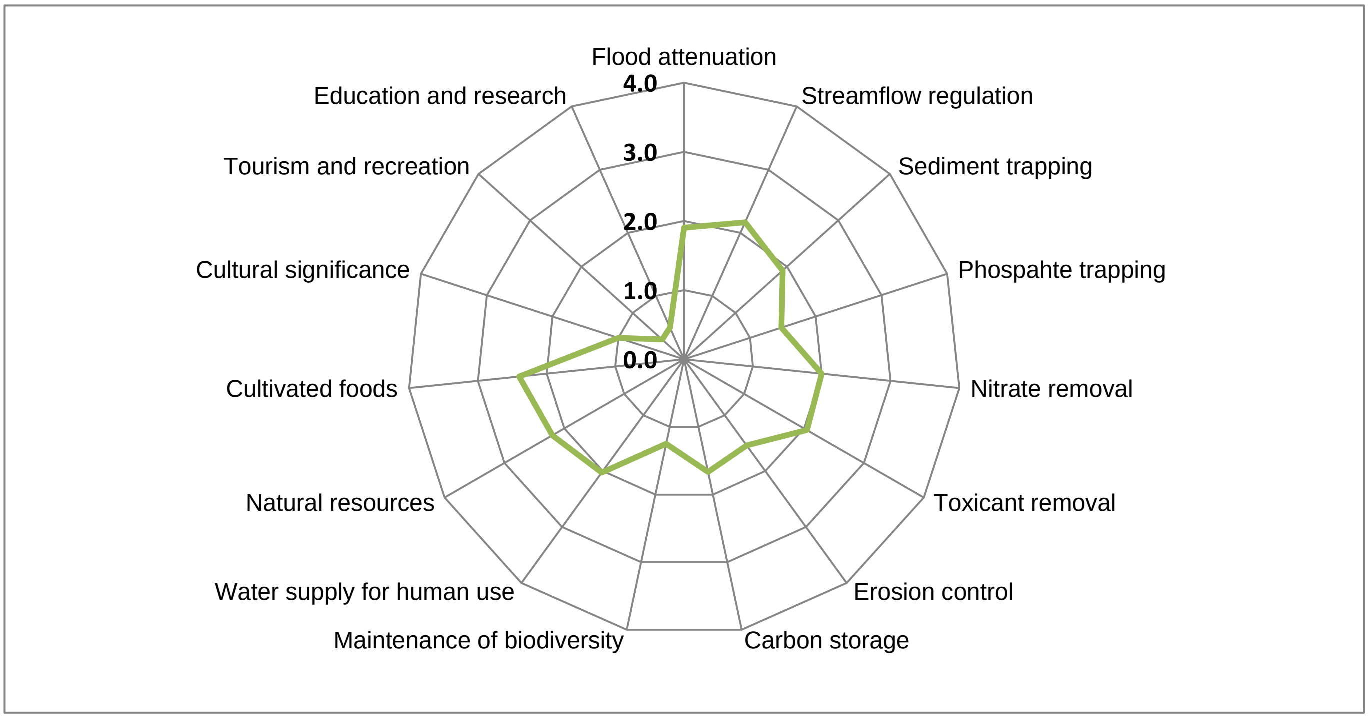
4.6 ECOLOGICAL SERVICES



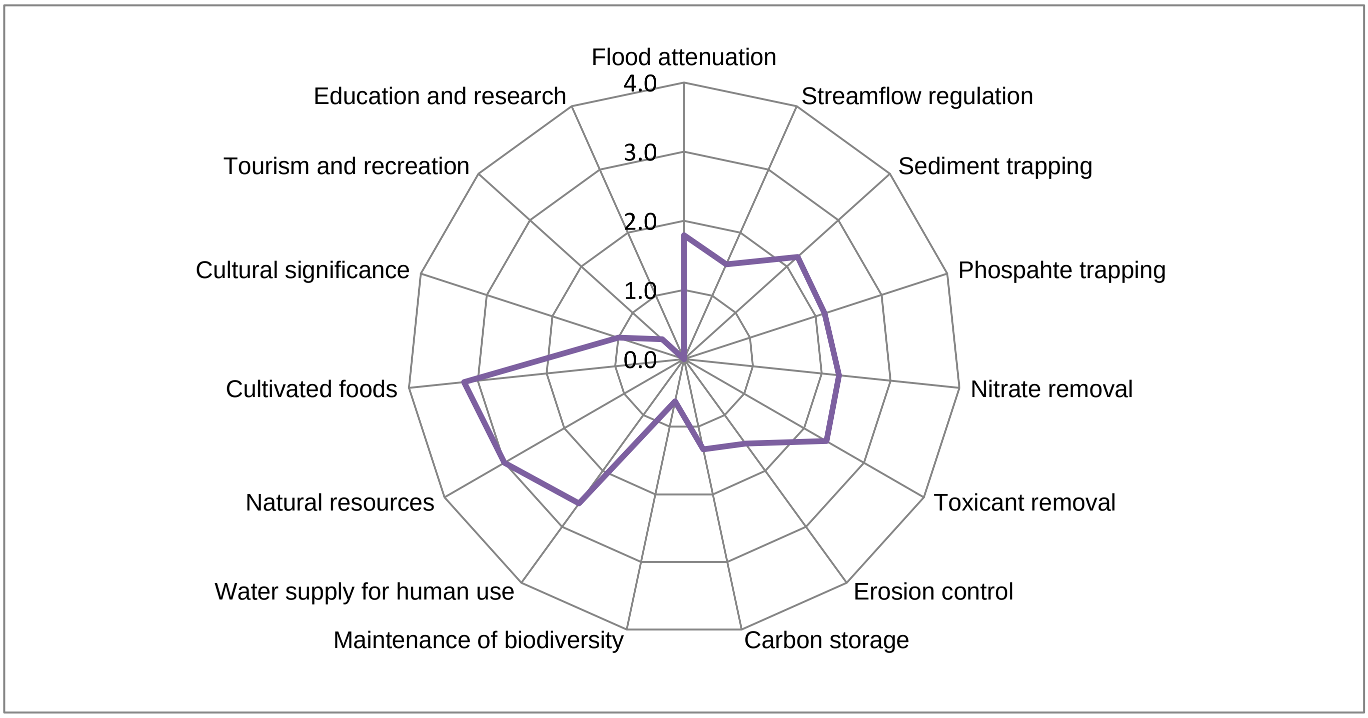
HGM 1



HGM 2



HGM 3



HGM 4

Figure 4.11. Ecological Services Provided by HGM units

Ecological services refer to the goods and services provided by each HGM in a wetland system. The services provided by each HGM are significantly influenced by the condition of the HGM, thus some services may be poorly provided, whereas provision of other services may be more substantial. As environmental conditions also change from each HGM, the services and the extent to which they are provided may also differ.
The services analysed include:

- Flood attenuation.
- Streamflow regulation.
- Sediment trapping.
- Phosphate trapping.
- Nitrate removal.
- Toxicant removal.
- Erosion control.
- Carbon storage.
- Maintenance of biodiversity.
- Water supply for human use.
- Natural resources.
- Cultivated foods.
- Cultural significance.
- Tourism and recreation.
- Education and research.

The provision of each service, within each HGM unit is depicted in Figure 4.11 above, furthermore these scores are displayed in Table 8.4 of the appendix.

From Figure 4.11 above, it can be deduced that the most significant ecological services provided by HGM 1 are the provision of natural resources (3), cultivated foods (3), toxicant removal (2.8), sediment trapping (2.7) and water supply for human use (2.7). Conversely, the ecological services which are less significantly provided by HGM 1 include; education and research (0.8), maintenance of biodiversity (0.9) and tourism and recreation (1.0).

The provision of ecological services of HGM 2 can be seen to be relatively similar to that of HGM 1. Services largely provided by HGM 2 similarly consist of the provision of natural resources (2.8), cultivated foods (2.8), sediment trapping (2.4) water supply for human use (2.4), and toxicant removal (2.3). Services which are poorly provided include; education and research (0.3), tourism and recreation (0.4), and maintenance of biodiversity (0.9).

The ecological services greatly provided by HGM 3 can be seen as; cultivated foods (2.4), stream flow regulation (2.2), natural resources (2.2), and toxicant removal (2.1). Whereas the significance of services such as, tourism and recreation (0.4), education and research (0.5) and, cultural significance (1.0), are reduced.

The ecological services of cultivated foods (3.2), natural resources (3.0) and water supply for human use (2.6), are the most significant ecological services provided in HGM 4. The least significant services provided by this HGM consists of; education and research (0- it is not provided at all), tourism and recreation (0.4) and maintenance of biodiversity (0.6).

It can be concluded that all HGM's have a great importance in the provision of cultivated foods and natural resources, however all HGM's contribute to a poor provision of education and research, tourism and recreation as well as maintenance of biodiversity.
Figure 4.12 below shows a comparison of the extent to which each ecological service is provided within each HGM.

Flood attenuation can be seen to be highest in HGM 1, and the lowest in HGM 2. Streamflow regulation, erosion control, carbon storage, maintenance of biodiversity and cultural significance all have a similar trend. HGM 1 and HGM 2 have the same values, HGM 3 is seen to have the highest score, whereas HGM 4 comprises of the lower scores. This trend is applicable for all five of the previously mentioned services, except for streamflow regulation and cultural significance where HGM 1 and 2 are the highest scoring units.

The ecological services of sediment trapping, phosphate trapping, toxicant removal and water supply for human use are all seen to have the highest scores in HGM 1, and the lowest scores in HGM 3. Additionally, nitrate removal has the highest score in HGM 1 and the lowest score in HGM 3, however it is established that along with HGM 1, HGM 4 is also the highest scoring unit with the same score as HGM 1.

Provision of tourism and recreation and education and research are the lowest scoring services throughout all HGM's, however HGM 1 is the highest scoring in both these services. The provision of cultivated foods is the highest scoring service throughout all the HGM's, particularly in HGM 4, which holds the highest score of this service.

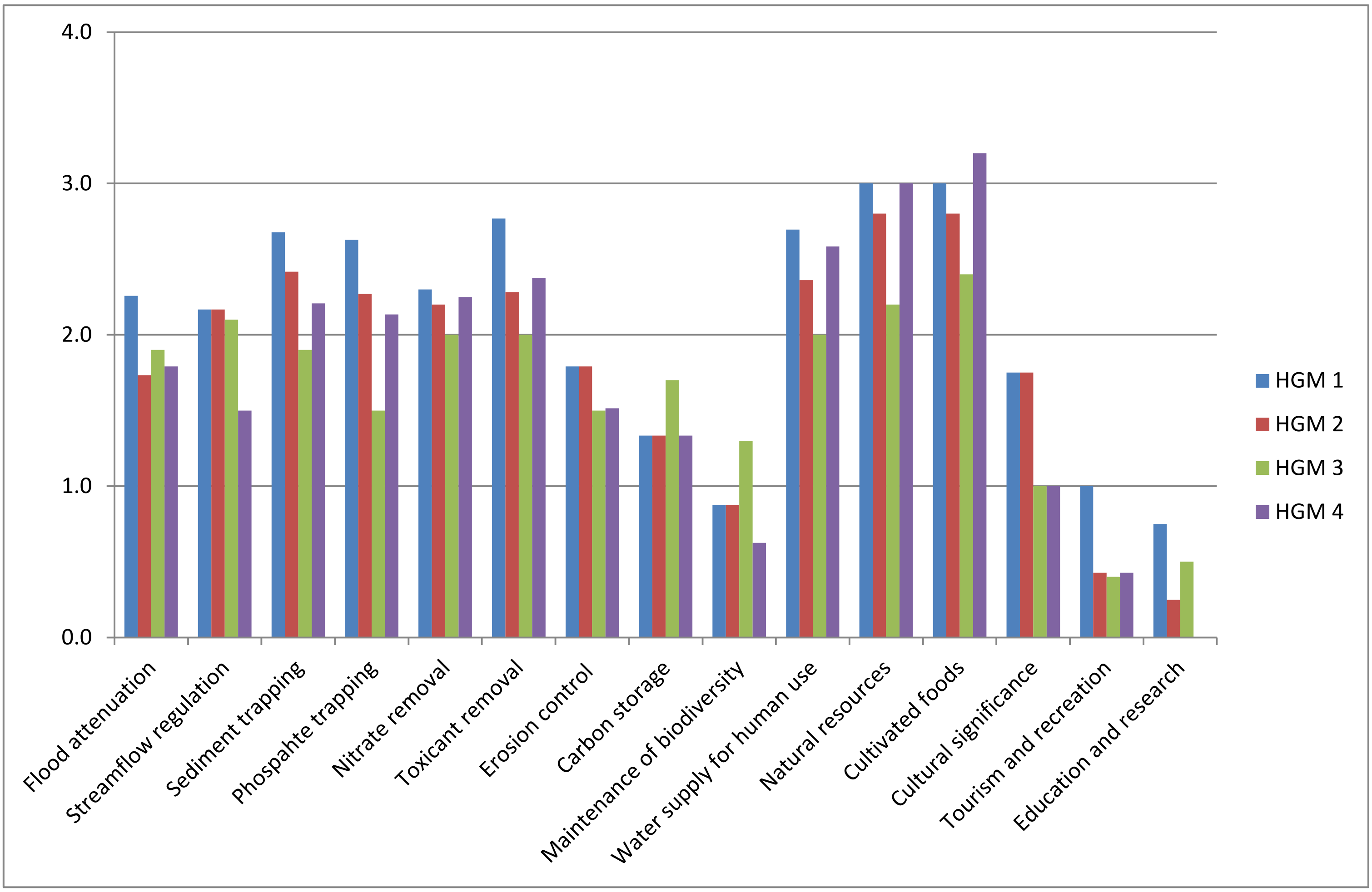


Figure 4.12. Comparisons of Ecological Services Provided in HGM's 1, 2, 3 and 4

4.7 FUNCTIONAL HEALTH

4.7.1 Hydrology

The hydrological health of a HGM unit refers to alterations in the movement and distribution of water through a wetland and its soils which occurs due to changes in activities within the catchment, and other modifications occurring in a wetland HGM that may alter the patterns of water distribution and retention within the wetland.

Table 4.2 below, displays the overall hydrological health of HGM 1, HGM 2, HGM 3 and HGM 4, in terms of PES scores and subsequent categories ranging from A-F (Table 3.2 of Chapter 3).

Table 4.2. Hydrological Health

HGM UNIT	AREA (Ha)	PES SCORE	PES CATEGORY	TRAJECTORY OF CHANGE
1	5.63	4.7	D	↓
2	0.3	4.5	D	↓
3	0.3	3.5	C	→
4	0.56	5.0	E	↓
OVERALL	**6.79**	**4.7**	**D**	↓↓

From the hydrology table above, the hydrological PES scores for each HGM can be deduced, as well as the PES category, and trajectory of change (whether a system is degrading ↓, stable →, or improving ↑).

HGM unit 1 and 2 has PES category D, which refers to a system where the consequence of modifications are clearly detrimental to the integrity of the hydrological regime, to the extent of which 50% of the hydrological integrity has been lost. The trajectory of change for each of these HGM's is a downward trajectory, suggesting the continued slight degradation of these HGM's over the next five years.

HGM unit 3 has a PES category C. A category C unit refers to a unit in which the impact of the modifications on the integrity of the hydrological regime is limited, but still clearly identifiable. The trajectory of change for HGM 3 is stable, signifying that the system, in terms of hydrology, should remain the stable over the next five years.

As seen in the table above, HGM unit 4 has a PES category of E. Category E refers to a system in which the impacts of the modifications clearly have a detrimental effect on the integrity of the hydrological regime, where 51%-79% of the hydrological regime has been diminished. The trajectory of change for HGM 4 is a downward trajectory, thus symbolising that the system is likely to slowly degrade over the next five years.

The overall hydrological health has a PES category D, similar to that of HGM 1, 2 and 4, where approximately 50% of the overall hydrological integrity has been lost. Furthermore this wetland system has a double downward trajectory of change, suggesting that the hydrological health will rapidly deteriorate over the next five years.

4.7.2 Geomorphology

The geomorphic health of a HGM unit refers to the distribution and retention patterns of sediment within a wetland. The geomorphic health of a HGM unit is influenced by excessive sediment inputs and/or losses of organic and mineralogical sediment.

Table 4.3 below, displays the overall geomorphic health of HGM 1, HGM 2, HGM 3 and HGM 4, in terms of PES scores and subsequent categories ranging from A-F.

Table 4.3. Geomorphological Health

HGM UNIT	AREA (Ha)	PES SCORE	PES CATEGORY	TRAJECTORY OF CHANGE
1	5.63	2.6	C	↓
2	0.3	2.3	C	↓
3	0.3	1.9	B	↓
4	0.56	2.4	C	↓
OVERALL	**6.79**	**2.5**	**C**	↓

HGM 1, 2 and 4 all are in a PES category of C. Category C, pertaining to geomorphic health, refers to units which are moderately modified, where a moderate change in geomorphic processes has occurred, but the units remain generally intact.

HGM 3 is in a B PES category. A category B refers to a system which has a few modifications, but remains largely natural, a slight change in geomorphic processes is noticed but the unit remains predominantly intact.

All of the HGM's have a downward trajectory of change, thus signifying that all the HGM's will be subjected to slight deterioration over the next five years.

The overall geomorphic health is in a C PES category, with a downward trajectory of change. Therefore this system as a whole can be said to be moderately modified, with regards to geomorphology, and is expected to diminish slightly over the next five years.

4.7.3 Vegetation

The vegetal health of an HGM refers to the composition and structure of the vegetation within a HGM unit and is influenced by the impacts of historic and current transformations and disturbances on site.

Table 4.4 below, displays the overall geomorphic health of HGM 1, HGM 2, HGM 3 and HGM 4, in terms of PES scores and subsequent categories ranging from A-F.

Table 4.4. Vegetation Health

HGM UNIT	AREA (Ha)	PES SCORE	PES CATEGORY	TRAJECTORY OF CHANGE
1	5.63	6.2	E	↓
2	0.3	5.0	D	↓
3	0.3	4.6	D	↓
4	0.56	5.6	D	↓
OVERALL	**6.79**	**6.0**	**E**	↓↓

HGM 1 is in an E PES category. This category refers to a HGM unit in which the composition of vegetation has been greatly modified, however some characteristic species do still remain, although the vegetation consists mainly of alien and/or introduces species. Additionally, HGM 1 has a downward trajectory of change, suggesting a slight degradation of the unit occurring over the next five years.

HGM's 2, 3 and 4 fall within a D PES category. A D PES category refers to HGM units in which the vegetation composition has been largely altered, and where alien species occur approximately as much as indigenous wetland vegetation. Similar to that of HGM 1, all of these HGM's furthermore have a downward trajectory of change, thus a slight degradation of theses HGM units may occur over the next five years.

The overall vegetation PES score for this HGM unit in the E PES category, with a double downward trajectory of change. As a result, this system can be assumed to be one where the vegetation has been substantially altered and will continue to degrade rapidly over the next five years.

4.7.4 Overall Health Status

The below results were obtained by using the PES scores of each HGM's hydrological, geomorphological and vegetation health (Tables 4.2- 4.4).

Table 4.5. Overall Health Status of the Melville Wetland and Hectare Equivalence

HGM UNIT	AREA (Ha)	OVERALL PES SCORE	PES CATEGORY	HEALTHY WETLAND (Ha)	LOSS OF WETLAND (Ha) (Hectare Equivalence)
1	5.63	4.5	D	2.475	3.155
2	0.3	4.0	D	0.180	0.120
3	0.3	3.4	C	0.198	0.102
4	0.56	4.4	D	0.314	0.246
TOTAL	**6.79**			**3.17**	**3.62**

It was thereby established that HGM unit 1 is in a PES category of D. Additionally, the amount of healthy wetland in HGM 1 was calculated to be 2.475 Ha, making the total loss of wetland 3.155 Ha. HGM unit 2 is in a D PES category. The total loss of wetland in HGM unit 2 is 0.120 Ha, thus leaving the total amount of healthy wetland at 0.18 Ha. The PES category of HGM 3 was derived as a C (making it the healthiest of all of the HGM units). The total loss of healthy wetland was recorded as 0.102 Ha, with the amount of healthy wetland remaining at 0.198 Ha. Lastly, HGM 4 was found to be in a D PES category. The amount of health wetland remaining in HGM 4 was calculated to be 0.314 out of a total 0.56 Ha, hence making the total loss of wetland 0.246 Ha.

Therefore the total cumulative loss of wetland in the Melville area was calculated to be a total of 3.62 Ha, leaving only 3.17 Ha of healthy wetland.

4.8 INDEX of HABITAT INTEGRITY OF RIVER RIPARIAN AREA

Table 4.6. PES for River Riparian Area

	PES SCORE	PES CATEGORY
DRIVING PROCESSES		
Hydrology	2.0	C/D
Geomorphology	2.0	C/D
Water Quality	2.3	C/D
WETLAND LAND USE		
Vegetation	1.4	C
OVERALL %	**68.7**	**C**

Table 4.6 is a depiction of the individual PES scores and category for hydrology, geomorphology, water quality and vegetation, as well as the overall PES scores and category for the entire river riparian system.

The hydrology and geomorphology for this region was calculated to be in a C/D PES category. The water quality of this region is in a PES category of C/D. Furthermore, the vegetation of this region is in a PES category of C.

Therefore, the overall PES percentage of the river riparian area is 68.7%, which puts in an overall C PES category. As a result the river riparian area can be concluded as being a region which is moderately modified with regards to its vegetation, geomorphology, hydrology and water quality.

4.9 WATER CHEMISTRY

The table below is a depiction of the average quantities of dissolved oxygen (D.O), total dissolved solids (TDS), pH, conductivity, salinity, phosphates and nitrates, present in the points displayed in Figure 3.3.

Table 4.7. Water Quality Results

PARAMETERS	SITE 1	SITE 2	SITE 3	SITE 4
D.O (%)	53	50	42	47
TDS (mg/L)	535.0	616.0	240.6	217.3
pH	7.5	7.4	6.9	7.2
CONDUCTIVITY (micro-siemens/cm)	1245.0	1344.3	560.0	505.6
SALINITY	0.4	0.5	0	0
PHOSPHATES (ppm)	0.38	0.04	0.07	0.01
NITRATES (ppm)	5.79	2.5	5.38	3.32

The above water quality results for the Melville wetland region were obtained and compared to the water quality standards as per the South African Water Guidelines for aquatic systems (1996).

Utilising these guidelines, it was established that the D.O concentrations in all four sites falls within the sub lethal category which is when there is > 60% D.O present. The standard for TDS was seen to fall within the range of 200-1100mg/L, as the samples taken at sites 1, 2, 3 and 4 were between 217.3mg/L (site 4) and 616.0mg/L (site 2). The standard pH for aquatic systems in South Africa is considered to be between 6-8, the pH of all four sites are therefore seen to be within this standard, ranging from 6.9 (site 3) to 7.5 (site 1). Electrical conductivity is known to have a strong correlation with TDS, which is further compounded by the results displayed above. It can be seen that the electrical conductivity increases with an increase in the amount of TDS present. Within all four sites the salinity values are 0.4, 0.5. 0 and 0, thereby falling within the standard for aquatic systems. Phosphate values within all four sites places within the standard of <5, indicative of oligotrophic conditions. Nitrate values of 2.5-5.79 ppm within all four sites all place within the 2.5-10 ppm standard, portraying eutrophic conditions.

4.10 CONCLUSION

The above results displayed in chapter 4 have concluded the types of HGM units present within the Melville system, the hydrological zones as well as the ecological, functional and water health of the system.

These results are explained and discussed further in Chapter 5.

CHAPTER 5

5. DISCUSSION

5.1 INTRODUCTION

In this chapter, discussion pertaining to the results portrayed in Chapter 4 is presented. This chapter offers an explanation of the classification of the permanent, seasonal and temporary zones within the Melville wetland system based on the soil and vegetation profiles observed. Additionally the vulnerability of the wetland system is explained, as well as reasoning of the extent to which the ecological services are provided and the functional health status of the wetland. The health of the river riparian area is also discussed, in terms of the IHI tool. This section is finally concludes with an explanation of the water chemistry results obtained.

5.2 CLASSIFICATION OF HYDROLOGICAL ZONES

Different hydrological zones of wetlands (permanent, seasonal and temporary zones) are generally classified according to the duration to which they are submerged by water. Permanent zones are permanently submerged, whereas seasonal zones are saturated for a minimum of three months per annum, with temporary zones being inundated by water for a period of less than three month per annum. These zones are often separated by different soil and vegetation profiles, which display different characteristics within the different zones.

5.2.1 Soil Profiles

Sizes of sediment grains are greatly dependent on factors such as parent material (the rock from which he grains were weathered), weathering history, the transport processes (wind or water), and the environment in which deposition occurs (high or low energy, in this case, low energy wetland environments).

Sediments found in wetlands can either be allochthonous which are generally mineral in nature, or autochthonous, which are mainly organic sediments. In the case of wetlands, such as the Melville wetland, allochthonous sediments are received from surrounding rivers and erosional activities whereas autochthonous sediment are derived from reducing activities, and the decomposing of plant roots and organisms.

Allochthonous sediments received by the Melville wetland, originate from minor seasonal streams originating from upslope areas, and transitions from a high to a low energy system. In the upper catchment, water flows at a high velocity due to the steep gradient. As a result of the high flow velocity, this system has immense energy and is therefore able to transport heavier sediments of large sizes. Gravel size particles are dragged through the river bed as bed load, and smaller particles are transported in suspension. As the water flows further down, the slope becomes less steep, thus reducing the flow velocity and in turn reducing the energy of the system as well as its ability to transport the larger sediments. Some of the larger sediments therefore get deposited in this region and smaller sediments, which the river is able to transport, are transported further downstream. By the time the river system meets the wetland, the energy has diminished to the point where only silt and clay sized sediment grains are able to be transported into the wetland. Wetlands are extremely low energy systems, and as a result, once the silt and clay particles arrive in the wetland majority of the grains sink to the bed of the wetland or are trapped by the roots of hydrophytes inhabiting the wetland.

Autochthonous sediments forming the Melville wetland are derived from the reducing activities occurring in the permanent zone of the wetland. These anaerobic conditions present, caused by constant saturation, accelerate the decomposition process of plant roots, and dead organisms, found within the wetland, thus forming dark, loamy soils, rich in O.M. Furthermore, erosion causing activities occurring in close proximity to the wetland can result in coarser sediments being deposited into the wetland during periods of heavy rain.

Site C, located 29°22'35.94"S and 31°15'22.47"E (see Figure 4.4), can therefore be established as the permanent zone due to the high amounts of silt and clay present as well as the high O.M content. The high amount of gravel present in this zone can be attributed to the abundance of erosion inducing activities (as noticed during site visits) and its subsequent deposition into the wetland during periods of high rainfall. Furthermore, the high Calcium Carbonate content is reflective of the amount of decomposing matter in the wetland, as there is a high amount of O.M in the permanent zone there is therefore a higher rate of decomposition

Site B, located 29°22'36.35"S and 31°15'22.66"E (see Figure 4.4), can be deduced as being a seasonal zone, as it also has a significant amount of silt and clay sediments, and a relatively high O.M content, but is less than Site C. This occurs due to periods of flooding causing this area to be submerged and in turn silt and clay sediments are gradually deposited in this zone. As a result of this area only being seasonally flooded, the water table is lowered, however still allowing anaerobic conditions occur, which leads to the decaying of O.M within the soil, and a decrease in the levels of Calcium Carbonate.

Site A, located 29°22'36.78"S and 31°15'22.47"E (see Figure 4.4), presents characteristics typical of a temporary zone. This area has a significantly lesser amounts of silt and clay and is dominated by coarser sediments such as sand sized grains. This is as a result of this area being predominantly characterised by the surrounding terrestrial sediments which are deposited in this zone. This zone furthermore has a low O.M relative to sites C and B due to there being only a small amount of plants and organisms inhabiting this region thus in turn leading to a lowered C.C content due to aerobic conditions becoming more prevalent in this zone due to the lack of submersion.

The delineation of the hydrological zones was further compounded by the characteristics of the soil profiles taken. The presence of mottles, the matrix value and matrix chroma are significant indictors of hydrological zonation.

Mottles are contained mostly within the matrix of a soil profile and are recognised as soft structures that are of an irregular shape and bright colours (usually orange, red or yellow). Mottling occurs due to the alternating of wetting and drying of the soil, and appears when the soil is exposed to air during dry periods allowing for the oxidation of metals, such as iron, to take place (Collins, 2005). It can therefore be understood that the permanent zone of a wetland would have little to no mottling as these soils are constantly submerged, therefore oxidation of these metals will not take place. However, due to a variations in the water table level, the uppermost layer of the soil may become exposed to the atmosphere thereby developing a few mottles. Conversely, the seasonal zone should have an abundance of mottles present due to a significant variation in the wetting and drying periods, allowing for oxidation of these metals to take place and thus the formation of mottles. Similar to the permanent zone, the temporary zone of a wetland would have little to no mottles present within the soil profile as these soils are very rarely wet long enough for the formation of mottles to occur.

The matrix and chroma values are correlated to the leaching of Fe-Mn oxides in the soil under saturated conditions, giving the soil a ‘greyish’ appearance. The more often a soil is subjected to saturation, the lower the chroma and matrix values will be, therefore as one moves from the temporary to the seasonal and then to the permanent zone of a wetland, the matrix values and chroma are expected to decrease (Verpraskas, 1995).

5.3 VULNERABILITY

Erosion activities within wetlands are one of the most significant causes of wetland degradation in South Africa. Therefore, when establishing the vulnerability of a wetland, headcut erosion is considered to be the underlying factor. The more prone a wetland is to headcut erosion, the more vulnerable it becomes.

One of the predominant factors influencing headcut erosion is the slope, as the steeper a slope, the more significant the erosion. Vulnerability of a wetland is thereby an essence of the relationship between the longitudinal slope and the area of a wetland.

A score of 0 for vulnerability proposes that no change is likely to occur. A vulnerability score of 2 or 5 suggests that change may occur slowly, but will eventually dissipate. A score of 8 or 10 indicates that headcut erosion will advance rapidly and cause substantial deterioration.

5.4 ECOLOGICAL SERVICES

Ecological services consist of the benefits provided to the surrounding ecosystems and people, by wetlands. Thus, ecological services can be said to be divided into environmental and socio economic benefits.

The ecological services provided can be affected negatively or positively by direct or indirect impacts. “These benefits may derive from outputs that can be consumed directly, indirect uses which arise from the functions or attributes occurring within the ecosystem, or possible future direct outputs or indirect uses" (Howe et al, 1991). These impacts on a wetland therefore relate to the extent and efficiency of the services provided by a wetland.

The ecological services and the extent to which they are provided by the Melville wetland were analysed in Chapter 5; the reasoning for such provision of services are as follows.

5.4.1 Flood Attenuation

Flood attenuation refers to the dispersion and impediment of flood waters, as a result decreasing the severity of floods downstream and consequently the potential damage it may cause. The ability of a wetland to attenuate floods are affected by the following factors:

- Size of the HGM unit relative to its catchment.

The greater in size the individual HGM is in relation to its catchment, the larger its influence will be on flood waters (Kotze et al, 2007). Therefore HGM 1 is seen to have the highest capabilities to attenuate floods relative to HGM's 2, 3 and 4.

- Slope of the HGM unit

The steeper the slope of individual HGM's, the greater the speed of water moving downslope. The gentler a slope is the greater the ability of individual HGM's to attenuate the flow of water (Kotze et al, 2007).

HGM 1 therefore has the greatest ability to attenuate score, due to it gentle slope of 0.6%. HGM 4 has one of the lowest scores for the attenuation of floods, relative to the other HGM's due to it have the steepest slope of 5.2%. However, HGM 2 has the lowest ability of flood attenuation, despite having a gentler slope than HGM 4. This can be attributed to the drastic modification of this region encompassing HGM 2, as well as agricultural activity occurring here. The removal of natural vegetation for agricultural and infrastructure development purposes leads to the increase in smooth surfaces, therefore when rainwaters hit the ground there is no form of friction to slow down the water before entering the HGM unit, hence reducing its ability to attenuate floods.

- Surface Roughness

The greater the surface roughness of a wetland, the greater the frictional resistance is to the water flow and thus the more efficient the wetland becomes in attenuating floods (Adamus et al, 2001). Surface roughness of wetlands is predominantly determined by vegetation, however hummocks; which are small, vegetation covered earth mounds, may also significantly contribute.

Vegetation coverage in HGM 1 is the highest in comparison to HGM 2, 3 and 4, and as a result has the greatest ability of attenuating floods, as there is a significant resistance to flows of water. HGM's 2, 3 and 4 are all surrounded by housing, which have subsequently encroached right on to the wetland, thus decreasing the resistance on water flows. Furthermore, agricultural activities are predominant in these HGM's, mainly in HGM's 2 and 4, the removal of natural vegetation for the growing of crops further decreases the surface roughness and the ability of a wetland to attenuate floods. HGM 2 is the least effective in attenuating floods, which can be attributed to the large alterations in surface roughness, such as the above mentioned housing encroachment, and removal of natural vegetation, as well as the development of a road which has subsequently divided the HGM into two, and the formation of a large concrete drain.

- Presence of Depressions

Depressions, dependant on their extent and depth, have the ability to significantly increase the confinement storage capacity of a wetland. However, depressions that stay filled to the near maximum capacity during the entire year are not likely to retain flood water (Kotze et al, 2007).

There were no depressions present in any of the HGM units, and therefore this factor was not applicable in the Melville wetlands ability to attenuate floods.

- Frequency with which Storm Flows are spread across the HGM unit

The more often storm flows surpass the capacity of a channel or channels passing through a HGM and are dispersed through a HGM, the greater the ability of an HGM to attenuate floods. Contrarily, the greater the extent to which storm flows are confined within a channel or channels passing through a HGM unit, the lower the HGMs effectiveness is in attenuating floods.

HGM 1 being an unchannelled valley bottom, therefore has a high frequency of storm flows being spread across the HGM, hence a higher ability for attenuating floods. HGM 2,3 and 4 are channelled valley bottom HGMs, and therefore spreading of storm flows throughout the HGM unit is less frequent, and thus a lesser affinity to flood attenuation.

- Sinuosity of the Stream Channel

For a given longitudinal slope of a HGM unit, the more sinuous a stream channel is, the more gentle the slope, and as a result the slower the flow of water into the wetland will be.
HGM 1 being an unchannelled valley bottom type, has no channel, however despite not having a channel, HGM 1 has a very gentle slope, thus aiding its ability to attenuate floods. HGM 2, 3 and 4, have low channel sinuosity throughout the unit, this coupled with the slope of each HGM, results in their ability to attenuate floods.

- Hydrological Zonation

If a wetland is already inundated with water immediately before a flooding event, its ability to attenuate these flows and in turn impede the flood peak would be lower than if the wetland were in a dry state. As a result, HGM units which are dominated by areas that continue to stay wet for most of the rainy periods (namely the permanent and seasonal zones), are more likely to be in a wet state upon the arrival of flooding events, as compared to a HGM in which the temporary zone dominates (McCartney et al, 1998).

From analysis of sediment and vegetation profiles (Chapter 4) it was deduced that HGM 1 comprised of a large permanent zone, with two small seasonal zones and one temporary zone. HGM’s 2, 3 and 4 comprised only of a permanent zone. This was as a result of houses being developed on top of the seasonal and temporary zones in all of the HGM’s. As a result this has caused a permanently wet zone to be prevalent, thus reducing the effectiveness of these HGM’s to attenuate floods.

- Slope of the Catchment

Similar to the effect of the HGM slope on flood attenuation, the steeper the slope the faster the speed of the runoff, the greater the runoff intensity, and thus the greater the potential for the occurrence of floods (Kotze et al, 2007).

The slope of the Melville wetlands catchment was calculated to be less than 3%. Due to the gentle slope of the catchment runoff is expected to travel slowly down into the HGM's, somewhat aiding in their ability to attenuate floods.

- Inherent Runoff Potential of Soils

The greater the runoff potential of soils in a HGM unit, the greater the amount of water that is runoff into the wetland; the less the runoff potential is, the greater the rate of infiltration, and the less water that is runoff into the wetland, thus aiding in flood attenuation (Schulze et al, 1989).

HGM 1 and HGM 3 were found to have a moderately high runoff potential which consisted of low infiltration rates, where permeability is restricted by layers which act to impede the downward movement of water. HGM 2 and HGM 4 were found to have a high runoff potential which consisted of very slow infiltration and permeability rates.

- The contribution of Catchment Land Uses to Changing Runoff Intensity from the Natural Condition

The various activities taking place on land within the catchment area have a significant influence on the intensity of runoff (Schulze et al, 1989).

Three main land use activities may act to increase the intensity of runoff:

1. Poor conservation practices in agricultural lands. Activities such as improper tillage practices, contour banks and soil compaction increase the rate of runoff and consequently decrease the rate of infiltration, in turn increasing the intensity of run off (Schulze, 1989).

2. Poor veld condition increases runoff intensity and decreases infiltration as compared to land where natural vegetation is prominent (Schulze, 1989).
3. Hardened surfaces in the catchment such as the presence of roads, buildings, footpaths etc. The greater the presence of hardened surfaces, the less area available for infiltration to take place, thus the greater the intensity of runoff (Neal, 1998).

Factors which may aid in decreasing the intensity of run off include dams and flood retention basins, particularly if they remain at low levels for extended periods of time (Neal, 1998).
All of the HGM's are subjected to poor conservation practices, poor veld conditions and the presence of hardened surfaces, which therefore diminishes their ability to attenuate floods, and furthermore there is a uniform absence of dams throughout.

Although all HGM's are affected by these increasing intensity factors, they are each subjected to these factors at different intensities. HGM 2 is severely impacted in this regard due to poor conservation practices, poor veld conditions and more prominently, the presence of hardened surfaces which dominate in this region. As in this HGM natural vegetation had been removed for both cultivation and infrastructure purposes. Houses have been built in hydrological zones of the wetland (similar to HGM 1, 3 and 4), and further more a road has been built across the HGM. In HGM 1, 3 and 4 there has been removal of natural vegetation, to varying degrees, for cultivation purposes as well as for the building of houses. Additionally, in these HGM's there are presence of dirt roads and dumping sites, increasing the exposure of hardened surfaces.

- Rainfall Intensity

Rainfall causes the occurrence of storm flows, with the amount of rainfall experienced being less important than the actual intensity of the rainfall event. Rainfall zones across South Africa have been demarcated into four zones with Zone I having the lowest intensity and Zone IV having the highest intensity (Kotze, 2007).
The KwaDukuza area falls into zone IV, therefore highlighting this area as a high rainfall intensity region. As a result this aids in diminishing the HGM's ability to attenuate floods.

- Extent of Floodable Infrastructure Downstream of the HGM unit

The greater the extent of floodable infrastructure downstream of the HGM, the greater its value will be in attenuating floods.

HGM 3 and HGM 4 have a large extent of infrastructure downstream, which therefore increases their value for attenuating floods. HGM 1 and HGM 3 are in close proximity to a primary school which is known to experience floods in certain events, thus increasing their value for attenuating floods.

5.4.2 Stream Flow Regulation

The regulation of stream flow refers to the assisting of a wetland on flows downstream during periods of low flow. It is known that wetlands do not generate water as they are recognised as being users of water through transpiration and evaporation. As a result, this limits a wetlands ability to contribute to the stream flow during periods of low flows, however wetlands are recognised as being a component of catchment processes and could, in some cases, be positioned in a way that allows them to regulate the movement of water through the catchment, especially when they are located in regions where the subsurface water is being discharged onto the surface (Kotze et al, 2007).

Factors influencing a wetlands ability to regulate stream flows are explained below.

- Link to the Stream Network

If a HGM is isolated from the stream system, then the HGM would be negligible in terms of contribution of water to the stream system (Marneweck and Bachelor, 2002).

HGM 1, 2 and 3 are intermediately connected to stream systems and are therefore able to contribute water during periods of low flow and regulate stream flow to an intermediate level. HGM 4 has a connection to the stream network which is moderately low and therefore is less significantly able to contribute water during low flow periods and thus less effective in stream flow regulation.

- Hydrological Zonation of a HGM unit

The hydrological zonation of a HGM acts as a good indicator of the ability of a HGM to release water into the stream system. A HGM which is permanently wet for extensive periods of time, would have a greater ability to release water into the stream network, as compared to a HGM which remains seasonally, or temporarily wet, given that this HGM is connected to a stream network (Marneweck, 2003).

All HGM's are permanently wet and therefore are able to disperse water into the stream network. As they are connected to the stream network to varying degrees, this influences the extent to which they are able to contribute water to the stream network.

- Geology Underlying the Wetlands Catchment

The presence of groundwater discharge regions are likely to be abundant in geological provenances characterised by increased levels of interaction between surface and ground waters (Kotze et al, 2007).

It was established that sandstone underlies all HGM's, hence it can be established that there is a relatively strong interaction between the surface and ground waters which will allow HGM 1, 2, 3 and 4 to contribute to stream flow regulation.

- Presence of any Important Aquatic System Downstream

The presence of an important aquatic system downstream of a HGM makes the service of stream flow regulation more valuable.

It was established that the Mvoti River was downstream of all HGM's. The Mvoti River is regarded as an important aquatic system due to the multiple uses of the river and more so due to the amount of people reliant on this river for water for a multitude of purposes.

5.4.3 Sediment Trapping

Sediment trapping refers to the retention and trapping of sediment which is delivered to a HGM by runoff waters (Kotze et al, 2007). Factors affecting the ability of an HGM to trap sediment are as follows.

- Effectiveness in Attenuating Floods

The more the sediment-filled runoff water is slowed down, the more sediment will be deposited in the HGM from the runoff waters. Therefore, the greater the ability of a HGM to attenuate floods, the more effective a HGM is in trapping sediment (Kotze et al, 2007).

Due to sediment trapping being directly related to flood attenuation, the ability of the HGM's to trap sediment is correlated to that of flood attenuation. If a HGM has a high potential for attenuating floods, the HGM subsequently has a high potential to trap sediment.

- Direct Evidence of Sediment Deposition in the HGM unit

The direct evidence of sediment deposition within a HGM unit would suggest that there is trapping of sediment within that HGM.

In HGM 1 there was significant evidence of sediment deposition, as there was an abundance of sediment particles on crops growing in this area, as well as sediment deposits covering rubbish piles which had been accumulating over an extended period of time. Similarly, in HGM 2 there was evidence of sediment deposition found on either end of the HGM in the form of sediment covered crops. In HGM 3 and 4 less evidence was found, however there was some evidence of deposition around alien plants.

- Reduction in Sediment Inputs from the Catchment

The greater the presence of dams and other structures which act to hold back sediment that would otherwise be deposited in the HGM, the greater the ability of the HGM to trap sediment is reduced (Kotze et al, 2007).

Throughout the catchment there was no presence of dams, therefore making this factor negligible in the Melville wetland for the service of sediment trapping.

- Extent of Sources of Increased Sediment in the Catchment

The larger and more prominent the sources of sediment inputs in the HGM units catchment, and the closer its proximity to the HGM unit, the greater the supply of sediment to the HGM unit.

All HGM's have a great extent of sediment sources in close proximity to the HGM. The presence of dirt roads and cultivated lands all act to supply sediment directly into the HGM unit, thus increasing its ability to trap sediment. Furthermore, HGM 2 has a large road dissecting it, which contributes a significant amount of sediment into this HGM, enhancing its ability to trap sediment.

5.4.4 Phosphate Trapping, Nitrate Removal and Toxicant Removal

5.4.5 Carbon Storage

The storage of carbon refers to the trapping of carbon, thereby acting as a carbon sink. It is recognised that the decomposition of organic matter is slowed down in wetlands, due to waterlogged conditions, therefore wetlands are known to have a high capacity for storing organic carbon (Roulet, 2000). The parameters concerning a HGMs ability to store carbon is explained below.

- Hydrological Zonation

A waterlogged condition encourages the building up of organic matter by slowing down the decomposition process. Therefore, a HGM subjected to the longest wet periods will potentially have the highest amounts of organic matter (Tiner and Veneman, 1988).
Thus all HGM's will have a great potential to store carbon as all HGM's of the Melville wetland consist primarily of permanent zones, which experience waterlogged conditions.

- Abundance of Peat

Peat is soil material that is predominantly made up of organic matter. Therefore, it can be deduced that the greater the amount of peat in a HGM, the greater the HGMs contribution would be to trap carbon (Joosten and Clarke, 2002).

Throughout all HGMs there was no peat found, therefore this served in reducing the HGM unit's ability to store carbon.

- Disturbance of the Soil

The disturbance of soil leads to the exposure of fresh soil to the atmosphere. This exposure leads to the depletion of organic matter and thereby reducing the amount of carbon stored by a HGM unit (Miles and Manson, 1992).

The disturbance of soil in all HGMs was established to be high in all HGM units (more so in certain HGM's than compared to others), due to agricultural activities throughout as well as the development of roads, houses and other infrastructures.

5.4.6 Maintenance of Biodiversity

Wetlands contribute to maintaining biodiversity by providing a habitat and by maintaining natural processes. The capability of a HGM to provide this service relies significantly on its integrity and specific attributes of the HGM such as the occurrence of red data species.

The following factors explained below, impact a HGM units capability to maintain biodiversity.

- Threatened or Rare Wetland Type and Cumulative Loss

The more threatened, or increased rarity of a wetland, the more important a wetland becomes in maintain biodiversity, as these types of wetlands usually consist of rare flora and fauna or species which are endemic to this region. Additionally, the loss of wetlands increases the importance of HGM units (Muchina and Rutherford, 2006).

HGM's 1, 2, 3 and 4 were not considered as a rare wetland type. However, these HGM units are considered to be threatened due to the degradation of these systems, these conditions are therefore less favourable for maintaining biodiversity. However, a large quantity of wetland has been lost and thus increases their value to maintain the biodiversity that they do provide a habitat for.

- Red Data Species

Red data species refer to those species that have been recognised as having a particular significance. Thus, the more important a HGM is to red data species, the more valuable a HGM becomes in terms of maintaining biodiversity (Kotze et al, 2007).

All of the HGM's assessed were found to not provide a habitat for any red data species, and therefore their importance in this regard was negligible for maintaining biodiversity.

- Buffer Zone Surrounding the HGM

A buffer is a boarder of relatively natural vegetation around a wetland. Many wetland species require both the wetland habitat and this non-wetland area of the buffer zone. Therefore, if there is no buffer of natural vegetation present the ability of a HGM to maintain biodiversity will be diminished. (Kotze et al, 2007).
Throughout all of the HGM units it was found that houses were encroaching right onto the wetland zones, therefore it was evident that no buffer was present, diminishing the ability of HGMs to maintain biodiversity.

- Alteration of the Hydrological and Geomorphological Regime

Hydrology is recognised as the most dominant factor affecting the functioning on a wetland. Therefore, if the functioning of a HGM unit is altered, it will become unable to efficiently maintain biodiversity (Howe et al, 1991). The geomorphological regime affects the maintenance of biodiversity in numerous ways. If there is an excess of sediment, this modifies the substrate in which the plants normally grow, and potentially smothering the plants. If there is a reduction in sediment, this may cause a change in a wetlands system from being an accumulator of sediment to an exporter of sediment. If majority of sediment is exported this may lead to the erosional degradation on a wetland and impact negatively on the maintenance of biodiversity (Kotze et al, 2007).

The hydrology is negatively impacted to different extents in all four HGM units as seen in Chapter 5. The geomorphology is less drastically impacted, but has still been degraded to a significant extent. Evidence of excess sediment was present in all HGM's, furthermore diminishing the ability of all of the HGM's to substantially maintain biodiversity.

- Removal of Natural Vegetation and Presence of Alien Species

Natural vegetation encourages the assemblage of species supported by the wetland and furthermore they provide a habitat for other species, thereby the removal of natural vegetation will decrease its ability to maintain biodiversity. Additionally, the introduction of alien species has a detrimental effect on overall biodiversity. Alien plants have less soil binding and erosion controlling properties, causing a greater loss of soil. Alien plants are known to utilise more water through transpiration in comparison to indigenous plants, which leads to an alteration in the hydrological regime. Furthermore, the grazing value of alien plants is much less than indigenous vegetation, thus causing a reduction in species within the HGM.

Natural vegetation has been significantly removed in all HGM's due to cultivation purposes and the building of houses and roads. There has subsequently been an increase in the introduction of alien invasive species which are clearly visible in clusters throughout all of the HGM units. These two factors coupled together have decreased the ability of the HGM units to maintain biodiversity.

5.4.7 Provision of Water for Human Use

This refers to the extraction of water directly from the wetland for agricultural, domestic, industrial, and other purposes. This service is directly related to the regulation of stream flow as the greater the importance of a HGM unit for streamflow regulation, the greater the likelihood of this HGM unit to provide a consistent supply of water. Therefore, there is a clear relationship viewed between the HGM units ability to regulate the streamflow and the provision of water for human consumption. Due to the close proximity of the wetland to multiple houses (which are in a rural area), and the consistent supply of water in all of the HGM's, the number of households dependant on the wetland for water is high within all units.

5.4.8 Provision of Harvestable Resources and Cultivated Resources

Harvestable resources obtained from wetlands include sedges, reeds, wood, fish and edible plants. Additionally wetlands provide suitable land for agricultural activities and thus the yielding of cultivated resources. The importance of a HGM unit to provide such resources is dependent on the following.

- The number of Natural Resources Used

The total number of resources used in each HGM unit varied. HGM 1 and 4 had a lot of the above mentioned resources present and therefore a lot of these resources were used by the surrounding community members for the building of crafts and medicinal purposes. However, the abstraction and use of these natural resources were found to be limited in HGM units 2 and 3 as the presence of these resources were not as prevalent as compared to HGM units 1 and 4. However, agricultural activities were found to occur to different extents in all HGM units. Agricultural activity was found to be most dominant in HGM 4, with majority of the land transformed into agricultural land, HGM 1 was also found to significantly support agricultural activities.

- Location of the HGM unit in a Rural Area and Level of Poverty

The assumption made is that if a wetland is located in a rural area, and if the level of poverty is high, the heavier the reliance on the natural resources produced by wetland will be and the more subsistence agricultural activities will take place. All HGM's are located in a region of KwaDukuza that is primarily rural and majority of those who live there do not earn a steady, high paying salary and therefore live in a state of poverty, and are thus heavily reliant on the wetland for the provision of natural resources and cultivated crops, increasing the wetlands value in providing these services.

5.4.9 Cultural Significance

Some wetlands are recognised for having cultural significance. The cultural significance of wetlands is dependent on whether a wetland is registered by the South African Heritage Resources Agency, and the extent to which cultural practices take place within the wetland (Kotze et al, 2007).

The Melville wetland was found to not be registered as a heritage site and there was little evidence found of cultural activities taking place in each of the HGM unit., thereby limiting the cultural significance of the wetland.

5.4.10 Tourism, Recreation and Scenic Beauty

The Melville wetland is situated in KwaDukuza which is an area that is heavily reliant on tourism for economic growth. However the utilisation of this wetland for recreational and tourism purposes is limited due to its heavily degraded condition, which has consequently diminished its scenic beauty. In relation to recreational activities such as hunting and fishing, the maintenance biodiversity has been severely reduced, therefore limiting the use of this area for such recreational activities.

5.4.11 Education and Research

Wetlands comprise of both terrestrial and aquatic systems and could therefore be of significant value for research and education, especially if the wetland is easily accessible. HGM's 1 and 2 are relatively easily accessible HGM units, which would make it convenient for research to take place, however HGM's 3 and 4 are moderately to completely inaccessible making the task of research hard to take place. Additionally the danger factor makes carrying out research difficult to undertake. Data concerning the Melville wetland does not currently exist, therefore there is no source of comparison for research or for education about the wetland to take place.

5.5 Functional Health of the Wetland

The health of wetlands is defined as its deviation from its natural reference condition. In order to establish the health of a wetland the hydrological, geomorphological and vegetation regime must be evaluated, as these are the three predominant components comprising of a wetland environment.

5.5.1 Hydrology

Hydrology of a wetland refers to the movement and distribution of water through a HGM unit and its soils. The hydrology of a HGM unit can be modified through any alterations occurring within the HGM which act to change the pattern of water retention and distribution within the wetland. The Melville wetland was found to be in a largely modified state and the factors influencing the degradation of the hydrological regime are examined below.

One of the essential attributes of climate that affects a wetlands vulnerability to a change in the water inputs is the ratio of MAP: PET (mean annual precipitation: potential evapotranspiration). The lower the ratio, the lower the contribution of direct precipitation entering the wetland, thereby causing the hydrology of the wetland to become more dependent on water flows from the catchment upstream, and thus more vulnerable to reduced inflows. The Melville wetland falls into a catchment zone where the MAP:PET ratio is relatively low, thus making the hydrological regime of the wetland exceptionally vulnerable to a lack of inflows from the upper catchment regions.

Land uses known to have an immense impact on the hydrology of the Melville wetland includes: the presence of alien vegetation and, the abstraction of water for irrigation and other purposes. Within all four of the assessed HGM units it was confirmed that the presence of alien vegetation was prevalent throughout, with their occurrence being more evident in some HGM's that others. Alien vegetation has a negative impact on hydrology due to their ability to take up large quantities of water, and thus have a large impact in excessively depleting water sources. As all of the HGM's support agricultural activities the hydrology is further depleted due to the removal of water for irrigating crops. Furthermore, agricultural practices occur throughout the year and irrigation practices are poor, thereby increasing the negative impact on the hydrological regime.

Canalisation refers to the development of artificial drains and incisions caused by erosion gullies, both of which tend to have a significant impact on the retention and distribution of water in a wetland. Artificial drains were found within some of the HGM units, however the most extensive was found to be in HGM 4. The presence of these artificial drains causes a reduction in the hydrological conductivity of sediments in a wetland. Hydrological conductivity refers to the easy facilitation of water through sediments, therefore by reducing the hydraulic conductivity, the distribution of water becomes limited.

The extent of hardened surfaces additionally has a significant impact on the hydrology of the Melville wetland. It was established that within each HGM there was an inordinate presence of hardened surfaces in the form of houses, dirt roads and other forms of infrastructure. Hardened surfaces aid in lowering the infiltration rate of storm waters thereby increasing the surface runoff and occurrence of flood peaks. The impact of hardened surfaces is further compounded by the vast removal of indigenous vegetation, which leaves large areas of bare soil exposed. If flooding continually occurs for extensive periods of time, this can result in the complete degradation of wetland habitat.

Impeding structures in a wetland, such as poorly constructed dirt roads (which are evident in Melville HGMs) can result in back flooding which is caused as a result of embankments along the road accommodating stream flow and causing flooding to occur upstream of the impeding structure. Additionally, impeding structures can cause localised drying up of the wetland downstream of the obstruction, causing a significant alteration to the hydrology.

5.5.2 Geomorphology

The geomorphology of a wetland refers to the retention and distribution patterns of sediment within a wetland. Wetlands are subjected to both, output and inputs of sediment such that in a natural reference condition, the input of sediment is equal to or slightly higher than the output of sediment (Macfarlane et al, 2007). It was established that the Melville wetland was in a moderately modified state with regards to the geomorphological regime, the probable causes of which are discussed below.

Erosion is one of the most significant issues facing South African wetlands and usually takes place through gullying. Erosion activities are governed by the basin morphology, flow patterns through a wetland, and substratum conditions, and can be induced by many factors. Improper farming methods used in this area (excessive tilling of the soil), increases the rate of erosion, as well as the removal of natural vegetation from the HGM units. If the rate of erosion is excessive, this may in turn cause large scale deposition, which will result in the damming effect of a wetland and its subsequent desiccation.

The artificial filling in of wetlands causes the confinement of water flows and geomorphic activities to a localised portion of a wetland which thereby decreases the frequency, extent, and the rate of erosion or deposition in those areas closer to the channel than would naturally occur. The presence of bridges and dirt roads in the HGMs of the Melville wetland provided evidence of artificial infilling. Furthermore, large amounts of debris were found to be deposited into the wetland by the surrounding inhabitants.

Figure 5.1. Debris Deposited into the Wetland

Many channels of the HGM units in the Melville wetland have been subjected to modification and have consequently been straightened. Channels are generally straightened for the purpose of flow improvement, flow diversion and/or drainage. However, the straightening of channels has a substantial influence on the geomorphic health as when a channel is straightened it steepens the slope of the channel, which in turns promotes headward erosion. Headward erosion is known to cause severe degradation to a HGM units geomorphic health.

Alterations to the runoff characteristics' of a HGM changes the ability of water to transport, lift and deposit sediment, which leads to erosion or deposition in a HGM unit. This is one of the primary factors causing geomorphological damage in a wetland. The runoff characteristics of the Melville wetland have been altered immensely due to the extensive removal of natural vegetation, the construction of houses within the wetland boundary and the development of roads and bridges. As a result, this has reduces the surface roughness allowing water to flow into the wetland at increased speeds due to no frictional barrier being present, and at increased volumes due to the infiltration rate being reduced. Both of these factors coupled together further encourage the occurrence of erosional activities.

Figure 5.2. Removal of Natural Vegetation

5.5.3 Vegetation

Vegetation health of a wetland refers to the compositional and structural state of the vegetation. The compositional and structural state of wetland vegetation serves as a habitat for multiple species and contributes a multitude of benefits. The vegetation of the Melville wetland was found to be in a seriously modified state due to the excessive removal of vegetation and the introduction of alien invasive vegetation species.

A significant portion indigenous vegetation was removed from each HGM due to the development of infrastructure such as houses, and roads. An extensive portion of the land in each HGM is utilised as crop lands. The development of these crop lands are generally characterised by the complete removal of natural vegetation and is replaced with predominantly introduced species such as maize.

Figure 5.3. Replacement of Natural Vegetation with Crop Lands

Within the Melville wetland a high concentration of alien vegetation was noted throughout all HGM units. Alien vegetation tends to outcompete indigenous vegetation and subsequently dominate the landscape, resulting in the complete removal of indigenous vegetation.

The infilling of a wetland as well as excessive deposition of sediment from the upper catchment of the Melville wetland causes a further transformation of the vegetation, causing majority of the indigenous vegetation species to die off due to the excessive smothering of sediment.

5.6 HEALTH OF THE RIVER RIPARIAN AREA

The health of the river riparian area is governed by the driving processes such as the health hydrology, geomorphology, water quality, as well as vegetation.

5.6.1 Hydraulic, Geomorphic, and Vegetation Health and, Water Quality Status

The health of the hydrology has been deduced as being moderately to seriously modified. The factors attributing to the degradation of the hydrology include the presence of alien invasive vegetation and agricultural activities. Alien invasive vegetation species are known to dominate the area and affect the hydrology by their immense ability to deplete water sources, thereby reducing the hydrologic flow. Similarly, agricultural activities in this area also assist in altering the hydrological regime by removing of water for irrigation purposes, and improper agricultural practices promoting erosion of the river channel.

The geomorphology of the wetlands was established to also be moderately to seriously modified. The geomorphology of this area is affected primarily by erosion inducing activities, including improper farming practices, and the increase of hardened surfaces. Improper farming activities cause an increase of the erodibility of the soil, thus reducing the geomorphic health regime. The increase of hardened surfaces in this region is caused due the extensive removal of vegetation and sand winning activities, in turn causing an alteration of the geomorphology as it reduces the cohesive properties of the soil. This subsequently affects the hydrological regime, as it causes an increase of runoff entering the system at a high velocity.

The quality of water was established to be poor, and is primarily affected by the farming (both occurring upstream in the wetland and along the river riparian boundary) and sand winning activities taking place. Due to the farming activities, the use of fertilisers and biocides, even though minimal, affects the quality of water when it is run off during storm events. The increased level of nutrients can also result in eutrophication, thereby diminishing the quality of water. Similarly, the runoff from sand winning activities also serves in diminishing the overall quality of the water in this area.

The health of vegetation was determined to be moderately modified, such modifications were caused by the removal of vegetation for the purpose of agricultural activities and sand winning activities, as well as the emergence of alien invasive species.

5.7 WATER QUALITY

5.7.1 Dissolved Oxygen

O_2 (oxygen gas), is derived from the atmosphere and is dissolvable in water, it is additionally produced by phytoplankton and photosynthesising aquatic plants. The D.O content in all four sites was established to be sub-lethal, therefore suggesting that the water was likely unable to support a vast array of aquatic biota (USEPA, 1986). The D.O is these regions are significantly reduced due to the expulsion of solid wastes and effluent into the water bodies as well as due to the runoff of pollutants from the surrounding homes encroaching onto the wetland and the agricultural activities taking place.

5.7.2 Total Dissolved Solids and Electrical Conductivity

Many dissolved substrates consist of an electrical charge, therefore there is a strong positive correlation between TDS and electrical conductivity (USEPA, 1986). Naturally occurring open water sources comprise of varying amounts of TDS as a result of the dissolution of the minerals found in soils, rocks and decomposing plant matter. Therefore the concentration of TDS is greatly dependant on the geological characteristics of the area concerned and the abundance of vegetation. Additionally, the concentration of TDS is also dependant on the rates of rainfall and evaporation (Allanson et al, 1990).

The underlying geology of the Melville region was established to be sandstone. From observations conducted the vegetation cover in all four sites was predominantly removed with sparse vegetated areas present. Furthermore, the KwaDukuza area has an average if 650-1200mm of rain per year. All these factors coupled together have contributed to the concentration of TDS present within the water, and thus the subsequent electrical conductivity values.

5.7.3 pH

The level of pH within a water body is dependent on the buffering capacity of the water. Majority of the fresh water systems in South Africa, such as the Melville wetland, are substantially buffered and are relatively neutral, consisting of pH values between 6 and 8. This is primarily governed by atmospheric and geological influences (APHA, 1989).

5.7.4 Salinity

Salinity in fresh water systems is expected to be non-existent (USEPA, 1986). However fractional quantities of salinity can be accounted for in freshwater bodies due to an increased pH, as seen in sites 1 and 2. Additionally, there may be a spike in salinity due to run off from surrounding agricultural lands and untreated effluent being discharged into the water from the surrounding households. Therefore the salinity levels can be explained in terms of the proximity of the sites to agricultural activities and the encroaching houses in the wetland.

5.7.5 Phosphates and Nitrates

Phosphates and nitrates may be introduced into a system through point and non-point sources. Point sources include discharges from domestic effluent; and non-point sources include urban and agricultural runoff, as well as atmospheric precipitation (USEPA, 1986). Phosphates and nitrates however, are readily taken up by the vegetation within a wetland thereby reducing the amount of nitrates and phosphates present (Dallas and Day, 1993).

It was established that, in terms if phosphates, the Melville wetland system demonstrated oligotrophic conditions which refers to a system that has low productivity levels, moderate abundance of species, rapid cycling of nutrients and zero growth of nuisance aquatic plants or algae (Wetzel, 1983).

In terms of nitrates, the wetland system displayed eutrophic conditions. Eutrophic conditions are characterised by low levels of biodiversity, generally are systems with high levels of productivity, and nuisance blooms of algae and aquatic plants

5.8 CONCLUSION

From the above discussions the following can be deduced:

All HGM units forming the Melville wetland provide the ecological services to different degrees. The extent to which the services are provided can be attributed to numerous physical and social factors which are influenced by land use activities as well as the geomorphology, hydrology, and vegetation. It can be concluded however, that the greatest influence on the provision of ecological services is the encroachment of buildings on the wetland boundary as well as the extensive agricultural activities taking place.

The overall health of the Melville wetland is determined by the collaboration of the wetlands hydrological, geomorphological and vegetation regime.

The hydrological regime of the Melville wetland was discovered to be largely modified. The degradation of the Melville wetland was found to be significantly attributed to the climate, land uses, canalisation, the extent of hardened surfaces and the presence of impeding structures. The geomorphological health was deduced as being moderately affected, and was primarily influenced by erosional activities. The health of vegetation in the Melville HGM units was found to be the most severely degraded, as it has been seriously modified. Disturbance classes causing this modification included infrastructure, wetland infilling, crop lands and the presence of alien invasive plants.

Therefore the health of HGMs 1, 2, and 4 were established to be largely modified, whereas HGM 3 was consider as being overall moderately modified. As a result of the degradation of the Melville wetland, the amount of remaining healthy wetland was calculated to be 3.17 Ha, out of a total of 6.79 Ha, making the total loss of wetland 3.62 Ha.

The health of the river riparian region was established by utilising the index of habitat integrity which encompasses the health of the hydraulic and geomorphic regimes, as well as the quality of water and the health of the vegetation. It was thereby concluded that the overall health of the river riparian region was moderately modified.

The overall water quality of the Melville wetland system was established to be polluted. The degradation of the water sources can be attributed to the surrounding land use activities, such as subsistence agricultural practices, as well as the close proximity of the houses to the water sources leading to the discharging of solid wastes and effluent directly into the water bodies. It is therefore necessary to implement relevant recommendations and mitigations measures in order to minimise the degradation of the wetland system caused by such impacts mentioned above. These recommendations and mitigations are suggested in the following chapter.

CHAPTER 6

6. CONCLUSION

6.1 INTRODUCTION

From analyses carried out in Chapters 5 and 6, it is established that the Melville wetland has been subjected to significant modifications of its hydrological, geomorphological and vegetation regimes, thereby drastically affecting the overall health status of the wetland, as well as diminishing its ability to provide certain ecological services. Therefore, this chapter focuses on the relevant recommendation and mitigation measures applicable to the Melville wetland system, in order to enhance its overall state.

The overall aim of this study was to assess the health of the Melville wetland system. Undertaking this assessment, the following key findings were established in deducing the health status of the Melville wetland system:

6.2 KEY FINDINGS

- The Melville wetland system was found to be made up of four hydrogeomorphic units and one river riparian system.
- Three of the four HGM units (HGM 2, 3 and 4) were identified as being channelled valley bottoms, with the largest of the HGM units, HGM 1, identified as an unchannelled valley bottom type wetland.
- Hydrological zones were identified by soil augers taken at different sites and the degree of saturation was noted as well as the vegetation profiles. Additionally, analyses was conducted on sediment grain sizes where it was found that grain sizes tends to increase as one moves further from the permanent to the temporary zones. The permanent wetland zones are dominated by silt and clay sized particles, whereas the temporary zone was seen to be dominated by medium sand sized particles.
- Conversely, to the grain size trend, O.M and C.C content is seen to decrease from the permanent to the temporary zone.

- Seasonal and temporary zones were found to be completely absent in HGM units 2, 3 and 4, and were present but very narrow t in HGM 1. These hydrological zones were evidently negatively impacted by the encroachment of houses and agricultural practices.
- The health status of the different HGM units was determined by utilising the WET-Health tool and, the ability of the wetland to provide certain ecological functions were determined by the WET-Ecoservices tool.
- The main ecological services provided by the Melville wetland was determined to be the provision of natural resources and cultivated foods.
- The overall health status of each HGM was concluded as the following:
    - HGM1 – D (largely modified)
    - HGM 2 – D (largely modified)
    - HGM 3 – C (seriously modified)
    - HGM 4 – D (largely modified)
- The overall health status of the river riparian area was determined by utilising the Index of Habitat Integrity tool, and was concluded to be in a seriously modified state (category C).
- The overall water quality of the areas at which samples were taken was established to be polluted due to the discharging of effluent and solid waste directly into the open water sources by the households in close proximity to the open water sources.

6.3 IMPACTS

The degradation of the hydrological, geomorphological and vegetation health of the Melville wetland was as a result of the following predominant impacts:

- Improper agricultural activities taking place within the wetland hydrological zones.
- Encroachment of houses into the wetland boundary.
- Development of dirt roads and bridges in close proximity to the wetland.
- Excessive dumping of solid waste into the wetland.
- Digging and development of man-made drains and trenches for agricultural purposes.
- Discharging of storm waters and other effluent directly into the wetland.

- Removal of indigenous vegetation.
- Encroachment of introduced and alien invasive vegetation.

The impacts mentioned above are experienced in the Melville wetland to different extents and all contribute to the consequential degradation of the wetland, it is therefore necessary to develop measures which aid in rehabilitating the wetland and maintaining or improving the current condition of the wetland.

6.4 RECOMMENDATIONS and MITIGATION MEASURES

Wetland rehabilitation is referred to as a process of aiding in the recovery of a wetland that has been degraded or a process that assists in maintaining the health of a wetland that is currently in the process of being degraded (Kotze et al, 2007). The following recommendation and mitigation measures aim to rehabilitate the Melville wetland in order to enhance the overall value and functioning of the system.

6.4.1 Install Gabion or Concrete Weirs

Within each of the HGM units a series of gabion or concrete weirs should be constructed. The construction of such structures will encourage the occurrence of back flooding and the re-establishment of a more natural wetness regime (Mullins, 2012). Additionally, these structures, in conjunction with re-vegetation efforts and the filling in of drains and gullies, will significantly contribute to halting the advancement of headcut erosion (Kotze et al, 2007). Weirs are particularly suitable as they are robust enough to withstand the high flow volumes in these systems (Rickard et al, 2003).

6.4.2 Re-vegetation

Prior to re-vegetation efforts taking place in cleared and degraded wetlands, it is imperative that all solid wastes are removed from individual HGM units and their immediate surrounding regions. Post solid waste removal, a mixture of indigenous species, including hydrophytic indigenous species, should be introduced to each HGM unit (Peters et al, 2012). The re-establishment of vegetation will increase these systems' ability to maintain biodiversity, the reduction in velocity and quantity of runoff waters into wetlands, the slowing down of water movement though a wetland thus aiding in trapping sediment and improving the overall quality of water (Mullins, 2012).

6.4.3 Controlling Alien Invasive Plants

The careful control of the dispersion of alien invasive vegetation within a wetland is imperative due to their degradation causing properties. The key to controlling the dispersion of alien vegetation is through early detection and removal. The removal and management of alien vegetation is essential in maintaining the ecological integrity of a wetland as well as its ability to maintain biodiversity (Richardson et al, 2007).

6.4.4 Minimising Human Disturbances

The Melville wetland currently experiences large volumes of anthropogenic disturbances in the form of illegal dumping, encroachment of houses and other infrastructure, as well as improper farming activities. Therefore, in order to manage and mitigate these threats faced by the wetland a suitable buffer, encompassing each HGM unit, should be determined. Given that development has already occurred in close proximity to the wetlands, a minimum buffer of 10m should be suggested for these areas, and where possible, larger buffers of up to 30m should be prescribed by the local municipality (Macfarlane, 2014 b). In an ideal situation no activity or access will be permitted within the boundary of the buffer zone (CSIR, 2014). By ensuring this, the wetland would be able to re-establish a more natural regime thereby enhancing the overall integrity of a wetland (Kotze et al, 2007). However, due to the presence of houses and subsistence farming activities already being established, this will not be fully possible. Instead, no further development should be allowed to take place within the established buffer zone, thus preventing any further excessive degradation of the wetland.

6.4.5 Storm Water Management

A storm water management programme should be developed to ensure that runoff is reticulated to previously approved discharged, municipal discharge drainage for controlled release (Mullins, 2012). These points should be suitably protected by scouring activities by gabion or reno mattresses and be diffused along the HGM unit to prevent the point source release of runoff (CSIR, 2014). Furthermore, these drainage systems need to be regularly monitored in order to ensure that no blockages have occurred (Mullins, 2012).

6.4.6 Reinstating a more Natural Diffuse Flow and Raising the Water Table

Reinstating the natural diffuse flow of a wetland aids in securing its integrity as well as the ecological services provided by the wetland, particularly the assimilation of nitrates, phosphates and toxicants (Kotze et al, 2005). Raising the water table of a wetland increases the level of wetness which also secures the integrity of a wetland as well as the ecological services provided by the wetland, particularly carbon storage (Kotze et al, 2007). This is achieved by raising the water level of drains and gullies by instating weirs, developing a sediment plug or fence across the drains and gullies, and constructing a spreader canal which diffuses flows (Kotze et al, 2007).

6.4.6 Legislation

The enforcement of relevant legislation pertaining to wetlands and the adherence to policies is vital for maintaining the health and overall integrity of wetlands.

6.5 CONCLUSION

From the assessment carried out on the Melville wetland it was found that the system was made up of four HGM units and one river riparian unit. The health status and functionality of the HGM units were assessed using the Wet-Health and Wet-Ecoservices tool, whereas the status of the river riparian unit was assessed utilising the IHI tool. It was thereby concluded that all the HGM units, with the exception of HGM 3 were in a largely modified state, with the river riparian unit and HGM 3 in a seriously modified state.

Wetlands are largely important systems in the environment and are imperative in providing ecological services such as stream flow regulation, flood attenuation, and the provision of cultivated foods, amongst others. Wetlands are especially important in the Melville, KwaDukuza region due to the present water shortages currently experienced in this area as well as the heavy reliance of the community on subsistence farming, and use of natural wetland resources for their survival.

However this wetland system is seen to be significantly degraded and more than half of the original wetland has been lost. From this study, it has been determined that 3.62Ha of the Melville wetland has been lost through such degradation, thus only 3.17Ha on health wetland remains. Therefore mitigation measures should be implemented and enforced to the fullest extent which will in turn allow for the preservation of the remaining wetland area.

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8. APPENDIX

Table 8.1. Field Sheets of Sediment Sample Sites

<table>
<tr><td>SAMPLE NO: 1</td><td colspan="3">LOCALITY DESCRIPTION: Housing and agricultural practices present. Dirt roads. Removal of natural vegetation and alien vegetation present.</td></tr>
<tr><td colspan="2">LATTITUDE: 29^0 22’ 35’’ S</td><td colspan="2">LONGITUDE: 31^0 15’ 47’’ E</td></tr>
<tr><td colspan="4">VEGETATION: Phragmites capensis</td></tr>
<tr><td colspan="4">SOIL MORPHOLOGY (0-10cm):</td></tr>
<tr><td>MOTTLING:</td><td colspan="2">PRESENT / NONE</td><td>CONTRAST: intermediate</td></tr>
<tr><td></td><td colspan="2">COLOUR: orange</td><td>ABUNDANCE: low</td></tr>
<tr><td>MARTIX HUE:</td><td colspan="2">MATRIX VALUE: 4</td><td>MATRIX CHROMA: 1</td></tr>
<tr><td colspan="4">SOIL MORPHOLOGY (30-40cm):</td></tr>
<tr><td>MOTTLING:</td><td colspan="2">PRESENT / NONE</td><td>CONTRAST: Intermediate</td></tr>
<tr><td></td><td colspan="2">COLOUR: Orange</td><td>ABUNDANCE: low</td></tr>
<tr><td>MATRIX HUE:</td><td colspan="2">MATRIX VALUE: 3</td><td>MATRIX CHROMA: 1</td></tr>
<tr><td colspan="4">HYDROLOICAL ZONE:</td></tr>
<tr><td>PERMANENT</td><td colspan="2">SEASONAL</td><td>TEMPORARY</td></tr>
<tr><td>SOIL PROFILE</td><td colspan="3"></td></tr>
</table>

SAMPLE NO: 2	**LOCALITY DESCRIPTION:** Close proximity to houses and informal settlements. Many dirt roads present. Farming present.	
LATTITUDE: 29^{0} 22' 35'' S	**LONGITUDE:** 31^{0} 15' 22'' E	
VEGETATION: Phragmites capensis, significantly vegetated land (lettuce, cabbage)		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: Intermediate**
	COLOUR: Orange	**ABUNDANCE: High**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 2**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: Intermediate**
	COLOUR: Orange	**ABUNDANCE: High**
MATRIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**
SOIL PROFILE		

SAMPLE NO: 3.	**LOCALITY DESCRIPTION:** Close to houses. Moderate to low erosion. Drain in close proximity.	
LATTITUDE: 29^{0} 22' 36'' S	**LONGITUDE:** 31^{0} 15' 22'' E	
VEGETATION: grasses/ no vegetation		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST:**
	COLOUR:	**ABUNDANCE:**
MARTIX HUE:	**MATRIX VALUE: 5**	**MATRIX CHROMA: 2**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST:**
	COLOUR:	**ABUNDANCE:**
MATRIX HUE:	**MATRIX VALUE:5**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**
SOIL PROFILE		

SAMPLE NO: 4	**LOCALITY DESCRIPTION:** Road separating HGM. Culvert and drains present. Moderate to high erosion and farming activities.	
LATTITUDE:29^{0} 22' 35'' S	**LONGITUDE:**31^{0} 15' 20'' E	
VEGETATION: Pennisetum Purpureum (Elephant grass), Cyperus Dives, Scleria Woodii		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST:**
	COLOUR:	**ABUNDANCE:**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA:1**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: Low**
	COLOUR: orange	**ABUNDANCE: Low**
MATRIX HUE:	**MATRIX VALUE: 3**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**
SOIL PROFILE		

SAMPLE NO: 5	**LOCALITY DESCRIPTION:** Close proximity to houses and a school. Moderate erosion. Alien vegetation present. Excessive dumping.	
LATTITUDE: 29^0 22’ 33’’ S	**LONGITUDE:** 31^0 15’ 21’’ E	
VEGETATION: Pennisetum Purpureum, Cyperus Dives		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT** / **NONE**	**CONTRAST: intermediate**
	COLOUR: orange	**ABUNDANCE: intermediate**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT** / **NONE**	**CONTRAST: Low**
	COLOUR: Orange	**ABUNDANCE: Low**
MATRIX HUE:	**MATRIX VALUE: 3**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**
SOIL PROFILE		

SAMPLE NO: 6	**LOCALITY DESCRIPTION:** Close proximity to houses. Moderate erosion. Alien vegetation present.
LATTITUDE:29^0 22’ 22’’ S	**LONGITUDE:**31^0 15’ 33’’ E
VEGETATION: Ficinia Nodosa, Cyperus Papyrus	

	SOIL MORPHOLOGY (0-10cm):	
MOTTLING:	**PRESENT / NONE**	**CONTRAST:**
	COLOUR:	**ABUNDANCE:**
MARTIX HUE:	**MATRIX VALUE: 3**	**MATRIX CHROMA: 1**
	SOIL MORPHOLOGY (30-40cm):	
MOTTLING:	**PRESENT / NONE**	**CONTRAST: Low**
	COLOUR: Orange	**ABUNDANCE: Low**
MATRIX HUE:	**MATRIX VALUE: 5**	**MATRIX CHROMA: 1**
	HYDROLOICAL ZONE:	
PERMANENT	**SEASONAL**	**TEMPORARY**

SOIL PROFILE	

Table 8.2. Vegetation Found within the Study Site

Type	Species
Dominant trees	*Ricinus communis**, *Melia azaderach**, *Solanum mauritianum**, *Psidium guajava**, *Eucalyptus* sp*, *Casuarina* sp., *Senna didymobotrya**, *Albizia adianthifolia, Leucaena leucocephala*, Acacia sp.*
Dominant herbs and Forbs	*Ageratum conyzoides**, *Lantana camara**, *Oxalis* sp., *Chromolaena odorata*, Cardiospermum grandflorum*, Canna indica*, Bidens pilosa*, Ageratina adenophora*, Cestrum laevigatum*, Anredera cordifolia*, Ipomoea purpurea*, Conyza albida, Datura stumonium*, Tephrosia grandiflora, Senecio sp.*
Domestic	*Cucurbita pepo/maxima*, *Amaranthus* spp., *Zea mays*, *Musa acuminata*
Dominant grass	*Cymbopogon excavatus, Cymbopogon validus, , Cyperus dives, Cyperus papyrus, Digitaria eriantha, Eragrostis capensis, Eragrostis curvula, Cynodon dactylon, Melinis repens, Scleria woodii, Panicum maximum, Pennisetum purpureum, Phragmites capensis, Themeda triandra, Tristachya leucothrix*

*Alien Invasive Vegetation

OBLIGATE WETLAND VEGETATION

1. Phragmites Capensis

2. Pennisetum Purpureum

3. Cyperus Dives

4. Scleria Woodii

5. Ficinia Nodosa

6. Cyperus Papyrus

ALIEN INVASIVE VEGETATION

1. Taraxacum Officinale

2. Helianthus

3. Solanum Mauritianum

4. Ricinus Communis

Figure 8.1. Vegetation Species found within the Melville Wetland System

Table 8.3. Coordinates of Water Samples

SAMPLE NO.	CO-ORDINATES
WQ 1	29°22'35.86"S 31°15'23.14"E
WQ 2	29°22'35.87"S 31°15'21.75"E
WQ 3	29°22'42.48"S 31°15'45.98"E
WQ 4	29°22'22.76"S 31°15'33.99"E

Table 8.4. Ecological Service Scores

	SCORE			
SERVICE	**HGM 1**	**HGM 2**	**HGM 3**	**HGM 4**
Flood attenuation	2.3	1.7	1.9	1.8
Streamflow regulation	2.2	2.2	2.1	1.5
Sediment trapping	2.7	2.4	1.9	2.2
Phosphate trapping	2.6	2.3	1.5	2.1
Nitrate removal	2.3	2.2	2	2.3
Toxicant removal	2.8	2.3	2	2.4
Erosion control	1.8	1.8	1.5	1.5
Carbon storage	1.3	1.3	1.7	1.3
Maintenance of biodiversity	0.9	0.9	1.3	0.6
Water supply for human use	2.7	2.4	2	2.6
Natural resources	3.0	2.8	2.2	3.0
Cultivated foods	3.0	2.8	2.4	3.2
Cultural significance	1.8	1.8	1	1.0
Tourism and recreation	1.0	0.4	0.4	0.4
Education and research	0.8	0.3	0.5	0.0

*All scores are out of a maximum score of 4.