# The potential effect of wetland rehabilitation on wetland ecosystem goods and services: an investigation of three South African case studies

By

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# ABSTRACT

Wetlands supply very diverse and important goods and services to society. Goods are tangible resources, e.g. harvestable resources, cultivated foods, water for human use, cultural significance, tourism and recreation, and education. Services are less tangible and include: flood attenuation, streamflow regulation, sediment trapping, phosphate and nitrate assimilation, toxicant assimilation, erosion control, carbon storage and biodiversity maintenance.

The literature reviewed confirms that these goods and services are dependent to varying degrees on the hydrology of a wetland. Dependence is due to the fact that hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and process occurring in wetlands. Ecosystem goods and services are normally lost during degradation of a wetland and to restore them is a challenge. Causes of degradation could result from chemical, biological and physical processes. In South Africa physical processes such as gully erosion are one of the greatest causes of wetland degradation.

Wetland rehabilitation generally seeks to retrieve the natural water regime or hydrology of a degraded wetland, with the aim of retrieving the ecosystem goods and services that were lost during degradation. The literature shows that there is a clear link between wetland rehabilitation, hydrology and ecosystem goods and services. To better understand this relationship, three selected South African wetlands were examined. The water tables and hydrological zonation of these wetlands were described and WET-EcoServices was used as a means of determining wetland functionality and assessing likely changes in function as the result of altered hydrology.

The hydrological zonation of the Pelham wetland and portion 2 of the Craigieburn wetland were similar in terms of water table depth and hydrological zonation (the temporary, seasonal and permanent zones were represented), while portion 1 of

the Craigieburn wetland had a much lower water table and degree of wetness (only the temporary zone was represented), which appears to be due to degradation. The general trend found in the second wetland is that the water table became lower towards the erosion head cut at the downstream end of the wetland.

Applying a WET-EcoServices assessment shows that the first site (Pelham wetland) and portion 2 of Craigieburn wetland, which had similar hydrology, showed similarities in terms of hydrological services, such as nitrate and toxicant assimilation, that are dependent on a high degree of wetness. This dependence is due to hydrologic conditions that influence nutrient cycling, nutrient availability and rates of organic matter decomposition.

In terms of goods, all three sites were important for research. Except for recreation, Pelham wetland provided little other direct benefits. In contrast, portion 1 and 2 of Craigieburn were very important for providing cultivated foods, which contribute significantly to the food security of the many poor households who use the wetland. However, portion 1 of Craigieburn was less important than portion 2 of Craigieburn for supplying natural resources (e.g. reeds for harvesting) and water for human use because of its drier condition. The Pelham wetland was found to be highly invaded by alien vegetation.

The study shows that in a rehabilitated wetland and through effective management, ecosystem goods and services do increase. But, due to the high cost associated with the rehabilitation process, the study highlighted the value of assessing the potential benefits of rehabilitating degraded wetlands, particularly ecosystem goods and services that will be secured.

# PREFACE

The research described in this mini-dissertation was carried out at the Centre for Environment and Development, University of KwaZulu Natal, Pietermaritzburg, under the supervision of Dr Donovan Kotze.

This Mini-dissertation represents the original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledge in the text.

Mncedi Nkosi

Dr Donovan Kotze

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# DEDICATION

This Study is dedicated to my late Mother: **Jabulile Virginia Manyoni**.

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# CHAPTER 1

# OVERVIEW

## 1.1 Introduction

Wetlands are natural ecosystems that provide a variety of important ecosystem goods and services that require special attention in a rapidly developing country like South Africa. Recent studies (Kotze, 1996b; Dini, 2004) have highlighted that there are many benefits that wetlands provide to humans, and thus wetland conservation is important to South Africa's sustainable development. Identification of these wetland goods and services has been helpful in building awareness about the importance of wetlands within South Africa.

Ecosystem goods and services are often lost during degradation of a wetland and to restore them is a challenge. Causes of degradation could result from chemical, biological and physical processes. In South Africa, physical processes such as gully erosion are one of the greatest causes of wetland degradation, normally with gullies typically having a desiccating effect on wetlands. South Africa, in particular, has recently embarked on rehabilitating degraded wetlands due to the growing awareness about the importance of wetlands (Dini, 2004; Macfarlane *et al.* 2005).

In addition, rehabilitation projects that address erosion attempt to halt the active advance of erosion gullies into wetlands, i.e. rather than reversing past degradation these management interventions attempt to halt future degradation. In such cases wetland rehabilitation does not result in retrieving lost ecosystem goods and services but rather securing them through the halting of future degradation.

Due to the fact that hydrology plays a vital role in the structure and the functioning of wetlands, this study examines the important characteristics of wetland hydrology such as hydric plants, hydric soils and the groundwater table. It would then elaborate on the way in which hydric plants and hydric vegetation act as indicators of the wetting regime in wetlands. The need to identify wetland hydrology as an important aspect of wetland rehabilitation will be shown.

There is a need to retrieve lost ecosystem goods and services in degraded wetlands. It is also important to assess the potential effect of future rehabilitation interventions on the ecosystem goods and services delivered by a rehabilitated site. All these issues will be addressed using a functional assessment tool, WET-EcoServices (Kotze *et al.* 2005), which rapidly assess wetland functional values. The interpretation of the results found during the assessment will form the basis for providing recommendations on management interventions required in the assessed wetlands.

## 1.2 Problem Statement

The importance of wetland benefits shows the need for proper management, conservation and rehabilitation of lost wetlands. Rehabilitation refers to "a series of actions promoting the reinstatement of the wetland's underlying forces to a level close to the original system (but seldom fully attaining it) so as to improve the wetland's capacity for providing services to society" (Nel, 2003). The process of rehabilitation is often very costly, and thus much greater attention needs to be given to examining the returns on investment for these projects than is currently undertaken in South Africa. Despite the high level of wetland degradation in South Africa and the impact of extensive rehabilitation of wetlands currently being undertaken, almost no assessment has been conducted of the effectiveness of rehabilitation on the provision of ecosystem goods and services.

In South Africa Working for Wetlands is entrusted with restoring the hydrological function and ecological integrity of the nation's wetlands. According to Dini (2004) Working for Wetlands operates through cooperative governance, where its support is drawn from all multiple government departments concerned with conservation and sustainable resource use. This programme integrates two of its biggest concerns: (1) conservation of wetlands in South Africa, (2) focusing on poverty relief, job creation and skills development (Dini, 2004).

Ellery (In prep) also confirms that despite several wetland rehabilitation projects in South Africa that have been conducted over the last two decades there has been no evaluation undertaken to determine the success of rehabilitation. Furthermore, very little has been done to gather and make use of valuable lessons derived from these projects. This study intend to reveal not only the importance of rehabilitation but also the successes or shortcomings of rehabilitation projects in bringing back or securing the goods and services supplied by the wetland. It further aims to identify valuable lessons learned from a rehabilitated site and also highlight the potential benefits of rehabilitation in sites without rehabilitation.

## 1.3 Research aim

The overall aim of the research was to examine the potential effect of future wetland rehabilitation on the provision of ecosystem goods and services using rapid field assessment and interviews with key informants.

The research took place in three sites: of which (a) two sites are under considerable threat from erosion by advancing gully erosion and they are currently without rehabilitation and (b) the other site is a wetland that has been rehabilitated through the removal of alien vegetation and replacement of natural vegetation.

## 1.4 The main objectives

1. To characterise the hydrological setting of the wetland and its hydrological zonation based on interpretation of soil morphology and vegetation.

2. To assess the current provision of ecosystem goods and services provided by the wetland based on the indicators given in WET-EcoServices.

3. To assess the potential effects of future rehabilitation on the provision of ecosystem goods and services.

## 1.5 Overview of the dissertation

The study is divided into two components namely Component A and B. Component A comprises of Chapters 2 and 3, Chapter 2 presents the literature review of wetland hydrological variables such as hydric plants, hydric soils and water table and further links them with ecosystem goods and services. Chapter 3 focuses on the description of study sites and the methodology adopted in achieving aims and objectives of the study. Component B is a summary of the study site descriptions, methodology and the results from the wetland assessment undertaken in all wetlands. Component B repeated some information from Component A, but it further includes the interpretation of results and final conclusions and recommendations.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Definition of Wetlands

A wetland is 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 that is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil" (National Water Act 36, 1998). Many definitions exist around the concept of wetland, but for the purpose of this study the definition will be used appropriate. This definition is considered appropriate because rewetting the wetland or retrieval of wetland hydrology is normally the aim of most rehabilitation projects. The relevance of this definition to this study is due to the fact that for an area to be classified as a wetland it must meet at least one of the following criteria (Carter *et al.* 1978:345):

- *at least periodically, the land supports predominantly hydrophytic vegetation;*
- *the substrate is predominantly undrained hydric soil;*
- *the substrate is not soil and is saturated with or covered by shallow water at some time during the growing season of each year.*

### 2.1.1 Hydrology

The above definition highlights the presence of the water table at or near the surface, or the land periodically covered with shallow water for at least portion of the year, which is an indication of wetland hydrology. Departement of Water Affairs and Forestry (DWAF) (2004:155) define hydrology as "the science of dealing with the properties, distribution, and circulation of water both on the surface and under the earth". Wetland hydrology forms the basis of this study and will be covered more fully in Section 2.2.

### 2.1.2 Hydric Soils

The U.S.D.A Soil Conservation Service (1985) defines hydric soils as "soils that in its undrained condition is saturated or flooded long enough during the growing season to develop anaerobic conditions favouring the growth and regeneration of hydrophytes". These soils are one of the distinctive and unique features that are expected to be present in a wetland when not disturbed. They are unique in a sense that wetland soils possess particular characteristics (e.g. a low chroma matrix) that result from their prolonged saturation conditions, and that can be readily described in the field (Braack *et al.* 2000).

### 2.1.3 Hydric Plants

One of the key components of a wetland is the distinctive plants adapted to wet conditions, which are known as hydrophytes or hydric plants. The definition used in this study further highlights hydrophytes, which are "an individual plant adapted for life in water or periodically flooded and/or saturated soils (hydric soils) and growing in wetlands and deepwater habitats; it may represent the entire population of a species or only a subset of individuals so adapted" (Tiner, 1999). Wetland plants (hydrophytes) are one of the most visible indicators of a wetland, and they are reliable indirect indicators of wetland hydrology that could be used to infer its presences when wetland hydrology has not been altered (Brouwer *et al.* 2003). Hydrophytes are capable of withstanding soil conditions associated with prolonged periods of saturation (anaerobic conditions) that most plants are poorly equipped to handle. They withstand these conditions through their "morphological, physiological and/or reproductive adaptation", and they "have the ability to grow, compete, reproduce and persist in anaerobic soil conditions" (DWAF, 2003:16).

## 2.2 Wetland Hydrology

The definition used in this study shows that the water regime is central to the definition of a wetland. Mitsch & Gosselink (1986) regard hydrology as the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes. Hydrology also affects aquatic primary production, organic accumulation, and the cycling of nutrients. Brouwer *et al.* (2003:52) highlights that "water acts as both stimulus and a limit to species composition and richness in wetland systems, depending on water storage and physical hydrodynamics". These statements show that the availability of water is essential to the survival of wetlands. The depth, duration and frequency of flooding is described by the hydrological regime, which is regarded as the primary determinant of wetland structure and functioning. Furthermore, hydrology is considered the most important variable influencing plant community composition and distribution (Breen *et al* 1988; Mitch & Gosselink, 1993; Rogers, 1995).

The use of the word 'transitional' in the definition of wetlands in Section 2.1 is an indication of hydroperiod. Mitsch & Gosselink (1986:72) define hydroperiod as "the seasonal pattern of the water level and act as a hydrologic signature of each wetland type and it describes the rise and fall of water levels from year to year". According to Mitsch & Gosselink (1993:72) hydroperiod "characterises each type of a wetland and the constancy of its pattern from year to year ensures a reasonable stability from that wetland." They further identified subsurface soil, geology and groundwater conditions, as some of the factors that cause hydroperiods. The availability of water in a wetland alone cannot do much in maintaining the processes without hydrological variables like hydric soils, hydric plants, and groundwater table. A high water table acts as a selective pressure to support vegetation communities often tolerant of anaerobic conditions (Brouwer *et al.* 2003).

### 2.2.1 Groundwater table

Depending on a wetland's structure, storage of water may be in the channel, the basin and groundwater. Kotze (1996a) define the groundwater table as the upper limit of the saturated zone in the soil. Furthermore, the groundwater table in a wetland lies close to or above the soil surface and changes with climatic and seasonal changes. Figure 1 shows groundwater table changes of two hypothetical wetland areas over a year. The first graph is a wetland that is temporally saturated with water; the water table is only close to the surface in a few months of the wet season. The second graph is a wetland that is permanently wet for almost the entire year and the water is above the surface almost the entire year except the last three months of the dry season. Kotze (1996a) highlights that saturation of soil should be developed enough for anaerobic conditions to be formed, in order to support wetland plants. Through this, the conclusion is made that the groundwater table is important in terms of the functioning of a wetland.

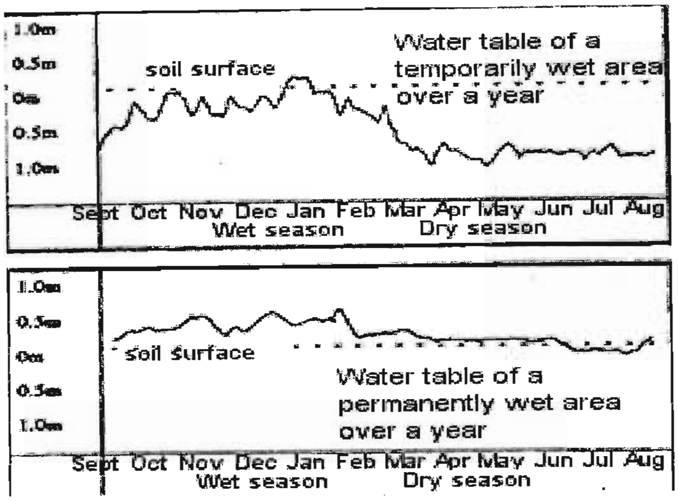



**Figure 1:** Water table changes over a year in two hypothetical wetland areas (Kotze, 1996a).

### 2.2.2 Soil morphology as a wetness indicator.

Interpreting the colour patterns of the soil can easily identify the presence of hydric soils, and water regime has a strong effect on these colour patterns. It "is not wetness per se that has the primary influence on the geochemistry and morphology of wetland soils, rather the anaerobic conditions that results from prolonged soil saturation/flooding" (Kotze *et al.* 1996a: 68). These are the conditions (anaerobic) that give water regime a strong effect on the colour patterns of the soil within a wetland. In terms of rehabilitation morphological features can provide information about the hydrological regime of a wetland. This is possible because when "a wetland is drained and the water regime is changed the soils retain their characteristic colour signatures forever" (Nel, 2003). For example in a disturbed hydrological regime the morphology of the soil would reflect the previous water regime. This helps in mapping where wetlands have been disturbed and assist in determining the extent of wetland lost (Nel, 2003).

In a well-drained soil there is enough oxygen present to oxidise the iron and lead the soil to be uniformly red/brown/yellow in colour (Kotze *et al,* 1996; Vepraskas, 1995). Under aerobic conditions iron is present as iron oxides (red in colour), which are insoluble and therefore are not removed from the soil. This prevents the iron from being leached out from the soil; and therefore the soil retains its red/brown colour. However, in saturated and anaerobic conditions, iron becomes reduced, and in this form it is soluble and there is no prevention of iron being leached from the soils.

In addition, this results in the grey matrix colour of wetland soils (Tiner & Veneman, 1988). Braack *et al.* (2000) further mention the formation of orange or red spots called mottles that result from the periodic drying up of anaerobic soils. Previous research has highlighted the periodic saturation caused by alternating anaerobic and aerobic soil conditions. Reduced levels of iron occur in localised areas in the mineral soil material each time the soil is aerobic, results in the formation of yellow orange, red or black mottles (Tiner & Veneman, 1988; Kotze, 1999). Figure 2 shows the range in colour and abundance of mottles that are caused by soils alternating between aerobic (dry) and anaerobic (wet), which depends on the wetness of each zone in a wetland.

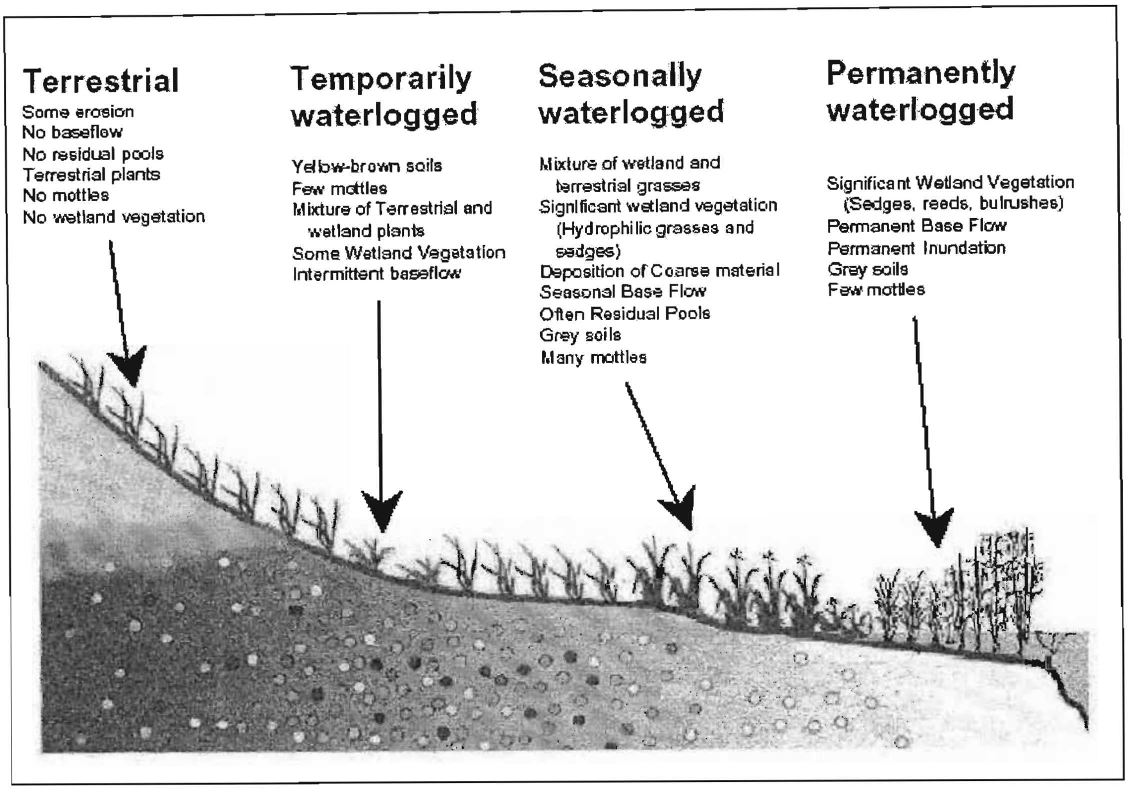



**Figure 2**: Cross section through a wetland showing the abundance of mottles with respect to different wetness zones (DWAF, 2003; Kotze, 1996).

Tiner & Veneman (1988) identified mineral soils and organic soils as two types of hydric soils that can be found in wetlands. Generally all soils contains some organic matter in them, but when soil has a percentage organic matter that is less than 20 to 35 percent that soil is considered mineral, while soils with a percentage organic matter greater than 20 to 35 are considered organic soils (Mitsch & Gosselink, 2000). Limited oxygen in hydric soil prevents the decomposition of organic matter. According to Tiner & Veneman (1988) and Kotze *et al.* (1996) the highest levels of organic matter accumulate in wetland zones that are exposed to the longest wet periods. Accumulation is due to the reduced rate of decomposing organic matter that is caused by the presence of anaerobic conditions associated with the wet periods. Thus we can conclude that levels of organic matter are higher in wetland soils than in dryland soils, and this generally results in wetland soils being darker or greyer in colour than dryland soils (Braack *et al.* 2000). Besides contributing to the wetland productivity and health, Pollard *et al.* (2004) also identified some of the contributions that soil organic carbon could make in a wetland. These contributions are the enhancement of the water holding capacity of the soil and the enhanced cation exchange capacity, which increases the amount of nutrients held in the soil that could be available for plants.

The saturation of soil, particularly where it is prolonged such as in wetlands, does not only affect mottling, but also has a characteristic effect on soil matrix chroma (DWAF, 2004). "Matrix refers to the 'background colour' of the soil while chroma is defined in terms of the relative purity of the spectral colour, which decreases with increasing greyness" (DWAF, 2004:45). When one moves from a dry area to a wet area the matrix chroma steadily decreases, while mottle hue and chroma initially increase but when approaching a wet area decrease as well (Kotze *et al.* 1994). Table 1 shows three different degrees of wetness identified based on an interpretation of soil morphology.

**Table 1:** Criteria used to distinguish different degrees of wetness within a wetland (Kotze *et al.*1994, DWAF 2004).

| | Degree of wetness | | |
|---|---|---|---|
| **Soils** | **Temporary** | **Seasonal** | Permanent /Semi-**Permanent** |
| Soil depth 0 – 10cm | Matrix brown to grayish brown (chroma 0-3, usually 1 or 2). Few/no mottles. Low/intermediate OM Nonsulphidic | Matrix brownish grey to grey (chroma 0-2). Many mottles Intermediate OM Sometimes sulphidic | Matrix grey (chroma 0-1) Few/no mottles High OM Often sulphidic |
| Soil depth 30 – 40cm | Matrix greyish brown (chroma 0-2, usually 1) Few/many mottles | Matrix brownish grey to grey (chroma 0-2) Many mottles | Matrix grey (chroma 0-1) Matrix chroma:(0-1) No/few mottles |

**OM=Organic Matter**

**High Organic Matter**: *soil organic carbon levels are greater than 5% often exceeding 10%*

**Low Organic Matter (OM):** *soil organic carbon levels are less than 2%*

*Sulphidic soil material has sulphides present which give it a characteristic 'rotten egg' smell*

### 2.2.3 Vegetation as an indicator of wetness

Within wetlands, three hydrological zones can be identified based on the degree of wetness, (i) the temporary, (ii) seasonal and (iii) permanent zones. Although hydric plants are the only plants that can tolerate prolonged saturated conditions found in wetlands, not all hydric plants can withstand all conditions in found in different zones found in wetlands. According to van Huyssteen (2003:10) "in areas of frequent and sustained flooding, hydrophytes with tolerances and adaptations for anoxic conditions and the associated conditions of high metal solubility are likely to dominate". Table 2 highlight that even wetland plants do not all survive in every location throughout a wetland, and it also depends on the type of hydrophytes. Wetting regime could be established through using soil and vegetation within a wetland or within particular zones in a wetland (DWAF, 2003). A set of criteria for soils (Table 1) and vegetation (Table 2) has been developed to assist when identifying the degree of wetness in a wetland.

**Table 2**: Criteria for distinguishing different soil saturation zones within a wetland (Marneweck & Kotze, 1999).

| | **Degree of wetness** | | |
|---|---|---|---|
| **Vegetation** | **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:<br>(1) Emergent plants, including reeds, sedges and bulrushes, usually >1 m tall; or<br>(2) Floating or submerged aquatic plants. |
| If Woody: | Mixture of woody species which occur extensively in non wetland areas, and hydrophytic plant species which are restricted largely to wetland areas | Hydrophytic woody species which are restricted to wetland areas | Hydrophytic woody species, which are restricted to wetland areas. Morphological adaptations to prolonged wetness (e.g. prop roots). |

**Table 3**: Classification of plants according to their occurrence in wetlands (Reed, 1988).

| | |
|---|---|
| Obligate wetland (ow) species | Almost always grow in wetlands (> 99% of occurrences). |
| Facultative wetland (fw) species | Usually grow in wetlands (67-99% of occurrences) but occasionally are found in non-wetland areas |
| Facultative (f) species | Are equally likely to grow in wetlands and non-wetland areas (34-66% of occurrences). |
| Facultative dry-land (fd) species | Usually grow in non-wetland areas but sometimes grow in wetlands (1-34% of occurrences) |

*(Note: only the ow and fw species are considered as wetland indicator species)*

Reed (1988) classified plants according to their occurrence in wetlands. Table 3 shows this classification. DWAF (2003) highlights that hydrophytes themselves could differ in terms of which plant can always grow in conditions such as permanent, seasonal and temporary. DWAF (2003) highlighted some of the significant wetland vegetation, which includes reeds, sedges, bulrushes, terrestrial grasses, and woody types. Figure 2 in section 2.2.2 shows how the soil wetness and vegetation indicators change as one moves along a gradient of decreasing wetness, from the middle to the edge of the wetland.

## 2.3 The concept of wetland ecosystem goods and services

### 2.3.1 Overview

Wetland ecosystems are productive systems, which produce very diverse and important goods and services to society. The goods that are considered to be most important in South Africa are normally tangible resources that a wetland could provide, e.g. harvestable resources, cultivated foods, water for human use, cultural significance, tourism and recreation, and education (Adamus, 1983; Kotze *et al.* 2005; Adamus & Stockwell, 1983). Services are less tangible and include: flood attenuation, streamflow regulation, sediment trapping, phosphate and nitrate assimilation, toxicant assimilation, erosion control, carbon storage and biodiversity maintenance (Adamus, 1983; Kotze *et al.* 2005; Adamus & Stockwell, 1983).

Wetlands posses special biological (i.e. biota), chemical (soils and water), and physical (i.e. hydrology) characteristics that are closely linked to goods and services (Kusler, 2005). The diversity of wetlands results in ecosystem goods and services varying from wetland to wetland. The importance of a wetland is normally drawn from the goods and services it provides. This indicates that a familiarity with the goods and services provided by a wetland could improve decision making today and protect values for future generations as well. Table 4 highlights the ecosystem goods and services that are important in South Africa.

**Table 4:** Ecosystem services included in WET-EcoServices (Kotze *et al*, 2005).

| | | | | |
|---|---|---|---|---|
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | | Flood attenuation |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | | Streamflow regulation |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | Water quality enhance-ment benefits | Sediment trapping |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | Water quality enhance-ment benefits | Phosphate assimilation |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | Water quality enhance-ment benefits | Nitrate assimilation |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | Water quality enhance-ment benefits | Toxicant assimilation |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | Water quality enhance-ment benefits | Erosion control |
| **Ecosystem services supplied by wetlands** | Indirect benefits | Hydro-geochemical benefits | | Carbon storage |
| **Ecosystem services supplied by wetlands** | Indirect benefits | | | Biodiversity maintenance |
| **Ecosystem services supplied by wetlands** | *Direct benefits* | | | *Provision of water for human use* |
| **Ecosystem services supplied by wetlands** | *Direct benefits* | | | *Provision of harvestable resources*[2] |
| **Ecosystem services supplied by wetlands** | *Direct benefits* | | | *Provision of cultivated foods* |
| **Ecosystem services supplied by wetlands** | *Direct benefits* | | | *Cultural significance* |
| **Ecosystem services supplied by wetlands** | *Direct benefits* | | | *Tourism and recreation* |
| **Ecosystem services supplied by wetlands** | *Direct benefits* | | | *Education and research* |

### 2.3.2 Indirect benefits

An ecosystem goods services provide a variety of benefits to humans. "Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Millennium Assessment, 2005:53). They have been named indirect benefits as their benefits are not felt directly or immediately by the society.

Flood attenuation is a good example of an indirect benefit. Wetlands are capable of slowing down and spreading out floodwaters, thereby reducing costly damage that otherwise might arise to commercial and residential infrastructure downstream (Kotze *et al.* 2005; Mitsch & Gosselink, 1986). Those wetlands with available storage capacity may potentially play a vital role in attenuating floods. This is because such wetlands have the capacity to temporarily store excess water and release it slowly over time, thus buffering the impact of floods (Cronk & Fennessy, 2001).

Flood attenuation could play an important role especially in urban areas where the land is normally dominated by impervious or hard surfaces. Impervious surfaces cause a significant increase in the volume of surface water entering wetlands, thereby increasing the flood peaks. According to Novitzki (1979) it is usually the peak flows that contribute to flood damage. Certain attributes such as the greater sinuosity, gentle slope, size of a wetland, and high surface roughness play a vital role in attenuating floods (Kotze *et al.* 2005). These attributes also contributes in regulating streamflow in wetlands. This possible because through these attributes wetlands delay the time in which water passing the through the system, thus enhance the storage of water and also prolong streamflow during low flow periods (Kotze & Breen, 1994).

Wetlands can maintain good quality water and improve the quality of contaminated water. They can trap, precipitate, transform and remove many of the water-related contaminants, and thus water leaving the wetland is generally cleaner than the water entering the wetland (Mitsch & Gosselink, 1993; Elder, 1987). There are a range of wetland attributes that makes them effective in improving water quality. Wetland vegetation contributes to the natural cleansing of water when incoming suspended solids settle from the water column due to the water velocity reduction found in wetlands (Johnston *et al.* 1984; Fennessy *et al.* 1994). Wetland vegetation further leads to high rates of mineral uptake by vegetation (Kotze, 2000)

In addition, the settling of suspended solids in a wetland can act as a sink for undesirable chemicals and sediments. Its capacity to spread water over a wide area gives enough opportunity for chemical interactions between soil and water (Kotze, 1996b). A variety of anaerobic and aerobic processes that occur in wetland areas, also function to precipitate or volatilise certain chemicals from the water column (Mitsch & Gosselink, 1986). These processes prevent pollutants that would otherwise flow in watercourses. Wetlands could further reduce sedimentation downstream that can result in habitat loss for aquatic life (downstream) and storage capacity in dams Conley *et al.* (1987) regards these problems as major problems in South Africa.

Sediments trapped in wetlands could carry undesirable nutrients such as phosphorus and nitrogen. Therefore wetlands assist in preventing eutrophication of rivers and dams and also improve water quality (King, 2004). Three processes by which nutrients are immobilised or removed from wetland waters are mentioned by Kotze & Breen (1994:5) as follows:

*(1) Accumulation by plants and microorganisms.*

*(2) Sedimentation, and*

(3) *Denitrification and ammonia volatilisation (applicable only to nitrogen)*

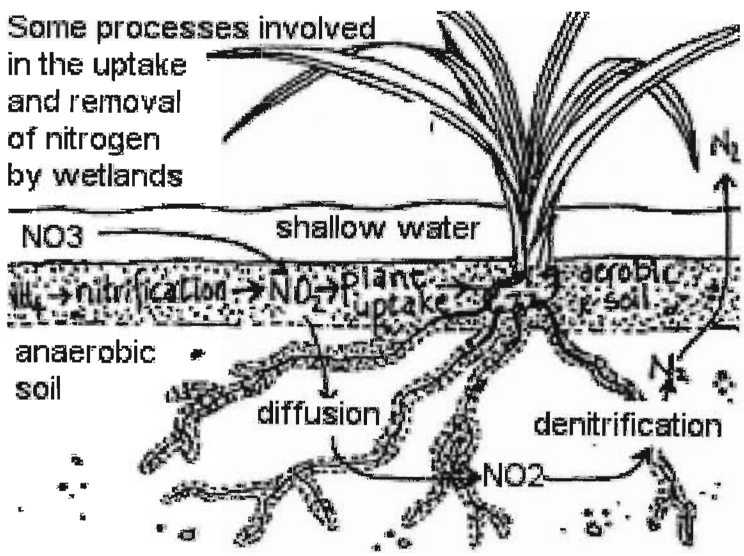



**Figure 3**: The process of denitrification, and the removal of nitrogen from the system by releasing it to the atmosphere (Kotze, 1996b).

The whole process shown above requires the presence of both aerobic and anaerobic substrates in order to take place, and the interface between aerobic and anaerobic substrates is greatly enhanced by the presence of plant roots

(Cronk & Fennessy, 2001). This process of nitrogen removal (denitrification) depends on continuous supply of $NO_3$ (associated with aerobic conditions) to anaerobic areas, and wetlands are suitable sites for this as they posses aerobic and anaerobic areas (Kotze & Breen, 1994).

Like nitrogen phosphorus is also a nutrient identified as pollutant and not required to be present in water courses. Sediments are regarded as carriers of pollutants in wetland including phosphorus; therefore a wetland that is capable in trapping sediments will perform well in assimilating phosphates. Richardson (1985) found that wetland mineral soils can retain more phosphorus than organic soils, thus the ability of a wetland to assimilate phosphorus through sediment trapping would be closely linked to its capacity to trap mineral soils (Hemond & Benoit, 1988).

Water entering a wetland could be caring lot of toxicants such as metals, organic pollutants bacteria and viruses. "A variety of processes including chemical precipitation, adsorption and ion exchange contribute to the effectiveness of wetlands in assimilating different toxicants" (Kotze *et al*, 2005). Water quality improvement provided by wetlands may be important for people who depend on wetlands for domestic water use. In urban areas, water purified by wetlands may also reduce the cost of purifying water that flows to dams.

Wetland vegetation decreases water velocity through friction, thus causing sedimentation and reducing the capacity of the water to detach and carry away sediment particles. This process enables wetland plants to contribute in controlling erosion in wetlands. Plants like *Phragmites australis* for example "have a high capacity of binding sediments as well as recovering rapidly from physical damage caused by flooding" (Kotze & Breen 1994:15). The ability of a wetland to control erosion depends on various factors such as (to name a few) the types of plant involved, the width of the vegetated shoreline band in trapping sediments and the soil composition of the bank (Kotze & Breen, 1994). Kotze *et* *al.* (2005) identified the physical disturbance of the soil and erodibility of the soil as some of the wetland characteristics that exacerbate erosion on site.

Anaerobic conditions present in wetlands slow down the decomposition process of organic matter. Through this process carbon is stored within soil (particularly within organic soil), instead of realising it into the atmosphere as carbon dioxide (Kotze & Breen, 1994). The cumulative effects of storing carbon are an important function within the carbon cycle, particularly given observations of global climate change (Kotze *et al.* 2005).

Section 2.2.3 highlighted plants that grow in a wetland such as reeds, grasses, sedges, bulrushes, phragmites, and woody types. These plants provide food and shelter for many animals (including endangered and threatened species), where some animals depend exclusively on wetlands (Cronk & Fennessy, 2001). Therefore wetlands play an important role in maintaining biodiversity because some of these animals (especially those who are completely dependent on wetlands) would not survive without wetlands. Species such as the white-wing flufftail (*Sarothura ayresi*) and wattled crane (*Bugeranus carunculatus*) are listed as Red Data species.

### 2.3.3 Direct benefits

Direct benefits are normally products that people obtain from the ecosystem. An example of this could be products such as water for human use, cultivated foods and natural resources (Kotze & Breen, 1994). However there are direct benefits such as education and research, cultural significance, and tourism and recreation, which are nonmaterial benefits that a wetland could provide (Kotze *et al.* 2005). The importance of these goods depends on various factors i.e. provisioning of water for human use by a wetland would be expected to be more useful in rural areas than in urban areas. According to Dugan (1990) more than anyone else, poor rural people depend on the life-support functions provided by wetlands, including water, food fibre for crafts and construction, and lands for cultivation.

The state and usage of a wetland system is also important in the provisioning of goods. A wetland, for instance, that supplies water for human use could do that only if the quality and quantity of water supply are adequate and could be used sustainably (Kotze, 2002). A wetland that is not degraded and located in a catchment that does not generate lots of contaminants would be suitable for human use. The supply of water by wetlands could also extend to industrial and agricultural purposes, and this contributes to the economy of the country.

Wetlands are among the most fertile and productive ecosystems in the world (Maltby, 1998). This feature allows people to grow crops in wetlands even in dry seasons. The fact that wetlands are productive ecosystems does not only allow people to cultivate foods, but also support natural resources that could be used to generate income through selling these resources (Dugan, 1990; Pollard *et al.* 2004). Plant species such as the rush *Juncus krausii* and the sedges, *Cyperus latifolius* and C. *textilis* could generate immediate cash returns when used for making handcrafts in South Africa (Nel, 2003). Developing countries like South Africa are in need of natural systems like wetlands to sustain the livelihoods of people. Figure 4 show some common South African wetland plants that are used to provide conference bags, mats and baskets.

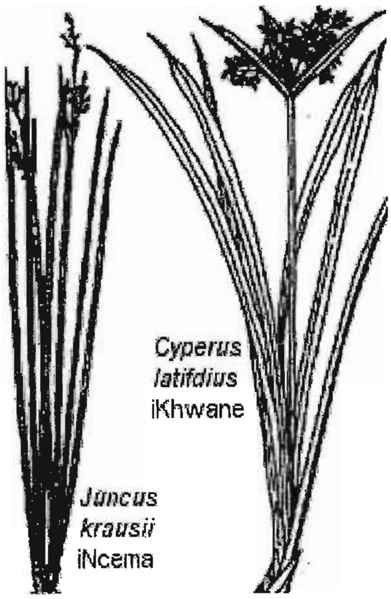



**Figure 4**: Common harvestable plants used to produce craft in South Africa. (Kotze & Breen, 1994).

Wetlands are sometimes used as places where baptisms and cleansing takes place, and thus wetlands could be culturally important for the diverse communities of South Africa. Wetlands provide great diversity and beauty that could be used for visual enjoyment. "Wetlands add to the diversity and beauty of the landscape...and diverse range of colours and textures and some very attractive flowers..." (Kotze, 1996b: 13).

The strategic location of a wetland in terms of catchment hydrology and its characteristics of possessing both terrestrial and aquatic systems make it a good education and research tool (Kotze *et al.* 2005). Through this, wetlands provide excellent and inexpensive education and research laboratories. Their complex ecosystem highlighted by the literature review so far could be used in research projects such as studies on water quality, wildlife, and alien vegetation or any vegetation surveys that could be conducted in a wetland.

### 2.3.4 The link between goods and services and hydrology

Mitsch & Gosselink (1986:104) identified five general principles underscoring the importance of hydrology in wetlands.

(1) *Hydrology leads to a unique vegetation composition but can limit or enhance species richness.*

(2) *Primary productivity and other ecosystem functions in wetlands are often enhanced by flowing conditions and pulsing hydroperiod and are often depressed by stagnant conditions.*

(3) *Accumulation of organic material in wetlands is controlled by hydrology through its influence on primary productivity or decreased decomposition and export.*

(4) *Nutrient cycling and nutrient availability are both significantly influenced by hydrologic conditions.*

(5) *Loss of soil organic matter is controlled indirectly by the effect hydrology has on development of anaerobic soil conditions, which limit decomposition of organic matter.*

Wetland hydrology supports many biogeochemical processes that are associated with some of the ecosystem services. According to Mitsch & Gosselink (1986) nutrients are transported into wetlands by hydrologic inputs such as precipitation, river flooding, and surface and groundwater inflows. One of the important ecosystem services highlighted by the literature in Section 2.3.2 was the removal of nitrogen through biogeochemical transformations. The hydroperiod of a wetland is known to have a "significant effect on nutrient transformations and on the availability of nutrients to vegetation" (Mitch & Gosselink, 1986:83).

Hydrology also has an indirect influence over the supply of goods and services through the effect that it has on wetland vegetation, which has a critical role in the provisioning of ecosystem goods and services. Cronk & Fennessy (2001:62) have identified that "plant establishment is influenced by a number of hydrologic process including inflow rates, water depth, internal flow rates and patterns, the timing and duration of flooding, and groundwater exchanges". Water flowing into a wetland has been implicated as the main transporters of nutrients to wetlands. This process of nutrient movement also enhances primary productivity in wetlands, and non-flowing wetlands have been found to have lower productivities than those open to flooding inflows (Mitch & Gosselink, 1986).

Wetland productivity has some implications in terms of the ecosystem goods and services provided by a wetland. An observation made by Kotze & Breen (1994) was that tall robust vegetation offers more frictional resistance than softer and shorter vegetation. This attenuates floods, and also enhances effectiveness in terms of trapping sediments, as they both depend on velocity reduction. The literature reviewed highlighted the capacity of plants to retain soils thus contributing to soil erosion control and prevention. Carter *et al.* (1978:352) mentioned three roles played by vegetation in wetlands in terms of erosion control. Firstly "it binds and stabilizes substrates", secondly it "dissipates wave and current energy," and lastly "it traps sediments". In many wetlands high plant productivity promotes high rate of mineral uptake by vegetation, thus promoting their water purification value (Collins, 2005).

The important service that wetlands provide as carbon sinks is enhanced through the accumulation of organic matter, which is also influenced by water regime. As stated in section 2.2.2 anaerobic conditions promote the accumulation of organic matter by reducing the rate of decomposition by aerobic microbes.

The effect on wetland goods and services associated with wetland hydrology can be felt in the wetland (on site), as well as across the catchment (off site). The rationale behind this statement is that there is a strong link between wetland hydrology and the catchment processes. Kusler (2005) summarises hydrological process that are related to goods and services both onsite and offsite (Table 5).

**Table 5**: Summary of both onsite and offsite ecosystem goods and services (Kusler, 2005).

| **Functions related to hydrological processes** | **Benefits, Products and services resulting from the wetland function** |
|---|---|
| Short term storage of surface water: the temporary storage of surface water for short periods. | **Onsite**: Replenish soil moisture, import/export materials, and conduit for organisms.<br>**Offsite**: reduce downstream peak discharge and volume, help maintaining and improve water quality |
| Storage of subsurface water: the storage of subsurface water | **Onsite:** Maintain biogeochemical processes.<br>Offsite: recharge superficial aquifers; maintain baseflow and seasonal flow in streams. |
| Long-term storage of surface water: the temporary storage of surface water for long periods. | **Onsite:** Provide habitat and maintain physical and biogeochemical processes<br>**Offsite:** reduce dissolve and particulate loading, help maintain and improve surface water quality. |
| Dissipation of energy: the reduction of energy in moving water at the land/ water interface. | **Onsite:** Contribute to nutrient capital of ecosystem.<br>**Offsite:** Maintain or improve surface water quality |
| Export of organic carbon: the export of dissolved or particulate organic carbon.<br><br>Maintenance of plant and animal communities: the maintenance of plant and animal community with respect to species composition, abundance and age structure. | **Onsite:** Enhances decomposition and mobilization of toxicants.<br>**Offsite:** support aquatic food webs and downstream biogeochemical processes.<br>**Onsite**: Maintain habitat for plants, animals and agriculture products, and aesthetics, recreational and educational opportunities.<br>**Offsite**: Maintain corridors between habitat islands and landscape/regional biodiversity. |
| Retention of particulates: the retention of organic and inorganic particulates on a short term and long-term basis through physical processes, provided by plants. | **Onsite:** Contributes to nutrient capital or ecosystem<br>**Offsite:** reduced downstream particulate loading helps to maintain or improve surface water quality. |
| Biochemical reactions | **Offsite:** Reduced downstream loading helps to maintain or improve surface water quality. |
| **Functions related to biogeochemical process** | **Benefits, Products and services resulting from the wetland function** |
| Cycling nutrients: the conversion of elements from one form to another through biotic process | **Onsite:** Contributes to nutrient capital or ecosystem.<br>**Offsite:** Reduced downstream particulate loading helps to maintain or improve surface water quality. |
| Removal of elements and compounds: the removal of nutrients, contaminants or other elements and compounds on a short-term or long-term basis through burial, incorporation | **Onsite:** Contributes to nutrient capital of ecosystem.<br>Contaminants are removed or rendered innocuous. |

## 2.4 A Conceptual framework linking wetland rehabilitation and the retrieval of ecosystem goods and service

To understand the rehabilitation of wetlands and associated processes a conceptual model has been developed. The rehabilitation process is the prime concern for this study as shown in the framework (Figure 5). The ultimate goal of most rehabilitation project is to re-establish wetland hydrology as it will secure the structure and functioning of a wetland. Wetland hydrology would help in facilitating some of the processes such as nitrate removal (denitrification) that results from the formation of anaerobic conditions due to prolonged saturation. It will further contribute in supporting plant growth in wetlands. The rehabilitation processes should be able to allow the accumulation of organic matter that will, in turn, increase wetland productivity and health (Pollard *et al.* 2004). When all the above variables are enhanced, this would allow biological, chemical and physical processes to interact so as to provide ecosystem goods and services. That is what the literature refers to as a self-sustaining system.

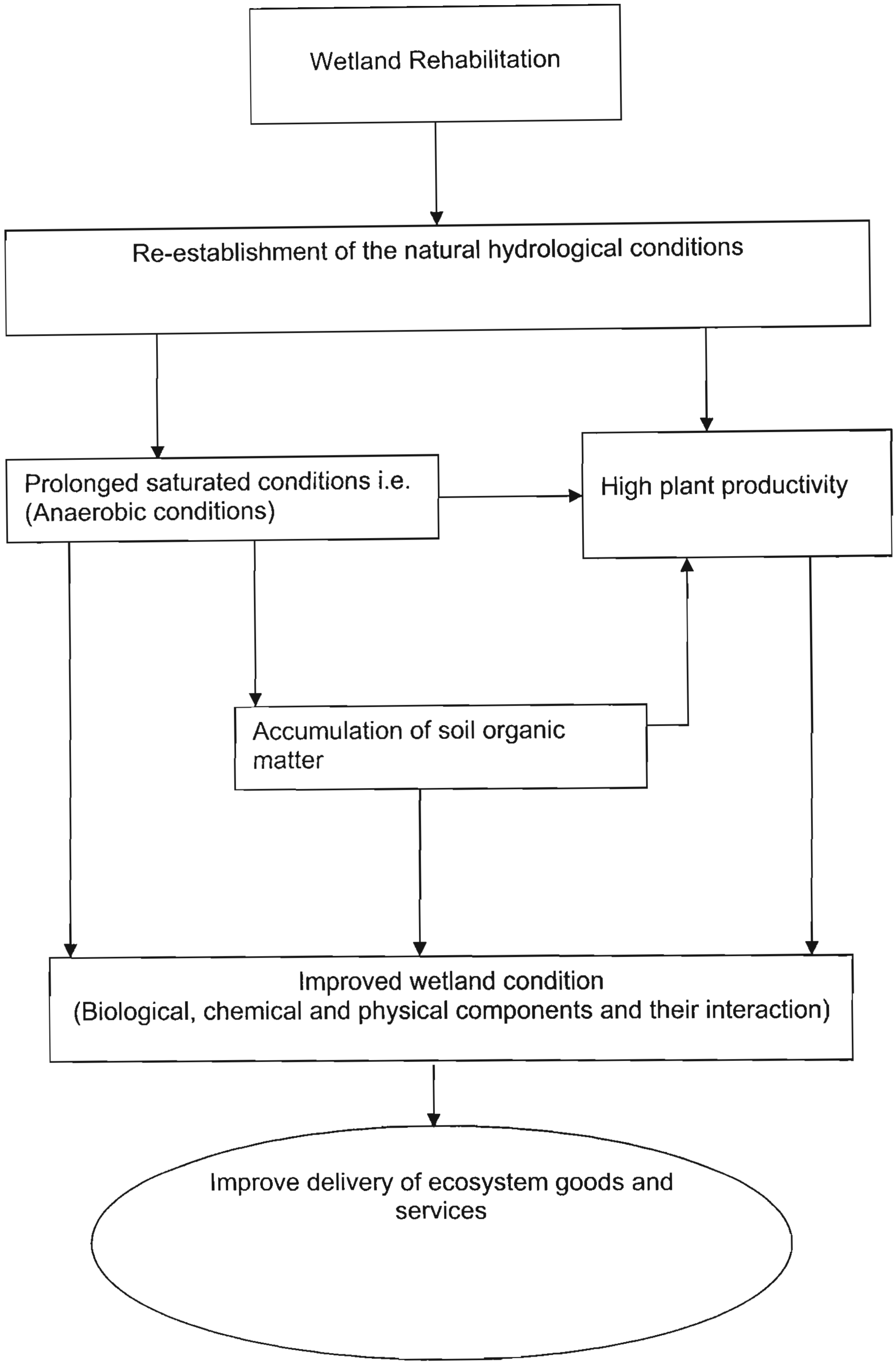



**Figure 5:** Conceptual model linking wetland rehabilitation with the delivery of ecosystem goods and services through wetland hydrology

## 2.5 Degradation of wetlands

Wetlands are sensitive ecosystems, and being sensitive means that any small changes in water availability, soil disturbance, or influx of pollutants could have negative impacts on wetland functions. Like any system, when negatively affected, a wetland would not perform its normal functions when degraded. Wetlands are among the most impacted and degraded of all ecological systems. A global overview indicates that many wetlands have been lost historically and the remaining ones are degraded or under threat of degradation (Finlayson & Spiers, 1999). This portion of the study will briefly look at three categories of wetland alterations namely physical, chemical and biological alterations. These categories sometimes overlap and they all tend to affect hydrological conditions of a wetland.

### 2.5.1 Physical degradation

Physical alteration has been regarded as the most destructive alteration to wetlands (National Research Council (NRC), 1992). Excavation, clearing, diverting or withholding sediment, drawing and filling of water have been identified as some of the common physical disturbances in wetlands (NRC, 1992). In South Africa, erosion head cuts are one of the key threats to the geomorphic integrity of wetlands, and have particular relevance to the management and structural rehabilitation of wetlands (Macfarlane *et al.* 2005). There are various causes of gully erosion and also factors that allow the process to propagate. According to Kotze & Breen (1994) wetlands under high grazing pressure together with soils having high erosion hazard and steep slope are most vulnerable to excessive erosion. These conditions might further contribute to the speed at which the gully propagates upstream. The advance of such a 'nick point' (headcut) may lead to extensive gully erosion in the wetland and a significant reduction in its integrity in the future (Macfarlane *et al.* 2005).

Most of the mentioned physical disturbances tend to impact negatively on wetland hydrology. Tiner (1984) identify agricultural practices as the greatest cause of historical loss of wetlands globally. This could be due to the fact that wetlands generally provide moist soils even in dry seasons; therefore they provide a good environment for cultivation at almost all times. Wetland soils also tend to be more fertile than the adjacent dryland soils because they tend to act as sinks to nutrients (Scotney & Wilbey, 1983). However, most conventional crops are not adapted to being water logged conditions, and thus wetlands are often drained to grow those crops (Kotze, 1996b).

Draining of wetlands could also result in disturbances such as erosion or sedimentation. It also results in reduced flood attenuation capacity due to the reduced capacity to detain stromflows (e.g. because of the removal of vegetation with a high frictional resistance Mashinini-Lefothane, 2002)

Furthermore, hardened surfaces in urbanised catchments and degraded agricultural lands increase the rate of delivery of stormflows to wetlands. According to Kotze & Breen (1994) huge amounts of water that are delivered to wetlands during flood peaks, particularly from the impervious urban surfaces, may result in increased levels of erosion. Increased peak flows also "transport more sediments to wetlands that, in turn may alter the wetlands vegetation communities and impact on animal species dependent on the vegetation" (Horner *et al.* 2001)

### 2.5.2 Chemical degradation

Chemical degradation tends to impact negatively on the water quality of a wetland. For chemical alterations to be present in a wetland there should be a source of those chemicals in the wetland's catchment. This makes fertilised lands, landfill sites or urbanised environments prime candidates releasing toxicants to wetlands. Horner *et al.* (2001) observed that increased sediments, metals and toxicants are high in wetlands receiving wastewater or storm water, especially in urbanised catchments and in catchments that are intensively used for agriculture.

### 2.5.3 Biological degradation

Biological degradation of wetlands could result from physical and chemical degradation. NRC (1992) identifies biological alteration as the result of the consumption and compaction of vegetation by animals (through grazing) or disruption of natural populations by human beings. The literature review highlighted that wetlands could provide natural resources that could be used for firewood and crafting. However, "If harvesting is beyond the resource's capacity for renewal, resource degradation will occur and the benefits derived by the users will be lost" (Kotze, 1996b: 19).

As a result of disturbance and habitat degradation, wetlands could also be invaded by non-native plants (NRC, 1992). Wetlands situated in urban areas are more vulnerable to biological alterations than wetlands found in rural areas. Mashinini-Lefothane (2002) also confirms that urban wetlands are more vulnerable to alien vegetation encroachment due to the disturbance through construction of roads, channels, parking lots and buildings. Non-native plants may be problematic especially when they dominate or out-compete the natural species. High nutrient levels generated from the catchment could also cause wetland degradation (e.g. by favouring one or two species such as *Typha capensis*).

## 2.6 Wetland rehabilitation and its relationship with hydrology and ecosystem goods and services

### 2.6.1 Rationale for wetland rehabilitation in South Africa

South Africa is a water-scarce country, thus faces a huge problem when it comes to water resources management. However, Section 2.3 shows that wetlands potentially have significant contribution in addressing these problems. Ecosystem goods provided by wetlands have been shown to range from food supplied to the generation of income for rural communities through the sale of natural resources. It should be noted that one of the greatest challenges South Africa faces is rural poverty. HSRC (2005) identified that rural communities have the highest rate of poverty in South Africa, and lack of education and monthly income are identified as some of the causes of poverty in rural areas. Therefore the provision of ecosystem goods and services that wetlands provide, particularly in rural areas, could contribute to human development in South Africa.

Although no systematic national survey of wetland loss has been undertaken in South Africa, studies in several major catchments have revealed that between 35% and 50% of the wetlands, and the benefits they provide, have already been lost or severely degraded (DWAF, 2004). Furthermore, there is a possibility that up to half of the wetland surface in South Africa has been lost or severely degraded as a result of socio-economic pressures (including water abstraction, drainage, mining, overgrazing, cultivation, sewage waste disposal, or infilling wetlands for land reclamation purposes) (DWAF, 2004). It is clear then that some of the benefits of wetlands have been lost due to the above activities that took place without proper management of wetlands or over use of wetland goods and services. As a signatory to the Ramsar convention, South Africa is obliged to show its commitment to the requirements of the convention through the wise use, conservation and management of wetlands (DWAF, 2004). Consequently there is a need to rehabilitate lost wetlands in order to retrieve goods and services. Rehabilitation refers to "a series of actions promoting the reinstatement of the wetland's underlying forces to a level close to the original system (but seldom fully attaining it) so as to improve the wetland's capacity for providing services to society" (Nel, 2003).

### 2.6.2 Integrating principles of rehabilitation and wetland hydrology.

The literature review thus far has identified that wetlands provide very diverse and important ecosystem goods and services. This shows that existing wetlands should be properly managed while rehabilitating degraded or lost wetlands. For successful rehabilitation there should be clearly understood guidelines or rehabilitation principles. Rehabilitation is not an easy task as it strives to "achieve a persistent, resilient system that is largely self-maintaining and can respond to change with little human intervention" (Nel, 2003). The interventions employed should aim to improve the system and allow the system to persist after correct interventions. This can happen only if the interventions are drawn from relevant rehabilitation principles or guidelines.

The National Research Council (NRC, 2001, 1992) highlights several recommendations and techniques that could be used to improve a wetland rehabilitation project, and they are as follows.

(a) *Hydrological variability is important in the structure and functioning of created and restored wetlands.*

(b) *A broad range of functions should be both required and measured for mitigation projects.*

Therefore the techniques for restoring wetlands should be:

(c) *re-establishing or managing wetland hydrology,*

(d) *re-establishing and managing native biota (may include control of nuisance species), and*

(e) *elimination or controlling chemicals or other contaminants affecting wetlands.*

The NRC principles and techniques seem to concentrate on important variables such as wetland functioning and hydrological variables. The above recommendations recognise the importance of wetland hydrology, which is central to many of the functions and processes in a wetland. Rehabilitation principles may be drawn from the type of degradation that occurred (NRC, 1992). This means that the disturbances of a wetland will inform the principles or rehabilitation guidelines. Wetlands appear in different types and they can even be defined differently. However, common features will always be present in any wetland across the world, and those common features will include hydrophytes, hydric soils and the availability of water in the wetland. This shows that rehabilitation principles should not differ that much when common features in a wetland should be restored. Braack *et al.* (2000), identified principles for successful wetland rehabilitation that are relevant in the South African context, as follows:

a) *Remove the cause of the damage, not the symptoms and manage the resource correctly.*
b) *Re-establish the natural water flow patterns within the wetland*
c) *Do not concentrate water always try and spread it out, this should reduce the possibility of erosion occurring.*
d) *Do not underestimate the force of the water during high flow periods.*
e) *Many wetland soils are highly erodible, be aware of this when designing structures.*
f) *Stabilising the problem area and maintaining the present condition of the wetland or reclaim the wetland area that has been lost.*

The most common feature of wetland rehabilitation principles between the NRC and Braack's principles is the re-establishment of hydrology or water flow in a wetland. This highlights that hydrology is central to all wetland rehabilitation projects across the world indeed; Cronk & Fennessy (2001), regard natural hydrology as the most important aspect of wetland rehabilitation and call for sufficient water flow that would maintain hydric soils and hydric vegetation. However, Cronk & Fennessy (2001:326) have two concerns about rehabilitation projects, namely: "can we duplicate the many complex functions of natural wetlands"? and "is it possible to recreate in a short period of time ecosystems that have taken centuries or longer to develop?" These concerns indicate that as much as we can manage to rehabilitate degraded wetlands, there is a need to protect wetlands that have not been degraded.

Retrieval of wetland "hydrology may involve providing or removing control structures in order to re-establish water flow or flooding regimes" (Cronk & Fennessy, 2001:326). The role played by hydrology in wetlands is so central in a sense that a lot of important variables could not be retrieved if hydrology is not restored. Hydrological rehabilitation often involves raising the water table that has been lowered through degradation. According to Pollard *et al.* (2004) raising the water table will contribute to restoring wetland functionality, and rehabilitation interventions should minimize groundwater loss from the wetland.

The literature reviewed so far regards a 'self-sustaining' ecosystem as critical in terms of rehabilitation. However the NRC (1992) sees management (or control) strategies as necessary in the initial phase of rehabilitation. Furthermore, strategies like stabilizing hydrology may be necessary to assist in the re-establishment of plant communities within a wetland (NRC, 1992). A large proportion of ecosystem goods and services depend on high plant productivity in a wetland, and therefore plant retrieval is critical in wetland rehabilitation. The desired ecosystem may lie in the introduction of additional planting during rehabilitation (NRC, 1992).

### 2.6.3 Linking hydrology and offsite activities in rehabilitation.

Wetlands are strongly affected by processes in their upstream catchments, and normally these processes are influenced by human activities. Thus wetland rehabilitation often needs to extend beyond just interventions within the wetland to include appropriate interventions in the wetland's catchment. As stated by Pollard *et al.* (2004: 53) "the isolated rehabilitation of wetlands without consideration of the role of the upstream catchment and in the functioning, formation and maintenance of these will result in failure". This shows that wetland rehabilitation should incorporate offsite rehabilitation strategies that would supplement the work done onsite. Pollard *et al.* (2004) highlighted a few catchment and wetland characteristics that must be taken into consideration when drafting a rehabilitation plan:

a) *The micro-catchment area has to allow rainwater to infiltrate, to slowly release this water subterraneously into the wetland and to have erosion from surface runoff reduced to the best minimum.*
b) *The wetland should have the capacity to receive both catchment and incident water without being eroded, hold excess water and release it slowly into streams.*
c) *The wetland must have capacity to accumulate organic matter.*
d) *The wetland needs to be able to receive and accommodate soil and solute eroded from the micro catchment area, and prevent scouring and gullying, reducing siltation in the stream.*
e) *The critical balance between inputs and outputs – water, nutrients and soil has to be maintained.*

Almost all the above characteristics are important in the successful retrieval of wetland hydrology. The first two characteristics are concerned with increased runoff volumes and the velocity with which water flows to a wetland. These two variables may have a significant contribution in terms of erosion control and accumulation of plants in a wetland.

Institutional setting may also play a major role in indirectly affecting wetland hydrology, both onsite and offsite. Wetland users, or landholders may need training or guidance on how to use wetlands effectively after rehabilitation (or even before rehabilitation), and that relates to the local institutions responsible. Therefore, rehabilitating wetland hydrology must be incorporated institutionally in the area under rehabilitation.

#### 2.6.4 Linking wetland rehabilitation with ecosystem goods and services.

A wetland rehabilitation goal could be trying to retrieve the functionality of a wetland either by trying to retrieve the natural state of a wetland or stopping any threat considered likely to compromise wetland health in future. Due to the cost associated with wetland rehabilitation projects, retrieval or securing of ecosystem goods or services should be achieved. Thus, it will be very useful to set rehabilitation goals according to ecosystem goods and services of a wetland.

The literature highlighted hydrology as a prime concern in any rehabilitation project. Re-instating natural flows would generally bring back services such as nitrogen assimilation and organic matter accumulation, which plays a major role in soil cohesiveness and thus contributes to erosion control and carbon storage.

In addition, re-establishment of plant communities through reinstatement of wetland hydrology is a crucial strategy during rehabilitation. This is due to the fact that most of the services such as flood attenuation, and sediment trapping and erosion control are highly dependent on the high density of plants. Plant communities also depend largely on the availability of the water table in a wetland. Thus ignoring the water table during rehabilitation could compromise plant growth.

Rural communities are often the greatest beneficiaries of the ecosystem goods and services provided by wetlands, particularly in terms of the provision of food security, which is needed in developing countries like South Africa where there are high levels of poverty. As pointed out by Pollard *et al.* (2004) there is no system (biophysical or social), that exists in isolation, and the development of a rehabilitation plan should not render people's livelihoods more vulnerable. An example of a rehabilitation plan that could sacrifice people's livelihood is one that severely limits access to a wetland after rehabilitation. This shows that there is a need for research before a rehabilitation plan is done, and affected communities should always be involved in rehabilitation projects.

Wetlands could provide harvestable natural resources that could generate income and sustain livelihoods of the people using the system. Rehabilitation projects such as re-vegetation of a wetland should find out about useful plants that are used by people to generate income. Re-establishment of wetland hydrology could also play a crucial role in support of water for human use. It could further support provision of cultivated foods and harvestable resources. Successful rehabilitation, where wetland plant communities are restored and then animal species are also retrieved, could play a role in education and research.

# CHAPTER 3

# STUDY SITES AND METHODS

## 3.1 Description of Site 1

Site 1 refers to a wetland that is situated in KwaZulu Natal Province in the city of Pietermaritzburg and the residential area of Pelham (29° 37 9`S and 20° 23 9`E). The catchment where this wetland is found is highly urbanised, and constitutes a middle class population, where there is a 100 percent access to basic services such as water, electricity, and sanitation. The wetland's hydro-geomorphic type is a channelled valley bottom, which has implications in respect of some of the services provided by this wetland. The main source of water feeding this wetland is a storm water drain that collects water from the roads and other storm water drains. An aerial photograph (Figure 6) illustrates the catchment land use and the location of the wetland within the catchment.


**Figure 6:** An illustration of the catchment land use and location of the Pelham wetland in its catchment.

### 3.1.1 Background of site 1 before rehabilitation

According to the principal of the Pelham primary in the vicinity of the Pelham wetland Mr Botha, the area served mostly as an illegal dumping zone and was not used for education or recreation (Botha, Pers.Comm.). He further highlighted that the area was mostly characterized by alien invasive species. The storm water drainage that cut through the Pelham area prevented runoff spreading across the wetland and also carried all sorts of litter that would be expected from a storm water system in a residential area. Because the site did not possess most of the wetland characteristics, it also lacked flood attenuation capacity and this, according to local knowledge (Botha, Pers.Comm.), had resulted in flooding of roads down stream of the wetland.

### 3.1.2 The site after rehabilitation

Based on the initiative of a local primary school principal (Mr Botha), the site was adopted under the 'Adopt a Spot' programme. The 'Adopt a Spot' programme promotes the adoption of any open space area by public or private organisations and civic sector partnership, in order to deal with problems such as litter, illegal dumping or alien vegetation on public sites. Through this programme members of the public voluntarily accept the responsibility to look after a specifically identified area.

The first step was to develop a clearly defined buffer zone for the wetland. The school started four phases of development namely: acquisition of tennis courts, development of a soccer field, acquisition of a local scout hall and the adoption of the spot for conservation purposes (Botha, Pers.Comm.). Although the tennis courts were for the school's recreation purposes, the local community members were also allowed to use them. This, according to Botha (Pers. Comm.), was a deliberate attempt to win support from the local community in future endeavours that the school would embark on.

Conservation in this wetland was enhanced through rehabilitating a previously neglected wetland area as well as rejuvenation of surrounding land (buffer zone). This buffer zone includes a soccer field that forms part of a grassland area next to the wetland. The rehabilitation on site was mainly removing alien vegetation and replacing them with indigenous tress. However, for biodiversity maintenance and for school learners to learn about alien plants, the removal of alien plants was not done all at the same time. Neighbouring residents who form part of the wetland's buffer zone also adopted the process of alien removal. Revegetation of indigenous trees and hydric plants that were found in a wetland area were not enough to stop the high intensity runoff from the storm water drain.

A pond was then built to form a depression that would store floodwaters, trap sediments and also provide habitat for fish and other wildlife. The depression (pond) is the most saturated portion of this wetland. Figure 7, which was the depression (pond) that was partly formed in the wetland by rehabilitation.

**Figure 7**: A photograph of the pond that was created at the Pelham wetland.

## 3.2 Description of Site 2 and Site 3

The Craigieburn wetland (24° 40' 83"S and 030° 58' 610"E) is situated in the northeastern region of South Africa in the Limpopo province. The Craigieburn wetland is located in the Lowveld in the Sand River catchment (Figure 8), which is one of the rivers flowing to Kruger National Park (Pollard *et al.* 2004). The area is characterised by periodic drought and receives 700mm of rain annually (King, 2004). Besides being part of the rivers that flows to the park, the wetland is also important as it is in the headwaters of the river, and according to Pollard *et al.* (2004) the entire catchment relies in the wetland and streams for its water supplies. Craigieburn is characterised by communal lands where the access to water is still not effective and the region is economically deprived. Pollard *et al.* (2004) also highlighted the fact that most families rely on income from pensions or wage remittances. The situation in the region makes the wetland a potentially important resource that could be useful in the livelihoods of the communities in the area.

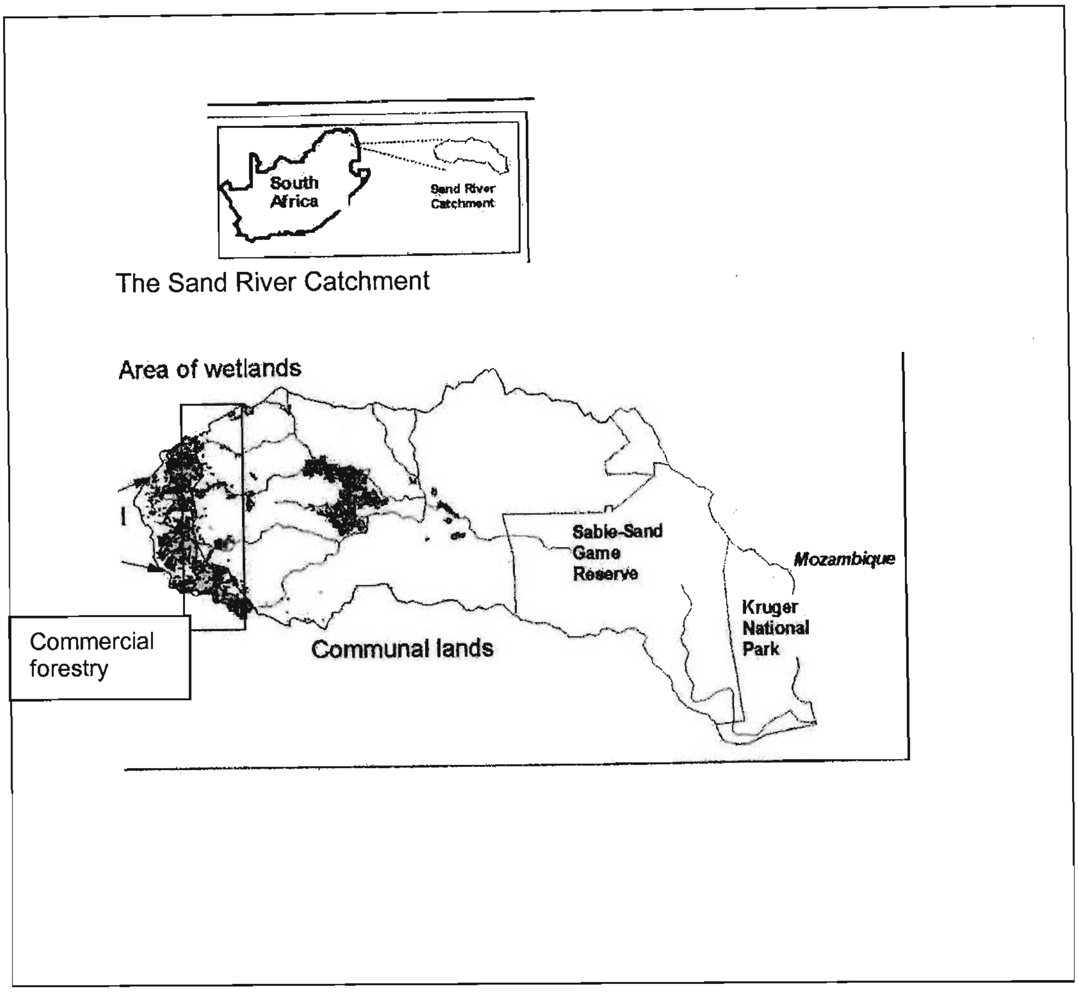



**Figure 8:** The Sand River Catchment and the region in the catchment where the wetland is situated (Pollard *et al.* 2004).

The wetland consists of two main parts, the upper wetland portion (portion 1 of Craigieburn) that forms the wetland's head, and the lower wetland portion (portion 2 of Craigieburn) extends narrowly along the valley. The hydro-geomorphic type of portion 1 of Craigieburn is an un-channelled valley bottom and portion 2 of Craigieburn is a channelled valley bottom, and the two portions are separated by a deeply incised gully. Thus, the two portions were assessed as two separate units. The wetland's head starts from the surrounding hill slopes and extends along the valley where it forms a narrow valley and the valley gradually deepens and narrows over a distance of 200m from the head of the wetland (Pollard *et al.* 2004).

The preliminary work that has been done in the Sand River catchment shows that over the past 15 years there have been a significant reduction in base flow (low flow) of the Sand River (Pollard *et al.* 2004). Pollard *et al.* (2004) regards this as result of inappropriate commercial forestry that is found in the upper catchment. According to Pollard *et al.* (2004), the unemployment rate in the area ranges from 40% to 80% and an estimated 55% of the population are women, heading 30% of the households. Due to this socio-economic situation there is a high reliance on the natural environment of the area. The high human density found in the catchment and the high level of agriculture, which is necessary for survival, puts the environment under huge pressure.

### 3.2.1 Farming and land tenure

The wetland has a higher fertility and higher soil moisture than the surrounding landscape, even in dry periods. This makes it feasible to cultivate throughout the year. The variety of cultivated crops supplied by this wetland is shown in a Table 6.

**Table 6:** Some wetland products from Craigieburn (Pollard *et al.* 2004).

| **Cultivated crops** |
|---|
| 1. Madumbes *(Colocasia esculenta)* |
| 2. Maize (*Zea mays* ) |
| 3. Morogo *(Greens)* |
| 4. Beans (*Phaseolus spp.*) |
| 5. Bananas = *Musa acuminata; Musa balbisiana* (hybrid) |
| 6. Sugarcane = *Saccharum giganteum* |
| 7. Ditshekge *(a traditional root vegetable)* |

Most of the farming taking place in the wetland is through raised beds that are prepared by clearing the wetland vegetation and then piling the soil together to form a raised bed surrounded by a narrow canal like a depression. Women cultivate most of these beds, although there is no formal legal ownership of the land in the wetland. The only way of indicating the land of a landholder was through fencing, which was observed during the field survey.

### 3.2.2 Degradation

As indicated, separating portion 1 and portion 2 of Craigieburn is a deeply incised erosion gully, which according to Pollard *et al.* (2004) is 35m wide and 6m deep. The head-cut of this gully continues to erode in an upstream direction, and threatens to severely erode this unit. Figure 9 shows this headcut.

**Figure 9:** The nick point at the head of the gully that separates portion 1 and portion 2 of the Craigieburn wetland.

Portion 2 of Craigieburn is also affected by a headcut that is found at the down stream end of this portion (Figure 10). This large headcut is eroding very actively and threatens the entire wetland.

**Figure 10:** The second head cut at the downstream end of portion 2 of the Craigieburn wetland.

Portion 2 of Craigieburn is also affected by a headcut that is found at the down stream end of this portion (Figure 10). This large headcut is eroding very actively and threatens the entire wetland.

**Figure 10:** The second head cut at the downstream end of portion 2 of the Craigieburn wetland.

## 3.3 Methods

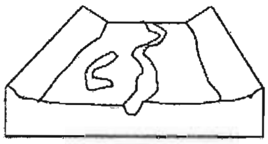
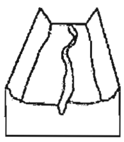
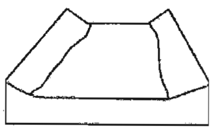
Assessment of wetlands is one of the ways of developing critical information that is needed for decision-making such as rehabilitation, conservation, management etc. Development of this information through assessment can be rapid and inexpensive. Kusler (2005) defines assessment as the identification of the status, and threats, to wetlands as a basis for the collection of more specific information through monitoring activities. All the wetlands in this study were assessed using a new South African functional assessment tool called WET-EcoServices. WET-EcoServices is useful in evaluating or assessing wetland ecosystem goods and services and predicting any potential changes to a wetland's function that may be caused by proposed activities, and it is also useful in assessing the success of wetland rehabilitation projects (Kotze *et al*, 2005).

Furthermore, the tool develops a functional index based on combining variables that are typically physical measures (e.g. longitudinal slope of the wetland) or indicators that are associated with one or more ecosystem functions. For example, indicators such as wetland slope, surface roughness, size of the wetland relative to its catchment, and sinuosity of the stream channel, are associated with the capacity to attenuate floods (See Appendix C) (Kotze *et al*, 2005).

### 3.3.1 Desktop analysis

Using Table 7 the wetland's hydro-geomorphic types were identified. Looking at the topography, inflow and outflow of water and the presence or absence of a channel in the wetland, the hydro-geomorphic type that best described the wetland in question was identified from Table 7. The desktop analysis was supported by the interpretation of 1:10 000 orthophotos, available for site 1 (Pelham Wetland), and aerial photographs of a 1:30 000 scale also for site1. The nature and the extent of different types of land use offsite and onsite were identified. Physical characteristics such as the extent of vegetation cover, extent of erosion and sedimentation, changes in flow regime and inundation, were also determined. The slope of the wetland and the catchment (as the slope is related to some services), together with the wetland size in relation to the wetland's catchment were also determined using aerial photographs. For the both portion 1 and 2 of Craigieburn, some of the existing information such as wetland slope was gained from an existing study done by Pollard *et al.* (2004). All this information was used to build a basic understanding of the wetland that would be useful in the rapid field assessment.

**Table 7:** Wetland hydro-geomorphic types typically supporting inland wetlands in South Africa *(Kotze et al. 2005).* Symbols in the last two columns are: *Contribution usually small ***Contribution usually important */*** Contribution may be small or important depending on circumstances.

| Hydro-geomorphic types | Description | Source of water maintaining the wetland | |
|---|---|---|---|
| | | Surface | Sub-surface |
| *Floodplain*  | Valley bottom areas with a well defined stream channel, gently sloped and characterized by the alluvial transport and deposition of material by water, and oxbow depressions or other characteristic floodplain features such as natural levees. | *** | * |
| *Valley bottom with a channel*  | Valley bottom areas with a well defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterized by the alluvial transport and deposition of material by water or may have steeper slopes and characterized by the loss of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes. | *** | *** |
| *Valley bottom without a channel*  | Valley bottom areas of low relief, alluvial sediment deposition and having no clearly defined stream channel. Water inputs mainly from channel entering the wetland and also from adjacent slopes. | *** | */ *** |
| *Hillslope seepage feeding a stream*  | Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from subsurface flow and outflow via a well defined | * | *** |
| *Hillslope seepage not feeding a stream*  | Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from subsurface flow and outflow either very limited or through diffuse subsurface and/or surface flow | * | *** |
| *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. | */ *** | *** |

### 3.3.2 Field Survey

The desktop phase was followed by a rapid field assessment phase. It is also the primary source of first hand information that forms the basis of the assessment. The presence of hydrological zones was determined by selecting transects that cut across the wetland at approximately 100 m intervals. Transects were divided into segments based on the degree of wetness (i.e. temporary, seasonal and permanent) that took place along transect. Determining the degree of wetness was based on a description of soils and hydric vegetation (described below). All transects were started from the boundary of the wetland and continued to the other boundary on the opposite side of the wetland. The length of each segment in transects was determined using a tape measure. Figure 11 shows the location of transects at Site 2 and 3 (Craigieburn wetland) and the same procedure was applied at Site 1 (Pelham wetland).

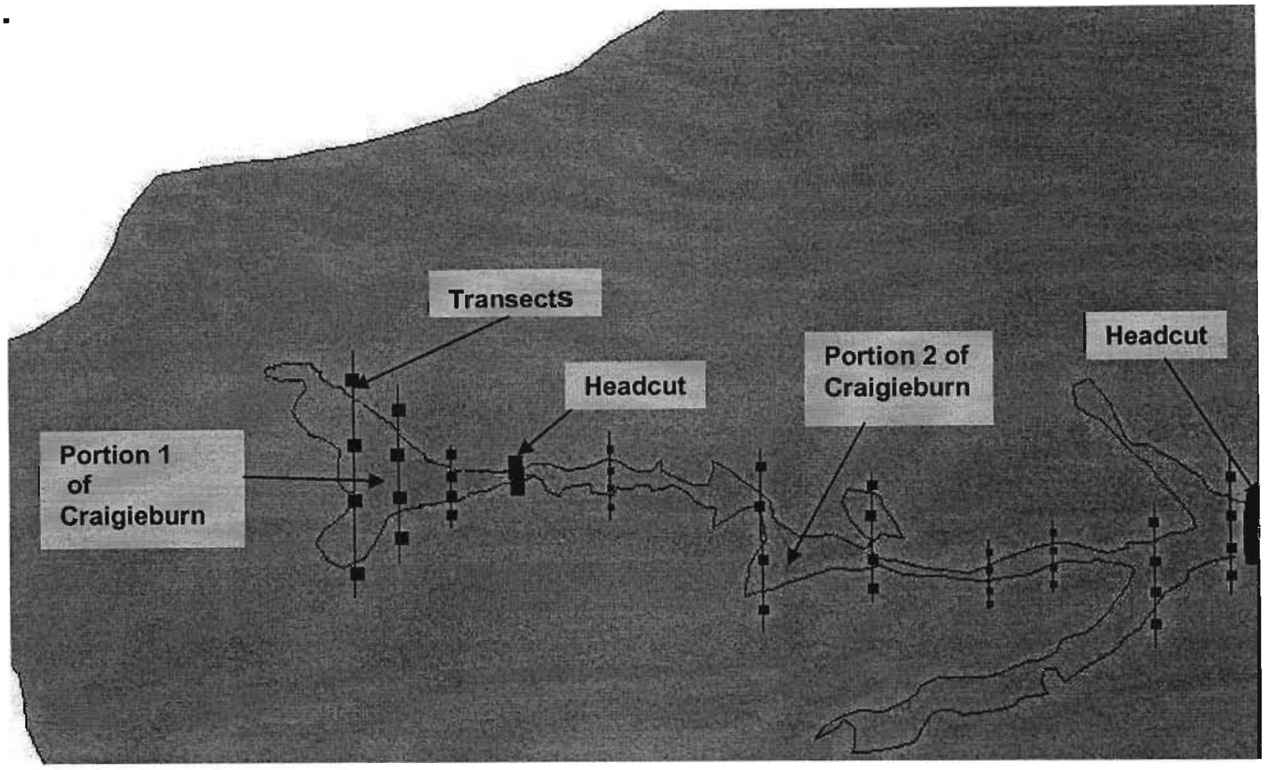



**Figure 11**: Location of transects that cut through Craigieburn wetland.

For each segment delineated, the plant species dominating in terms of aerial cover were identified and then the total aerial cover provided by the vegetation was estimated. The overall aerial cover for the wetland was determined based on a weighted average percentage for all the segments combined. The data on plant species composition was recorded to determine the extent of hydric vegetation abundance, and dominance. The plant assessment further included identifying alien species onsite and indigenous trees that were planted. This was done concurrently with the determination of the hydric character of the soil that was used to indicate wetness character of the soil. This soil wetness character was determined by interpreting soil morphological features such as chroma of the soil matrix, and intensity and depth of mottling of the soil (Kotze *et al.* 1996).

Characterizing soil wetness and describing hydric vegetation was also useful in identifying the boundary of the wetland. Soil samples were collected using a Dutch screw auger to a depth of 0.5 m. To measure the water table, the auger hole was continued until water was encountered, and, after allowing the level to equilibrate, the depth of the water table from the soil surface was measured. The hydric character of the soil and vegetation were used to assign each segment in the transects according to its degree of wetness, i.e. temporarily wet, seasonally wet, permanently/semi-permanently wet, and non-wetland with reference to Table 1 and Table 2.

In addition, for each soil sample described, a rapid field assessment was further conducted to determine if the soil was peat by squeezing it in the hand and checking to see if clear water was expressed, leaving the hand still fairly clean, which indicates the presence of peat. The water table was measured at three locations down the length of the wetland, for each at the lowest point in the valley cross section, but outside of a channel, if present. In a cultivated wetland with raised beds, the heights of raised beds were measured and their wetness zone was determined. The orientation of raised beds, which influences the way water flows in a wetland, was also noted. During the course of the field survey, erosion features such as gullies were also noted. All this information is shown in Appendix A and B.

Local knowledge (land users or local service providers) and existing reports (especially Pollard *et al.* 2004) were used to provide insight into the characteristics of the wetland. The local knowledge was also used to provide the historical background of a wetland that could not be observed during field survey, and the uses (especially goods) of a wetland to local people.

### 3.3.3 Scoring the importance of ecosystem goods and services

All the information collected in the desktop analysis and field survey was then integrated in a WET-EcoServices assessment and used to determine the level of delivery of ecosystem goods and services. The following ecosystem goods were assessed: harvestable resources, cultivated foods, water for human use, cultural significance, tourism and recreation, and education. Also, the following services were assessed: flood attenuation, streamflow regulation, sediment trapping, phosphate and nitrate assimilation, toxicant assimilation, erosion control, carbon storage and biodiversity maintenance.

Ecosystem goods and services were scored following the guidelines given in WET-EcoServices. The scoring system depended largely on the characteristics of a wetland that are indicators of a particular ecosystem service (See Appendix C). Each characteristic relevant to a particular ecosystem service was rated from 0-4 depending on its value. The total score was determined based on the average score for all the relevant characteristics. An example of the scoring system used in WET-EcoServices is illustrated in Table 5.

**Table 8:** The scoring systems of two hypothetical wetland units for the wetland benefit "flood attenuation" based on an abbreviated list of characteristics (Kotze *et al.* 2005).

Wetland unit A

| **Wetland characteristics** *Score:* | *0* | *1* | *2* | *3* | *4* |
|---|---|---|---|---|---|
| *Effectiveness of the wetland* | | | | | |
| Size of wetland unit relative to the wetland unit's catchment | <0.5 % | 0.5%-5% | 0.6-4.9% | 5-10% | >10% |
| Slope of wetland unit | >5% | 2-5% | 1-1.9% | 0.2-0.9% | <0.2% |
| Surface roughness of wetland unit | Low | Moderately low | | Moderately high | High |

Wetland unit B

| **Wetland characteristics** *Score:* | *0* | *1* | *2* | *3* | *4* |
|---|---|---|---|---|---|
| *Effectiveness of the wetland* | | | | | |
| Size of wetland unit relative to the wetland unit's catchment | <0.5 % | 0.5%-5% | 0.6-4.9% | 5-10% | >10% |
| Slope of wetland unit | >5% | 2-5% | 1-1.9% | 0.2-0.9% | <0.2% |
| Surface roughness of wetland unit | Low | Moderately low | | Moderately high | High |

The overall rating for Wetland A is (4+3+4)÷3= 3.7 and for Wetland B it is (1+1+0)÷3= 0.7).

# CHAPTER 4

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Component B

# An ecosystem service assessment of potential effects of wetland rehabilitation on three wetlands

Component B intended to submit to:
South African Journal of Aquatic Scientist

# 1. Introduction

Wetlands are natural ecosystems that provide a variety of ecosystem goods and services to society. Goods are normally tangible resources that a wetland could provide, including harvestable resources, cultivated foods, water for human use, cultural significance, tourism and recreation, and education (Adamus, 1983; Kotze *et al.* 2005; Adamus & Stockwell, 1983). Services are less tangible and include: flood attenuation, streamflow regulation, sediment trapping, phosphate and nitrate assimilation, toxicant assimilation, erosion control, carbon storage, and biodiversity maintenance (Adamus, 1983; Kotze *et al.* 2005; Adamus & Stockwell, 1983).

Less tangible resources (services) such as flood attenuation and streamflow regulation result from the fact that wetlands have the capacity to temporally store excess water and release it slowly over time, thus buffering the impact of floods (Cronk & Fennessy, 2001). Certain attributes such as the greater sinuosity, gentle slope, size of a wetland, and high surface roughness also play a vital role in attenuating floods and regulating streamflow (Collins, 2005).This is possible because through these attributes wetlands delay the time in which water passes through the system, thus enhance the storage of water and also prolong streamflow during low flow periods (Kotze & Breen, 1994).

Through its capacity to remove phosphate, assimilate nitrate, assimilate toxicant, and trap sediments wetlands can maintain good quality water and improve the quality of contaminated water. They can trap, precipitate, transform and remove many of the water-related contaminants, and thus water leaving the wetland is generally cleaner than the water entering the wetland (Mitsch & Gosselink, 1993; Elder, 1987). Wetland vegetation contributes to the natural cleansing of water when incoming suspended solids settle from the water column due to the water velocity reduction found in wetlands (Johnston *et al.* 1984; Fennessy *et al.* 1994).

In addition, the settling of suspended solids in a wetland can act as a sink for undesirable chemicals and sediments.

Erosion control is enhanced through wetland plants such as *Phragmites australis* for example "has a high capacity of binding sediments as well as recovering rapidly from physical damage caused by flooding" (Kotze & Breen 1994:15). The ability of a wetland to control erosion depends on various factors such as (to name a few) the types of plant involved, the width of the vegetated shoreline band in trapping sediments and the soil composition of the bank (Kotze & Breen, 1994). Wetland plants further provide food and shelter for many animals (including endangered and threatened species), where some animals depend exclusively on wetlands (Cronk & Fennessy, 2001). Thus maintain biodiversity for some species especially those who would not survive without wetlands. Wetlands contribute through storing carbon within soil, particularly within organic soil, instead of realising it into the atmosphere as carbon dioxide (Collins, 2005).

Degradation of wetlands tends to destroy ecosystem goods and services supplied by wetlands. One of the highest causes of wetland degradation in South Africa is gully erosion. Some of the impacts of lost ecosystem services have been highlighted by Marneweck *et al* (unpublished), where he identifies exacerbated magnitude of floods, reduction of base flow in streams, and declining water quality through increased sediment load in rivers. However, South Africa has embarked on a programme of rehabilitating degraded wetlands (Macfarlane *et al.* 2005). In South Africa Working for Wetlands is entrusted with restoring the hydrological function and ecological integrity of the nation's wetlands. According to Dini (2004) Working for Wetlands operates through cooperative governance, where its support is drawn from all multiple government departments concerned with conservation and sustainable resource use.

Despite the extensive rehabilitation of wetlands currently being undertaken in South Africa, expand almost no assessment has been conducted of the effectives of this rehabilitation with respect to the provision of ecosystem goods and services.

In order to investigate the effect of wetland rehabilitation on ecosystem service this study will compare and contrast the potential effect of rehabilitation found in one rehabilitated site and two sites that are without rehabilitation. The first wetland has been rehabilitated through the removal of alien vegetation and re-planting of indigenous trees, and also building a pond. The second wetland comprises two portions both of which are currently under threat of gully erosion in which two gullies progressively eroding upstream. The comparison will be done using a new South African functional assessment tool called WET-EcoServices (Kotze *et al*, 2005). WET-EcoServices is useful in evaluating or assessing wetland ecosystem goods and services and predicting any potential changes to a wetland's function that may be caused by proposed activities, and it is also useful in assessing the success of wetland rehabilitation projects. Comparing the hydrological states of these wetlands will support the assessment.

## 2. Research aim

The overall aim of the research was to examine the potential effect of wetland rehabilitation on the provision of ecosystem goods and services, (by comparing rehabilitated site and sites without rehabilitation), using a rapid field assessment and interviews with key informants. The research took place at three sites. One site is under considerable threat from erosion and the other wetland has been rehabilitated through removal of alien vegetation, planting of natural vegetation, and the creation of a pond.

## 3. The main objectives

1. To characterise the current hydrological setting of the wetland and its hydrological zonation based on interpretation of soil morphology and vegetation.

2. To assess the current provision of ecosystem goods and services provided by the wetland based on the indicators provided in WET-EcoServices.

3. To assess the potential effect of future rehabilitation on the provision of goods and services in sites without rehabilitation.

# 4. Description of the study sites

## 4.1 Description of Site 1

Site 1 refers to a wetland that is situated in KwaZulu Natal Province in the city of Pietermaritzburg and the residential area of Pelham (29° 37 9`S and 20° 23 9`E). The catchment where this wetland is found is highly urbanised, and constitutes a middle class population, where there is a 100 percent access to basic services such as water, electricity, and sanitation. The wetland's hydro-geomorphic type is a channelled valley bottom, which has implications for some of the services provided by this wetland. The main source of water feeding this wetland is a storm water drain that collects water from the roads and other storm water drains

According to Botha (pers.comm.) historically the area served mostly as an illegal dumping zone and was not used for education or recreation. He further highlighted that the area was mostly characterized by alien invasive species. The storm water drainage that cut through the Pelham area prevented runoff spreading across the wetland and also carried all sorts of litter that you would expect from a storm water system in a residential area. Because the site lacked most typical wetland characteristics, it also lacked flood attenuation capacity and this, according to local knowledge (Botha, pers.comm.), had resulted in flooding down stream of the wetland.

Based on the initiative of a local primary school principal (Mr Botha), the site was adopted under the 'Adopt a Spot' programme. The 'Adopt a Spot' programme promotes the adoption of any open space area by public or private organisations and civic sector partnership, in order to deal with problems such as litter, illegal dumping or alien vegetation on public sites. Through this programme members of the public voluntarily accept the responsibility to look after a specifically identified area. Conservation in this wetland was enhanced through rehabilitating a previously neglected wetland area as well as rejuvenation of surrounding land (buffer zone). This buffer zone includes a soccer field that forms part of a grassland area next to the wetland.

The rehabilitation on site was mainly removing alien vegetation and replacing them with indigenous tress. For biodiversity maintenance and for school learners to learn about alien plants, the removal of alien plants was not done all at the same time. Revegetation of indigenous trees and hydric plants that were found in a wetland area were not enough to stop the high intensity runoff from the storm water drain. Thus a pond was then built to form a depression that would store floodwaters, trap sediments and also provide habitat for fish and other wildlife. The depression is the most saturated portion of this wetland.

### 4.2 Description of Site 2 and 3

The Craigieburn wetland (24° 40' 83"S and 30° 58' 10"E) is situated in the northeastern region of South Africa in the Limpopo province. It is located in the Lowveld in the Sand River Catchment, which is one of the rivers flowing to Kruger National Park (Pollard *et al.* 2004). The area is characterised by periodic drought and receives average annual rainfall of 700mm (King, 2004). Besides being part of a river that flow to the park, the wetland is also important as it lies in the headwaters of the Sand River, where much of the catchment's water is produced.

Craigieburn falls within land held under tenure of communal lands where access to water is still not effective and the region is economically deprived. Pollard *et al.* (2004) also highlighted the fact that most families rely on income from pensions or wage remittances. The unemployment rate in the area ranges from 40% to 80%, an estimated 55% of the population are women, and 30% of the households are headed by women (Pollard *et al.* 2004). Due to this socio-economic situation there is a high reliance on the natural environment of the area. The high human density found in the catchment and the high level of agriculture, which is an option to survive, puts the environment under a considerable pressure. People farm in the wetland through raised beds that are prepared by clearing the wetland vegetation and then piling the soil together to form a bed surrounded by a furrow.

The wetland consists of two main portions, the upper wetland portion (portion 1 of Craigieburn) that forms the wetland's head and the lower portion (portion 2 of Craigieburn) that extends down the valley. The hydro-geomorphic type of portion 1 of Craigieburn is an un-channelled valley bottom and portion 2 of Craigieburn is a channelled valley bottom. The wetland's head starts from the surrounding hill slopes and extends along the valley, which gradually deepens and narrows over a distance of 200m from the head of the wetland (Pollard *et al.* 2004). Portion 1 of Craigieburn extends narrowly along the valley for a distance of approximately 500 metres (Pollard *et al.* 2004). Due to the different hydro-geomorphic types and to differing level of degradation, these two portions were assessed as separate units.

The two portions are both affected by gully erosion at their down stream ends. The first deeply incised gully separates the two portions. According to Pollard *et al.* (2004) the first gully is 35m wide and 6m deep. The head-cuts of the two gullies are very actively eroding and continue to propagate upstream each year into the respective portions. Gullies threaten to destroy these wetland areas (see Figures 1 and 2).

**Figure 1**: The head cut that threatens portion 1 of the Craigierburn.

**Figure 2:** The development of the second head cut at the downstream end of portion 2 of the Craigieburn wetland.

# 5. Methods

## 5.1 Data collection and analysis

### 5.1.1 Determination of soil morphology

The presence of hydrological zones was determined by selecting transects at intervals of approximately 30 m or less that cut across the wetland. Transects were divided into segments based on the degree of wetness (i.e. temporary, seasonal and permanent) along transect. The length of each segment in transects was measured. Determining the degree of wetness was based on soil morphology and vegetation, which reflects long-term hydrology, and can be used as surrogate indicators of hydrology (Kotze *et al.* 1996). A Dutch screw auger was used to excavate holes. The first 50cm of the soil profile was examined for indicating long term soil wetness, using the matrix chroma and mottling as indicators (Kotze *et al.* 1996). In each soil sample, a rapid assessment was further conducted to determine if the soil was peat, by squeezing it in the hand and checking it, if clear water is expressed, leaving the hand still fairly clean, the presence of peat is indicated.

### 5.1.2 Determination of vegetation cover

In each segment delineated, the dominant plant species in terms of aerial cover, were identified and then the total aerial cover provided by the vegetation was estimated. The overall aerial cover for the wetland was then determined based on a weighted average percentage for all the segments combined. The data on plant species composition was recorded to determine the extent of hydric vegetation, abundance, and dominance. Vegetation assessment further included identifying alien species on site and indigenous trees that were planted. Ellery *et* *al.* (1993) identified a close relationship between vegetation community distributions, groundwater and soil chemistry on Islands in the Okovango Delta.

### 5.1.3 Ground water determination

Water table measurements were obtained through digging a hole with an auger, allowing the water level to equilibrate and measuring the depth to the water table from the soil surface. In order to assess any change in relation to the different zonation, this procedure was done at three locations down the length of the wetland, each at the lowest point in the cross section, but outside of a channel, if present. In a cultivated wetland with raised beds, the heights of raised beds were measured. The orientation of raised beds, which influences the way water flows in a wetland, was also noted. During the course of the field survey, erosion features such as gully erosion were also noted. Details of the survey are provided in Appendix A and B.

## 5.2 Assessments of ecosystem goods and services.

All three wetlands in this study were assessed using a new South African functional assessment tool called Wet-EcoServices (Kotze *et al.* 2005). This tool was adopted as it was specifically developed for South African conditions and requires data to be collected at a level of detail appropriate for the study. WET-EcoServices is useful in evaluating wetland functions and predicting any potential changes to a wetland's function that may be caused by proposed activities thus it is also useful in assessing the success of wetland rehabilitation projects. The tool develops a functional index based on combining variables that are typically structural physical measures (e.g. longitudinal slope of the wetland) or indicators that are associated with one or more ecosystem functions. For example, indicators such as wetland slope, surface roughness, size of the wetland relative to its catchment and sinuosity of the stream channel are associated with the capacity to attenuate floods (Appendix C) (Kotze *et al.* 2005).

Local knowledge (land users and local service providers) was used to provide insight into the characteristics of the wetland. All this information was then integrated in a functional assessment and used to determine the likely ecosystem goods and services. The following ecosystem goods were assessed:

- harvestable resources,
- cultivated foods,
- water for human use,
- cultural significance,
- tourism and recreation,
- Education.

Also, the following services were assessed:

- flood attenuation,
- streamflow regulation,
- sediment trapping,
- phosphate and nitrate assimilation,
- toxicant assimilation,
- erosion control,
- carbon storage
- biodiversity maintenance.

Ecosystem goods and services were scored following the guidelines given in WET-EcoServices. The scoring system depends largely on the characteristics of a wetland that are indicators of a particular ecosystem service (See Appendix C). Each characteristic relevant to a particular ecosystem service was rated from 0-4 depending on its value. The total score was determined based on the average score for all the relevant characteristic

# 6. Results and discussion

## 6.1 Hydrological state of the wetland

The hydrological state of a wetland is one of the most important characteristics of a wetland as it supports the wetland's unique features such as hydric plants and hydric soils. Hydrology is the single most important determinant for the establishment and maintenance of specific types of wetlands and of wetland processes such as primary production, organic accumulation, and the cycling of nutrients (Mitsch & Gosselink, 1986; Brouwer *et al.* 2003).

Ground water, soil morphology and wetland vegetation was used here as a baseline information in determining wetland hydrology. Wetland soils helps in determining the previous or current hydrological regime of a wetland, while vegetation could be used to determine wetland health and the representation of different hydrological zonation. This is because some wetland plants are good indicators of the degree of wetness as they could only be found in wetland areas or in seasonally or permanent zone. Ground water table is the good indicator of the availability of water in the wetland, as most healthy wetlands have water table close to the surface.

### 6.1.1 Groundwater tables

One of the most important features of a wetland is its capacity to store water on its surface and underground as groundwater. In the Pelham wetland, for the entire length of the wetland the water table lies fairly closely to the soil surface but is slightly closer in the middle and lower parts of the wetland (Figure 3)

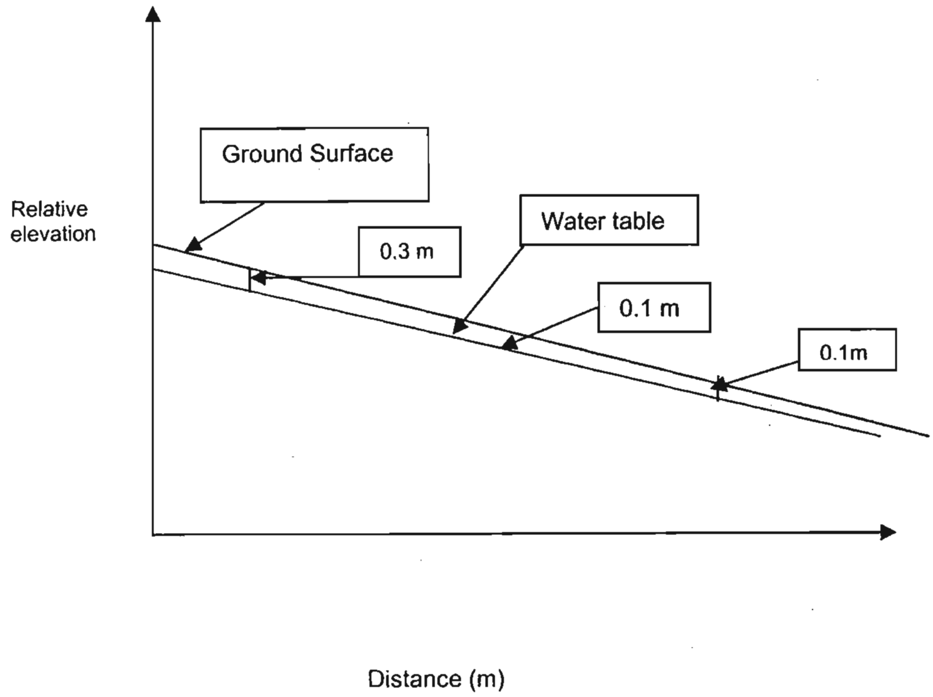


**Figure 3**: The water table in the Pelham wetland.

Figures 4 and 5 illustrate the water table in portions 1 and 2 of the Craigieburn wetland that was taken at the end of the dry season. At the time of the assessment in both wetlands it was noted that the water table became progressively lower towards the head cut lying at the downstream end of each wetland (Figure 4 and 5). It was suspected that the headcuts were the cause of the lowered water table in portions 1 and 2 of Craigieburn. Given the relationship that exists between erosion and desiccation of the wetland (Pollard *et al.* 2004), it is likely that the lower water table caused by the headcuts.

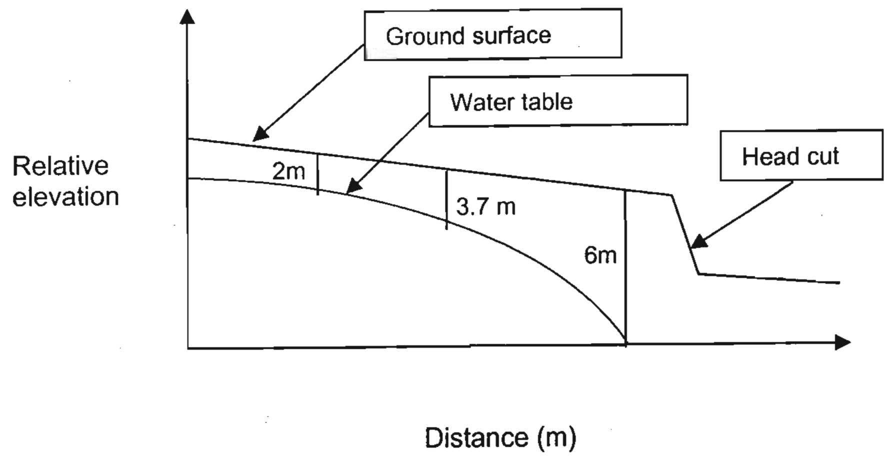


**Figure 4:** A schematic of the position of the water table in the upper part (portion 1) of the Craigieburn wetland (Ellery and Riddell, Pers. Comm.).

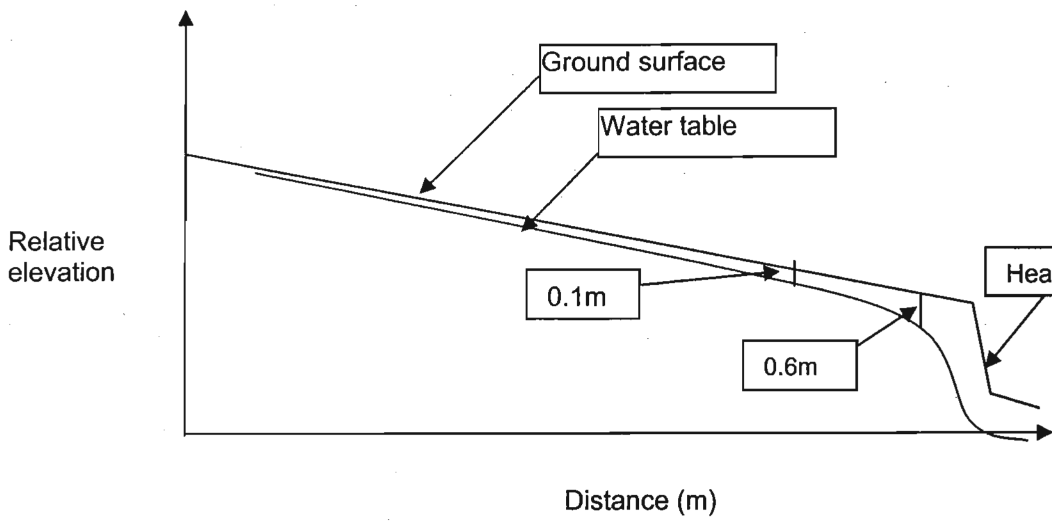


**Figure 5**: A schematic of the position of the water table in the lower part (portion 2) of the Craigieburn wetland (Ellery and Riddell, Pers. Comm.).

During the field survey of portion 1 of Craigieburn, an old well approximately 1.5 m deep was found in the wetland and is no longer used due to a drop in the water table. This could indicate that the place was once more saturated with water than is currently so. The water table in portion 2 of Craigieburn was found near the soil surface and above the soil surface in most areas. One could conclude that this was the most saturated portion of the wetland. As shown in Figure 5 the water table was measured and found not to be distant from the surface of the soil. The increase in water table depth towards the lower end of portion 1 of Craigieburn was considerably greater than the corresponding increase for the lower end of portion 2 of Craigieburn. A comparison of Figure 4 and 5, suggests that the headcut erosion has lowered the water table to a greater extent in portion 1 of Craigieburn than in portion 2 of Craigieburn, which seems to explain, to some extent the much drier state of portion 1 of Craigieburn.

In summary, there exist a relationship between the water table drop and headcuts that have formed at the end of portion 1 and 2 of the Craigieburn wetland in Figures 4 and 5 suggest that the water table has been affected by the two headcuts. However, this still needs a detailed study that will confirm the effect of headcuts in the water table. The lowering of the water table also appears to have affected the hydrological zonation in the wetland, particularly in portion 1 of Craigieburn, in which only the temporary zone is present (see Section 6.1.2).

The general trend in portion 1 and 2 of Craigieburn wetland contrasts with the Pelham wetland, where the water table became higher towards the mid and lower end of the wetland (see Figure 3).

### 6.1.2 Soil analysis

The wetness zones of each wetland that were found through soil interpretation are shown in Table 1. The temporary, seasonal and permanent hydrological zones were all represented in portion 2 of the Craigieburn and Pelham wetland, although the permanent zone was more extensive in the Pelham wetland. Only the temporary zone was represented in portion 1 of Craigieburn.

Figures 3, 4 and 5 indicate the water tables found in the three wetlands assessed. The hydrological zonation of these wetlands confirms the results found in water table measurements. Portion 1 of Craigieburn only contains a temporary zone and its water table is substantially lower than the other three sites. Pelham wetland and portion 2 of Craigieburn have a water table that lies fairly close to the soil surface. This gives effect to the results shown in the Table 1 where wetlands with higher water tables had greater representation of seasonal and permanent zones.

**Table 1**: The proportion of different wetness zones in each of the three study sites.

| **Wetland** | **Zone** | **Total Percentage** |
|---|---|---|
| Pelham | Temporary wet | 22 |
| | Seasonal wet | 42 |
| | Permanent wet | 48 |
| portion 1 Craigieburn | Temporary wet | 100 |
| portion 2 Craigieburn | Temporary wet | 26 |
| | Seasonal wet | 38 |
| | Permanent wet | 36 |

### 6.1.3 Vegetation analysis

Vegetation plays an important role in wetlands as it contributes to most of the ecosystem services provided by wetlands, particularly to the hydrological services, such as water purification, flood attenuation and erosion control (Kotze, 1996b). In the Pelham wetland, plant species dominating in terms of aerial cover were found to be high. However, assessment shows that indigenous hydric species were limited in the wetland and that the most dominant plants were alien (Appendix B).

In portion 1 of the Craigieburn wetland *Phragmites mauritianus* and *Imperata clyndrica* were the most frequently found species occurring in the temporary zone of the wetland. According to DWAF (2003) these are classified as facultative wetland species respectively, which indicates their ability to inhabit both terrestrial and wetland environments. Portion 2 of Craigieburn possesses considerably more obligate hydric species than portion 1 of the Craigieburn wetland. Plants found in portion 2 of Craigieburn, include *Schoenoplectus brachyceras* (Letshago), *Pycreus mundii*, *Thelypterus sp* (a hydric fern) and *Cyperus latifolius* were dominant in terms of aerial cover (See Appendix A).

It should be noted that at the time of field visit to the Craigieburn wetland, much of portion 1 of the Craigieburn wetland and a small area of portion 2 of Craigieburn had been burnt. It would appear that the burnt area was less in portion 2 of Craigieburn owing to the limited cover in the extensive cultivated lands present in this portion. The burnt vegetation affected two factors: (1) it made the identification of species difficult and, (2) it reduced the aerial cover for portion 1 of Craigieburn in particular, (although it is expected that this cover will increase rapidly with regrowth after the fire). Thus the assessment of aerial cover is likely to be an underestimate for portion 1 of Craigieburn. Figure 6 shows an estimate of the percentage cover of Pelham wetland, portion 1 and 2 of Craigieburn.

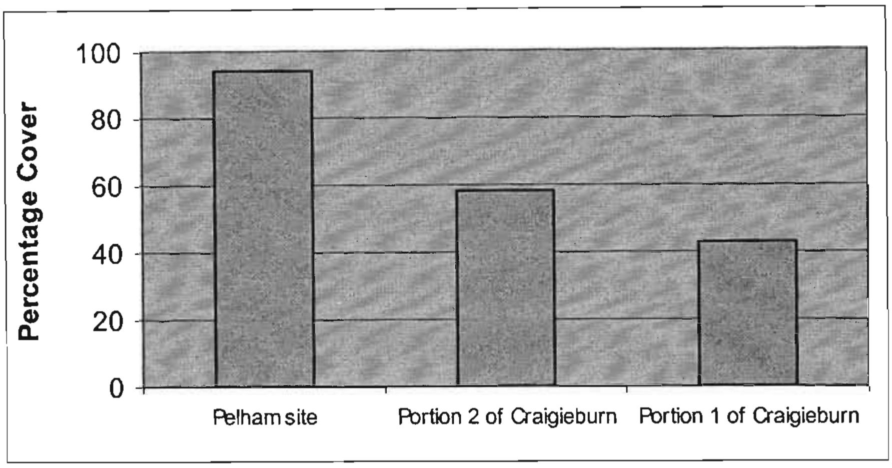


**Figure 6:** The average percentage vegetation cover of the three assessed wetlands.

The substantially higher vegetation cover in the Pelham wetland compared with the Craigieburn wetland (Figure 6) suggests that the Pelham site is expected to perform hydrological functions related to vegetation more than the other two wetlands. However, it should be noted that the rehabilitated site (Pelham) comprises few indigenous hydric species, and a high abundance of alien vegetation. Dominant alien plants such as *Ipomea purpurea* (morning glory); *Verbena bonariensis* (Purpletop vervain), *Schinus terebinthifolius* (Brazilian pepper tree), *Cirsium vulgare* (Scottish thistle) and *Japonicum* sp. (Privet) were observed in the wetland (See Appendix B). Although portion 1 and 2 of Craigieburn comprise more hydric species and alien plants were much more limited in extent than in the Pelham wetland, agricultural crops have replaced extensive areas of natural wetland vegetation.

Replacement of natural wetland vegetation generally has a negative impact on wetlands. Rogers (1997) highlighted that vegetative disturbance could exacerbate wetland degradation and reduce its integrity. The picture below (Figure 7) shows the creation of raised beds that are used for farming in portion 2 of the Craigieburn wetland. Creation of these beds caused most of the soil disturbance and vegetation removal.

**Figure 7**: Vegetation removal in portion 2 of the Craigieburn wetland.

The exposure of soil through the removal of native vegetation and replacing this vegetation with crops, and also soil disturbance from the creation of raised beds is a threat to the integrity of this wetland. In most of the cultivated plots, litter, which was generally sparse, was found to be the main cover, which does not play much role in terms of soil protection. The exposure of soil through the removal of native vegetation that used to protect the wetland from erosion is now evident in the Craigieburn wetland and in some places replaced by crops. Kotze & Breen (1994: 20) highlight that "even if flooding occurred when the crops are fully established and cover was at its maximum, the cover provided would be lower than that offered by native wetland vegetation". This shows that the cumulative effect of removing native plants in the Craigieburn wetland combined with exposure of soil shown in Figure 7 could exacerbate the current erosion onsite.

### 6.2 A rapid assessment of ecosystem goods and services

This part of the assessment was based on the current ecosystem goods and services provided by wetlands. The results of the groundwater table investigation, soil analysis and vegetation analysis were important information incorporated into the WET-EcoServices assessment. Table (2 & 3) provide an overview of the WET-EcoServices scores.

**Table 2:** Delivery of indirect benefits by the wetlands assessed.

| Ecosystem services | Wetland sites | | |
|---|---|---|---|
| | Pelham | portion 1 Craigieburn | portion 2 Craigieburn |
| Flood attenuation | 2.1 | 2.8 | 2.0 |
| Streamflow regulation | 1.8 | 1.7 | 2.0 |
| Sediment trapping | 2.0 | 2.8 | 2.6 |
| Phosphate trapping | 2.2 | 2.2 | 2.0 |
| Nitrate removal | 2.2 | 1.7 | 2.2 |
| Toxicant removal | 2.6 | 2.0 | 2.1 |
| Erosion control | 3.5 | 2.1 | 1.8 |
| Carbon storage | 2.0 | 0.7 | 1.0 |
| Maintenance of biodiversity | 1.9 | 1.6 | 1.3 |

| Level of importance of ecosystem service: | <0.5 Low | 0.5-1.2 Moderately low | 1.2-2.0 Intermediate | 2.1-2.9 Moderately high | >2.9 High |
|---|---|---|---|---|---|

**Table 3:** Delivery of direct benefits by the wetlands assessed

| Ecosystem goods | Wetland sites | | |
|---|---|---|---|
| | Pelham | portion 1 Craigieburn | portion 2 Craigieburn |
| Water supply for human use | 1.0 | 1.5 | 2.8 |
| Natural resources | 0.0 | 2.5 | 3.3 |
| Cultivated foods | 0.0 | 3.6 | 3.6 |
| Cultural significance | 0.8 | 1.3 | 0.3 |
| Tourism and recreation | 1.9 | 0.4 | 0.5 |
| Education and research | 3.3 | 3.0 | 3.0 |

| Level of importance of ecosystem service: | <0.5 Low | 0.5-1.2 Moderately low | 1.2-2.0 Intermediate | 2.1-2.9 Moderately high | >2.9 High |
|---|---|---|---|---|---|

### 6.2.1 Indirect benefits

The Pelham wetland and portion 1 of the Craigieburn wetland both scored *moderately high* in terms of flood attenuation, while portion 2 of the Craigieburn scored *intermediate* with respect to this service (Table 2). Kotze & Breen (1994) highlight that the potential of a wetland to attenuate floods is generally lower in the wetlands is already covered with standing water, in comparison to a wetland with no standing water. Therefore the contribution of a small pond in the Pelham wetland to its flood attenuation capacity is not as high as might be expected, because the pond generally remains full for the wet season.

Ammann & Stone (1991) identify the amount of storage potential in the wetland and how slowly the wetland releases the stored waters, as the major factors that determine a wetland's ability to attenuate floods. The high surface roughness provides friction for water flows during water floods, and dense stands of vegetation can slow the velocity of flood (Adumus *et al.* 1987). The vegetation analysis made in the Pelham wetland indicates that this wetland is highly vegetated 94% cover, (see Figure 6). Portion 1 of Craigieburn was dominated by *Phragmites mauritianus*, a tall robust plant that helps in the attenuation of floods. Portion 2 of Craigieburn scored *intermediate*, which was due to the high removal of natural wetland vegetation and replacement by crops that were planted in cleared raised beds (see Figure 7).

Wetlands act as sponges, thus the water that is captured during the rainy season is slowly released during the dry season; this causes Rivers and streams to have sustainable flows long after the rain has stopped. According to Kotze *at al.* (2005) permanently saturated wetlands have higher potential to regulate streamflow than seasonally saturated wetlands. All wetlands assessed scored *intermediate* in terms of streamflow regulation (Table 2). Two of the assessed sites had limited permanent zones, while portion 1 of Craigieburn had only a temporary zone, which diminished its value in regulating streamflow. Additionally, the absence of peat reduces the score. According to Kotze *et al.* (2005) peat increases water storage capacity of the soil. The Pelham wetland *scored very low* in this respect.

For a wetland to have a high value in trapping sediments, potential sources of sediments must be present in the wetland's catchment (Kotze *et al.* 2005). The Pelham wetland had no evidence of sediment transported into the wetland, while the Craigieburn wetland (portions 1 and 2 of Craigieburn) experience high sediment inputs. This is due to the fact that the soil in the wetland's catchment is erodible and there is a lot of erosion evident in the wetland's catchment. Thus, the Craigieburn wetland has a high opportunity to trap sediments. The effectiveness in trapping sediment is related strongly to effectiveness in attenuating floods, which was *moderately high*. Overall therefore, portion 1 and 2 of Craigieburn thus scored *moderately high* for trapping sediment. The Pelham wetland scored *intermediate* in its importance for trapping sediments.

Phosphates and nitrates are regarded as one of the undesirable nutrients in wetlands. According to Collins (2005) phosphorous occurs in a sedimentary cycle in contrast to nitrogen, which occurs in a gaseous cycle. This implies sediments transported in a wetland sometimes carries phosphorous into the wetland. However, phosphorous in the transported sediments depends on whether there is a source of phosphate in a catchment or not. The Pelham wetland and portion 1 of Craigieburn both scored *moderately high* with respect to the removal of phosphate (which is influenced by the fact that these wetlands both scored *moderately high* in terms trapping sediments), while portion 2 of Craigieburn scored *intermediate* (see Table 2). The Craigieburn catchment is located in a catchment where the sources of phosphate are limited, thus there is a limited potential for this wetland to assimilate phosphates. The score is not as high as that of the Pelham wetland, which has greater sources of phosphates from its highly developed catchment.

The functional assessment undertaken further shows that portion 1 of the Craigieburn wetland is of *intermediate* importance in terms of nitrate removal. This results from the reduced vegetation growth and the level of wetness in this wetland that limit the capacity of the wetland to remove nitrate. However, Pelham wetland and portion 2 of Craigieburn both scored *moderately high* for assimilating nitrates (see Table 2) but portion 1 of Craigieburn could have *scored higher* if the vegetation growth had not been reduced as much.

The similar approach hold for toxicants, where for a wetland to score high for toxicant assimilation there have to be sources of toxicants in the wetland's catchment that will contribute to the opportunity afforded to a wetland for removing toxicants. Like phosphates toxicants are bound to be carried by sediments into wetlands (Boto and Patrick, 1979). Thus, the Pelham wetland had the opportunity of removing toxicants and it scored *moderately high*. This was because the wetland catchment is urbanised and there are potential sources of toxicants in the catchment. Portion 1 of Craigieburn scored *intermediate* while portion 2 of Craigieburn scored *moderately high*, which was because of the scattered pit-latrines in the catchment. Fertilizer application on the lands was very low and no biocides were used. The Pelham wetland and portion 2 of the Craigieburn wetland have a hydrological zonation including temporary, seasonal, and permanent zones. A wetland with a permanently saturated zone would enhance the capacity of a wetland to effectively assimilate toxicants, thus the two wetlands are effective in this regard (Zafiriou *et al.*, 1984; Wieder and Lang, 1986; Hemond and Benoit, 1988). Portion 1 is not effective as it lacks the permanent zone.

In terms of erosion control, vegetation plays a vital role in reducing the risk of erosion by binding the soil with its roots, and protecting the soil with its leaves and stems (Kotze and Breen, 1994). The high surface roughness and cover that was found in the Pelham wetland resulted in a *high* score with respect to erosion control, compared to portion 1 and 2 of the Craigieburn wetland. However, portion 1 of Craigieburn still has *Phragmites mauritianus* that dominates much of the wetland, contributing to it scoring *moderately high*. Portion 2 was the most cleared part of the Craigieburn wetland (see Figure 7), with the natural vegetation being replaced with crops that are not as effective as wetland plants in terms of covering and binding the soil. Therefore portion 2 of Craigieburn *scored intermediate* (see Table 2).

The last ecosystem service was carbon storage, which was found to be *intermediate* in the Pelham wetland and *moderately low* in portion 1 and 2 of Craigieburn (Table 2). The absence of peat and the limited extent of permanently saturated areas resulted in the wetlands not scoring high on carbon storage. This applies most especially to portion 1 of the Craigieburn wetland, which was found to be the least saturated of the three sites. The high level of soil disturbance in both portion 1 and 2 of Craigieburn diminish their capacity to store carbon because the disturbance of soil contributes to increased rates of organic matter decomposition (Miles & Manson, 1992)

Wetlands can provide habitat for wetland dependent species, but this depends on the integrity of the wetland and attributes of the wetland unit (i.e. habitat provided for Red Data species) (Collins, 2005). In terms of biodiversity maintenance, all the wetlands were of *intermediate* importance (Table 3). In the Pelham wetland there is an increasing number of fish and bird species that are beginning to use the wetland for feeding and breeding. In the Craigieburn wetland, limited species were observed during the field survey. In all the wetlands there were no Red Data species that were identified in these wetlands. In the Pelham wetland, the extensive alien plants are reducing the biodiversity value and in portion 1 of Craigieburn and especially in portion 2 of the Craigieburn wetland, cultivation is having a negative effect on biodiversity.

### 6.2.2 Direct benefits.

The Pelham wetland is located in an urbanized catchment where the standard of living is high, and there is therefore no direct reliance on the natural environment in order to sustain livelihoods. In the functional assessment, the importance of Pelham wetland for supplying natural resources, cultivated foods and water for human use was low (Table 3). However, the wetland is currently used for recreational purposes by local residents. In addition, the pond adds to the aesthetic value of the wetland. Thus, it scored *intermediate* for recreation (Table 3). The Pelham wetland is next to a University and a Primary School and is currently used for education and research. The school in particular uses the wetland frequently as an outdoor classroom. School children are introduced to environmental studies through the different functions and vegetation (wetland plants, alien species, and indigenous trees) by taking them to the wetland.

According to Botha (Pers. Comm.) there are two types of study programmes that a wetland is used for, Micro and Macro programmes. The Micro programme consists of 30 learners undertaking water studies and a wetland study in a wetland (Botha Pers. Comm.). The wetland is particularly important for this kind of study, as urban areas do not have many natural sites. The Macro programme involves 160 grade 4 and 7 learners. For grade 4 it is just a place used for story telling and to study history, while grade 7s are introduced to the exotic plants found in a wetland. Learners are taught about exotic plants by smelling them, touching or feeling them, and also learn about features that can only be found in wetlands. The school also have a science week every year where the Micro and Macro plan are utilised extensively prior and during the science week. This contributes to the wetland scoring high in terms of education and research (Table 3)

According to Botha (Pers Comm.) there is an emerging cultural significance of the wetland as people located next to the wetland come to plant a tree whenever there is a death in a family in remembrance of that particular late member of the family. However, since this trend is growing the wetland did not score *high* in terms of cultural significance.

The Craigieburn wetland is in a rural area in an economically deprived region, and thus wetland goods are likely to be important in the area. Pollard *et al.* (2004) indicate that this wetland is currently playing a vital role in terms of sustaining the livelihoods of the neighbouring community by providing goods. The main use for this wetland to the community is harvesting of natural resources, cultivation, grazing of cattle and water supply. However, portion 1 and 2 of Craigieburn differ from each other as portion 1 of Craigieburn is 100 % temporary wet (Table 1) and portion 2 of Craigieburn comprises temporal, seasonal and permanent zones, and thus portion 1 of Craigieburn supplies less water and natural resources.

Both portion 1 and 2 of Craigieburn are very important for cultivated foods, especially because farmers face severe soil fertility & water availability constraints in dryland areas of Craigieburn. Based on the data gathered by Pollard *et al.* (2004) it was determined that portion 1 of Craigieburn provides cultivated land for approximately 6 households while portion 2 of Craigieburn provides for at least 23 households from the local area.

The natural resources are used for purposes ranging from the supply of firewood to the creation of mats or craft. *Schoenoplectus corymbosus* (Leshago) (this plant requires permanent saturation to grow) *Cyperus latifolius, Pragmites mauritianus* are some of the species harvested by local people for home use and for sale of the craft or mats made from these plants (Pollard *et al.* 2004). Harvesting of natural resources indicates that even those who do not have plots in a wetland could also harvest reeds to sell. Collation of data collected by Pollard *et al.* (2004) shows that portion 2 of Craigieburn supplies more reeds than portion 1 of Craigieburn (see Figure 8). This is most likely because the plant most extensively used, Leshago, is absent in portion 1 of Craigieburn because it is too dry but is locally abundant in some of the permanently saturated areas of portion 2 of Craigieburn.

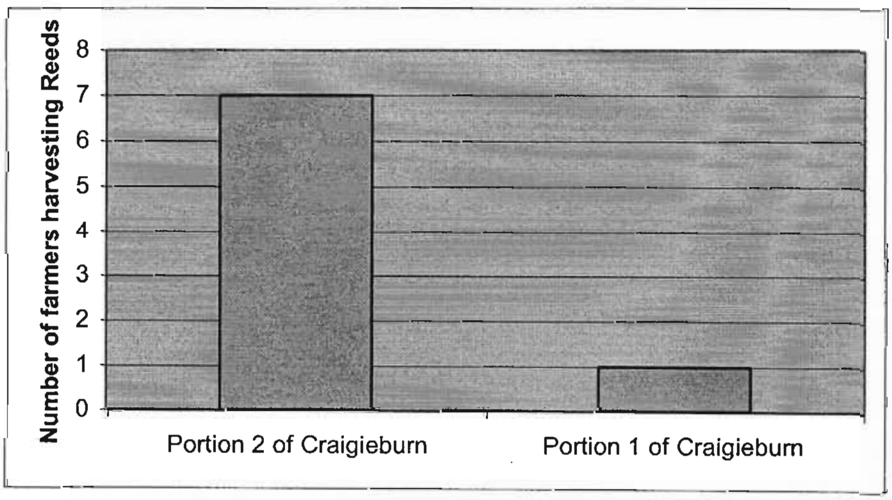


**Figure 8**: The number of farmers harvesting reeds in portion 1 and 2 of Craigieburn (data from Pollard *et al.*, 2004).

Pollard *et al.* (2004) further identifies the wealth status of people that are using a wetland in order to determine their likely dependence on the natural environment. People were categorised according to their wealth through the following:

*Category 1= these are the poorest households who lack formal employment and do not receive a grant (i.e. child care grant or pension)*

*Category 2 and 3 =Households who depend on grants.*

Category 4 = high, people who are employed and have other sources of money.

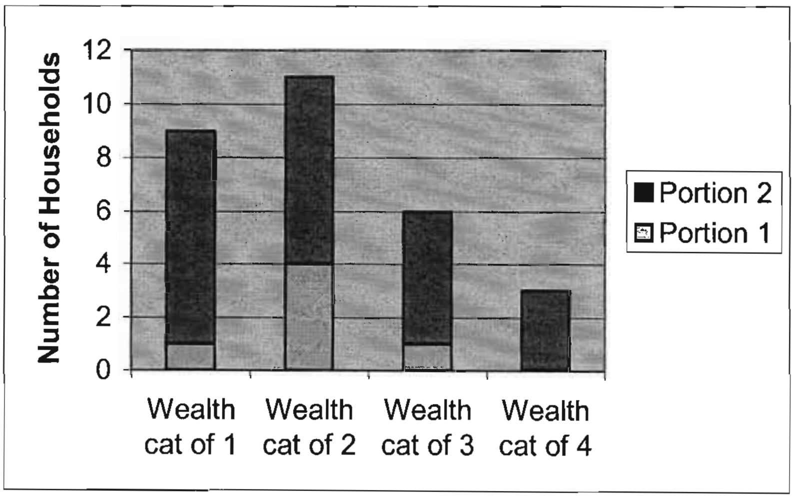


**Figure 9**: Wealth category for households depending on the wetland in Craigieburn (data from Pollard *et al.* 2004).

In both portions of the Craigieburn wetland, the majority of households fall in the poorest two classes. It is likely, therefore that if the two portions were both to severely erode, impacts on food security of the individual households would be great. It is assumed that a greater impact will be experienced by households with a low wealth category due to the limited options available for these households to substitute the benefits derived from a wetland.

The main crops that grown in the area were maize, madumbes, bananas, sugarcane and tomatoes (Pollard *et al.* 2004). Uncontrolled grazing of cattle also takes place in the wetland. The functional assessment also confirms the supply of natural resources and cultivated foods. Thus, the wetland scored as follows: portion 1 of Craigieburn *scored moderately high* on natural resources and *scored high* on cultivated foods, while portion 2 of Craigieburn *scored high* in both natural resources and cultivated foods.

The domestic water supply system of the area is a pipe that collects water from the escarpment to the village. At the time of the field visit, the pipe was broken and the communities were using the wetland for domestic water use. During the interaction with people gathering water people said that the pipe for water supply is not effective, and thus the wetland is a very good substitute for the pipe. Because of these problems with water supply, people rely on the wetland and thus portion 1 of Craigieburn is of *intermediate* importance as it is exclusively delineated as temporarily wet and the water table depth is far from the surface, resulting in limited water being available for domestic purposes. Portion 2 of Craigieburn includes seasonal and permanent zones, with the water table close to the surface, and flowing water is observed in the site. Therefore it scores *moderately high* (see Table 3).

The wetland is interesting due to the intensive nature of the research the wetland therefore scored *high* for studies range from linking socio-economic situations of rural livelihoods to the natural environment. The studies further include the link between natural environment (hydrology, geomorphology) and the livelihoods of rural communities.

## 6.3 Comparison of ecosystem goods and services before and after rehabilitation.

In the three investigated sites there is only one wetland that has been rehabilitated and that is the Pelham wetland. Portion 1 of Craigieburn is the most degraded wetland and was without rehabilitation at the time of the assessment. Portion 2 of Craigieburn is less degraded than portion 1 of Craigieburn and also without rehabilitation. All three wetlands provide valuable ecosystem goods and services, which need to be enhanced in the degraded site and managed properly or maintained in the less degraded sites.

In portion 1 of Craigieburn, the entire wetland is temporarily wet, and thus fails to support most ecosystem services related to wetness. The rehabilitation intervention is to put a structure downstream of this wetland, with the aim of both stabilizing erosion and raising the water table. Increasing the water table in this wetland would likely result in the development of a seasonal zone, but permanently wet areas would be unlikely to develop or be very restricted. This is due to the steepness of the slope in portion 1 of Craigieburn as compared to portion 2 of Craigieburn. The slight increase in wetness from a temporary zone to a seasonal zone is assumed to influence a slight increase in vegetation cover and roughness in this wetland. Table 4 illustrates the ecosystem goods and services that are predicted to be enhanced due to the increased wetness, vegetation cover and roughness.

In portion 2 of Craigieburn the aim of rehabilitation would be to maintain the current ecosystem goods and services, by stabilising the gully erosion that is threatening the wetland. Thus, there is no significant hydrological change that is expected after rehabilitation, and therefore little change in the delivery of ecosystem services is expected. The hydrology of the Pelham wetland was altered significantly by the rehabilitation. This will be described later in this section, and the effects of this changed hydrology in the delivery of ecosystem goods and services will also be assessed (Table 5).

**Table 4**: Anticipated change in the delivery of ecosystem goods and services by Craigieburn Portion 1 wetland after rehabilitation.

| **Ecosystem service** | ***Anticipated change after rehabilitation*** | **Comments** |
|---|---|---|
| **Flood attenuation** | *Slight increase or no change* | The increase in surface roughness will offer greater frictional resistance, thus the wetland will be more effective in attenuating floods (Reppert *et al.* 1979; Adamus et al. 1987). However, the increased wetness that is anticipated may counteract this positive effect by reducing the volume of floodwaters that can be stored in the wetland's soils |
| **Streamflow regulation** | *Slight increase* | Dense vegetation would facilitate slow movement of water and detain it for a while, thus facilitate streamflow regulation. However, the steep slope of this wetland will not allow it to retain more as compared to Portion 2 of Craigieburn, which has a gentler slope than Portion 1 of Craigieburn. In addition, actively transpiring vegetation would limit the wetland's capacity to regulate streamflow. |
| **Sediment trapping** | *Significant increase* | Higher surface roughness will allow the wetland to trap more sediment. The wetlands catchment releases lot of sediments, and thus there is a potential for a wetland to trap sediments. |
| **Phosphate assimilation** | *Significant increase* | According to Kotze *et al.* (2005) the greater the extent of sediments trapped, the greater the removal of associated phosphates adsorbed to the sediments. The high vegetation cover will also enhance the assimilation of phosphates. However, the potential sources in the wetlands catchment are limited and thus the wetland is not afforded a high |

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| | | opportunity to assimilate phosphates. |
| **Nitrate assimilation** | *Significant increase* | Transforming some of this wetland from temporary to seasonally wet, will support the process of denitrification which occurs extensively in seasonally wet areas (Hammer, 1992 & Reddy and Patrick, 1984). Vegetation cover will supply organic matter required by the microbiota to assimilate nitrate and provides habitat for the microbes in the soil surrounding roots (Kotze *et al.* 2005). However, the opportunity for the wetland will not increase as there are limited sources of nitrates in the catchment. |
| **Toxicant assimilation** | *Slight increase* | Seasonality of Portion 1 of Craigieburn will not contribute in assimilating toxicants as compared to the other two wetlands which possesses permanent wet zones. However, toxicants such as mercury can be emitted to the atmosphere by plants and plants can further take metals from water and sediments (Kotze, 2000). However, the opportunity afforded to the wetland is limited as there are no sources of toxicants in the catchment. |
| **Erosion control** | *Significant increase* | Increased vegetation cover provides better protection to the soil from water that passes through a wetland. The roots further bind and stabilize the soils, thus reducing erosion. Increased roughness slows down the water flow more, which reduces the power of the water to erode. |
| **Carbon storage** | *Slight increase* | Because of the seasonal zone, the decomposition of organic matter will be reduced. Thus carbon will be trapped in wetlands as soil organic matter. However, this would be less than areas with permanent zones (Tiner & Veneman, 1988). |
| **Biodiversity maintenance** | *Slight increase* | Vegetation cover could serve as food and habitat for wetland dependent species, however the integrity of wetland has been compromised and it is not anticipated that changes resulting from rehabilitation |

| | | |
|---|---|---|
| | | will attract Red data species to the wetland. |
| **Ecosystem Goods** | ***Anticipated change after rehabilitation*** | **Comments** |
| **Water supply for human use** | *Slight increase* | Achieving a seasonally wet zone in portion 1 of Craigieburn is unlikely to provide a permanent supply as of water as this requires a permanent zone. |
| **Natural resources** | *Slight increase* | The increased plant growth resulting from the increased wetness is likely to increase the value of the area for grazing and may also support plants used for craft production. |
| **Cultivated foods** | *Significant increase* | One of the crops planted in the wetland fields are the Madumbes, which require wet conditions for them to grow effectively. Changing the wetland to seasonally wet will support these crops and many other crops which are currently planted in the wetland. |
| **Cultural significance** | *No change* | Attributes such as wetness and vegetation cover that will be achieved after rehabilitation do not link directly to the provision of cultural significance. |
| **Tourism and recreation** | *No change* | Attributes such as wetness and vegetation cover that will be achieved after rehabilitation do not link directly to the provision of tourism and recreation. |
| **Education and research** | *Significant increase* | Currently the wetland is highly utilised as an education tool. If rehabilitation becomes successful it might provide very useful lessons that can be learnt from rehabilitation, and this will increase its utilisation as an education tool. |

Pelham wetland was rehabilitated, but there was no formal assessment of ecosystem goods and services before rehabilitation. This makes it difficult to properly compare the status before and after rehabilitation. However, through the local knowledge (Mr Botha) the status of some of the ecosystem services before wetland rehabilitation could be easily identified for comparative purposes. The wetland used to have an artificial drainage (about 1m deep) that ran through the entire length of the wetland, and thus the stormflow used to run through the channel. The following was achieved after rehabilitation:

- Increase in vegetation cover and surface roughness across the wetland.
- The pond that was placed across the channel changed the pattern of flow (spreading water across the wetland) and keeping more water in the wetland.
- Increase in level of wetness as a result of the pond increasing the extent of the seasonal and permanent zones.
- Integrity of the wetland was enhanced through the removal of alien vegetation.
- The scenic beauty of the wetland was enhanced through the removal of litter

In Table 5 the influence of these changes on the provision of ecosystem goods and services after rehabilitation is highlighted.

**Table 5**: Changes in the delivery of ecosystem goods and services by the Pelham wetland after rehabilitation.

| **Ecosystem service** | ***Change after rehabilitation*** | **Comments** |
|---|---|---|
| **Flood attenuation** | *Slight or significant increase* | A change was due to the dense wetland vegetation cover and water being spread out across the wetland, as compared to before rehabilitation where water used to run directly through an artificial drainage channel. The pond also contributes to the depression storage capacity of the wetland, but this is only slight because the pond is often filled close to its full capacity. The increased wetness of the wetland would also slightly counteract the other positive effects. |
| **Streamflow regulation** | *Slight increase* | As a result of rehabilitation this wetland posses a permanent zone which have a greater potential to regulate stream flow as compared to other hydrological zones. However, the actively transpiring vegetation and absence of peat in wetland limits its capacity to regulate streamflow, because peat increases the water storage capacity of the soil in the wetland (Kotze *et al.* 2005). |
| **Sediment trapping** | *Slight increase* | Increased roughness and vegetation cover in Pelham wetland offers increased frictional resistance to trap sediments. But this wetland is in an urban environment and does not afford the wetland an opportunity to trap sediments as there limited sources or evidence of sediments in the wetlands catchment. |
| **Phosphate assimilation** | *Significant increase* | Increased vegetation cover and less canalized low flows have enhanced assimilation of phosphates. Enhanced trapping of sediments transported in a wetland also contributes to enhanced phosphate assimilation because phosphates are adsorbed to |

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|---|---|---|
| | | sediments. The wetland's catchment also affords the wetland an opportunity to trap phosphate. |
| **Nitrate assimilation** | *Significant increase* | The greater level of wetness (promoting increased denitrification) and the less canalized flow (allowing greater contact of waters with wetland sediments) both contribute to enhanced nitrate assimilation. The wetland is in an urban environment, thus an opportunity of removing nitrates is afforded as there are sources of nitrates in the catchment. |
| **Toxicant assimilation** | *Significant increase* | According to Collins (2005) many different processes, including chemical precipitation, adsorption and ion exchange remove toxicants. These processes depend on physico-chemical conditions which are affected by the hydrological regime.<br>Thus, by resulting in good representation of all of the three zones (temporary, seasonal and permanent) and by causing less canalized flow and increased sediment trapping, the rehabilitation has enhanced toxicant assimilation. |
| **Erosion control** | *Significant increase* | Increased vegetation cover provides better protection to the soil from water that passes through a wetland. The roots further bind and stabilize the soils, thus prevent erosion. Increased roughness slows down the water flow more, which reduces the power of the water to erode. |
| **Carbon storage** | *Slight increase* | Presence of permanent and seasonal zones enhances the reduction of decomposed organic matter. Thus carbon will be trapped in wetlands as soil organic matter. Due to the presence of permanent zone this is less in Pelham wetland as compare to both portions of Craigieburn Wetland. |
| **Biodiversity maintenance** | *Significant increase* | This is due to the enhanced vegetation cover of 94% that provides food and habitat for animal species and the reduction in cover of alien plants. The pond also contributes to increasing habitat diversity (e.g. for fish species). |

| Ecosystem goods | change after rehabilitation | Comments |
|---|---|---|
| **Water supply for human use** | *No change* | The wetness enhanced during the rehabilitation does afford enough water for supply. However, the wetland is located in an urban catchment where people do not rely on the local natural environment for their water. Thus there is no opportunity afforded to the wetland to supply water. |
| **Natural resources** | *No change* | The wetland is located in an urban catchment where people do not rely on the local natural environment, and thus there is no opportunity afforded to the wetland to supply natural resources. |
| **Cultivated foods** | *No change* | No cultivated food is grown in the wetland as it is located in catchment where the standard of living is high and people do not need to rely on the wetland for their food. |
| **Cultural significance** | *No change* | Achieved wetland attributes (ie. wetness, flow pattern, etc.) does not support any cultural value of the wetland. |
| **Tourism and recreation** | *Significant increase* | The pond plays a major role in this regard as it contributes to the scenic beauty of the place and attracts lot of people who use the wetland for recreation. The reduced litter also contributes to scenic beauty. |
| **Education and research** | *Significant increase* | All the achieved attributes collectively contribute in bringing back the integrity of the wetland, thus making it an interesting site for education. Vegetation cover also attracts lot of birds which makes the wetland and interesting site for studies related to bird species. |

# 7 Conclusions and recommendations

The Pelham wetland and portion 2 of the Craigieburn wetland shared some similar important hydrological characteristics. Both Pelham wetland and portion 2 of Craigieburn had representation of the temporary, seasonal, and permanent zones. Portion 1 of Craigieburn tended to be much drier compared to the other two sites, and had a temporary zone only. Portion 2 of Craigieburn and Pelham wetland consist of a water table close to the surface while portion 1 of Craigieburn suffers a severely reduced water table.

Some of the ecosystem goods and services provided by a wetland are linked directly with the water table and hydrological zonation. Assimilation of nitrates and toxicants and storage of carbon are dependent on good representation of areas with a high degree of wetness because hydrologic conditions significantly influence nutrient cycling, nutrient availability and organic matter decomposition (Mitsch & Gosselink, 1986). In Table 2 assimilation of nitrates and toxicants were found to be *moderately high* in both portion 2 of Craigieburn and in the Pelham wetland. Carbon storage for these wetlands scored differently but they both scored *higher* than portion 1 of Craigieburn in this regard. This is due to the good representation of areas with a high degree of wetness, as compared to portion 1 of Craigieburn, which therefore scored low for these.

Some ecosystem services, notably flood attenuation, sediment trapping and phosphate assimilation are not dependent on a high degree of wetness. This is evident in Table 2 as portion 1 of Craigieburn manages to score *high* in these services even though it is regarded as the most affected wetland in this study. In the Pelham wetland the creation of a pond tended to indirectly affect some of the ecosystem services such as flood attenuation, but the wetness of the pond for the entire season resulted in the capacity of the Pelham wetland to attenuate floods not being as high as expected.

Portion 1 of Craigieburn failed to supply most of the natural resources because the most favoured species for harvesting *Schoenoplectus corymbosus* (Leshago) requires permanently wet areas to grow. Portion 2 of Craigieburn demonstrated a reasonable number of household that harvest reeds due to the wetness of the wetland that facilitates reed growth. Portion 2 of Craigieburn supplies water to the immediate community, but portion 1 of Craigieburn due to the reduced water table fails to provide water for human use.

The extent of degradation in portion 1 of Craigieburn wetland requires its wetland hydrology to be completely retrieved through rehabilitation in order to bring back its ecosystem goods and services. In portion 2 of Craigieburn rehabilitation is required only to stabilize the existing ecosystem goods and service due to a lesser extent of degradation. Retrieval of wetland hydrology is based in a fact that lot of ecosystem goods and services are purely dependent on the hydrology of a wetland. Thus retrieving wetland hydrology will automatically bring back lost ecosystem goods and services. The latter theory has been proved to be correct in the Pelham wetland, where hydrology of a wetland was retrieved and some of the goods and services were returned. Services such as, phosphate and nitrate assimilation, toxicant assimilation, erosion control and biodiversity maintenance (indirectly dependent on hydrology) have been significantly changed. The rest of the goods and services dependent on hydrology changed slightly.

Returning hydrology in portion 1 of Craigieburn has shown to have a remarkable potential in retrieving the lost ecosystem goods and services. Services such as sediment trapping phosphate and nitrate assimilation, and erosion control will change significantly if the water table of this wetland is raised. However due to slope, hydrological zonation and its location some services related to hydrology will slightly change.

The high reliance on the natural environment for the vulnerable community of Craigieburn was highlighted. In areas where the goods are deemed not be important, indirect benefits could still play a major role in protecting human beings from floods and providing other ecosystem services. However, these benefits could be lost easily when use is unsustainable and degradation of the wetlands continues. Thus there is a need to secure existing services by stabilizing an actively degrading wetland.

The limited effectiveness of governance structures in managing the wetland could also pose a threat to the wetland due to the uncontrolled use of the system. The Sand River catchment contains of a number of different wetlands in addition to Craigieburn, and according to Pollard *et al.* (2004) most are used for cultivation. If the benefits of these wetlands could be managed and used sustainably, their cumulative input is likely to contribute positively to the current socio-economic situation of the area. The local institution needs the capacity and local support to be able to control land-use activities in the wetlands. There should be recognition from the local institution such as traditional authority or any available structure. The study made in these wetlands suggests the following recommendations:

Recommendations for Craigieburn wetland:

- There is a clear need of management and rehabilitation interventions in both portions of the Craigieburn wetland. Without rehabilitation both portions of the Craigieburn are under great threat by very active headcut erosion. If not rehabilitated, both these sites are likely to severely erode and dry out. The extent of drying out of the two wetlands will impact negatively to the community that depends on the ecosystem goods and services that sustain their livelihoods.
- Therefore headcut erosion that threatens the Craigieburn wetland and its goods and services should be stabilized.

- This study supports the recommendations made by Pollard *et al.* (2004) that the objective of rehabilitation in portion 1 of Craigieburn is to arrest degradation and reclaim lost function and in portion 2 of Craigieburn it is mainly to arrest degradation.
- Cultivation inside the wetland is discouraged, while cultivation outside the wetland is encouraged through water harvesting and other means of enhancing the productive potential of the dryland fields.
- Harvesting of natural resources should be controlled. This could be done through clearly defined institutions in place for the effective control of natural resources use in the Craigieburn wetland.
- Agricultural practices within beds or plots should be improved through employing management practices that will discourage exposure or disturbance of soil onsite, and discourage beds that are parallel to the flow of water.

Recommendations for Pelham wetland

- In the Pelham wetland the re-infestation of alien species should be monitored at all times, while the current available alien vegetation is removed from the wetland.
- The Pelham wetland is dominated by a wide variety of alien plants, including some less well known species such as *Arundo donax*, *Iaponicum* sp. and *Schinus terebinthifolius*. It seems that in previous clearing operations some of these were not noticed as alien plants. Therefore, it is recommended that for future clearing operations close attention be given to the alien plants listed in Appendix B.
- Burning of the wetland should be adopted to control healthy state, enhance rapid re-establishment of vegetation and assist in alien control (Kotze & Breen, 1994).

Overall, the study has successfully achieved its first two objectives of characterizing the hydrology and assessing current delivery of ecosystem services by two wetland sites. The third objective has been a difficult one to achieve in determining exactly the effect of rehabilitation on the delivery of ecosystem services, particularly before and after rehabilitation. However, the study has demonstrated that through retrieving favourable hydrological regime of the wetland, some ecosystem services are likely to be improved. The problem of not getting a clear cut of the situation after rehabilitation is mainly because the study was rapid and short term. Using Wet-EcoServices to assess the effect of rehabilitation and conclude based on the information generated could be misleading. This is because in the Pelham wetland the state of the ecosystem goods and services in a wetland before rehabilitation was not formally assessed but was based on local knowledge. Therefore, a formal comparison of the before and after situation could not be easily done.

In the Craigieburn wetland, the study was undertaken while the rehabilitation was still in the planning phase. This study could contribute in terms of assessing the potential benefits of the rehabilitation project in terms of ecosystem goods and services that will be secured. A long-term study is needed that will assess whether the potential benefits of adopting this rehabilitation project have been achieved.

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## Personal communication

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| Appendix A | | | | |
|---|---|---|---|---|
| Transects 1 (*Burned a month ago*)<br>Hydrological zonation of **Portion 1 of Craigieburn** | | | | |
| **Distance (m)** | **Zone** | **Bare soil %** | **Dominant Plants** | **Boundary (m)** |
| 0-10 | Temporary | 60 | *Imperata cylindrica* | |
| **Note: 16-20m there was an old well found there** | | | | |
| 10-34 | Temporary | 50 | *Phragmites mauritianus* | |
| | | | | **43-58** |
| 58-65 | Temporary | 95 | Recently cultivated soil | |
| Transects 2 (*Burned a month ago*) | | | | |
| 0-32 | Temporary | 65 | *Imperata cylindrica* | |
| 32-44 | Temporary | 30 | *Phragmites mauritianus*<br>*Paspalum dilatatum* | |
| 44-50 | Temporary | 60 | *Phragmites mauritianus* | |
| 50-59 | Temporary | 40 | *Phragmites mauritianus*<br>*Paspalum dilatatum* | |
| 59-70 | | 99 | | **59-70** |
| Transects 3 (*involves raised beds*) | | | | |
| 0-5 | Temporary | 30 | *Phragmites mauritianus*<br>*Paspalum dilatatum*<br>Thatch grass<br>*Imperata cylindrica* | |
| 5-6 | Temporary | 0 | *Paspalum dilatatum* | |
| 6-9 | Temporary<br>*(50cm bed)* | 85 | *Phragmites mauritianus* | |
| 9-10 | Temporary | 0 | *Phragmites mauritianus*<br>Pynchrias mundae | |
| 10-18 | Temporary<br>*(50cm bed)* | 65 | *Phragmites mauritianus* | |
| 10-30 | Temporary<br>*(Over two beds:<br>1st-60cm<br>2nd-50cm)* | 30 | *Phragmites mauritianus*<br>*Imperata cylindrica* | |
| 30-30.5 | Temporary | 10 | Pynchrias mundae | |
| 30.5-39 | Temporary<br>(60cm bed) | 60 | *Phragmites mauritianus* | |
| 39-56 | Temporary | 70 | *Phragmites mauritianus*<br>*Imperata cylindrica* | **39-56** |

| Transects 4<br>(Portion 2 of Craigieburn) | | | | |
|---|---|---|---|---|
| **Distance (m)** | **Zone** | **Bare soil %** | **Dominant Plants** | **Boundary (m)** |
| 0-2.5 | Temporary | 65 | *Phragmites mauritianus* | |
| 2.5-4 | Seasonal (Channel) | 0 (Lot of litter) | Nunu | |
| 4-8.5 | Seasonal | 40 | *Thelypteris sp*<br>*Phragmites mauritianus* | |
| 8.5-13.5 | Seasonal (60cm bed) | 100 (Just been ploughed) | | |
| 13.5-18.5 | Seasonal | 75 | *Phragmites mauritianus* | |
| 18.5-20 | Permanent (Channel) Water table at 1m | 5 | Nunu<br>*Cyperus latifolius* | |
| 20-24 | Seasonal (60cm bed) | 70 | *Thelypteris sp*<br>*Phragmites mauritianus* | |
| 24-27 | Seasonal | 55 | *Imperata cylindrica* | |
| **Note: there is a road separate these two zones** | | | | |
| 27-29 | Temporary | 70 | Thatch grass | **37** |
| Transects 2 (D2) | | | | |
| 0-1 | Non wetland | | | |
| 1-3 | Temporary | 65 | Cotton wool grass<br>*Imperata cylindrica* | |
| 3-4 | Seasonal | >5 | *Pycreus mundii*<br>*Leersia hexandra*<br>*Kyllinga erecta*<br>*Phragmites mauritianus* | |
| 4-9.5 | Temporary (60 cm bed) | 50 | Nunu<br>*Leersia hexandra* | |
| 9.5-12.5 | Permanent | 5 | *Schoenoplectus brachyceras*<br><br>*Pycreus mundii*<br>*Leersia hexandra* | |
| 12.5-16 | Temporary (60 cm bed) | 60 | Nunu<br>*Leersia hexandra* | |
| 16-18 | Permanent | 5 | *Pycreus mundii* | |
| 18-23 | Bed | 75 | | **18-23** |
| Transects 3 (D3) | | | | |
| 0-8.5 | Temporary | 30 | *Phragmites mauritianus* | |

| | | | | |
|---|---|---|---|---|
| | | | *Imperata cylindrica* | |
| 8.5-10 | Permanent (Channel) Water table at surface | 0 | *Thelypteris sp*<br>*Phragmites mauritianus*<br>*Cyperus latifolius*<br>*Leersia hexandra*<br>*Schoenoplectus brachyceras* | |
| 10-18.5 | Seasonal (50cm bed) | 50 | Nunu<br>*Litter* | |
| Transects3 (D3) continues… | | | | |
| **Distance (m)** | **Zone** | **Bare soil %** | **Dominant Plants** | **Boundary (m)** |
| 18.5-20 | Permanent (Channel) Water table at surface | 0 | Nunu<br>Litter | |
| 20-39.5 | Seasonal (50 cm bed) | 20 | Sugar cane<br>Sugar cane litter | |
| 39.5-44.5 | Permanent (Channel: water table at surface) | 0 | *Phragmites mauritianus*<br>*Thelypteris sp*<br>Black dot<br>*Cyperus latifolius* | |
| 44.5-54.5 | Seasonal (65 cm bed) | 90 | *Pycreus mundii* | |
| 54.5-56.5 | Permanent (Channel) | 0 | *Cyperus latifolius*<br>*Thelypteris sp* | |
| 56.5-61.5 | Temporary (65 cm bed) | 80 | Nunu<br>*Phragmites mauritianus* | **65** |
| Transects 4 (D4)<br>*The most cleared part of the wetland i.e. overgrazed and lot of beds* | | | | |
| 0-10.5 | Temporary | 99 | | |
| 10.5-11 | Seasonal (Channel) | 0 | Litter | |
| 11-17.5 | Temporary (Bed) | 99 | Cleared | |
| 17.5-18.5 | Permanent (Water table at surface) | 0 | *Schoenoplectus brachyceras*<br>Litter | |
| 18.5-27 | Seasonal (50cm bed) | 80 | Nunu | |
| 27-28 | Permanent (Channel: water table at surface) | 0 | Nunu<br>Maize<br>Sugarcane litter | |
| 28-34.5 | Seasonal (60cm bed) | 99 | Litter | |

| | | | | |
|---|---|---|---|---|
| 34.5-40 | Permanent (Main Channel) Running water | 0 | *Cyperus latifolius* Black Dot *Thelypteris sp* | |
| 40-50 | Seasonal (70 cm bed) | 99 | Nunu (few) | **53.5** |
| Transects 5 (D5) | | | | |
| 0-9.5 | Temporary (30 cm bed) | 85 | Maize Litter No species | |
| 9.5-11 | Permanent (Channel) | >5 | *Phragmites mauritianus*<br><br>Schoenoplectus brachyceras<br><br>*Pycreus mundii* | |
| Transects 5 (D5) continues... | | | | |
| **Distance (m)** | **Zone** | **Bare soil %** | **Dominant Plants** | **Boundary (m)** |
| 11-18 | Temporary (65 cm bed) | 40 | *Phragmites mauritianus* | |
| 18-27 | Permanent (Channel) | 0 | *Phragmites mauritianus* *Pycreus mundii* *Schoenoplectus brachyceras* | |
| 27-29.5 | Non wetland (60 cm bed) | 99 | | |
| 29.5-33.5 | Permanent (Running water) | 0 | *Cyperus latifolius* *Phragmites mauritianus* | |
| 33.5-36.5 | Seasonal (40 cm bed) | 100 | | |
| 36.5-37.5 | Permanent (Channel: water table at surface) | 0 | *Imperata cylindrica* Nunu *Schoenoplectus brachyceras* | |
| 37.5-42.5 | Temporary (60cm bed) | 60 | Maize Litter& morogo | |
| 42.5-47 | Seasonal (Channel) | >5 | *Cyperus latifolius* Nunu *Schoenoplectus brachyceras* | **47-50** |
| Transects 6 (D6) | | | | |
| 0-4.5 | Temporary | 30 | Rooi grass Umtshiki | |
| 4.5-6 | Seasonal (Channel) | 30 | Nunu | |
| 6-10 | Temporary 50 cm bed | 15 | *Hemarthria altissima* | |

| | | | | |
|---|---|---|---|---|
| 10-15 | Seasonal (Water table at 40 cm) | >5 | *Phragmites mauritianus*<br>Pynchrias mundae<br>Kyllinga | |
| 15-23.5 | Temporary (50 cm bed) | 90 | *Phragmites mauritianus* | |
| 23.5-25.5 | Permanent (Channel: water table at surface) | | *Schoenoplectus brachyceras*<br><br>*Pycreus mundii* | |
| 25.5-43.3 | Temporary (65 cm bed) | 99 | | **45** |
| Transects 6 (D6) | | | | |
| 42.3-64.3 | Semi permanent | | *Phragmites mauritianus*<br>*Leersia hexandra* | |
| 64.3-70 | Temporary (30 cm bed) | 75 | *Phragmites mauritianus*<br>Senna<br>Cynodan doctylan | |
| 70-93 | Non-wetland 40 cm bed | >10 | | |
| Transects 6 (D6) continues… | | | | |
| **Distance (m)** | **Zone** | **Bare soil %** | **Dominant Plants** | **Boundary (m)** |
| 93-112 | Temporary | 30 | Nunu<br>*Phragmites mauritianus*<br>*Paspalum dilatatum* | **117** |
| Transects 7 (D7)<br>*Just after the second gully and there is abandoned beds* | | | | |
| 0-11 | Temporary | 65 | *Phragmites mauritianus* | |
| 11-19 | Seasonal | >10 | *Phragmites mauritianus* (very robust)<br>*Paspalum dilatatum* | |
| 19-23 | Permant (Running water) | 0 | *Cyperus latifolius* (big)<br><br>*Schoenoplectus brachyceras*<br><br>*Phragmites mauritianus*<br>*Paspalum dilatatum* | |
| 23-26 | Temporary (Eroded bank: very grey soils but dry) | 99 | | **30** |

## Appendix B

| Distance (m) | Zone | Bare soil % | Dominant Plants | Boundary (m) |
|---|---|---|---|---|
| **Transects 1 (Pelham wetland)** | | | | |
| 0-25 | Permanent | | Across the Pond | |
| 25-29 | Seasonal | 98 | *Ipomea* purpurea<br>Nunu<br>Spanish Reeds | |
| 29-34 | Seasonal | 95 | Yellow Flowers<br>Senna<br>*Ipomea* purpurea | |
| | | | Bulrushes | |
| 34-37.5 | Permanent (Channel) | | Knot weed<br>Light Blue Flower<br>*Ipomea* purpurea | |
| 37.5-41 | Seasonal | | Yellow Flowers<br>*Paspalum dilatatum*<br>Knot weed | |
| 41-45 | Temporal | 92 | *Paspalum dilatatum* | **55** |
| **Transects 2** | | | | |
| 0-17 | Temporal | 97 | Yellow flowers<br>*Verbena bonariensis*<br>*Leersia hexandra*<br>*Ngongoni grass* | |
| 17-31 | Seasonal | 92 | Bernia<br>Small yellow flower<br>*Verbena bonariensis* | |
| 31-37 | Permanent | 98 | Nunu<br>Small yellow flower<br>*Verbena bonariensis*<br>*Japonicum* sp. | |
| 37-40 | Permanent (Channel) | 99 | Small yellow flower<br>Bug weed<br>Previtti<br>*Japonicum* sp.<br>Mexican Pepper<br>Nstikane | |
| 40-43 | Seasonal | 96 | *Ipomea* purpurea<br>*Verbena bonariensis*<br>Plantego | **44.5** |

| | | | | |
|---|---|---|---|---|
| Transects 3 | | | | |
| 0-16 | Temporal | 99 | Big yellow Flower<br>Ngongoni grass<br>*Verbena bonariensis*<br>*Schinus terebinthifolius* | |
| 19-25 | Seasonal | 95 | Snake food<br>Ngongoni grass<br>Small yellow Flower | |
| 25.4-34 | Seasonal | 96 | *Paspalum dilatatum*<br>Snake food<br>Ngongoni grass<br>Yellow flower | |
| 34-37 | Permanent (Channel) | 99 | *Japonicum* sp.<br>Lantana<br>*Schinus terebinthifolius*<br>Big yellow flower | |
| 37-46 | Seasonal | 98 | Mexican Pepper<br>*Verbena bonariensis*<br>Plantego<br>Small yellow flower | **53** |
| **Transect 4** | | | | |
| 0-15 | Temporary | 94 | *Paspalum dilatatum*<br>*Verbena bonariensis*<br>*Cirsium vulgare* Scotish thistle)<br>Senna | |
| 15-24 | Seasonal | 96 | *Cirsium vulgare* Scotish thistle)<br>*Verbena bonariensis*<br>*Ntsikane*<br>*Paspalum dilatatum* | |
| 24-27 | Permanent (Channell) | 92 | Bug weed<br>*Japonicum* sp.<br>Knott weed | |
| 27-35 | Seasonal | 95 | Ngongoni<br>*Cirsium vulgare* Scotish thistle)<br>*Verbena bonariensis*<br>Plantego | **36** |
| **Transect 5** | | | | |
| 0-9 | Temporary | 99 | *Japonicum* sp.<br>*Verbena bonariensis*<br>*Paspalum dilatatum*<br>Knott weed | |
| 9-10.5 | Permanent | | Bugweed | |

| | | | | |
|---|---|---|---|---|
| | (Chanell) | | *Leersia hexandra* | |
| 10.5-14.5 | Seasonal | 97 | Mexican Pepper<br>*Japonicum* sp.<br>Ngongoni<br>Big yellow Flower | **19** |

## Appendix C

| | 0 | 1 | 2 | 3 | 4 | Wetland unit 1 | | |
|---|---|---|---|---|---|---|---|---|
| Date of assessment | | | | | | 2005 | | |
| Name/s of assessors | | | | | | D Kotze, S Pollard, M Nkosi, E Riddell, Vusi | | |
| Details of owner/authority | | | | | | N/A | | |
| Location (Latitude; Longitude) | | | | | | 24° 40' 83"S and 030° 58' 610"E | | |
| **Wetland name** | | | | | | **Portion 1 of Craigieburn** | | |
| **Hydro-geomorphic setting of wetland** | F=Floodplain, VC=Valley bottom with channell, V=Valley bottom without channel, HW=Hillslope seepage feeding a water course, H=Hillslope seepage not feeding a watercourse, D=Depression | | | | | V | | |
| **Size (hectares)** | | | | | | | 7 | |
| | 0 | 1 | 2 | 3 | 4 | Score | Conf-idence rating | Additional notes |
| **WETLAND UNIT'S CATCHMENT** | | | | | | | | |
| Average slope of the wetland unit's catchment | <3% | 3-5% | 6-8% | 9-11% | >11% | 2 | 1 | |
| Inherent runoff potential of the soils in the wetland unit's catchment | Low | Mod low | | Mod high | High | 1 | 1 | |
| Contribution of catchment land-uses to changing runoff intensity from the natural condition | Decrease | Negligible effect | Slight increase | Moderate increase | Marked increase | 3 | 3 | |
| Rainfall intensity | Low (Zone I) | Moderately low (Zone II) | | Mod. high (Zone III) | High (Zone IV) | 3 | 3 | |
| Extent to which dams are reducing the input of sediment to the wetland unit | High | Mod high | Intermediate | Mod low | Low | 4 | 4 | |
| Extent of sediment sources delivering sediment to the wetland unit | Low | Mod low | Intermediate | Mod high | High | 3 | 3 | |
| Extent of other potential sources of phosphates in the wetland unit's catchment | Low | Mod low | Intermediate | Mod high | High | 0 | 0 | |
| Extent of nitrate sources in the wetland unit's catchment | Low | Mod low | Intermediate | Mod high | High | 0 | 0 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Extent of toxicant sources in the wetland unit's catchment | Low | Mod low | Intermediate | Mod high | High | | 0 | 0 |
| **WETLAND UNIT** | | | | | | | | |
| Size of wetland unit relative to the wetland unit's catchment | <1% | 1%-2% | 3-5% | 6-10% | >10% | | 4 | 4 |
| Slope of the wetland unit (%) | >5% | 2-5% | 1-1.9% | 0.5-0.9% | <0.5% | | 1 | 1 |
| Surface roughness of wetland unit | Low | Mod. low | | Mod. high | High | | 3 | 3 |
| Depressions | None | Present but few or remain permanently filled close to capacity | Intermediate | Moderately abundant | Abundant | | 0 | 3 |
| Frequency with which stormflows are spread across the wetland unit | Never | Occasionally but less frequently than every 5 years | | 1 to 5 year frequency | More than once a year | N/A | N/A | |
| Sinuosity of the stream channel | Low | Moderately low | Intermediate | Mod. high | High | | 2 | 4 |
| Representation of different hydrological zones | Permanent & seasonal zones lacking (i.e. only the temporary zone present) | Seasonal zone present but permanent zone absent | Permanent & seasonal zones both present but collectively <30% | Seasonal & permanent zone both present & collectively 30-60% | Seasonal & permanent zone both present & collectively >60% of total wetland unit area | | 3 | 2 |
| Link to the stream network | No link (i.e. hydrologically isolated) | | | | Linked to the stream system | | 4 | 4 |
| Presence of fibrous peat or unconsolidated sediments below a floating marsh | Absent | Present but limited in extent/depth | | Moderately abundant | Extensive and relatively deep (>0.5 m) | | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Reduction in evapotranspiration through frosting back of the wetland vegetation | Low | Moderately low | Intermediate | Moderately high | High | 0 | 0 |
| Wetland unit occurs on underlying geology with strong surface-groundwater linkages | No | | Underlying geology quartzite | Underlying geology sanstone | Underlying geology dolomite | 3 | 3 |
| Direct evidence of sediment deposition in the wetland unit | Low | Mod low | Intermediate | Mod high | High | 2 | 4 |
| Flow patterns of low flows within the wetland | Strongly channelled | Moderately channelled | Intermediate | Moderately diffuse | Very diffuse | 3 | 3 |
| Extent of vegetation cover in the wetland unit | Low | Mod low | Intermediate | Mod high | High | 2 | 2 |
| Contribution of sub-surface water inputs relative to surface water inputs | Low (<10%) | Moderately low (10-20%) | Intermediate (20-35%) | Moderately high (36-50%) | High (>50%) | 2 | 3 |
| Direct evidence of erosion | High | Mod high | Intermediate | Mod low | Low | 0 | 4 |
| Current level of physical disturbance of the soil in the wetland unit | High | Mod high | Intermediate | Mod low | Low | 1 | 3 |
| Erodibility of the soil in the wetland unit | Low | Mod low | Intermediate | Mod high | High | 3 | 3 |
| Abundance of peat | Absent | Present but limited in extent/depth | Intermediate | Moderately abundant | Extensive and relatively deep (>0.5 m) | 0 | 3 |
| Wetland unit is of a rare type or is of a wetland type or vegetation type subjected to a high level of cumulative loss | No | | | | Yes | 0 | 4 |
| | | | | | | | |
| Red Data species or suitable habitat for Red Data species | No | | | | Yes | 0 | 3 |
| Level of significance of other special natural features | None | Mod low | Intermediate | Mod high | High | 1 | 3 |
| Alteration of hydrological regime | High | Mod high | Intermediate | Mod low | Low/negligible | 1 | 2 |
| Complete removal of indigenous vegetation | >50% | 25-50% | 5-25% | 1-5% | <1% | 1 | 3 |
| Invasive and pioneers species encroachment | >50% | 25-50% | 5-25% | 1-5% | <1% | 2 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Presence of hazardous/restrictive barriers | High | Mod high | Intermediate | Mod low | Low/negligibl e | 4 | 3 |
| Current level of use of water for domestic purposes | No use | Mod low | Intermediate | Mod high | High | 1 | 3 |
| Number of dependent households that depend on the direct provision of water from the wetland | None | 1-2 | 3-4 | 5-6 | >6 | 4 | 4 |
| Substitutability of the water resource from the wetland unit | High | Mod high | Intermediate | Mod low | Low | 4 | 3 |
| Number of different resources used | None | 1 | | 2-3 | >3 | 4 | 4 |
| Is the wetland in a rural communal area? | No | | | | yes | 4 | 4 |
| Level of poverty in the area | Low/ negligible | Mod low | Intermediate | Mod high | High | 3 | 3 |
| Number of households who depend on the natural resources in the wetland unit | None | 1 | 2-3 | 4-5 | >6 | 4 | 4 |
| Substitutability of the natural resources obtained from the wetland | High | Mod high | Intermediate | Mod low | Low | 4 | 3 |
| Total number of different crops cultivated in the wetland unit | None | 1 | | 2-3 | >3 | 4 | 4 |
| Number of households who depend on the crops cultivated in the wetland unit | None | 1 | 2-3 | 4-6 | >6 | 4 | 4 |
| Substitutability of the crops cultivated in the wetland | High | Mod high | Intermediate | Mod low | Low | 4 | 3 |
| Registered SAHRA site | No | | | | Yes | 0 | 2 |
| Known local cultural practices in the wetland unit | None | Historically present but no longer practised | | Present but practised to a limited extent | Present & still actively & widely practised | 4 | 3 |
| Known local taboos or beliefs relating to the wetland unit | None | Historically present but no longer so | | Present but held to a limited extent | Present & still actively & widely held | 4 | 3 |
| Scenic beauty of the wetland unit | Low/negligibl e | Mod low | Intermediate | Mod high | High | 3 | 3 |
| Presence of charismatic species | None present | Very seldom seen | Occasionally present | Generally present | Always present | 3 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Presence of hazardous/restrictive barriers | High | Mod high | Intermediate | Mod low | Low/negligible | 4 | 3 |
| Current level of use of water for domestic purposes | No use | Mod low | Intermediate | Mod high | High | 1 | 3 |
| Number of dependent households that depend on the direct provision of water from the wetland | None | 1-2 | 3-4 | 5-6 | >6 | 4 | 4 |
| Substitutability of the water resource from the wetland unit | High | Mod high | Intermediate | Mod low | Low | 4 | 3 |
| Number of different resources used | None | 1 | | 2-3 | >3 | 4 | 4 |
| Is the wetland in a rural communal area? | No | | | | yes | 4 | 4 |
| Level of poverty in the area | Low/ negligible | Mod low | Intermediate | Mod high | High | 3 | 3 |
| Number of households who depend on the natural resources in the wetland unit | None | 1 | 2-3 | 4-5 | >6 | 4 | 4 |
| Substitutability of the natural resources obtained from the wetland | High | Mod high | Intermediate | Mod low | Low | 4 | 3 |
| Total number of different crops cultivated in the wetland unit | None | 1 | | 2-3 | >3 | 4 | 4 |
| Number of households who depend on the crops cultivated in the wetland unit | None | 1 | 2-3 | 4-6 | >6 | 4 | 4 |
| Substitutability of the crops cultivated in the wetland | High | Mod high | Intermediate | Mod low | Low | 4 | 3 |
| Registered SAHRA site | No | | | | Yes | 0 | 2 |
| Known local cultural practices in the wetland unit | None | Historically present but no longer practised | | Present but practised to a limited extent | Present & still actively & widely practised | 4 | 3 |
| Known local taboos or beliefs relating to the wetland unit | None | Historically present but no longer so | | Present but held to a limited extent | Present & still actively & widely held | 4 | 3 |
| Scenic beauty of the wetland unit | Low/negligible | Mod low | Intermediate | Mod high | High | 3 | 3 |
| Presence of charismatic species | None present | Very seldom seen | Occasionally present | Generally present | Always present | 3 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Current use for tourism or recreation | No use | Mod low use | Intermediate use | Mod high use | High | 2 | 2 |
| Availability of potential locations for facilities | None | Mod low | Intermediate | Mod high | High | 4 | 2 |
| Location within an existing tourism route | Low/negligibl e | Mod low | Intermediate | Mod high | High | 2 | 2 |
| Recreational hunting and fishing and birding opportunities | None | Mod low | Intermediate | Mod high | High | 2 | 3 |
| Extent of open water | None | Present, but very limited | | Extent somewhat limited | Extensive | 0 | 3 |
| Current use for education/research purposes | No use | Mod low | Intermediate | Mod high | High | 3 | 4 |
| Reference site suitability | Low | Mod low | Intermediate | Mod high | High | 3 | 3 |
| Existing data & research | None | Mod low | Intermediate detail/ time period | Mod high | Comp-rehensive data over long period | 3 | 3 |
| Accessibility | Very inaccessible | Moderately inaccessible | Intermediate | Moderately accessible | Very accessible | 2 | 3 |
| | | | | | | | |
| **DOWNSTREAM OF WETLAND UNIT** | | | | | | | |
| Extent of floodable property | Low/ negligible | Moderately low | | Moderately high | High | 1 | 1 |
| Presence of any important wetlands or aquatic systems downstream | None | | Intermediate importance | | High importance | 2 | 1 |
| | | | | | | | |
| **LANDSCAPE** | | | | | | | |
| Extent of buffer around wetland | Low | Mod low | Intermediate | Mod high | High | 2 | 3 |
| Connectivity of wetland in landscape | Low | Mod low | Intermediate | Mod high | High | 2 | 3 |
| Level of cumulative loss of wetlands in overall catchment | Low | Mod low | Intermediate | Mod high | High | 3 | 3 |
| | | | | | | | |
| | | | | | | | |
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**THREATS & OPPORTUNITIES**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Level of threat to existing ecosystem services supplied by the wetland | Low | Moderately low | Intermediate | Moderately high | High | 4 | 4 |
| Level of future opportunities for enhancing the supply of ecosystem services | Low | Moderately low | Intermediate | Moderately high | High | 2 | 3 |

**DERIVED CHARACTERISTICS**

**These are characteristics that are derived from other characterisitcs and therefore do not need to be entered directly**

| | | |
|---|---|---|
| Runoff intensity from the wetland unit's catchment | 2.25 | 2.0 |
| Alteration of sediment regime | 4 | 3.3 |
| Alteration of nutrient/toxicant regime | 0 | 0 |