

**THE HYDROGEOMORPHOLOGY OF THE FEATHERSTONE KLOOF
CATCHMENT**

A thesis submitted in fulfilment of the requirements for the degree of

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To my Mother, Hombakazi (Wathi Marhadebe, ekunyamezeleni ukhona umvuzo)

ABSTRACT

Wetlands are an important part of the landscape as hydrogeomorphological ecosystems. Over the centuries their importance has not received relevant attention; instead they have been treated as wastelands impeding development for maximum economic benefits. Research evidence from different parts of the world has influenced the change of such negative perceptions to an extent that the issue of wetlands' rehabilitation/restoration, conservation and management is firmly on the global agenda and local agendas of various countries, as evidenced by the adoption of the Ramsar Convention in 1971, and the Working for Water and Working for Wetlands programmes of the South African government.

The aim of this research was to investigate the hydrological and geomorphological functions of a headwater wetland located in the Featherstone Kloof Catchment near Grahamstown, South Africa. The research was based on the hypotheses that wetlands store sediments, attenuate floods, store water and prolong downstream flows. A literature survey was conducted to gauge the state of knowledge about wetlands, particularly their hydrogeomorphology. An attempt was made to locate the study area within the broad historical and spatial context using a number of methods, including the radiocarbon dating of wetland sediments, the review of relevant literature and the analysis of historical hydroclimatic data. The results revealed that the wetland has existed for approximately 2000 years – as the oldest radiocarbon date obtained was 1850 ± 50 BP. An analysis of more than a century (+120 years) long Grahamstown rainfall series indicated a steady fluctuation of rainfall around the mean, with regular decadal cycles of wet and dry spells. Years with more rain below average were more common than those with higher rainfall, and storms events were quite common in the

area over the period. The distribution of seasons in the area over a calendar year period was demonstrated through the use of evaporation data.

An intensive monitoring of hydrological and geomorphological variables was carried out using a combination of methods. The topography of the instrumented site was determined using a Total Station from reference benchmarks. Hydrological measurements included a nest of forty-eight piezometers for water table monitoring, and streamflow gauges at the upstream and downstream limits of the study site. Soil stratigraphic analysis was carried out through field techniques and laboratory measurements. A survey of wetland sediments was carried out after the main floods events. Data generated were used to analyse relationships between various variables and their role on the functioning of the wetland. The water balance of the wetland was quantified.

The results indicated that the wetland was able to perform the cited hydrogeomorphological functions to some extent. For example, one of the key findings of this research is that the wetland was important in sustaining base flows under normal circumstances. However, the wetland did little to attenuate large floods. The results also revealed some important questions that require further research, including the role played by extreme flood events in altering wetland characteristics, the contribution of each water balance component in the hydrological functioning of wetlands, and importance of quantifying sediment budgets of headwater wetlands. The study demonstrated the complex nature of the wetland hydrogeomorphology and that certain questions about wetlands require direct field monitoring to be better understood.

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Chapter One: RESEARCH BACKGROUND

*"All streams run to the sea,
But the sea is not full,
The place where the streams flow,
There they flow again".
(Ecclesiastes 1:7)*

1.1 INTRODUCTION

The importance of water has been recognised since time immemorial. Over the centuries mankind has been striving to manage this resource in various ways. Unfortunately, in that quest for the management of water as a resource, wetlands as hydrological ecosystems have not received equal attention as other water bodies such as the oceans, rivers and lakes. This is confirmed by an observation by Williams (1990, p3) that, "before the early 1960s wetlands were largely neglected and unappreciated, and were probably the most poorly understood of the landscapes and ecosystems, being neither sound land nor good water". Gopal (1992, p277) also remarked that throughout the wetlands have long been treated as wastelands, impeding development for maximum economic benefits, and they have been drained, filled or modified. However, in recent years there has been a paradigm shift in terms of people's perceptions and attitudes towards these ecosystems. This shift was symbolised by the adoption of the Wetland Convention at a conference of the International Union for the Conservation of Nature and Natural Resources (IUCN) held at Ramsar in 1971. The Ramsar Convention, as it is commonly called, became a catalyst for the designation of numerous sites throughout the world as being Wetlands of International Importance. This landmark convention also ushered a period whereby countries, through their governments and other interest groups, started wetlands work more intensively and extensively.

South Africa's situation is not different from the scenario outlined above. The country is very poor in terms of water resource endowment as it has large areas of arid climate and landscapes. Realising this precarious state of affairs, huge amounts of resources, financial and otherwise, have been harnessed for better management of the water resources. Unfortunately wetlands have, until recently, always been left out as areas of lesser priority. The Department of Environmental Affairs and Tourism (1999) acknowledged that, "wetland conservation is extremely poor in South Africa

and the majority of wetlands fall outside of protected areas. Exceptions to this include the 15 Ramsar Sites [sic] in the country, which are recognised in terms of the Convention on Wetlands of International Importance, especially as Waterfowl Habitat (Ramsar Convention) and protected through various laws. These total some 488,859 hectares.” The unprotected areas, where most wetlands in South Africa are found are farm areas and communal land. In a study of the wetlands of Natal, Begg (1985, p2) observed that “for generations farmers have recognised the potential value of wetlands for pasture production, the grazing of cattle and the cultivation of various crops, but they (and others) have seldom realised the downstream consequences of these activities”. The drainage of wetlands in the name of reclamation and settlement developments is one of the main culprits that have led to the degradation and even complete loss of wetlands in the country.

However, in recent years South Africa has started to put the wetlands issues as one of its top conservation priorities. South Africa became the fifth contracting party to the Ramsar Convention when two wetlands were designated on 12 March 1975 for the Ramsar list (Cowan, 1995). There is also a major wetlands rehabilitation exercise being led by the Working for Water (Working for Wetlands) programme of the government. People from various sectors, government, non-governmental organisations, academia, and so on, are becoming more aware of the functions and values of wetlands as signified by initiatives such as the annual meetings of the South African Wetlands Action Group (SAWAG) and the provincial wetlands forums (see Appendix 1 for details).

On the research side, interest in wetlands has been mainly the province of botanists and palaeobotanists, who have only recently been joined in their endeavours by geomorphologists and hydrologists (Newson, 1994). This interdisciplinary nature of wetlands research can be attributed to the fact that these systems are too complex in nature to be fully understood from one perspective. Orme (1990) made an effort to trace what he termed the scientific background of wetlands over the years. He reported that the physical character of wetlands began to attract serious scientific attention in the seventeenth century. He recognised that major advances began after the middle of the twentieth century with the emergence of geomorphology, hydrology and sedimentology as discrete disciplines. Thereafter, three phases of scientific

enquiry are recognised: before 1950, between 1950 and 1970, and since 1970 up to the present.

Before 1950 emphasis was on descriptive disciplinary studies rather than comprehensive approaches. The late nineteenth century and earlier twentieth centuries also witnessed major advances in the study of interior wetlands, first in the Northern Europe and then in North America. Following the Second World War, the second phase saw improved instrumentation leading to the accumulation of much empirical data. Wetland ecology, especially water chemistry, also received much attention, but cross-disciplinary research was uncommon. The present phase of wetland research since about 1970 has seen the growth of specialisation and cross-disciplinary studies in which morphology, hydrodynamics and sedimentation are interwoven. In the mid-1960s sedimentologists began relating sedimentary structures to flow dynamics, just as geomorphologists began seriously examining the relationships between form and process, and ecologists were examining more closely the relations between hydrology and plant distribution in wetlands. Orme (1990, p46) further noted that, “despite these advances much remains to be discovered. For example, little is known about the functioning of wetland systems in tropical Africa”. This study seeks to investigate the hydrogeomorphological functions of a typical headwater wetland system in the Featherstone Kloof Catchment, South Africa.

1.2 RESEARCH CONTEXT

Wetlands research in South Africa has focused on coastal and larger inland wetland systems. The smaller systems, such as the headwater wetlands, have not been viewed with similar interest. Walmsley (1998) made a similar observation when he remarked that many people fail to recognise that the loss of smaller, less conspicuous, but collectively no less important wetlands has been occurring insidiously in South Africa over the past centuries. When compiling a directory of South African Wetlands, Cowan and van Riet (1998, p37) stated that, "at the scale of a national inventory numerous small but important seep-lines and seepage areas will not be registered". That becomes a problem because if they do not appear on these registers they remain neglected when it comes to policy and research efforts. In a brief review of South Africa's inland waters, Davies and Day (1986, p14) argued that, "sponges" which "are high altitude wetlands that develop around the sources of many rivers" and "are doubtless of great importance in protecting a river's water, almost everything about them is poorly understood". Rowntree (1992) conducted a hydrogeomorphic survey of the wetland areas in the north Eastern Cape forested areas, which was one of the few attempts aimed at contributing to the limited body of knowledge about wetland hydrogeomorphic functions. This lack of understanding of headwater wetlands is negative for a water scarce country like South Africa. The Department of Water Affairs and Forestry (2000) reported that South Africa's rainfall is irregular across the country and varies from year to year. The average annual rainfall is 500mm compared with the global average of 800mm. The aggravating factor of this water scarcity is the fact that 60% of the river flow arises from only 20% of the land area. It is therefore important to investigate the hydrological role of wetlands located at the headwaters of such rivers. According to Bullock et al. (1997), descriptions of the hydrological functions of wetlands have attracted much attention in wetland policy as complex hydrological processes become generalised statements such as wetlands reduce flooding or wetlands promote groundwater recharge.

The hydrological functions of wetlands are intimately related to the geomorphology of the landscape upon which they are found. This is succinctly put in a definition of wetlands by Phillips (1989, p868) that, they "are elements of the landscape that:

- Are wetter than at least some other landscape elements, in terms of frequency and duration of inundation, depth of the water table, or soil moisture status;

- Maintain their moisture status as a result of their morphology, topographic setting, or location relative to water bodies;
- Have low relief, or are topographically inverted (i.e. surface depressions); and
- Are composed of alluvial, coastal, lacustrine, or palustrine sediment of recent origin”

This definition emphasises that the combined influence of hydrology and geomorphology is the key to understanding the functioning of these systems.

Numerous studies have been conducted over the years to understand the hydrogeomorphology of wetlands, especially in North America. Mitsch and Gosselink (2000) compiled a comprehensive bibliography of such studies, especially those conducted in the United States of America. Price and Waddington (2000) reviewed the hydrological research in Canadian wetlands. The scope of hydrological processes discussed in their review included runoff, surface and groundwater-flows, evaporation, microclimate, water balance, geochemical and solute transport phenomena, carbon dynamics, isotope studies, exploitation and restoration of wetlands. Although their initial intention was to include all types of Canadian wetlands, they tended to show a bias to peatlands. An earlier review of wetland ecosystem studies from a hydrologic perspective was conducted by LaBaugh (1986). After realising the deficiencies in those studies, LaBaugh (1986, p8) proposed that it would be “only when all water budget components of a wetland are measured, will questions about the importance of hydrologic processes to wetland ecosystem structure and function be resolved”. It is argued in this study that in addition to the hydrological variables, geomorphological ones can better explain the functioning of wetlands. This research uses the following hydrogeomorphological functions of wetlands as its hypotheses:

- Wetlands have high water tables
- Wetlands prolong downstream flow
- Wetlands attenuate floods
- Wetlands store sediments

1.3 RESEARCH AIM

The main aim of this research is to investigate the hydrological and geomorphological characteristics and functions of a headwater wetland located in the Featherstone Kloof Catchment. To achieve this aim, an attempt is made to answer a number of key questions:

1.4 RESEARCH OBJECTIVES

1. What is the current state of knowledge regarding wetlands and wetland hydrogeomorphology?

This question will be answered in two parts. The first part is an overview of concepts relating to wetland definition, classification systems and functions. The second part is a detailed review of literature and pertinent issues pertaining to the hydrogeomorphology of wetlands, which includes climatic, hydrological and geomorphological effects, as well as the impact of environmental extremes on wetlands.

2. What are the historical events and processes at various spatial scales that might have led to the current characteristics of the Featherstone Kloof Wetland and its catchment?

To answer this question, the general location of the study area will be described. A review of the historical geography of the surrounding region, taking into consideration both natural and anthropogenic factors, will be done and supplemented with the results of radiocarbon dating performed on the wetland sediments. An assessment of rainfall variability for the past century will be given. And the general distribution of seasons in the area will be demonstrated through the use of evaporation data.

3 What are the recent and contemporary events and processes that have taken place in the Featherstone Kloof Catchment?

This question will be answered by analysing the rainfall data of the decade preceding the monitoring period (1990 to 2000), paying particular attention to the frequency and magnitude of rainfall (storm) events. The intention is to determine how exceptional was the rainfall situation during the monitoring period (August 2001 to September 2002).

4 What are the hydrogeomorphological characteristics of the Featherstone Kloof Wetland?

To answer this question, the presentation of results based on the analysis of the data generated during the hydrogeomorphological monitoring will be done, which includes watertable levels, discharge, rainfall, soil characteristics and wetland topography. Secondly, the hydrological situation of wetland will be quantified using the water balance method.

5 What are the implications of the characteristics of the wetland and the surrounding catchment for its hydrogeomorphological functioning?

A general discussion of the research results will be done. Conclusions will be drawn and recommendations for wetland management and future research will be stated.

1.5 THESIS LAYOUT

The above key questions are used as the basis for the chapter layout in the thesis, including chapters on research design and methods; general conclusion and recommendations; cited references; and appendices.

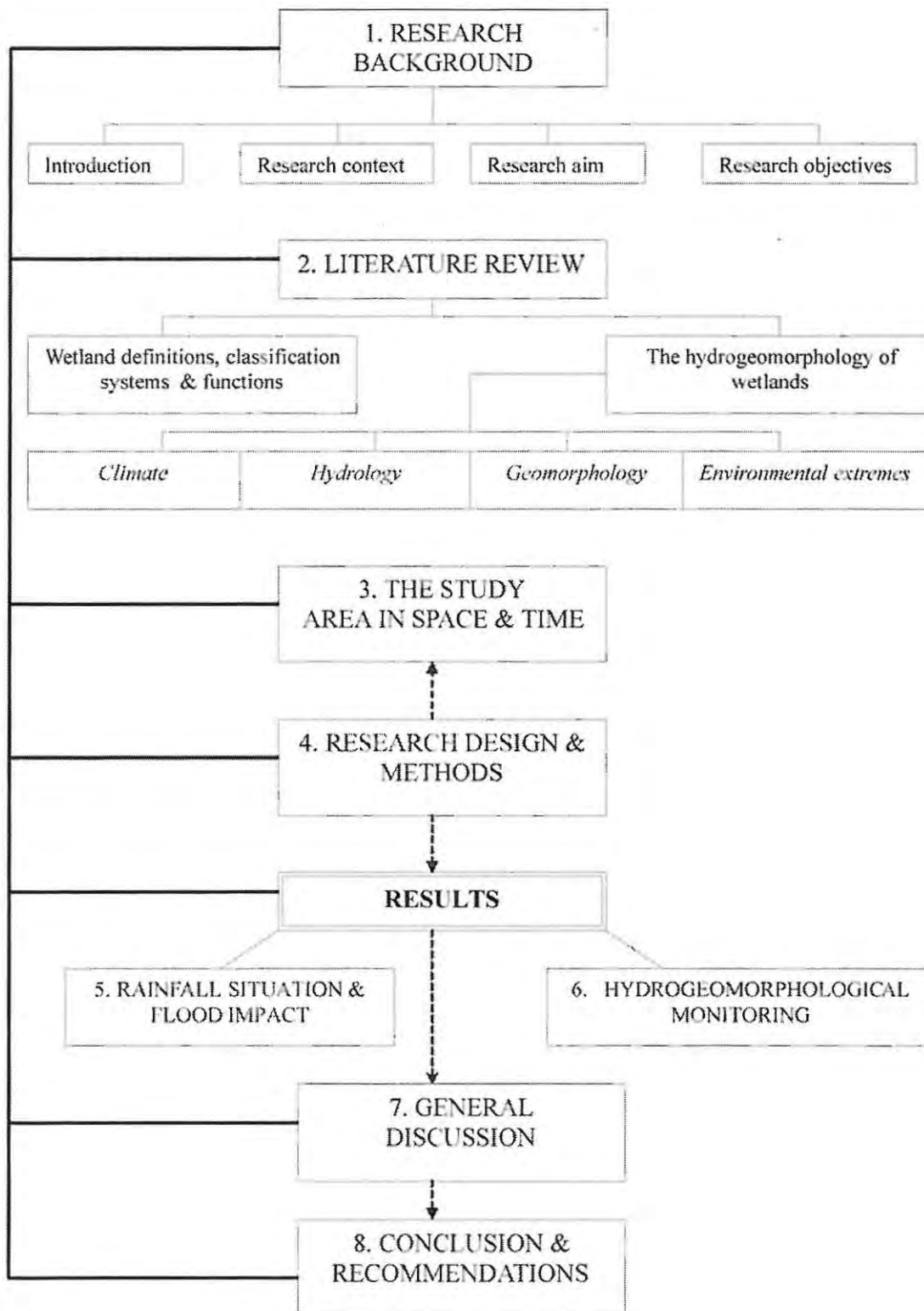


Figure 1.1: Thesis layout

Chapter Two: LITERATURE REVIEW

2.1. WETLAND DEFINITION, CLASSIFICATION SYSTEMS AND FUNCTIONS

2.1.1 Wetland definition

Various authors define wetlands in different ways that vary from place to place and from discipline to discipline. However, in recent years there seems to be a wide acceptance of the Ramsar definition that, “wetlands are areas of marsh, fen, peatland or water, whether artificial, permanently or temporarily, with water that is static or flowing, fresh, brackish or salt including areas of marine water to the depth of which at low tide does not exceed six meters” (Ramsar article 2.1. in Cowan, 1995). This is a broad definition that encompasses wetlands of all types and addresses the concerns of all sectors of the society. After giving a broad review of various definitions of wetlands, Mitsch and Gosselink (2000, p26) concluded that, “wetland definitions, then, often include three main components, namely: wetlands are distinguished by the presence of water, either at the surface or within the root zone; they often have unique soil conditions that differ from adjacent uplands; and they support vegetation adapted to the wet conditions (hydrophytes) and, conversely, are characterised by an absence of flooding-intolerant vegetation”. They referred to this as a three-level approach to the definition of wetlands as illustrated in Figure 2.1.

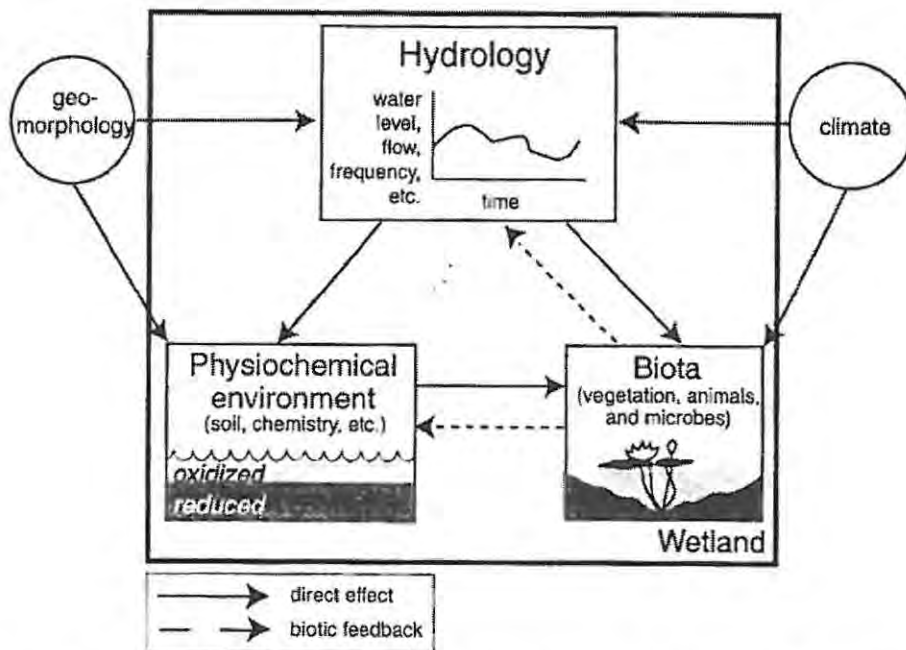


Figure 2.1. The three-component basis of a wetland definition: Hydrology, physiochemical environment, and biota (after Mitsch & Gosselink, 2000)

The aspects of wetlands highlighted in Figure 2.1 have been widely recognised in developing wetland classification systems worldwide. It is therefore important to give a brief review of some of the wetland classification attempts that have laid a basis for the current understanding of wetlands.

2.1.2 Wetland classification systems

There are numerous attempts to classify wetlands for their better management and scientific understanding. At a global scale more advanced attempts have been done in Europe and North America. The most used classification system is by Cowardin et al. (1979) entitled “The Classification of Wetlands and Deepwater Habitats of the United States of America”. This system will be presented here and discussed briefly. There are several other classification systems that are country specific such as the Canadian Wetland Classification System. However, these systems do not necessarily show deviations from the Cowardin system; instead they adopt new terms to suit their unique circumstances. This is also true for the proposed South Africa classification system that will be outlined later.

i). Cowardin’s wetland classification system

This classification system is a product of other classification systems that were used in the United States of America (USA) since the 1900s. It is the system that is currently used by the USA, and it has great influence on wetland classification systems of other countries around the world. Its main purpose was to describe ecological taxa, arrange them in a system useful to resource managers, furnish units of mapping, and provide uniformity of concepts and terms. It recognises that wetlands are defined by plants (hydrophytes), soils, (hydric soils), and frequency of flooding. This is in agreement with Mitsch and Gosselink’s (2000) three-level approach to wetland definition given above. Ecologically related areas of deep waters, traditionally not considered wetlands, are included in the classification as deepwater habitats. The inclusion of rivers and lakes, in particular, supports Newson’s (1994, p120) observation that:

“river managers are also increasingly realising the relationship between freshwater habitats and neighbouring wetland and terrestrial habitats is crucial to sustained ‘naturalness’ in the freshwater environment. Rivers and

lakes do not exist as isolated elements, divorced from their immediate surroundings because they are aqueous media; the riverbank, the valley floor, lakeshore environments all link together. The principle of ecotones (boundary environments) is especially relevant to banks, shores, and corridors, permitting not only biological diversity but the operation of natural processes of modulation (wetlands storing flood waters) and moderation and purification (wetlands stripping nutrients) on runoff products of the catchment hinterland”.

This is also true for the oceans and their coastal areas where wetlands are known for their shoreline stabilisation role and many other functions.

a. The structure of the classification system

The Cowardin system is hierarchal in nature as depicted on Figure 2.2. Systems form the highest level of the classification hierarchy. Five systems are defined, namely: Marine, Estuarine, Riverine, Lacustrine, and Palustrine. Marine and Estuarine Systems each has two subsystems, subtidal and intertidal; the Riverine System has four Subsystems, Tidal, Lower Perennial, Upper Perennial, and Intermittent; the Lacustrine has two, Littoral and Limnetic; and the Palustrine has no subsystems. Within the subsystems, classes are based on the substrate material and flooding regime, or on vegetative life forms. The same Classes may appear under one or more of the Systems or Subsystems. The Cowardin classification is summarised in Figure 2.2.

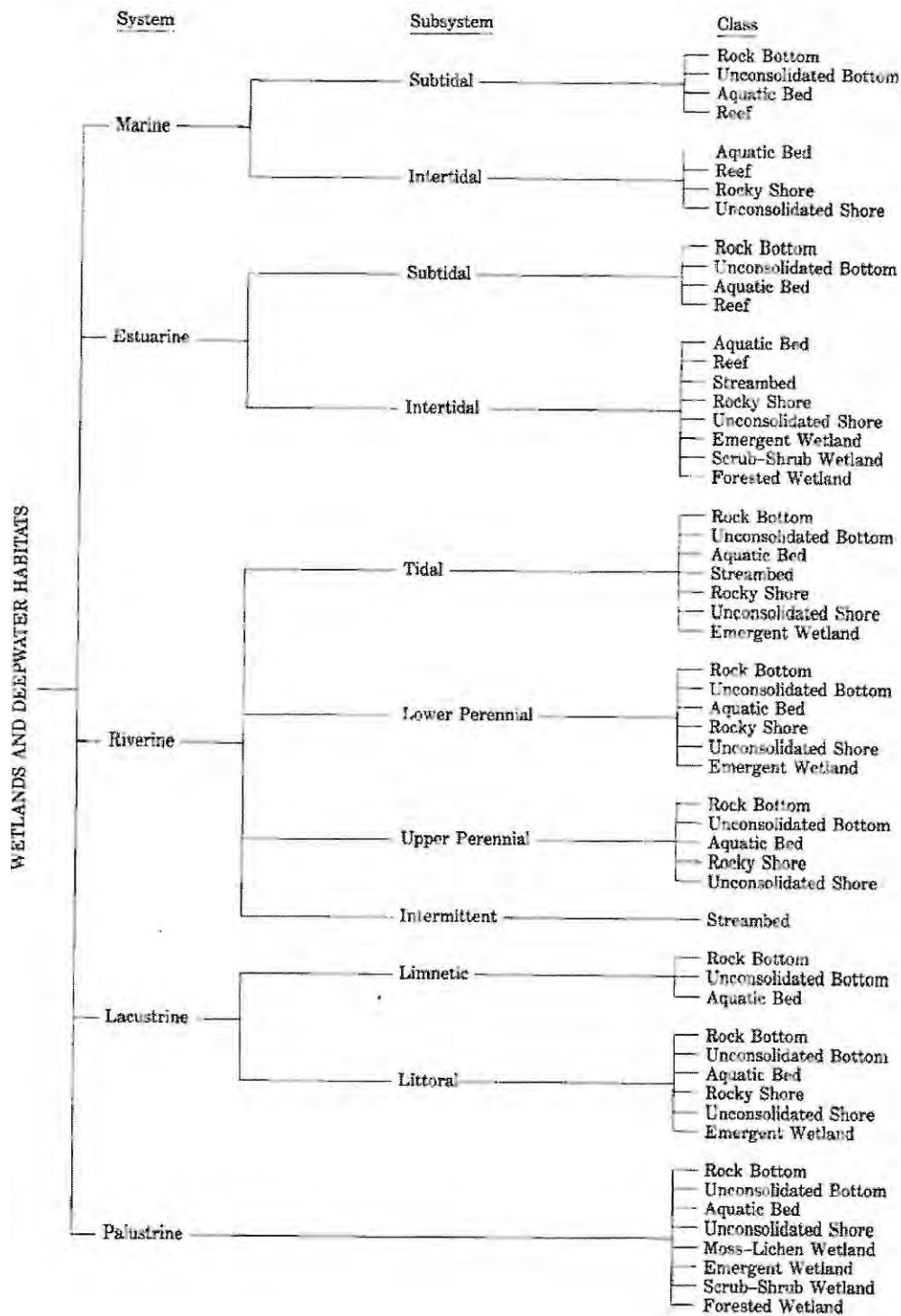


Figure 2.2: Wetland and Deep Water Habitat classification hierarchy showing systems, subsystems, and classes. (After Cowardin et al., 1979).

ii) Wetland classification in South Africa

South Africa is at a stage of developing its own wetland classification system. The Cowardin's classification system exerts great influence on the South African wetland classification attempts. Dely et al. (1999, p52) noted that, "in South Africa, both Morant (1983) and Breen (1988) proposed that the Cowardin classification of wetlands and deepwater habitats be used, subject to modification, for the purposes of establishing a National Inventory of Wetlands. Silberbauer and King (1991) based their classification of wetlands in the south-western Cape on the Cowardin classification system as did Schwabe (1989) in the study of the wetlands of the Maluti/Drakensberg Mountain catchment. Rowntree (1992), although conducting a hydrogeomorphic classification of wetlands in the North Eastern Cape, used the Cowardin classification as a preliminary descriptor for the classification of wetlands". Dini et al. (1998) took the most significant step towards a classification system for South Africa's wetlands in their proposal of South African National Wetland Inventory. The most notable modification of the Cowardin's system is the subdivision of palustrine system into subsystems. This is important for this study because it is where headwater wetlands, such as the one under study, are classified.

a. The South African Palustrine Wetland Classification subsystem

A. Definition

The palustrine system includes:

1. all non-tidal wetlands dominated by trees, shrubs, persistent emergents, mosses or lichens (greater than 30% surface area coverage);
2. tidal wetlands where salinity due to ocean-driven salts is less than 0,5 g/l; and
3. wetland habitats lacking the vegetation listed in (1), but with all of the following characteristics:
 - area less than 8 ha
 - water depth in the deepest part of the basin less than 2m at low water;
 - lacking water active wave-formed or bedrock shoreline features; and
 - salinity due to ocean derived salts less than 0,5 g/l

If a wetland qualifies as Palustrine under the above criteria, but additionally possesses all of the following characteristics, then it is classified within the Endoheiric system:

4. roughly circular to oval in shape, sometimes kidney-shaped or lobed;
5. flat basin floor;
6. less than 3m deep when fully inundated; and closed drainage (lacking any outlet).

B. Description

The Palustrine System groups together vegetated wetlands traditionally called marshes, swamps, and bogs, fens and vleis, which are found throughout South Africa. Palustrine wetlands may be situated shoreward of river channels, lakes or estuaries, on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind and water are of minor importance except during severe floods.

C. Boundaries

The palustrine system is bounded by:

7. non-wetland; or
8. Marine, Estuarine, Lacustrine or Riverine Systems.

D. Subsystems

Cowardin did not divide the Palustrine System into any subsystems. Dini (et al. 1998) expressed a concern that, considering the palustrine nature of the majority of South Africa's wetlands, valuable information would be lost by not distinguishing this System into more finely resolved subsystems. As a result, four subsystems have been defined, primarily on the basis of the position of the wetland in the landscape.

- Flat: wetland habitats occurring on areas of comparatively level land (slope less than 1%) with little or no relief, but not directly associated with either a valley bottom or floodplain feature.
- Slope: wetland habitats occurring on areas with a gradient of greater than 1%, but not directly associated with either a valley bottom or flood plain feature. Usually slopes will be found along the topographical continuum between the plateau or crest and the valley bottom.

- Valley bottom: wetland habitats occupying the bottom of the topographical sequence. They are not necessarily associated with a river channel.
- Flood plain: wetland habitats falling within areas that are:
 - i. adjacent to a well-defined river channel;
 - ii. built of sediments during the present regime of the stream; and
 - iii. covered with water when the river overflows its banks during a 1-in-10 year magnitude flood event.

Distinct morphological features, such as levees and oxbow lakes may be present and the substrate is dominated by alluvial and hydric soils.

The link of wetlands with their landscape recognises the importance of geomorphology. In the last decade, there has been a move towards linking geomorphology and hydrology in the classification of wetlands. Some of the hydrogeomorphic classifications are reviewed below.

iii) Hydrogeomorphic classification of wetlands

US Army Corps of Engineers is currently consolidating its hydrogeomorphic (HGM) wetland classification system for the USA. According to Clairain (2002), the HGM approach is a collection of concepts and methods for developing functional indices, and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. It is based on three factors that influence how wetlands function:

- Geomorphic setting
- Hydrology (water source), and
- Hydrodynamics (flows and fluctuation)

Brinson (1993) further argued that this functional approach narrows the focus of attention to a specific type or subclass of wetland, the functions that wetlands within the subclass are most likely to perform, and the landscape and ecosystem factors that are most likely to influence how wetlands in the subclass function. This HGM approach uses reference to establish the range of functioning of the wetlands, and also uses a relative index of function calibrated to reference wetlands, to assess wetland functions. It is not the intention of this research to propose or reject any classification

system, but it seeks to investigate the hydrogeomorphological functions of a single wetland. A review of wetland functions is done in the following discussion.

2.1.3 Wetland functions

The wetland functions are usually the main thrust of the activities directed to their restoration, conservation and management. According to DeBusk (2001), a wetland function refers to ecological, hydrological, or other processes that contribute to the self-maintenance of the wetland and typically exerts an influence (either positive or negative) on surrounding ecosystems. The Ramsar Convention states that wetland functions are the result of the interactions between biological, chemical and physical wetland components such as soils, water, plants and animals, and include: water storage; storm protection and flood mitigation; shoreline stabilisation and erosion control; groundwater recharge; groundwater discharge; retention of nutrients, sediment and pollutants; and stabilisation of local climatic conditions; particularly rainfall and temperature (Finlayson, 1996). Some of these functions appear to be contradictory in nature, for example, the promotion of both groundwater recharge and discharge. Begg (1986) referred to this contradiction as a dualistic role of the wetlands in the environment as they can be shown to both sustain and deplete water yield (Figure 2.3).

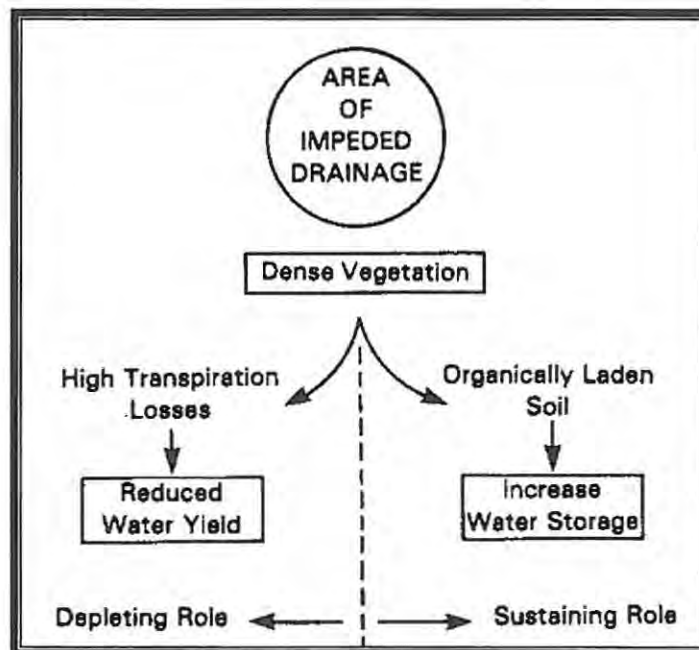


Figure 2.3: The dualistic role of wetlands in the environment (After Begg, 1986)

Begg (1986, p13) further pointed out that, “there is a popular misconception that wetlands release water”, and argued that, “the fact of the matter is, that in most wetlands the passage of water through the soil profile is slow due to the high clay content of the soil, and the factors controlling its movement are normally geologically or topographically determined”. This argument is supported by DeBusk’s (2001) assertion that the functioning of wetlands in the landscape is strongly influenced by local and regional scale environmental factors related to climate, geomorphology and source of water (hydrology). These factors act as controls on the functioning of wetlands. Human alteration of wetlands and their surrounding landscape through land-use is a secondary factor. In the following discussion these controls will be dealt with in greater detail as they form the crux of this research.

2.2 THE HYDROGEOMORPHOLOGY OF WETLANDS

In this section, the discussion of wetland functions will be taken a step further with a special focus on the influence of climatic, hydrological, and geomorphological factors on wetland functioning. These factors are not treated as mutually exclusive, but are viewed as having a combined effect on the functioning of wetlands. The section concludes with the discussion of the role of environmental extremes, especially floods, on the functioning of wetlands.

2.2.1 Climate effects

The most significant element of climate that has tremendous effect on wetland functioning is precipitation. In South Africa, rainfall is the most common type of precipitation. It contributes to runoff and groundwater and, therefore, plays an important role in the water balance of wetlands. According to Mitsch and Gosselink (2000, p190), climate, through the balance of precipitation and evapotranspiration, influences surface water quality. Arid regions tend to have higher concentrations of salts in surface waters than do humid regions. It also has a considerable influence on the type and extent of vegetation on the land, and it therefore indirectly affects physical, chemical and biological characteristics of soils and the degree to which soils are eroded and transported to surface waters. That also applies to wetlands as landscape features.

DeBusk (2001) pointed out that the timing or pattern of rainfall in the region, including the proportion of annual rainfall occurring during the growing season, is very important. For example, given the fact that in South Africa's rainfall is greatest in the eastern and northern parts of the country, and potential evaporation is greatest in the western parts, it could be expected that more wetlands will be found on the eastern and northern parts. At the same time, the seasonal nature of rainfall can also affect the characteristics of wetlands in various parts of the country. Temperature exerts great influence on the rate of evapotranspiration. It would therefore be expected that the season of higher temperatures is also associated with high rates of evapotranspiration. Temperature also plays a significant role on the biological processes of wetlands such as the decomposition of organic materials. Wetlands are more prevalent in cool or wet climates than in hot or dry climates (Mitsch &

Gosselink, 2000). Cool climates have less water loss from the land via evapotranspiration, whereas wet climates have excess precipitation.

Of paramount importance to the functioning of wetlands are the extremes of climate in the form of drought and flood events. Newson (1994) pointed out that the history and philosophy of natural sciences are full of references to the role of climatic and other extremes as major forces. He further reported that, recently “there has been something of a trend back towards catastrophism...i.e. a special role of extremes in, for example, bringing about geomorphological change” (Newson, 1994, p64). As stated before, some of the wetland functions that are common in literature are that they attenuate floods and store water during periods of drought, which also recharges the ground water. Something that most of these reports fail to mention is the impact of floods and droughts on wetland functions in general and how these impacts can be mitigated. Thompson and Finlayson (2001) do make a reference to the fact that these extreme events often play an influential role in the development of wetlands and in controlling their physical and ecological characteristics. It is always these unpredictable or catastrophic events that play a significant role in initiating changes in wetland vegetation communities (Niering, 1988). During periods of drought, wetland water levels recede and plants adapted to higher water level conditions are detrimentally affected, and during floods extraordinary amounts of water affect such vegetation. This theme will be pursued further under the section on the role of environmental extremes.

2.2.2. Hydrological effects

(i) Source of water

From the foregoing discussion it is clear that hydrology is intimately linked to climate, and both have some controlling effects on wetlands. The two hydroclimatic variables, precipitation and evaporation, play a significant role on the water balances of wetlands, especially in warmer and semi-arid regions of the world, including South Africa. Most of the water found on the earth’s surface is primarily from precipitation in the form of rain or snow. The source of water can also be used to identify wetlands according to function. Wetland water sources can be grouped into three broad categories, namely: precipitation (rainfall), surface water and groundwater (DeBusk, 2001; Brinson, 1993).

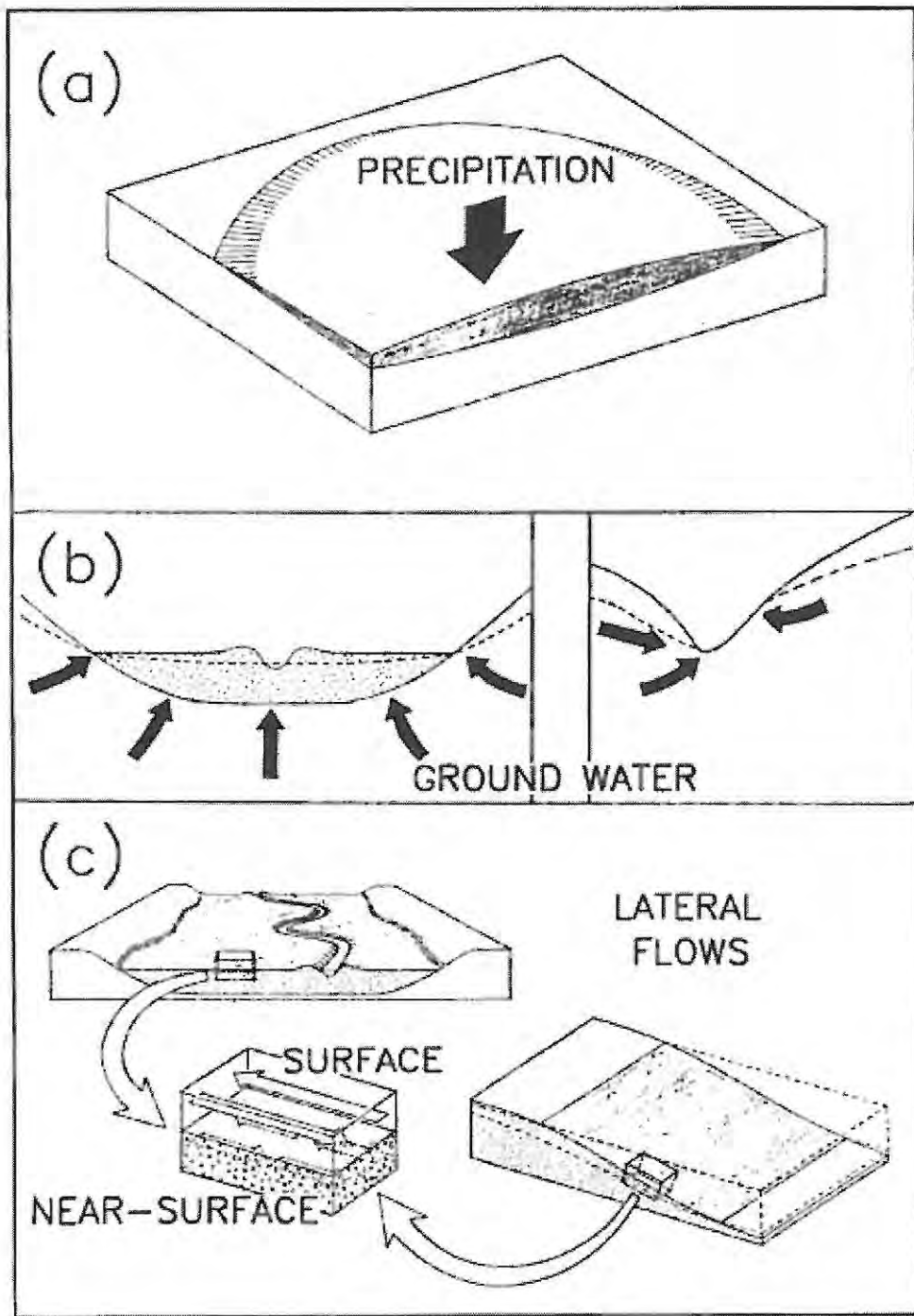


Figure 2.4: Principal sources of water (After Brinson, 1993)

The source of water to a wetland also affects the wetland hydrological regime, which, as Thompson and Finlayson (2001, p155) put it, “is supremely important for maintaining a wetland’s structure and functional characteristics. Unique physiochemical conditions distinguish wetlands as ecotones between well-drained terrestrial systems and deepwater aquatic systems”.

Mitsch and Gosselink (2000) argued that the starting point for the hydrology of a wetland is the climate and basin geomorphology, and when they are combined with hydrology into one unit, it is referred to as wetland’s hydrogeomorphology.

“The hydrology of a wetland directly modifies and changes its physiochemical environment, particularly oxygen availability and related chemistry such as nutrient availability, pH, and toxicity... Hydrology also transports sediments, nutrients, and even toxic materials into wetlands; thereby further influencing physiochemical environment...Hydrology also causes water outflows from wetlands that often remove biotic and abiotic materials such as dissolved organic carbon, excessive salinity, toxins, and excess sediments and detritus. Some modifications in the physiochemical environment, such as build-up of sediments, can modify the hydrology by changing the basin geometry or affecting the hydrologic inflows or outflows...When hydrologic conditions in wetlands change, even slightly, the biota may respond with massive changes in species composition and richness and in ecosystem productivity (Mitsch & Gosselink, 2000, p108)”.

This point highlights the sensitivity of wetlands to changes in hydrological conditions in the surrounding wetland catchment. Thompson and Finlayson (2001) noted several key hydrological attributes common to freshwater wetlands, namely: wetland water-level regime, wetland water-balance, hydrological extremes and wetland level-area-volume relationships. The first two attributes will be discussed briefly as they relate directly to this study. The wetland level-area-volume relationships are more pronounced in wetlands where water is above the surface for most of the time such as pans. A reference has been made to hydrological extremes several times and further elaboration is done under the section on environmental extremes.

(ii). Wetland hydroperiod

Wetlands are identified by the amount of water they contain relative to the surrounding landscape. This water level varies over time within a single wetland and from wetland to wetland. This variation is usually referred to as the hydroperiod. According to Mitsch and Gosselink (2000, p112), “the hydroperiod is the seasonal pattern of the water level of a wetland and is like a hydrological signature of each wetland type. It defines the rise and fall of a wetland’s surface and subsurface water. It characterises each type of wetland, and the consistency of its pattern from year to year ensures a reasonable stability for that wetland”. Thompson and Finlayson (2001) referred to it as the wetland water-level regime. Because wetlands are hydrological features, the focus of wetland management and other programmes has been on ensuring that a desired state of water-level regime is maintained for all other ecological processes to continue. It has been observed by a number of researchers (Fredrickson & Reid, 1990; Thompson & Finalyson, 2001) that wetland restoration or rehabilitation initiatives have resulted in fundamental modifications to water-level regimes, thereby leading to their further destruction and degradation. Fredrickson and Reid (1990), further argued that what many people fail to recognise is that not all wetland flora and fauna require water in all stages in their life cycle.

Cowardin (1979) proposed typical water-level regimes that characterise different wetland types. Such water-level regimes range from permanently flooded wetland on one extreme to intermittently flooded ones on the other (Table 2.1)

Table 2.1: Definitions of wetland hydroperiods for non-tidal wetlands (After Cowardin et al., 1979)

| | |
|---------------------------------|--|
| Permanently flooded | Flooded throughout the year in all years |
| Intermittently exposed | Flooded throughout the year except in years of extreme drought |
| Semi-permanently flooded | Flooded during the growing season in most years |
| Seasonally flooded | Flooded for extended periods during the growing season, but usually no surface water by end of growing season |
| Saturated | Substrate is saturated for extended periods during the growing season, but standing water is rarely present. |
| Temporarily flooded | Flooded for brief periods during the growing season, but water table often otherwise well below surface |
| Intermittently flooded | Surface is usually exposed with surface water present for variable periods without detectable seasonal pattern |

The definition of hydroperiod given above also highlights the importance of time scale of wetland inundation. Mitsch and Gosselink (2000) distinguished between flood duration (the amount of time that a wetland is in standing water) and flood frequency (the average number of times that a wetland is flooded in a given period). This cycle of flooding is not always regular within a single wetland. Williams (1998) reported that this irregular cycle of inundation is common in Africa and Australia. In a study of a wetland system similar to the Featherstone Kloof Wetland, Rosenberry and Winter (1997) observed frequent changes in water table configurations following wet and dry periods over a five-year period of investigation. Their study dealt with two wetlands located near each other. There was a seasonal wetland situated about 1.5m higher than a nearby semi-permanent one, suggesting an average water table gradient of 0.02. The water table mound was caused by high rainfall whereas the trough was caused by evapotranspiration. Water table mounds that formed in response to rainfall events caused reversals of direction of flow that frequently

modified the more dominant water table trough during severe droughts. The presence of these different water table configurations confirms that wetland hydrodynamics, especially the water-level regimes of headwater wetlands, can be very complex. The wetland hydroperiod is intimately linked to its water balance.

(iii). Wetland water balance

The hydroperiod of a wetland is a product of the interaction between various components of the hydrological cycle. Mitsch and Gosselink (2000, p119) pointed out that the “hydrologic state of a given wetland can be summarised as being a result of the following factors:

- The balance between the inflows and outflows of water
- The surface contours of the landscape
- The subsurface soil, geology, and groundwater conditions”

The first point is the one that describes the water balance of any wetland. The water balance concept has long been used to quantify the relative amount of water inputs and outputs and their relationship with water storage at various temporal and spatial scales, and it will be used in this research.

The distinguishing feature of all wetlands is that they contain more water than the surrounding landscape. Unlike the terrestrial ecosystems that surround them, wetland water balances are dominated by storage, particularly in the saturated parts of the soil (Thompson and Finlayson, 2001). This dominance of storage within wetlands has been attributed to gentle topographic and hydraulic gradients combined with the texture of wetland soils, which frequently provides high storage coefficients, and resistance to flow associated with vegetation (Gilman, 1994). That has led to a generalisation that wetlands act as sponges as they store water and release it slowly during drier periods. This is the subject of investigation for this study.

Numerous studies have been conducted to investigate water balances of various wetlands around the world. Such results have led to very variable results, which are sometimes inconsistent in nature. This variability can be attributed to lack of resources and time constraints over which they were conducted. That is also linked to

different instrumentation used to collect the hydrological data, which requires an application of different versions of the water balance model. LaBaugh (1986) presented a summary of methods used in some of the key wetland water balance studies he managed to compile as shown in Table 2.2.

Table 2.2: A list of methods used in calculating the water balances of various wetlands (After LaBaugh, 1986)

| Site | Wetland type | Reference | Precipitation | Evaporation | Stream inflow | Stream outflow | Overland runoff | Water storage | Ground water storage |
|------------------------------------|------------------------|--------------------------|---------------|-----------------|---------------|----------------|-----------------|---------------|----------------------|
| Rough Sike, UK | Pennine Moorland | Crisp (1966) | OG | P-SO | NA | RG | NC | NC | NC |
| Heron Pond, Illionis | Alluvial cypress swamp | Mitsch et al. (1979) | OG (1Km) | DS, PAN (24 Km) | RG | RG | DS | RG | RES |
| Control Watershed 2, Minnesota | Upland Peatland | Verry and Timmons (1982) | OG | RES | NA | RG | HS | RG | OM |
| Thoreau's Bog, Massachusetts | Tidal Salt Marsh | Valiela, et al. (1978) | RG (4Km) | HS | NA | OM | HS | RG | OM |
| Three areas in North Dakota | Prairie Potholes | Eisenlohr (1972) | RG | MT, RES | NA | NA | DS | RG | RES |
| Cottonwood Lake Area, North Dakota | Prairie Potholes | Winter and Carr (1980) | RG | MT | NA | NA | NC | OG, RG | FN |

Explanation of table notation:

OG = Observer read gauge, non-contiguous record

P-SO = Calculated by difference between precipitation input and streamflow output, and calibrated against lysimeter and Penman equation

NA = Does not occur.

RG = Recording gauge, continuous record (flume, weir, stilling well, etc).

NC = Not considered.

DS = Calculated from change in wetland storage

PAN = Evaporation pan.

RES = Calculated as the residual of the water balance.

HS = Calculated by hydrograph separation technique

OM = Occasional measurement.

DIL = Calculated from dilution of seawater by groundwater to account for salinity of ebb tide

MT = Mass transfer method.

FN = Flow net analysis with water table wells and piezometer nests.

Number in parentheses indicates distance of gauge from site.

The calculation of the water balance is also important for identifying hydrological extremes, such as droughts and floods, and their impact on each element of the wetland water balance. That is also linked to the geomorphology of the area where the wetland is located.

2.2.3. Geomorphological effects

Most wetland related activities have tended to treat wetland hydrology and ecology separately from their geomorphology. According to Debusk (2001), geomorphology, referring to landforms and landscape relief, plays a major role in wetland hydrology and ecology. Geomorphology encompasses the shape, size and location of wetlands in the landscape and, therefore, it should be taken as a priority when carrying out programmes related to wetland inventories, classification systems and wetland delineation. The basic geomorphological unit in relation to inland wetlands is the catchment area. Catchment hydrological and sediment processes determine the functioning of a wetland. For example, sediment sources, pathways and areas of deposition are related to the geomorphic setting of the wetland.

(i). Wetland geomorphic setting

Geomorphic setting, which refers to the location of the wetland on the landscape, is very important to the functioning of wetlands. Brinson (1993, p19) argued that “implicit in the hydrology of a particular wetland is its landscape position, or geomorphic setting, which will accommodate the flows and storages of water. From a broad and long-term geomorphic perspective, water flows and position are inextricably linked”. That also points to the fact that it is very important to trace the hydrogeomorphological history of a wetland to be able to understand its current status and predict its future dynamics. Various types of wetlands are identified on the basis of their location on the landscape, namely, depressional, riverine, and fringe categories. The riverine category is discussed below as it relates to the wetland under study.

(ii). Riverine (riparian) wetlands

There is always a difficulty in distinguishing palustrine wetlands from riverine wetlands, particularly when it comes to headwaters of streams. The definition of the riverine wetland system according to the proposed South African Classification

system by Dini et al. (1998) is that it includes all wetlands contained within a channel, a channel being an open conduit, either natural or artificial, which periodically or continuously contains flowing water. The definition also acknowledges that palustrine islands may occur in the channel or adjacent floodplains. This distinction may be valid for wetland classification systems aimed at the management of these ecosystems. However, from a geomorphological point of view, DeBusk (2001) argued that riverine or riparian wetlands represent a transitional zone between terrestrial (upland) and aquatic (stream) ecosystems. He further pointed out that since they are hydrologically connected to both the stream and adjacent uplands, they are of major importance in regional hydrology. This implies that, despite the fact that some of the wetlands found on the catchment slopes and headwaters of streams do not necessarily contain open channels, they are symbiotically linked to the river, and therefore, they are part of the broader river system.

Riverine wetlands intercept surface and subsurface (groundwater) runoff from the upland regions of the catchment, and also interact periodically with floodwaters from the streams, which can have significant effect on stream water quality. According to DeBusk (2001), of particular significance to downstream water quality are riparian wetlands associated with low-order (smaller) streams because of the large hydraulic throughput in these wetlands relative to the flow in the river or stream. They generally occur in the upper reaches of watersheds. He further argued that, although the riparian zone of a single low-order stream may seem insignificant to water quality in the watershed, the cumulative impact of the multitude of riparian wetlands along low-order streams can be extremely significant. These systems are hydrogeomorphologically very dynamic as it will be shown later in the results of this study. Brinson (1993) gave examples of geomorphic settings of riverine wetlands and related that to research evidence, functions and ecological significance as shown in Table 2.3 below.

Table 2.3: Examples of geomorphic setting as a property of hydrogeomorphic classification (Adapted from Brinson, 1993).

| Examples of geomorphic setting | Qualitative evidence | Quantitative evidence | Functions | Ecological significance |
|---|--|--|---|--|
| Streamside zones of intermittent streams | Headwater position; first order stream | Flows not continuous' flow lacks headwater flooding and over bank flow properties. | Interface of landscape where groundwater and surface water sources change phases to fluvial environment | Riparian zone critical to maintaining buffer between upland and stream flow. |
| High gradient: -Down cutting portions | Bedrock controlled channel | Substrate lacks alluvium. Flow may be continuous but likely flashy. | Scour precludes extensive wetland development. Unvegetated reaches allow light penetration to support aquatic production. | May impede wildlife movement and cover if corridor too narrow. Maintains in-stream riffle habitat. |
| -aggrading portions | Substrate controlled by fluvial processes. | Stratigraphy shows interbedding and coarse particle size (gravel and larger) | Wetland on coarse substrate maintained by upslope groundwater source | Unstable substrate in high-energy environment colonised by pioneer species. Streamside vegetation contributes to allochthonous organic supply. |
| Middle-gradient landform. | Channelised flow, evidence of oxbows, meander scrolls, etc. Consistent with fluvial processes. | Flow likely continuous with moderate to high base flows. | Channel processes establish variation in topography, hydroperiod, and habitat interspersed on a floodplain. | Alluvium is renewed by surface accretion and point bar deposition; interspersed of plant communities contributes to better diversity |
| Low-gradient alluvial. Floodplain of bottomland hardwood. | As above, but in low-gradient landform. | Flow continuous with cool season flooding. High suspended sediments in stream. | Flood storage; conserves groundwater discharge. | Major habitat for wildlife biodiversity; strong biochemical activity and nutrient retention. |

(iii). Geomorphology and wetland hydrology

The influence of geomorphology on wetland hydrology cannot be overemphasised. The morphology of individual basins or wetlands influences flooding depth as well as hydroperiod, which, as stated before, refers to the frequency and duration of inundation. The impact of floods on wetlands differs from catchment to catchment depending, primarily, on the morphology of those catchments. Steep slopes are prone to high water velocities which results in accelerated erosion. Gentle slopes are also susceptible to deposition of sediment, and wetlands are mainly associated with such areas as sediment sinks. Flood sediments can bring about drastic changes to wetland hydrogeomorphology. The geomorphology of the surrounding landscape does not only influence the surface water flows, but it also exerts a strong influence on surface and groundwater connections between the wetland and adjacent terrestrial and aquatic ecosystem (DeBusk, 2001), especially that wetlands are transitional landforms between terrestrial and aquatic parts of the landscape.

(iv). Wetland sediments

Erosion and deposition are geomorphological processes that are very active on wetlands and wetland catchments all over the world. The erosion/deposition cycle is responsible for the removal, transportation and subsequent storage of sediments on the landscape. From a geomorphological point of view, wetlands can be regarded as both degradational and aggradational landforms.

a. Erosion

The process of erosion is a product of many factors taking place in the wetland catchment and the wetland itself. Erosion is very common on South Africa's landscape and it has been the focus of dry-land research for quite some time as shown by studies compiled by, for example, Dardis and Moon (1988). Gullies and head-cuts, which are in most circumstances caused by erosion, are a common feature on the inland wetlands of South Africa. They are usually viewed as a symptom of wetland degradation as shown by current wetland rehabilitation initiatives by the government through the Working for Wetlands project. In most cases the assumption is that anthropogenic factors are responsible for that degradation. Newson (1994, p144) warned that, "since wetlands are a dynamic feature of landscapes, changes in their status may not always originate from an artificial cause". Unfortunately, if such

programmes do not take into consideration the role played by geomorphology in the formation of those gullies they are likely to fail.

b. Deposition

Besides restoring wetland water levels, the goal of many wetland rehabilitation programmes is usually the revival of the wetland sediment retention capacity. One of the widely accepted functions of wetlands is their ability to store sediments. According to Phillips (1989, p868), “alluvial wetlands are depositional features in the genetic sense, as all are created as a result of sediment deposition... This accumulation of sediments in channels and floodplains may be viewed as either a sediment sink or storage, depending on the nature of the wetland feature and the time scale of interest. Over the timescales of interest to geomorphologists – generally years to millennia – alluvial wetlands are best viewed as temporary storage sites”. Sedimentation rate is important to the soil building process, alters water storage capacity and thus the flood attenuation function of wetlands, and colonisation, growth and survival of plants (Payne, 2000). Wetland sediment dynamics should be viewed from a catchment perspective because of the broad nature of the spatial scale where they occur.

This sediment storage function of wetlands has been found to be useful in tracing environmental change over a geological timescale as shown by several studies, including the evidence for sea level change gathered by Baxter and Meadows (1999) at Verlorenvlei, Western Cape. The sedimentological history of a wetland can be studied to trace its genesis so as to understand contemporary sediment dynamics and predict future processes. That information can also help in guiding wetland restoration programmes aimed at enhancing wetland sediment storage function. Wetland soils are the main store for such wetland sediments. Wetland soils are able to reflect the dominant type of sedimentation in a particular wetland, whether it is clastic, organic or chemical sedimentation. Even if the wetland is no longer functional from a hydrological and ecological point of view, soil is able to keep evidence of its past existence as shown, for example, by the presence of palaeoflood sediments in river-terraces, and pollen data in peatlands such as those studied by Grundling et al. (1998). The significance of soil in wetland hydrogeomorphology needs special treatment, as will be done in the following discussion.

(v). Wetland soil

Climate, geomorphology and hydrology interact to produce wetland soils with very distinct characteristics. In an investigation of spatial variability in palustrine wetlands, Stolt et al. (2001, p527) stated that, “systematic variability in wetland soils is the result of differences in parent material, elevation, erosional and depositional environment, frequency of flooding, vegetation, pedogenic effects, and hydrology”. Wetland soils form a template upon which many wetland ecological processes take place. Their distinguishing characteristic is the high organic matter content, which is the result of anaerobic conditions prevailing in the wetland. The anaerobic conditions are caused by the presence of wetland water for an extended period of time. Such conditions produce a kind of soil known as hydric soil. The hydric soil is soil that in its undrained condition is saturated or flooded long enough during the growing season to develop anaerobic conditions that favour the growth and regeneration of hydrophytes (U.S.D.A. Soil Conservation Service, 1985). Wetland soils are grouped into mineral and organic soils.

a. Mineral hydric soils

According to the US Army Corps of Engineers (1997), mineral hydric soils are those periodically saturated for sufficient duration to produce chemical and physical soil properties associated with a reducing environment. Mitsch and Gosselink (2000, p163) remarked that, in practice, the determination of whether a mineral soil is a hydric soil is a complicated process. They stated that soil colour is the most important indicator of mineral hydric soils. This importance of colour was confirmed by the US Army Corps of Engineers (1997, p21), who stated that mineral hydric soils “are usually grey and or mottled immediately below the surface horizon, or they have thick, dark coloured surface layers overlying gray or mottled subsurface horizons”. It is these colour patterns that distinguish mineral hydric soils from organic hydric soils, and are very useful in distinguishing between wetland areas and non-wetland zones.

b. Organic hydric soils

When wetland plants and other organisms die, they decompose to form the organic component of wetland soils. As stated before, the anaerobic conditions created by poorly drained soils promote the accumulation of the remains of plants in various

stages of decomposition, resulting in peats and mucks (US Army Corps of Engineers, 1997; Mitsch & Gosselink, 2000). Organic soils (histosols) are classified into four groups, three of which are considered hydric soils:

- Saprist (muck). Two thirds or more of the material is decomposed, and less than one-third of plant fibres are identifiable.
- Fibrists (peat). Less than one-third of material is decomposed, and more than two-thirds of plant fibres are identifiable.
- Hemists (mucky peat or peaty muck). Conditions fall between saprist and fibrist soil.
- Folists. Organic soils caused by excessive moisture (precipitation > evapotranspiration) that accumulates in tropical and boreal mountains; these soils are not classified as hydric soils as saturated conditions are the exception rather than the rule (Mitsch & Gosselink, 2000, p160).

c. Soil hydromorphic properties

Several studies have been conducted over the years to understand different soil morphological properties and their relationship with wetland hydrology. Kotze et al. (1994), in an attempt to develop a wetland soils classification system for KwaZulu/Natal, concluded that soil morphology (mainly soil colour patterns) provides a useful surrogate for determining water regime. After reviewing a number of studies, they proposed a Provisional Three Class System for determining the degree of wetness of wetland soils based on soil morphology (Table 2.4)

Table 2.4: A provisional three class system for determining the degree of wetness of wetland soils based on soil morphology (After Kotze et al., 1994)

| SOIL | DEGREE OF WETNESS | | |
|------------------------|---|---|--|
| | Temporary | Seasonal | Permanent/Semipermanent |
| Soil depth 0-10cm | Matrix chroma: 1-3 Few/no mottles Low/intermediate OM nonsulphidic | Matrix chroma:0-2 Many mottles Intermediate OM Seldom sulphidic | Matrix chroma: 0-1 Few/no mottles High OM Often sulphidic |
| Soil depth 30-40 cm | Few/many mottles Matrix chroma: 0-2 | Many mottles Matrix chroma: 0-2 | No/few mottles Matrix chroma: 0-1 |
| VEGETATION | Predominantly grass species | Predominantly sedges and grasses | Predominantly reeds, sedges and bulrushes |

Key to the table:

High OM: soil organic carbon levels are greater than 5%, often exceeding 10%

Low OM: soil organic carbon levels are less than 2%

Sulphidic soil material has sulphides present which give it a characteristic "rotten egg" smell.

From this table it is clear that the absence, presence, and nature of mottles have become key morphological features for the inference of soil drainage conditions, as it is often impractical (Pickering & Veneman, 1984) to measure the soil moisture regime directly through long-term monitoring. It is therefore necessary to reflect briefly on the development of these redoximorphic features in soils.

d. Development of redoximorphic features in soils

The redoximorphic features (formerly called wetness or drainage mottles) constitute distinctive colour patterns in wetland soils. The seasonal or permanent inundation of wetland soils leads to the development of soil colours ranging from black, grey, red, brown, yellow to orange. When soils are not saturated with water, iron oxides give

the soil its typical red, brown, yellow or orange colour, and manganese oxides give the soil dark to black colours (Robenhorst & Parikh, 2000; Mitsch & Gosselink, 2000). The physiochemical processes that describe the transformation of these oxides are very complex.

In an attempt to describe these transformations, Robenhorst and Parikh (2000) stated that, when soils become saturated with water, anaerobic conditions can develop if an oxydisable carbon source is present and temperatures are warm enough for microorganisms to be active. If anaerobic conditions persist, soils may become sufficiently reduced that ferric (III) iron oxide minerals begin to be reduced to the ferrous (II) state. The particular redox potential at which this transformation occurs is dependant on pH and other factors. Seasonal variations in rainfall and evapotranspiration lead to the fluctuations in water table levels in wetlands giving rise to alternating conditions of reduction and oxidation with respect to iron oxides. Mobilisation of ferrous iron during periods of reduction can lead to the segregation of iron oxides and the formation of some zones that are depleted and others that are enriched in iron. Vepraskas (1992), when describing redoximorphic features for identifying aquic conditions, stated that the colours of depleted zones reflect the colours of the coated mineral grains and are typically grey or white. In extreme cases, the iron oxides are not only depleted from small zones but may be largely removed from soil leading to depleted or gleyed matrix. Conversely, the zones where oxides have been concentrated typically appear redder or browner than matrix soil colour and have been termed masses, coatings, porelinings, depending on where they appear with regard to natural surfaces within the soil.

e. Possible problems in using soil morphology as an indicator of hydric conditions

Kotze et al. (1994) listed soils which are problematic when using soil morphology as an indicator of hydric conditions. They grouped such soils into two categories:

- Hydric soils which lack hydromorphic features because of such factors as being recently formed, and
- Non-hydric soils with apparent hydromorphic features, such as low chromas, that developed under hydromorphic conditions.

Robenhorst and Pakish (2000) also made an attempt to give possible explanations for what they termed “anomalous hydromorphology”. They identified two classes of explanations.

- Those related to chemical conditions in the soil environment, and
- Those related to the inherent properties of the soil itself.

Chemical conditions in the soil environment have been attributed to oxyaquic conditions, where the soils were wet but for some reason did not develop reducing conditions. Vepraskas and Sprecher (1997) reported that oxyaquic conditions may occur where soils contain low quantities of decomposable organic matter; soil temperatures are so low that biological activity is limited; or where rapid flow of groundwater may prevent depletion of the oxygen levels. Regarding properties inherent in soils themselves, the first may be that the colours of uncoated mineral grains themselves are brownish showing high chroma, rather than low chroma colour. A second reason may be that certain iron oxides can be more resistant to reduction than others (Robenhorst and Parikh, 2000).

f. Relationship between soil hydromorphic properties and topography

The geomorphic setting influences the water-level regime of the wetland, which in turn influences the nature and the extent of hydromorphic properties in a wetland soil profile. D’Amore et al. (2000, p1535) remarked that, “linking geomorphology, soil stratigraphy and soil hydrology provides a basis for interpreting saturation patterns and wetland extent without extensive monitoring in similar areas”. This relationship has been a subject of investigation in wetland studies (especially those on peatlands) and other pedogenic studies such the ones conducted by Coleman and Fenton (1982), Pickering and Veneman (1984), Osher and Buol (1998), and numerous others. Tiner and Veneman (1988) proposed a schematic cross-section of a hydrosequence showing soil morphological changes with landscape position, which does not differ much from numerous other models used in wetland delineation (Figure 2.5)

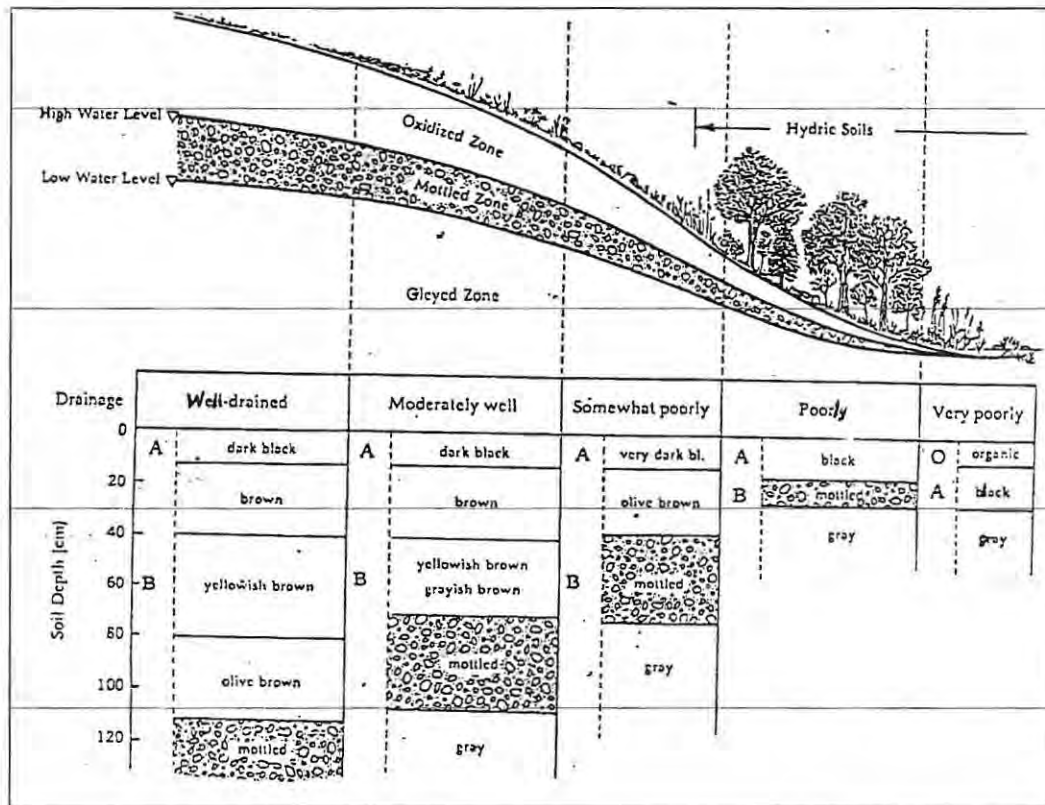


Figure 2.5: Schematic cross-section of a hydrosquence showing soil morphological changes with landscape position (After Tiner and Veneman, 1988).

Palustrine wetlands favour relatively gentle slopes with the exception of slope wetlands that result from impeded drainage or groundwater discharge. The bottomlands at the foot of mountains and headwaters of streams are likely to have wetlands, and they are very common in South Africa, including the wetland system under study.

2.2.4. The role of environmental extremes

Environmental extremes bring about drastic changes on the physical landscape. Their impact is so far reaching that it becomes important to consider them when carrying out environmental management programmes, including wetland rehabilitation and conservation. Such extremes are a combination of climatic, hydrologic and geomorphic/geologic factors. Examples include floods, droughts, mudslides, tectonic activity, avalanches, and so on. Tectonic activity can lead to change in the course of

streams and rise in sea levels, thereby affecting both coastal and marine wetlands (a example is the Okavango Delta in relation to the Rift Valley). Floods can accelerate the rate of erosion in catchments resulting in the initiation of gullies and change in local base levels. The impact of floods has been raised several times under the sections on climatic, hydrologic and geomorphological effects. In this section, a discussion of qualitative concepts that can be used to explain the impacts of such events on wetlands is presented.

The impact of environmental extremes on the landscape is widely recognised in literature dealing with the evolution of the landscape. Newson (1994) reported that environmental scientists continue their quest for a general model of extremes and their effect on physical variables. Certain trends and patterns of landscape development have been traced within the context of geological timescales. Vandenberghe (1995, p637) proposed four timescales that modulated the evolution of fluvial systems:

- (i) At the scale of hundreds of thousands of years (glacial/interglacial sequences) the fluvial evolution is, in general terms and within its tectonic framework, climatically dependant.
- (ii) At the scale of tens of thousands of years (one cold-warm cycle) the fluvial response is determined by the climate derivatives: vegetation, soil cohesion and runoff. Short instability phases alternate with long periods of stability. The instability phases occur at climatic transitions.
- (iii) At the scale of thousands of years (one instability phase): the response is governed by intrinsic evolution within the system.
- (iv) At the scale of hundreds of years (climatic changes of lower order) well-pronounced effects of (local) thresholds are most striking (climatic thresholds: duration and intensity of climatic change; landform and sedimentary thresholds: valley gradient, diameter and quantity of sediment to be transported).

The evolution of headwater wetlands can be analysed in the context of the evolution of the broader fluvial landscape. However, given the fact that wetlands are storage areas for sediments of recent origin in geological terms, the most recent timescales, that is, hundreds of years, will be more appropriate for such an analysis.

Wetlands, as elements of the landscape and hydrogeomorphologically dynamic ecosystems, are very sensitive to such environmental extremes as evidenced by the presence of gullies and headcuts, especially in the headwaters of streams lining South Africa's landscape. Newson (1994) further argued that the concepts of thresholds and meta-stability are becoming popular as interim models for sudden change in natural systems. This assertion corresponds well with time scales 3 and 4 highlighted in Vandenberghe's (1995) proposition. Newson (1994) gave an illustration of such change as depicted in Figure 2.6 below.

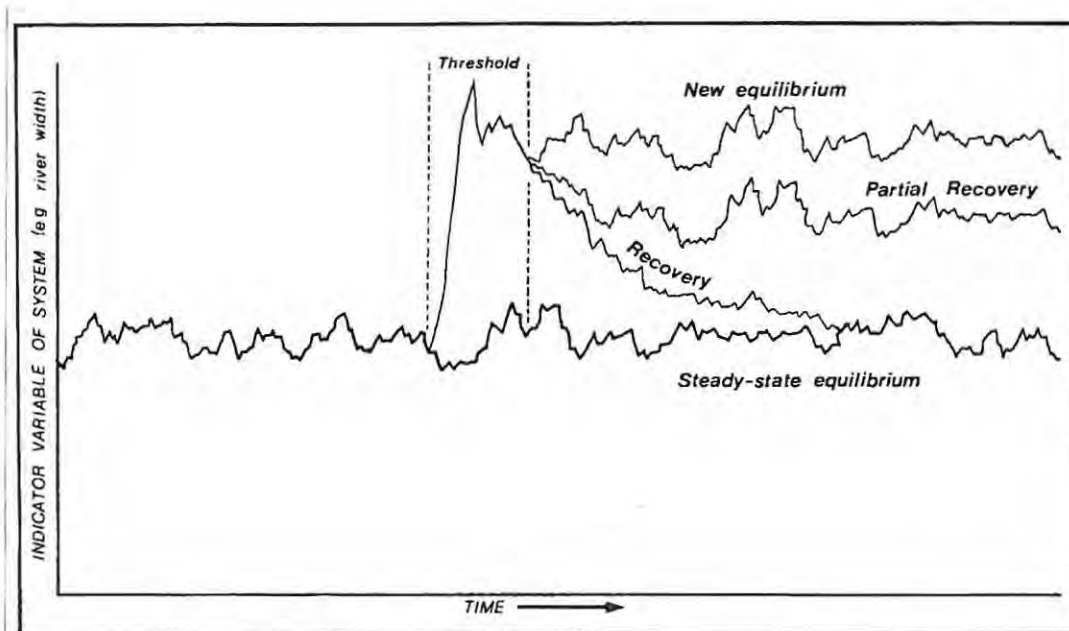


Figure 2.6: Pictorial representation of states in natural ecosystems vulnerable to threshold change behaviour (Newson, 1994)

As Figure 2.6 indicates,

“the dynamic equilibrium state of a system, such as a river channel, may be disturbed in the direction of the extremes of its range with either temporary or permanent effects. In the former case there is recovery of the system so that the river channel which may have had bankside vegetation scoured by a flood, revegetates with the same species. The new equilibrium may be slightly different if, for example, bank erosion is such that trees will never find suitable conditions for growth again as they did before flood. Quasi-permanent threshold changes modify the main system variables, preventing recovery – as

might be the case where flood erosion of the bank was accompanied by a landslide which transforms the channel into a sandy bed when previously it was composed of boulders; channel shape will adjust to the new substrate as will stream and bank plants and animals (Newson, 1994, p66)”.

This explanation can also apply to wetlands, particularly the incision (gullying) phenomenon in headwater wetlands.

In the context of wetlands, the erosion/deposition cycle as propagated by environmental extremes can be viewed as operating within the limits of environmental thresholds. Rowntree (1988, p177) took these equilibrium concepts a step further to explain soil erosion in semi-arid areas of South Africa. Citing Schumm et al. (1984), she argued that “gullies are part of a drainage network and an active eroding gully represents an unstable landform which is part of a drainage network transformation... Rejuvenation of a drainage network is the result of some geomorphological threshold being exceeded so that rapid erosion is initiated” (Rowntree, 1988, pp176-177). The coupling concepts, as introduced to geomorphology by Brunson and Thornes (1979), in the context of landscape sensitivity, are intimately linked to the equilibrium concepts. Wetlands can be viewed as sensitive geomorphological features since their presence and extent is both a reflection and determinant of the magnitude of sediment storage (or remobilisation) within a drainage basin (Phillips, 1989, p872).

According to Harvey (2002), coupling behaviour conditions how the system responds to the disturbance, and is therefore important in determining the geomorphic response to human induced, climatically induced or tectonically induced environmental change. Coupling operates in two directions. Downsystem coupling involves the transmission of sediment through the system from hill-slope and headwater sources, and from reach to reach of the river system. Upsystem coupling relates to the propagation upstream of the effects of base-level change. Sediment is usually transmitted from the head cuts of streams and deposited on the wetlands located downstream creating a series of local base levels. Downstream of the wetland there may be re-initiation or rejuvenation of the process of erosion through the formation of other head-cuts ‘eating’ into the wetland. This process becomes more pronounced after flood events as it will be demonstrated in the results of this study. These events may be individual

events or secular changes in the process of the environment and may be related to intrinsically or extrinsically induced thresholds (Schumm, 1979; Rowntree, 1988). After the flood event the stream capacity may become low as there is insufficient discharge or velocity to erode further, and sediment deposition occurs. Such deposition is also promoted by the presence of vegetation, which slows down the velocity at which floodwaters flow.

The role of vegetation in the hydrogeomorphological processes of erosion and deposition is widely recognised. Rowntree (1988, p178) pointed out that vegetation and soil should be considered as closely related parts of one system so that the stability of one is reflected in the stability of the other, and the qualitative effects of vegetation include the: “protection of the soil from raindrop impact, increases infiltration rates both through improvements in soil structure and utilisation of soil moisture and increased resistance of the soil to surface erosion”. After a long period of field measurements of gully headwall retreat rates and vegetation encroachment rates, Harvey (2002) proposed a model of gully development and stabilisation as shown in Figure 2.7 below.

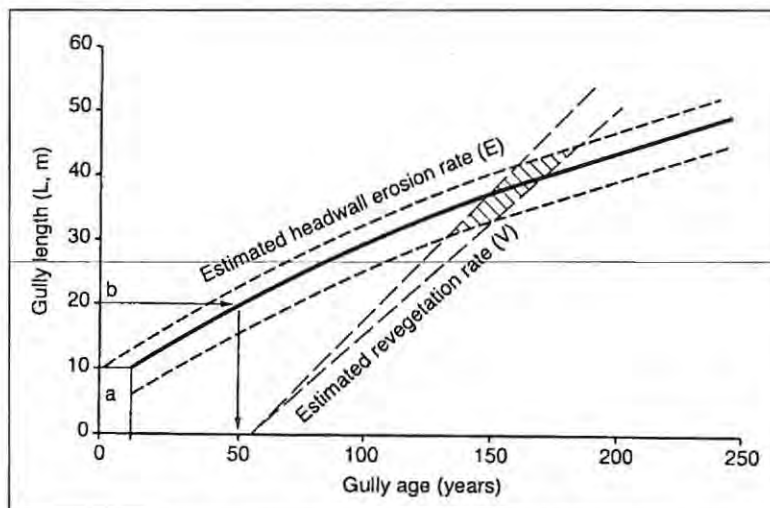


Figure 2.7: Model of gully development and stabilisation, calibrated by field monitoring. E (m/year) is best estimate for headwall erosion rate, based on the regression equation: $E=0.94 L^{-0.51}$ (where L is gully length, m). V (m/year) is estimated (Harvey, 2002)

An understanding of these concepts can also help in the current wetland rehabilitation initiatives by Working for Wetlands project of the South African government. The removal of alien vegetation species from riparian zones and on wetlands, and their replacement with endemic species and the construction of erosion control structures can be done more successfully if the thresholds of the physical environment are taken into consideration. Environmental extremes, particularly floods events, have proved to be one of the factors that reduce the lifespan of such wetland rehabilitation structures.

2.3. CHAPTER CONCLUSION

This review has shown that there is a fair understanding of wetland hydrogeomorphology in the literature. However, that understanding remains highly theoretical in nature. There is very limited literature on the testing or application of such theory. Broad conclusions from this discussion can be drawn that:

- The knowledge about the definition of wetlands and classification systems is well advanced, but it is underscored by the lack of consensus on their functions, mainly because of lack of basic research about such functions.
- Climate and hydrology control the functioning of wetlands through their effect on the wetland water-level regime and the water balance.
- Geomorphology controls the functioning of wetlands through its effect on sediment characteristics and processes as reflected in soil characteristics, particular, and the surrounding catchment, in general. The topography of the area is also very important in determining the functioning of wetlands.
- The role of environmental extremes, especially flood events, is seen exerting tremendous influence on the nature and functioning of small wetland systems like the headwater wetlands.

This literature review forms a conceptual context for this research. The issues from various literature sources will be assessed in light of the findings of this research.

Chapter Three: THE FEATHERSTONE KLOOF IN SPACE AND TIME

3.1 INTRODUCTION

In this chapter, the general location of the study area is described. A review of the historical geography of the region, taking into consideration both natural and land-use issues, is given and supplemented by the results of radiocarbon dating done on the wetland sediments. Then, an assessment of rainfall trends and events of the recent past will be done.

3.2 THE LOCATION OF THE FEATHERSTONE KLOOF WETLAND

The study area is located in the Featherstone Kloof Catchment, Grahamstown, South Africa (Figure 3.1). Featherstone Kloof Catchment is found at approximately 33°20' south and 26°30' east. It is a first order catchment of the Kowie River. The area is located in the transitional zone between the summer rainfall region to the north and east (subtropical), and the winter rainfall region to the south and west (Mediterranean) (Thompson, 1965). The result is a very unclear distinction between rainy and dry seasons in the area. Hiller and Taylor (1992) reported that quartzites, sandstones and shales of Witteberg Group underlie the area. Weaver (1979) pointed out that sandy soils are associated with quartzites, and loams with the shales. The catchment slopes are covered in grass and exotic tree species. The latter are being removed (most have been removed) by the Albany Working for Water project of the South African Government. Some natural forest patches remain in the upper parts of the catchment.

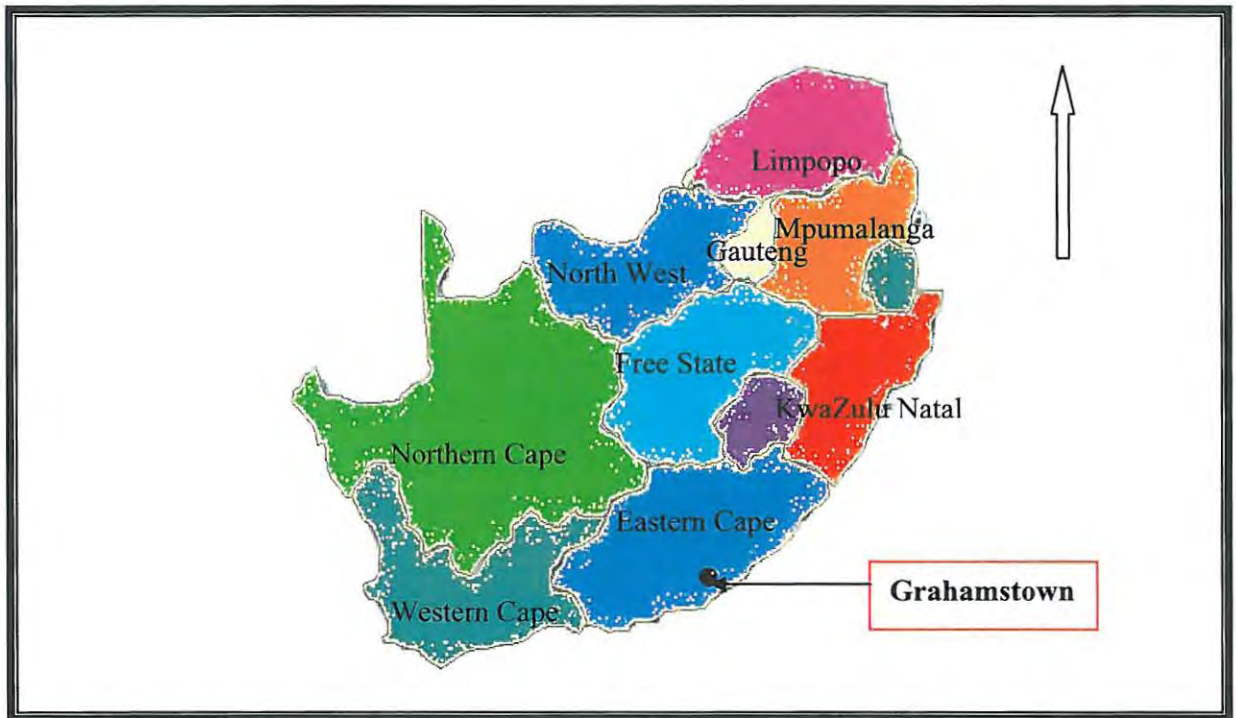


Figure 3.1: The location of Grahamstown in relation to other areas in South Africa

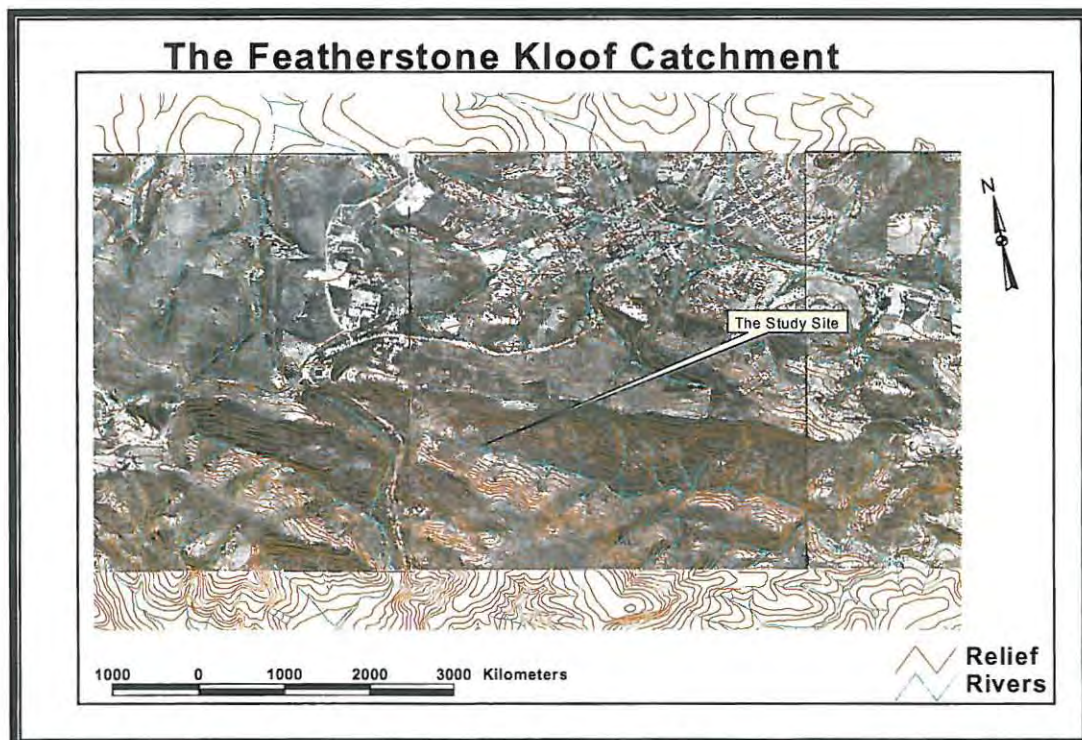


Figure 3.2: The location of Featherstone Kloof Catchment in relation to Grahamstown (contour interval 20 m).

3.3 A PALAEOENVIRONMENTAL CONTEXT

In an attempt to understand the current processes in the Featherstone Kloof Catchment and its wetland, it is important to locate these processes within the context of the past environmental change that has occurred in the surrounding area and the region. As an introduction to the geomorphology of southern Africa, Moon and Dardis (1988) gave a brief review of the development of the southern African landscape at a geological timescale and concluded that the interpretation of the subcontinental-scale geomorphology of southern Africa indicates that the development of the landscape at macro-scale has occurred in discrete stages. Such stages were summarised in tabular format by Patridge and Maud (1987) as shown in Table 3.1.

Table 3.1: Stages in the development of southern Africa (After Patridge and Maud, 1987)

| Date | Event | Geomorphology |
|--|--|---|
| Late Pliocene to Holocene | Climatic fluctuations, sea level changes, small scale tectonism. | Marine benches, coastal dunes, river terraces |
| | Post-African II erosion | Post-African II surface formed (limited extent), incision of gorges |
| Late Pliocene (~2,5 Ma) | Major uplift (up to 900 m) | Asymmetric uplift of continent, west tilting |
| Early mid-Miocene to late Pliocene | Post-African I erosion | Post-African I erosion surface formed (imperfectly planed), major deposition in Kalahari basin |
| End of early Miocene (~18 Ma) | Moderate uplift (200-300 m) | Interruption of African erosion phase, westward tilting of African surface |
| Late Jurassic/early Tertiary to end of early Miocene | African erosion | Large-scale planation of African surface (at different levels above and below escarpment), deep weathering on erosion surface |
| Late Jurassic/early cretaceous | Fragmentation of Gondwanaland | New base levels formed, rapid erosion |

The landscape of the Eastern Cape, in general, and the Grahamstown region, in particular, bears the imprints of the environmental change since the fragmentation of the Gondwanaland super-continent. The 'Grahamstown Peneplain', as recognised by Mountain (1980), forms part of the African Erosion Surface, which is the result of prolonged fluvial erosion. Lewis (1995, p6) observed that, "the dominant features of the Grahamstown Peneplain are gentle slopes on either side of what appears to have been a major valley. The slopes are evidence of the final stages of peneplanation, where only just enough gradient remained for sluggish drainage to occur. More recent cycles of erosion are witnessed by the valleys that have cut into the Peneplain. These include the eastward flowing Bloukrans River and its tributaries, and the westward flowing New Years River and its tributaries". The Kowie river, which joins the Bloukrans River in its middle reaches, has its headwaters located in the Featherstone Kloof, where the wetland under study is located.

Meadows (1988, pp296-297) acknowledged the complexity of the study of landforms and land-forming processes in the context of environmental change and proposed that, "rather, it is a more manageable task to assess the effects of changing climates of the Quaternary on geomorphology (Figure 3.3) and, more particularly, the effects of changing environment within the later Pleistocene and Holocene, since within this period dating control (mainly through radiocarbon dating) is adequate and more precise chronological resolution is feasible. Moreover, humans have become an important ecosystem component during this time and, notwithstanding that the period has been very short in relation to the total age of the earth, the environmental changes that have occurred therein have been far from slight".

It is against this background that in the context of this research, a palaeogeography of the area for the period covering the Late Quaternary (the Holocene), that is, from about 2000 years before present (BP) up to the present, is presented briefly. The period covering the past two centuries (nineteenth and twentieth centuries) is regarded as the period of historical record because most of the data are available from traveller's journals, settler's diaries and other historical sources.

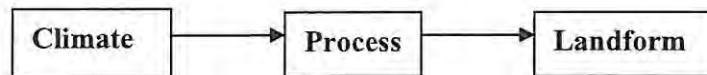


Figure 3.3: The link between climate and landforms (After Meadows, 1988).

In line with Meadow's proposition of the link between climate and geomorphology (Figure 3.3.), numerous authors acknowledge that the Holocene is characterised by climatic oscillations (Vandenberghe, 1995; Tyson, 1986; Lewis, 1996 and Huffman, 1996) that have had significant impact on the landscape of the region. Unfortunately, there is limited data to concretely reconstruct the palaeogeography of southern Africa, in general, and the Eastern Cape Province, in particular. This fact was acknowledged by Van Zinderen Bakker and Coetzee (1988) in a review of palaeobotany and palynology of eastern and southern Africa. They attributed this lack of dated palaeoclimatic sequences for the Holocene to varied material that is used for determining the age and chronology of events, for example, former lake levels, spring activity, fossils, pollen, tufa formation, and caves and open sites. Tyson and Preston-Whyte (2000) reported that the longest high-resolution Holocene proxy series in Southern Africa are the stalagmite oxygen-isotope records for the Makapansgat Valley and Cango Cave for the last six millennia. They made a comparison of the two data as depicted in Figure 3.4.

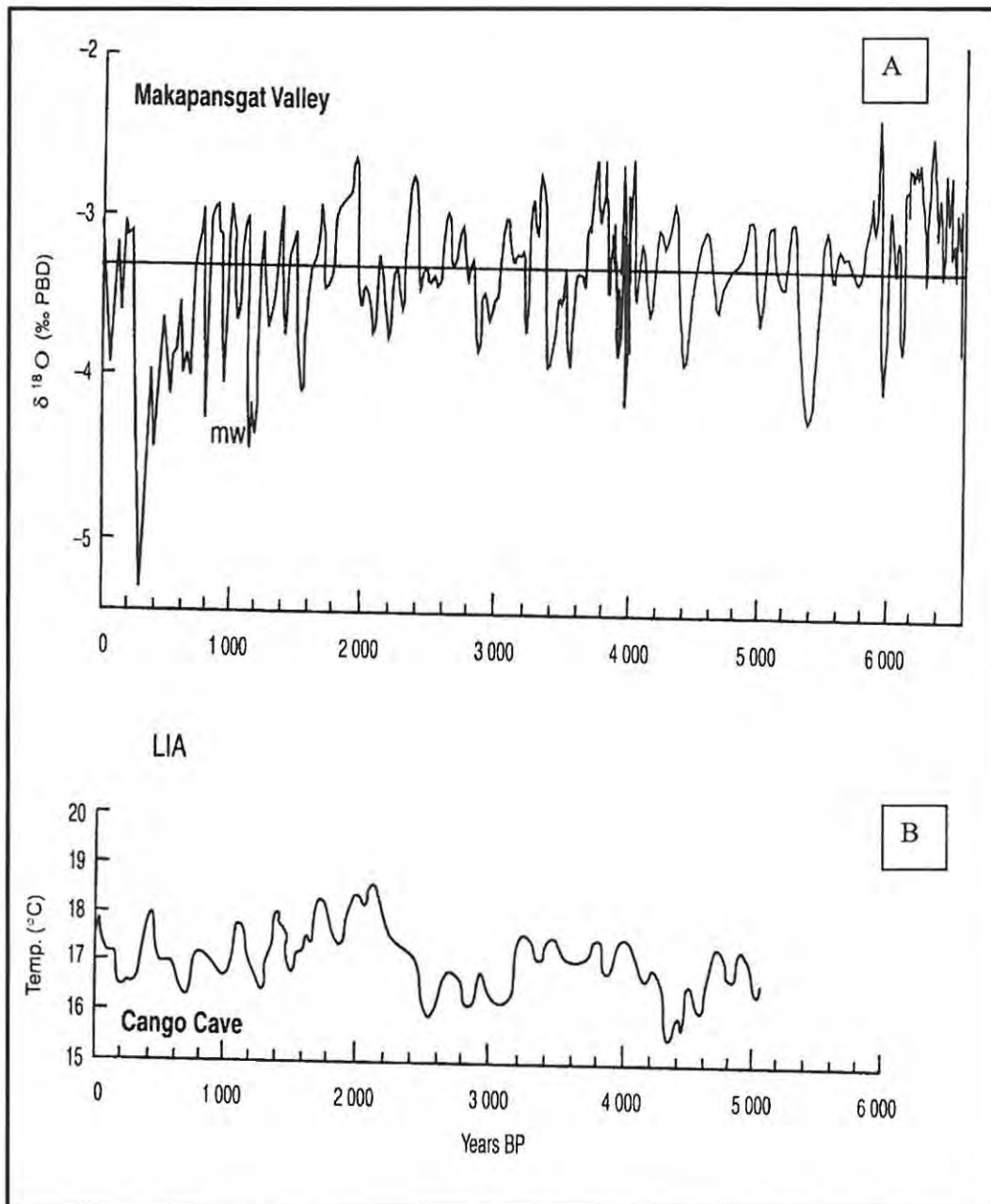


Figure 3.4 A and B: A comparison of stalagmite oxygen-isotope records for the Makapansgat Valley and Cango Cave over the last six millennia. LIA denotes Little Ice Age, mw medieval warming (After Tyson and Preston-Whyte, 2000).

In Figure 3.4, the Makapansgat data represents conditions in the northern part of South Africa and the Cango Cave represents conditions in the South Western parts of the country. When comparing the two data sets, Tyson and Preston-Whyte (2000, p319) stated that, all major events at the northern site are replicated in the southern, except for that occurring before 2000BP at Makapansgat Valley, which had a warmer counterpart at Cango Cave. The cool periods were almost always of longer duration in the south, whereas warm periods were almost always of longer duration in the north. The implications of this evidence for the results of this study are discussed in the following discussion.

3.4 THE RADIOCARBON DATING RESULTS

Notwithstanding the above concerns about the paucity of data pertaining to the paleoenvironmental change data in the region, the radiocarbon dating technique appears to have been widely used for dating materials that fall within the Holocene in the Eastern Cape. This notion is confirmed by the recent collation of 193 radiocarbon dates for the Eastern Cape province by Lewis (2002). He concluded that, “since 1966 when the first radiocarbon date on a sample from the Eastern Cape was published, much has been discovered about the Late Quaternary environmental and human pre-history in that province” (Lewis, 2002, p67).

Table 3.2: Radiocarbon dates for a cutting in the Featherstone Kloof Catchment

| Anal. No. Pta- | Sample Designation | $\delta^{13}\text{C}$ (‰PDB) | Radiocarbon Age, yrs BP | Calibrated date |
|----------------|------------------------------|------------------------------|-------------------------|-------------------|
| 8703 | Featherstone KC Sa 1, 80 cm | -20.2 | 950± 45 | 1035(1157)1189 AD |
| 8704 | Featherstone KC Sa 2, 130 cm | -20.0 | 1 850± 50 | 134(228)252 AD |

For this study, two radiocarbon dates were obtained from an organic soil layer on a cutting from an incision area upstream of the wetland area. The procedure followed in order to obtain these dates is outlined in Chapter 4 on research methods. The results are presented in Table 3.2. These indicate that the bottom of the organic layer, at a depth of 130cm, was dated 1850±50BP. The top section of the layer, at a depth of 80cm, was dated 950±45. The calibrated dates are 1189AD and 252AD, respectively. The difference of about 900 years between these two dates, when compared with the

difference of about 50 cm between the two depths at which the samples were taken, suggests an accumulation of organic matter during a period of environmental stability. Tyson and Lindsay (1992) summarised various phases in climate change in southern Africa for the past 2000 years as shown in Table 3.3:

Table 3.3: Climate change in southern Africa over the last 2000 years (Adapted from Tyson and Lindsay, 1992)

| AD | Temperatures |
|-------------|--------------|
| 1790 – 1810 | Warm |
| 1675 – 1780 | Cool |
| 1500 – 1675 | Warm |
| 1300 – 1500 | Cool/Cold |
| 900 – 1300 | Warm |
| 600 – 900 | Cool |
| 250 – 600 | Warm |
| 100 – 200 | Cool |

The information given on Table 3.3 depicts a cyclic nature of climate during the late Holocene. Although it was warm between AD250 and AD600, cooler between AD600 and AD900, and warmer again between AD900 and AD1300, there was general climatic stability, which was abruptly disrupted by an extremely cold period between AD1300 and AD1500. This period is regarded as the Little Ice Age (Tyson, 1986; Huffman; 1996). Tyson and Preston-Whyte (2000) reported that the most prolonged and consistently warm period in the last three millennia was from 40 to 440AD, and the four centuries from 900 AD to 1300AD were generally warmer, with warm period punctuated by short cool periods, and are the regional expression of the Mediaeval Warm Epoch observed elsewhere in the world (Figure 3.4). The two radiocarbon dates obtained from Featherstone Kloof fall within this period, that is, 252AD to 1189 AD. The high temperatures of this period might have created conducive conditions for the decomposition of organic matter in the wetland soil by enhancing microbial activity. At the same time warm climate is also associated with wet conditions, which are also good for the growth of wetland plants that would eventually die and add to the organic matter. The general environmental stability of

this period is further confirmed by studies on palaeofluvial geomorphology. Quoting Dollar (in preparation), Lewis (2002, p67) reported that, “fluvial incision that was responsible for river terrace formation from ca. 43 000BP was succeeded, in the southern Drakensberg, by floodplain deposition by ca. 1000BP”. Large-scale deposition usually takes place under stable hydrogeomorphological conditions, all other factors being equal.

Following the Mediaeval Warm Epoch was the Little Ice Age which, according to Huffman (1996), began at about AD1300. Its impact was severe. The severity of the Little Ice Age might have had a negative impact on the continued accumulation of organic matter in the area, as the date obtained from the sample taken from the top part of the organic layer is AD1189, and corresponds closely with the onset of the Little Ice Age. Tyson (1996, p61) argued that, “it would appear that the effects of the Little Ice Age were experienced throughout the subcontinent and came to an end in the Northern areas of South Africa and somewhat later in the south-western Cape. The late eighteenth centuries were benign and generally wetter over most of the summer rainfall region. Thereafter, the climate changed again to become similar to the conditions that have prevailed during the period of meteorological record”.

Hall (1976) presented evidence from tree-ring studies that the end of the eighteenth century experienced high and sustained rainfall, which supports the preceding arguments. Le Vaillant (1796) described abundant fauna near Cradock in an area now barren and unable to support such populations. Barrow (1801, 1804) described vegetation in parts of the Karoo that could only have been supported by a higher rainfall than that obtaining at present. This increased rainfall was accompanied by an attendant increase in land-use activities such as agriculture. That is confirmed by reports by Huffman (1996) that there was an introduction of maize and marked increase in settlements in Natal towards the end of the eighteenth century. The geomorphological evidence points to the fact that floodplain deposition terminated ca. AD 1890 (Lewis, 2002) as white farmers overstocked the uplands, resulting in overgrazing, accelerated erosion, channel siltation and aggradation, and possibly also channel incision (Rowntree & Dollar, 1996).

3.5 THE ROLE OF NATURAL AND ANTHROPOGENIC EVENTS

The expansion of settlements which, obviously, was accompanied by extensive land-use activities is a well-known phenomenon in the Grahamstown area since the arrival of the Eighteen Twenty settlers from Europe. Illgner and Haigh (2000) compiled a timeline of events affecting the Featherstone Kloof Catchment (Table 3.4 A and B).

The history presented in Table 3.4 A and B reflects a combination of landuse and geophysical events, such as earth tremors, snowfalls, and flood events. Based on their timeline of events they managed to identify four eras in the history of the area, namely:

- Pre-European settlement (to c.1820)
- Private ownership of the land under European management, introduction of alien trees (1831-1886/1903)
- Public ownership under European management and increasing spread of invasive plants (1886/1903-1995)
- Public ownership under a democratic government and introduction of increasing alien clearing (1995-present) (Illgner and Haigh, 2000).

The problem of accelerated erosion as a result of the human factor could have affected areas such as the Featherstone Kloof Catchment, where there is channel incision and head-cut erosion. This situation was also observed in the Dambos of Zimbabwe, as Whitlow (1992) reported that the early European farmers in that country found that the *dambos* (another type of wetlands) were ideal sites for cultivation. This cultivation on wetlands usually necessitated drainage to allow use of the machinery for land preparation. The cheapest, easiest and most effective way of doing this was to excavate a ditch down the centre of a *dambo*, a practice that led to serious local incision. However, human induced soil erosion in the study area appears not to be an initiating factor, but an secondary one. The sub-humid climate of the region where Featherstone Kloof Wetland is located is associated with high natural erosion rates. According to Table 3.4 A, a number of heavy storms were recorded over the period from 1823 to 1998. Rowntree and Dollar (1996, p36) noted this situation and argued that, "although heavy storms occur infrequently [in the area], when they do occur the sparse vegetation cover provides little protection for the soil. Land-use activities of



the nineteenth century have caused further degradation of vegetation and intensification of erosion". The sparseness of vegetation could have encouraged the spread of alien species, which have encroached onto the slopes of Featherstone Kloof Catchment. As noted in Table 3.4 B, attempts to remove alien vegetation from the area were made as early as 1937. Currently, there are major attempts by the Working for and Working for Wetlands project of the government to remove such alien vegetation and introduce endemic species as a way of rehabilitating the catchment. At the same time, vegetation density could have been affected by the frequency of fire in the area as reflected in Table 3.4A.

3.6 THE HISTORICAL CLIMATE RECORD

The later part of the period of historical record is also known as the period of meteorological record by climatologists (Tyson, 1986). The availability of this historical and meteorological data has not only brought about better information on the environmental conditions during this period, but it has also opened doors for much debate about the extent, cause and direction of environmental changes, both at temporal and spatial scales. Tyson (1986, p61) pointed to the fact that there has been a debate on rainfall conditions obtaining over South Africa over this period, "whether the country has undergone, or is undergoing, progressive desiccation, or some sort of cyclic or quasi-cyclic rainfall variation". He further reported that the observations of early explorers and missionaries suggest that in former times, periods of heavy rainfall and expanses of standing water occurred. However, after presenting evidence from a number of empirical studies, he concluded that, "the variation of rainfall over southern Africa during the period of meteorological record has been distinctive. No evidence exists to support the notion of steady progressive changes. Instead, weak oscillations of a quasi-periodic nature may be discerned underlying a large measure of random variability. The most prominent of these oscillations has a period of about 18 years; it seldom accounts for more than 30 percent of the variance. Other peaks appearing in rainfall spectra...are centred at about 2.3, 3.5, 4-5, 6-7, and 10-12 years (Tyson, 1986, p88)". This rainfall variability has great significance for hydrogeomorphological systems such as wetlands and a detailed analysis of a rainfall record for the area is done in the following section.

Table 3.4 A and B: A timeline of historical events in the Featherstone Kloof and surrounding areas (Adapted with permission from Illgner and Haigh, 2000)

a. Natural events

| Date | Event |
|--------------------|--|
| 1823, October | Heavy rain for 10 days |
| 1850, 21 May | Earth Tremor |
| 1863-1868 | Severe drought and general depression in the Cape Colony |
| 1870, 3 August | Earth Tremor |
| 1879, 14 September | Most rain in a 24 hour period for September (1877 – 1999), 141.5 mm |
| 1883, 9 August | Snowfall |
| 1889, 19 December | Most rain in a 24 hour period for December (1877 – 1999), 149,9 mm |
| 1895, 9 April | Earth Tremor |
| 1909, 5 July | Severe frost |
| 1909, August | Snow |
| 1910, 24 May | Heaviest recorded rainfall for a 24 hour period in Grahamstown (1877 – 1999), 184.9 mm |
| 1910, October | Earth Tremor |
| 1912, 20 February | Earth Tremor |
| 1922, 14 June | Most rain in 24 hour period for June (1877 –1999), 66,8 mm |
| 1922, 4 November | Most rain in a 24 hour period for November (1877 – 1999), 101.6 mm |
| 1931, 7 September | Snowfall |
| 1932, 9 August | Earth Tremor |
| 1934, 7 July | Snowfall |
| 1941, 30 October | Most rain in a 24 hour period for October (1877 – 1999), 124 mm |
| 1946, 7 September | Fire |
| 1948, 19 April | Most rain in a 24hour period for April (1877 – 1999), 129.0 mm |
| 1951, 11 January | Most rain in a 24hour period for January (1877 – 1999), 106.7 mm |
| 1953, 20 January | Earth tremor |
| 1955, 18 September | Fire |
| 1961, 8 August | Fire |
| 1963, 7 March | Most rain in a 24 hour period for March (1877 – 1999), 113 mm |
| 1963, 25 December | Fire |
| 1964, 10 December | Fire |
| 1968 | Snowfall |
| 1969, 29 September | Earth tremor |
| 1972, 18 September | Fire |

...Table 3.4 continues

| | |
|-------------------|---|
| 1975 | Fire |
| 1976, 20 June | Snowfall |
| 1979, 12 June | Snowfall |
| 1979, 20 August | Most rain in 24hr period for August (1877 – 1999), 175 mm |
| 1980 | Fire |
| 1981, 3 March | Heavy rain. 25.6mm (1/ 2hr) |
| 1981, 27 March | Heavy rain. 10.9mm in 15minutes |
| 1983, 25 July | Most rain in a 24 hour period for July (1877 – 1999) 155.0 mm |
| 1986, 23 July | Fire |
| 1995, 28 February | Most rain in a 24 hour period for February (1877 – 1999), 70.0 mm |
| 1998, 30 December | Hailstorm |

b. Land-use activities

| Date | Event |
|---------------------|---|
| Pre written history | Undated occupation of the area by the San people. |
| 1818, 2 November. | Robert Featherstone arrives in Cape Town. |
| 1827 | William Smith surveys Kowiefontein |
| 1831, June | Henry Ulyate granted Kowiefontein as perpetual quit-rent farm (1264 morgen 510 sq roods 43 sq feet |
| 1834, 8 July | Robert Featherstone acquires 497 morgen 44sq feet of Kowiefontein. This land is called Featherstone Kloof |
| 1856 | The brothers William and John Henry Featherstone buy out their siblings' respective equal shares of the farm |
| 1860, 17 November | The Featherstone brothers pay the transfer duty on the above purchase, with William later selling his share to John Henry |
| 1860, 15 December | Robert Featherstone's eldest son, John Henry Featherstone, takes ownership of the Farm |
| 1886 | J.E. Wood gives sections of Featherstone Kloof, including Fern Kloof to the municipality |
| 1903, 22 July | The remaining area of the original Kowiefontein is bought by the Grahamstown municipality |

...Table 3.4 continues

| | |
|-------------------|--|
| 1932, 17 March | A preliminary meeting of interested parties for a proposed nature reserve. A Mrs van der Riet suggested that the removal of "fir trees" begins immediately |
| 1932, 18 April | Nature reserve established at the top end of Featherstone Kloof |
| 1935, October 15 | The Grahamstown Nature Reserve Society protests against the sale of Featherstone Kloof to the City Council |
| 1937, 14 June | Annual meeting of the Grahamstown Nature Reserve Society. The mayor "pointed out that the council had done some work in getting rid of Hakea & Rhenoster and was legislating about grazing" (Minutes of Nature Reserve Society, 14 June, 1937) |
| 1943, 31 August | The lease to Grahamstown Nature Reserve Society is finalised |
| 1945, 31 December | The transfer of the lease from the Grahamstown Nature Reserve Society to the Botanical Research Institute takes place. At the time the Botanical Research Institute was known as the Division of Botany and Plant Pathology" within the Department of Agriculture and Forestry |
| 1982, 31 December | The end of the lease (50 years) to the Botanical Research Institute |
| 1990, 31 March | The Botanical Research Institute terminates its management of Grahamstown Nature Reserve |

3.7 GRAHAMSTOWN RAINFALL VARIATIONS AND TRENDS IN THE PAST CENTURY

3.1.7 Context

Featherstone Kloof Catchment and the surrounding areas are also susceptible to the climatic changes outlined above. As mentioned in Section 3.2, Grahamstown area is situated in the transitional zone between the winter rainfall region to the west and the summer rainfall region to the east. This results in a situation whereby the area receives rainfall at any time during the year. Grahamstown has one of the longest rainfall records in the region and that provides an opportunity for analysing the trends and fluctuations in rainfall for the past one hundred and twenty years.

Rainfall has long been used to analyse climatic change of a place. Dollar (1992) listed numerous methods of analysis that have been used or suggested by various workers in the past to analyse climatic change using rainfall data, namely, moving average, frequency distributions, the calculation of percentage deviations from the mean, the use of residual mass curves, least square method, principle component analysis, the percentage deviation of above and below normal rainfall as estimated using a polar planimeter, a relative conditional probability distribution and coefficient of variation. He then concluded that no single method appears to be dominant in literature. Instead, the method applied seems to depend on the type of rainfall series used, the length of data series and, most importantly, the type of information and statistical parameters required for the data series.

3.7.2 Methods of analysis

In this study, a summary of descriptive statistics for rainfall figures dating from 1878 to 2001 is presented. A simple linear regression analysis is employed based on the argument given by Dent et al. (1987) that it is a common form of rainfall analysis and can be used as a predictive tool. The regression analysis is performed on the annual rainfall figures to determine whether there has been a progressive rainfall trend. The results are then expressed as the regression of precipitation (dependent variable) through time in years (independent variable). Barry and Chorley (1992) remarked that the great year-to-year variability of climatic conditions may conceal gradual trends from one type of a regime to another and the effect of short-term irregularities can be determined using the moving average. Dollar (1992) also used a five-year

moving average as a way of smoothing his data series, allowing the easy recognition of wet and dry periods. Dollar also used a Standardised Anomaly Index (SAI), which, as he argued, is a commonly used index for determining climatic fluctuations. The index provides an index of relative rainfall yields based on the standardisation of rainfall (z-score). The construction of the index involves subtracting the historical mean from each yearly total and dividing by the historical standard deviation. In this study, the rainfall indices are averaged for all the years to produce a z-score. In addition to that, the variability of rainfall between the months over the whole period (1878 to 2001) is analysed using the variance and mean averages for each month. The results are presented in the form of diagrams.

3.7.3 Results and discussion

In the website of the South African Embassy: Jakarta (2003), the following information about the South Africa's rainfall situation is given:

“South Africa has an average annual rainfall of only 464 mm, against a world average of 857 mm. Twenty-one per cent of the country has a total rainfall of less than 200 mm annually, 48 per cent between 200 mm and 600 mm, while only 31 per cent records more than 600 mm. In total, 65 per cent of the country has an annual rainfall of less than 500 mm... South Africa's rainfall is typically unreliable and unpredictable. Large fluctuations in the average annual figure are the rule rather than the exception in most areas of the country. Years where a below-average figure is recorded are more common than years with an above-average total. South Africa is periodically afflicted by drastic and prolonged droughts which often end in severe floods”

The information succinctly describes the rainfall situation in the country, and that lays a good context for the interpretation of the Grahamstown data. The analysis of rainfall data of Grahamstown for the years 1878 to 2001 reveals that the mean annual average rainfall for the region is 672.8mm, which is higher than the national average of 464mm. That qualifies the area to be classified as semi-humid. The average does not differ much from the median, which is 649.7mm, but both are significantly higher than the mode (548mm). However, if one considers the standard deviation from the mean (158mm) and the historical minimum (365.4) and maximum (1139.6), it is clear that the situation is more complex than the average conditions. To get a better picture

of the rainfall trends and variability over the same period, the results of the linear regression analysis combined with the analysis of 5 per moving average are presented in Figure 3.5.

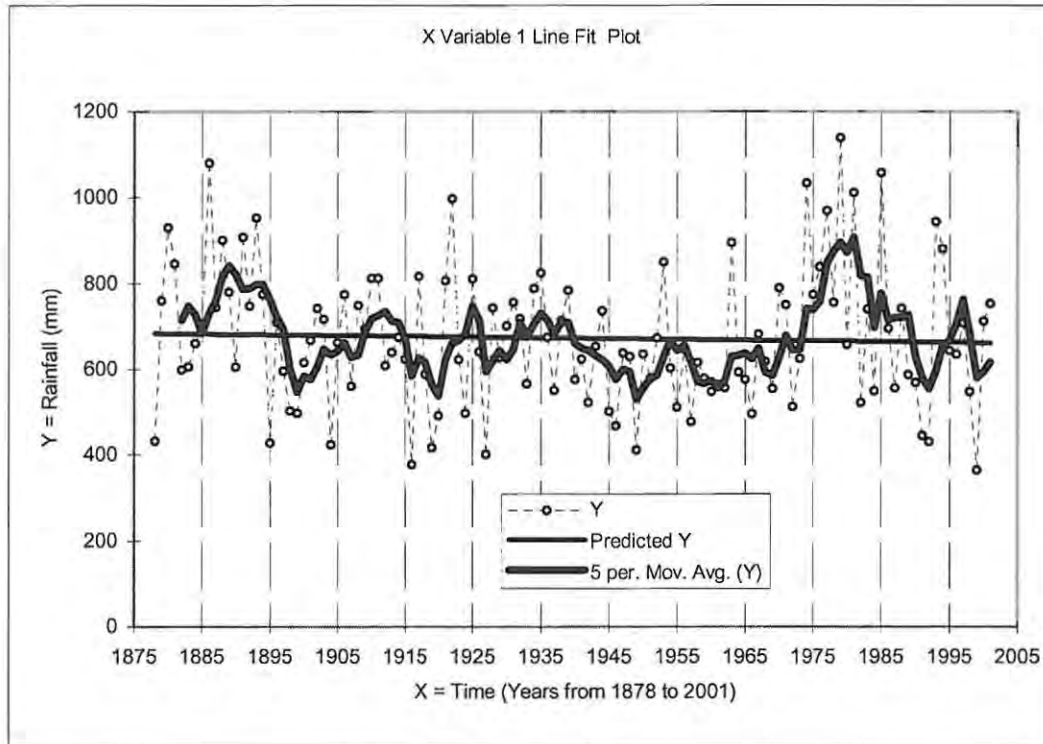


Figure 3.5: Regression of Grahamstown rainfall on time with multiple $r = 0.040$, $r^2 = 0.0016$, adjusted $r^2 = -0.065$ and standard error = 158.520, based on 124 observations.

The rainfall situation depicted in Figure 3.5 indicates a climatic fluctuation around a steady state mean. Dollar (1992) distinguished between the concepts of 'progressive climatic trend' and a 'climatic fluctuation'. He argued that a progressive trend refers to a state where there is a gradual increase or decrease in volume of rainfall for a given area over a specified time, whereas a climatic fluctuation refers to a fluctuation around a steady state mean, typical of the situation in Figure 3.5. The smoothing of the fluctuations using the 5 year moving average method reveals a pattern that somehow conforms to Tyson's (1986) hypothesis that, in the rainfall spectra of southern Africa, weak oscillations of a quasi-periodic nature may be discerned underlying a large measure of random variability. The dotted lines in Figure 3.5 group

the results, though arbitrarily, into decades to see if whether there would be any uniformity in the rainfall cyclicity. The various ranges of periods suggested by Tyson (1986) were attempted, beginning with the highest range of 18 to 22-years and ending with the lowest (2.3-years), but they did not really demonstrate any discernible pattern. The decadal range shows that the period dating from 1885 to 1895 was very wet, followed by a dry period (1895-1905), and the cycle continues to the end. Although the three decades dating from 1945 to 1975 do follow the same cyclicity, theirs occurs below the mean. That confirmed the information given by the South African Embassy: Jakarta's website cited before that, years where a below-average figure is recorded are more common than years with an above-average total. If one follows the fluctuation, it is clear that the decade starting from the early 1970s to the early 1980s was very wet, resembling the situation towards the end of the previous century (the decade from 1885 to 1895). The drier decade of the 1980s to early 1990s is disrupted by a sharp rise to a wetter period in the mid-1990s, which immediately drops before the end of the decade. In period after 1995 there is an apparent change on rainfall fluctuation to a scale of less than 10, and that would require more detailed investigation for any conclusion to be drawn.

The above patterns are more in line with Tyson and Preston-Whyte's (2000, 322) observation that, "since the turn of the century eight approximately 9-year spells of either predominantly wet years, which average to show above-normal rainfall during the spell, or predominantly dry years, showing below normal rainfall, have occurred. A simple comparison of the areally averaged regional rainfall series for the summer-rainfall region of South Africa given by Tyson and Preston-Whyte (2000), with the Standardised Anomaly Index for the Grahamstown rainfall series, both from 1910 to 1990, is given in Figures 3.6A and 3.7B, respectively.

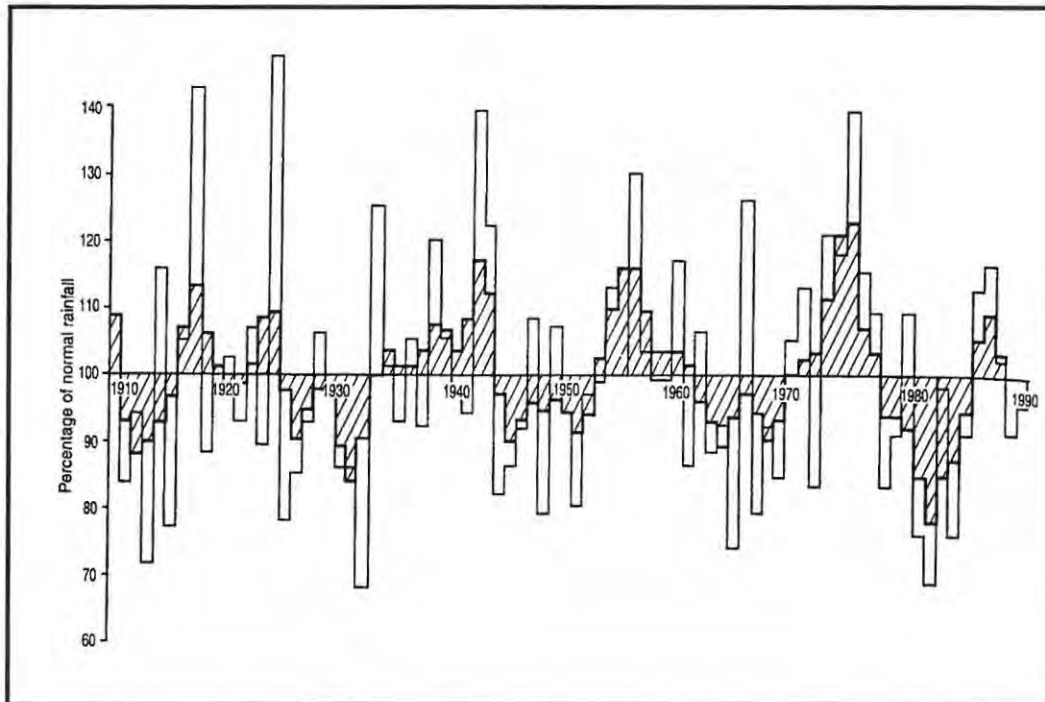


Figure 3.6A: An areally averaged regional rainfall series for the summer-rainfall region of South Africa (After Tyson and Preston-Whyte, 2000)

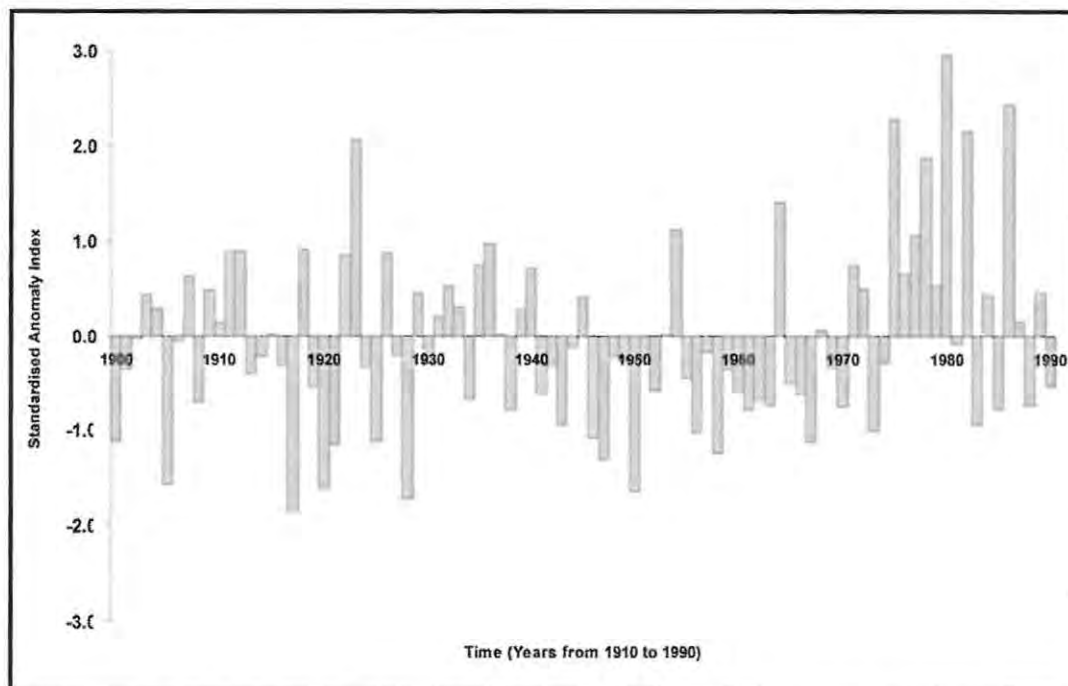


Figure 3.6B: A standardised Anomaly Index for the Grahamstown rainfall series

Although the methods of data analysis used for these rainfall series differ, mainly due to the fact that the first (Figure 3.6A) is regionalised, whilst the second (Figure 3.6B)

is based on one station, there are similar patterns that can be observed. The patterns are also similar to the earlier analysis in Figure 3.5, particularly the 5-per moving average fluctuation. This is further confirmed by the interpretation of Figure 3.6 by Tyson and Preston-Whyte (2000, p322) that:

“The [decadal] spells have affected most of southern Africa, not always exactly at the same time and not always affecting all regions equally... The period 1981/82 –1989/90 was dry over most of the country. During the 1971/72-1980/81 wet spell high positive rainfall anomalies were experienced almost everywhere. The period 1962/63-1970/71 was uniformly dry, whereas the 1953/54-1961/62 spell was generally wet except for parts of the central interior and one eastern area. The 1944/45-1952/53 dry spell was exceedingly dry over the whole country... The driest spell on average was that of 1925/26-1932/33”.

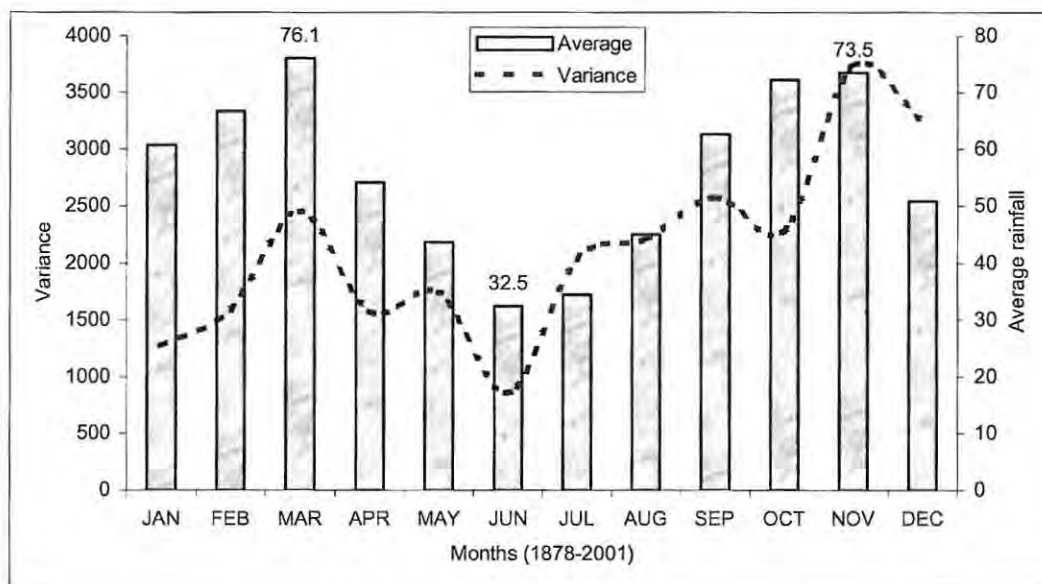


Figure 3.7: Average monthly rainfall fluctuation plotted against time for Grahamstown

Figure 3.7 is the result of the rainfall data (Grahamstown historical rainfall data) that were analysed in order to see whether there is any seasonality in climate change in the area. Monthly averages were computed for a calendar year time-scale (January to

December). The rainfall distribution clearly shows a bimodal distribution of rainfall, with most rainfall occurring during the month of March (76.1mm) and another peak rising from the month of September and reaching its maximum during November (73.5mm). However, a plot of variance gives a slightly different picture, which indicates a variability of rainfall over the year. Based on these observations, a general conclusion can be drawn that, although most of the rainfall occurs during the mid-autumn (March) and late spring to early summer (September to November), the area does not necessarily have a clear-cut seasonality in rainfall distribution.

It was deemed important to use a variable that occurs all the year round to illustrate the general distribution of seasons in the area. Evaporation figures from Loerie Dam were used as depicted in Figure 3.8.

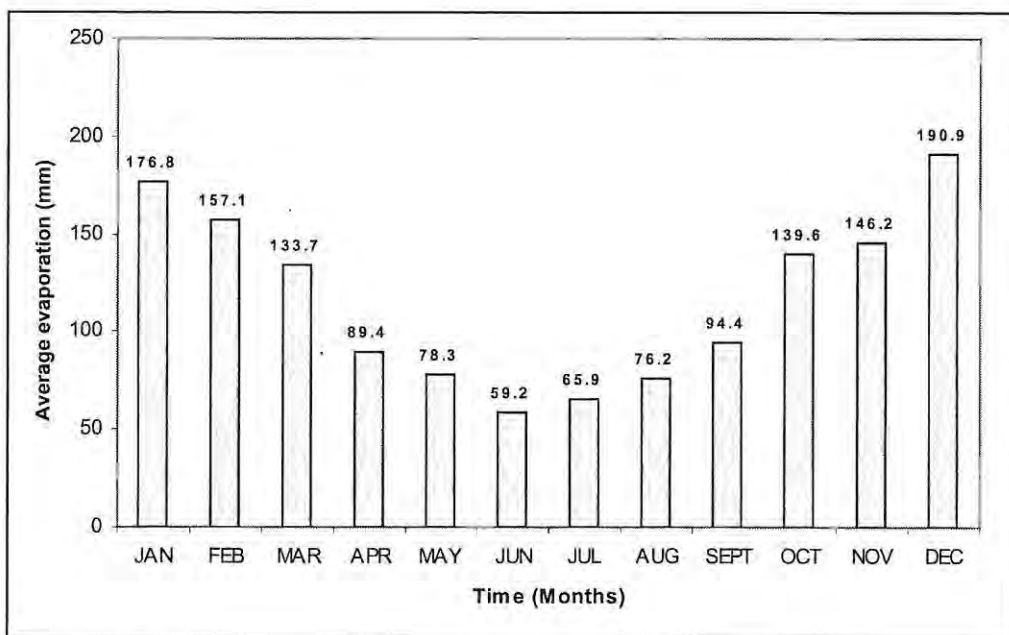


Figure 3.8: Average monthly evaporation for years 2000 to 2002

Figure 3.8 shows monthly average pan evaporation figures for Loerie Dam. To obtain the averages, monthly figures of years 2000, 2001 and 2002 were added and their sum divided by three. This helps in illustrating the distribution of seasons in the area as summarised in Table 3.5.

Table 3.5: A generalised grouping of various seasons in the Grahamstown Area

| Summer | Autumn | Winter | Spring |
|----------------|---------------|--------------|---------------|
| Late October | Late February | Late April | Late August |
| November | March | May | September |
| December | Early April | June | Early October |
| January | | July | |
| Early February | | Early August | |

3.8 CHAPTER CONCLUSION

This chapter has sought to investigate the historical events and processes that might have led to the current characteristics of the Featherstone Kloof Wetland. A brief review of literature dealing with the palaeogeography of the region was done, and a general conclusion was that climate change has direct influence on landforms at both geomorphological and historical timescales. The radiocarbon dating results obtained from the study site were interpreted according to that framework. In the subsequent period of meteorological record, the influence of both anthropogenic and natural factors on landforms were highlighted. What became prominent in the timeline of natural events was the prevalence of severe rainfall events (the theme is pursued further in Chapter 5). Taking on from that, a more rigorous analysis of the rainfall situation of the area for the last century was done. The results of the analysis indicated a steady fluctuation of rainfall around the mean, with regular decadal cycles of wet and dry spells. Years with more rain below average were more common than those with higher rainfall. There is some degree of seasonality in rainfall, though the area experiences rainfall at any time of the year. The general distribution of various seasons in the area was illustrated using evaporation data.

A comparison of the results of this study with regional (South African) information derived from literature demonstrated a degree of similarity with the Grahamstown situation. However, deviations from the regional situation can be explained by the location of the study area in a transitional climatic region as shown by the lack of clear distinction between completely dry and wet seasons. The problems posed by the analysis of the climate of this region are succinctly captured in the following quote:

“Along the-eastern coastal area of South Africa and the adjacent interior [where Grahamstown is located], the changes in the transitional, all seasons-rainfall region may at times be difficult to interpret. The region is influenced by the atmospheric circulation and weather processes affecting both the summer-and winter-rainfall regions. As such it is highly sensitive to small changes in the boundary between the two. The consequence may be that at certain times the same relationships will naturally obtain between the all-seasons-and-summer-rainfall regions. At other times different or even inverse relationships will prevail. When changes driven primarily by tropical circulations prevail sufficiently far south, then the conditions experienced in the two regions will correlate positively. The same will happen when temperature or sub-polar westerly circulations expand sufficiently far north. If neither happens, then changes in the all-seasons region are likely to correlate imperfectly, not at all, or even inversely with changes occurring in the summer-rainfall region” (Tyson and Preston-Whyte, 2000, p319).

It is therefore concluded that this historical overview of the geography of the Grahamstown region has laid a context for the understanding of the current characteristics and processes obtaining in the Featherstone Kloof Wetland. In Chapter 5, a detailed analysis of the rainfall situation for the recent past (1990 to 2001) is done, including the impact of the flood events observed during the monitoring period.

Chapter Four: RESEARCH DESIGN AND METHODS

4.1 RESEARCH DESIGN

The general introduction, context, aims and objectives of this research were detailed in Chapter 1. The hypotheses that form the crux of this thesis were formulated in the section on research context as follows:

- Wetlands have high water tables
- Wetlands prolong downstream flow
- Wetlands attenuate floods
- Wetlands store sediments

These hypotheses are general statements based on conventional wisdom about the functions of wetlands. The formulation of the hypotheses did not necessarily imply an intention to perform statistical tests to prove or disprove them, but they were framed with the purpose of serving both as tentative answers and guides to the research. The intention was to allow flexibility in the research process to avoid simply searching for statistically significant relationships in the data. These hypotheses define the hydrological and geomorphological functions of wetlands. It is against this background that the main aim of this research was to investigate the hydrogeomorphological characteristics and functions of the Featherstone Kloof Wetland. To achieve this aim, a number of objectives were formulated as summarised below:

- The state of knowledge about wetlands
- Spatial and historical context of the study area
- Recent events and processes that have had an impact on the wetland
- Hydrogeomorphological processes and characteristics of the wetland
- The implications of the wetland's hydrogeomorphology

The study used a combination of approaches to achieve these objectives. Firstly, given the lack of literature on wetland hydrogeomorphology, it was deemed useful to conduct a broad conceptual review, to map the state of knowledge regarding the subject. Secondly, the wetland was viewed as located within a particular spatial and temporal context, and as such, a description of its location in the regional and

catchment context was given with the aid of maps. A broad analysis of the historical developments (both natural and anthropogenic) in the area was done. Thirdly, the historical analysis provided an impression that rainfall (and attendant flood events) was probably the most important hydroclimatic variable affecting the landforms in the area, including the wetland under study. Therefore, a more focused analysis of rainfall for the past decade was performed. That also provided a context for the understanding of the impact of the flood events observed during the monitoring period. Fourthly, the contemporary characteristics and processes obtaining in the wetland were monitored and described. Then, fifthly, the implications of the research findings were discussed and related to the existing literature. Conclusions were drawn and recommendations were made. The research methods used are described in Section 4.2. The design of this research is summarised in Figure 4.1.

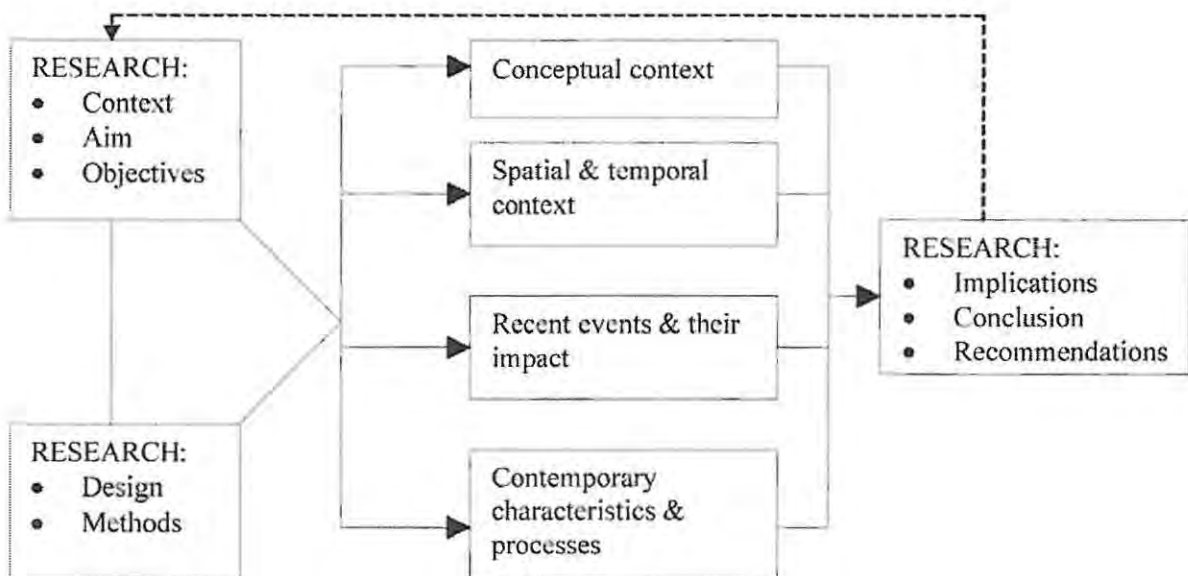


Figure 4.1: The research design

4.2 RESEARCH METHODS

4.2.1 Setting the context

As highlighted on the research design, a number of approaches were used to achieve the purpose of the research. That also implied the use of various methods to generate and analyse data. A number of issues are noted that set the context for the presentation of the research methods, namely:

- The major component of this research was about field monitoring. That required the design of the experimentation site (the term is used loosely, not implying that there were certain variables that were held constant), where a number of instruments were installed for data generation. Therefore, the description of the site will be done since it will have implications for the analysis and interpretation of the data generated (data 'generation' is a preferred concept in this research as opposed to data 'collection' or 'gathering')
- Not all the methods used will appear in this section because some are detailed somewhere else in the thesis. The reason for this is that, in the author's view, the presentation of certain results would lose their flow if the methods to generate data were physically separated from the main argument, for example, the computation of the water balance.
- Some methods were used as a prelude to the design of a particular tool that would form part of a broader method. The case in point is the origin of the 'porosity coefficient' used in the water balance calculations.

4.2.2 The study site

The general setting of the study site is already detailed in Section 3.2 and Figure 3.2.

The study site was conveniently divided into three main areas, namely:

1. Main wetland at the valley bottom;
2. Seep wetland on the catchment slope; and the
3. Contributing catchment as illustrated in Figure 4.2.

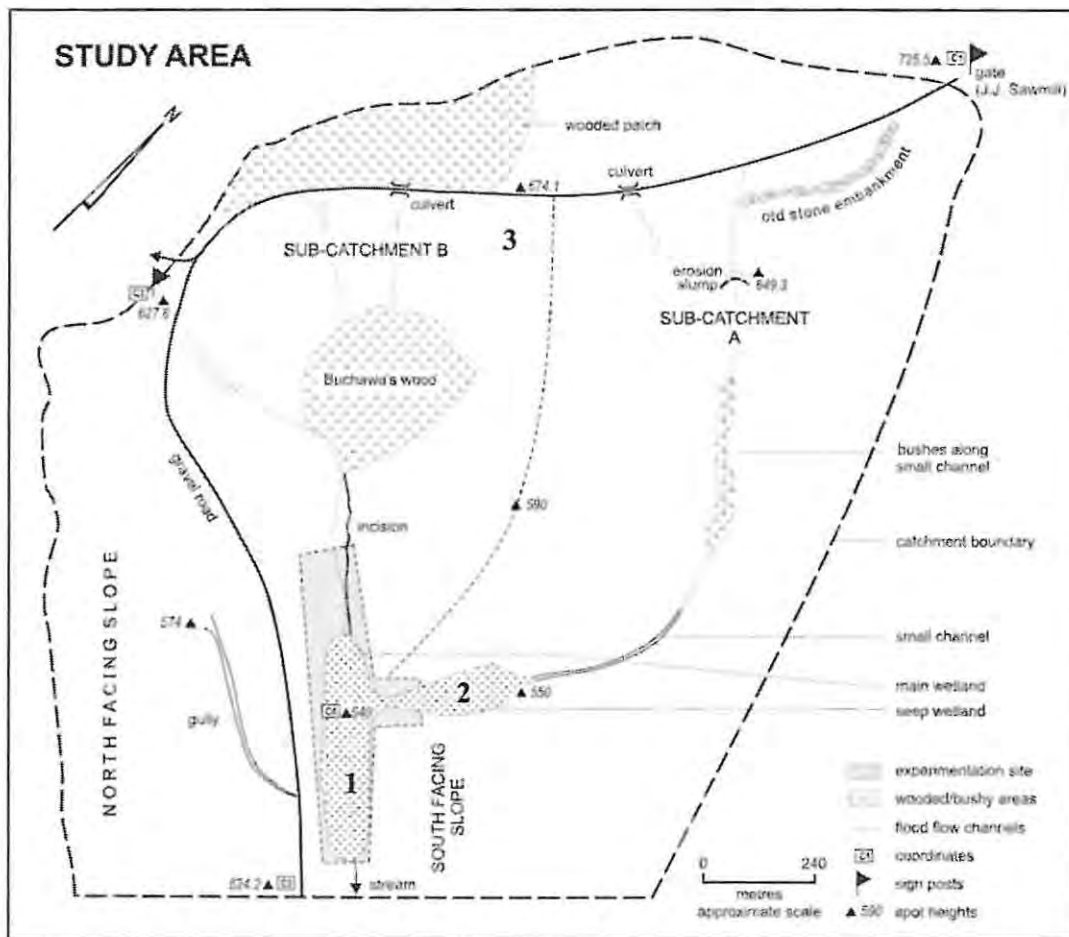


Figure 4.2. A sketch map of the study area showing the location of the experimentation site and the characteristics of the surrounding catchment

(i) General characteristics of the wetland catchment

The total area that contributes water to the wetland site is approximately 60 hectares (i.e. an estimated effective catchment area for storm runoff, which excludes the north-facing slope above the gravel road). The catchment is traversed by a gravel road that enters through the gate next to a partly defunct J.J. Sawmill factory, at an altitude of 725 metres above sea level, and goes down the slope where it ultimately passes the bottom end of the wetland area at an altitude of 524 metres above sea level (the altitude was recorded using the Geographical Positioning System, which is not a very accurate instrument to carry out the task). The sawmill factory was used to process alien wood that used to cover the slopes of the Featherstone Kloof Catchment and the surrounding areas, which have recently been cleared by the Albany Working for

Water project of the government. On the northwestern parts of the catchment, the road has culverts that collect surface runoff from the road and upper slopes to flow down to the valley bottom. The same road also collects most of the surface runoff from the north-facing slope and bypasses the wetland area with that water, thereby acting as a catchment boundary for the wetland area. Although this road might not have been good for the environmental functioning of the area, it helped in limiting the wetland watershed for easy hydrological monitoring. The road is also assisted by a number of features in channelling overland flow on the catchment, such as the stone embankment on the northwestern side and a gully across the north-facing slope. The remaining catchment is divided into two sub-catchments, A and B, which contribute to the seep wetland and the main wetland, respectively. The general view of the wetland and its catchment is depicted in Plate 4.1.

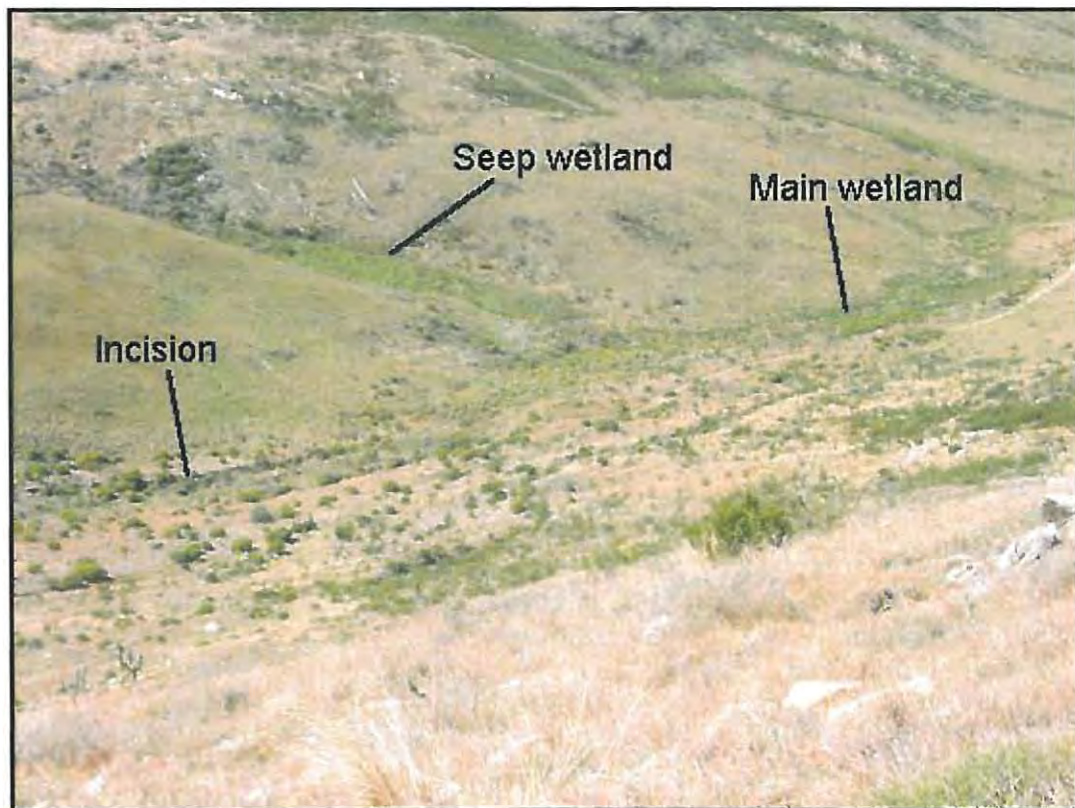


Plate 4.1: The view of the study site from the north-facing slope (Courtesy of Kate Rowntree)

(ii) Sub-catchment A and the seep wetland

Sub-catchment A (approximately 24 hectares) is covered in grasslands and a small amount of bushes that are mainly found along the channel upstream of the seep wetland. The channel is quite steep and confined, and is dominated by exposed bedrock. These characteristics lead to an accelerated flow of water after significant floods, which also result to temporary waterfalls and rapids (Plate 4.2 A and B).



Plate 4.2 A and B: Water-flow in the channel of sub-catchment A during flood events.

At the foothill, where the slope starts becoming gentle, a small and continuous spring appears. This spring feeds into the seep wetland, which is located upslope of the valley bottom wetland, at an altitude of 550 metres above sea level. This area is quite pristine in appearance, with the exception of a small head-cut that is found at its lower end where it joins the main wetland at the valley bottom wetland area.

(iii) Sub-catchment B and the main wetland

Sub-catchment B (approximately 36 hectares) is characterised with a fair mixture of grassland (about 60%) and wood patches (about 40%). The first wood patch is located

on the northwestern side just below the crest of the slope above the road. The water that comes from the wood patch is mainly channelled down-slope through a culvert located on the road that marks the lower margin of the wood patch. The water flows as surface runoff after major rainstorms in the form of rills or small flood-flow channels into another wood patch known as the Buchawe's wood, located upstream of the main wetland. The Buchawe's wood is joined by a number of other small intermittent channels that ultimately feed into an incised channel entering the main wetland area.

The main wetland area is located on the valley bottom, at an altitude of 540 metres above sea level at its centre. Unlike the seep wetland, the main wetland displays symptoms of disturbance such as the presence of an incision upstream and a restored head-cut at the lower end. The head-cut, known as Echo Bowl Head-cut, was rehabilitated through the installation of anti-erosion structures in February 2001. Besides this restored head-cut, this wetland has no clearly defined channel that acts as a conduit for water flow. This qualifies it to be categorised as a palustrine wetland according to the current South African wetland classification system proposed by Dini et al. (1998). Most of the instruments were located in this part of the study site.

4.2.3 The instrumented area

As mentioned before, this research involved monitoring of hydrological variables and soil characterisation with the aim of understanding the hydrogeomorphological functioning of the wetland system. The monitoring instruments were installed in the main wetland area and the lower parts of incision and seep areas as illustrated in Figure 4.3.

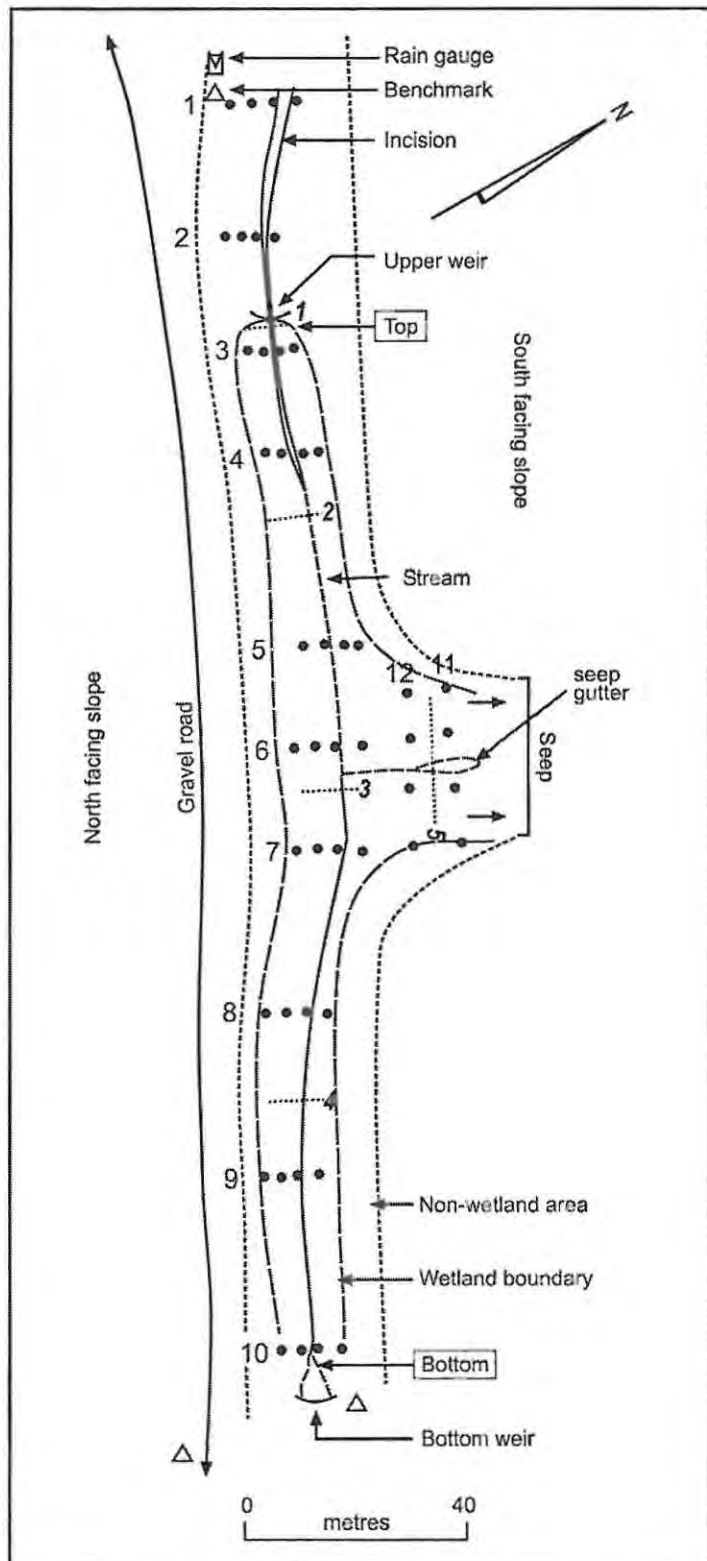


Figure 4.3: A sketch diagram of the instrumented area.

Figure 4.3 is a sketch diagram of the instrumented area where forty-eight piezometers, a raingauge, two v-notch weirs, a gutter, and benchmarks, were installed. In the diagram, bigger numbers 1 to 12 indicate the numbers of transects where groups of four piezometers were located. The dashed lines with smaller numbers 1 to 5 indicate transects where soil core samples to a depth of one meter were taken for various laboratory tests. The wetland perimeter is described in terms of top, bottom and seep areas. The small arrows in Figure 4.2 indicate that the seep area continues beyond the depicted structure. [Only the piezometer heights and the benchmarks were surveyed, and the rest of the diagram is based on free-hand drawing]. This experimental design will be used as a reference for the rest of this thesis.

4.2.4 Hydrological monitoring

(i) Wetland water table levels

As the theoretical review in Chapter 2 highlighted, the wetland hydroperiod is one of the most important aspects of wetland hydrology. The monitoring of the watertable levels was conducted to study the wetland hydroperiod. Monitoring was carried out on a weekly basis, starting from the week ending on 01 October 2001 to the one ending on 30 September 2002. A nest of forty-eight piezometers was used to monitor depth to the watertable at various points in the wetland. Those piezometers were installed along twelve transects of four. The piezometers were constructed from PVC pipes with a diameter of four centimetres each. Individual total length for forty piezometers was one and a half meter. Eight two metre ones were installed across the incision area. These were installed along eight transects across the wetland and two transects across the seep. All piezometers were screened at the bottom to a length of half metre each. An auger of similar diameter and length was used to install them. The soil cores were used to document sediment characteristics so as to reconstruct wetland stratigraphy. A battery powered dropline meter and a tape measure were used to measure the depth to the water table on a weekly basis.

(ii) Wetland discharge

In a wetland like this one it can be expected that water flows at both the surface and subsurface. The surface inflows and outflows were the most conspicuous and easiest to monitor. Monitoring commenced on different dates due to logistical difficulties

relating to instrument installation. The following areas were monitored: the seep area (from 29 November 2001), the lower weir (from 01 February 2002), and the upper weir (from 08 March 2002). The seep area was monitored using a one-meter long PVC gutter with a width of 12cm, which was installed on a small head-cut where the seep wetland joins the valley bottom wetland (Plate 4.3). The gutter was put into a furrow of similar size and anchored using construction cement. Upstream of the gutter the furrow was extended both in length, depth and width to allow for the collection of possible overland flow that may bypass the monitoring point.



Plate 4.3: A gutter used as a discharge measuring instrument at the bottom end of the seep wetland where it joins the main wetland.

Both weirs were made from galvanised metal plates using the design procedure illustrated in Figure 4.4.

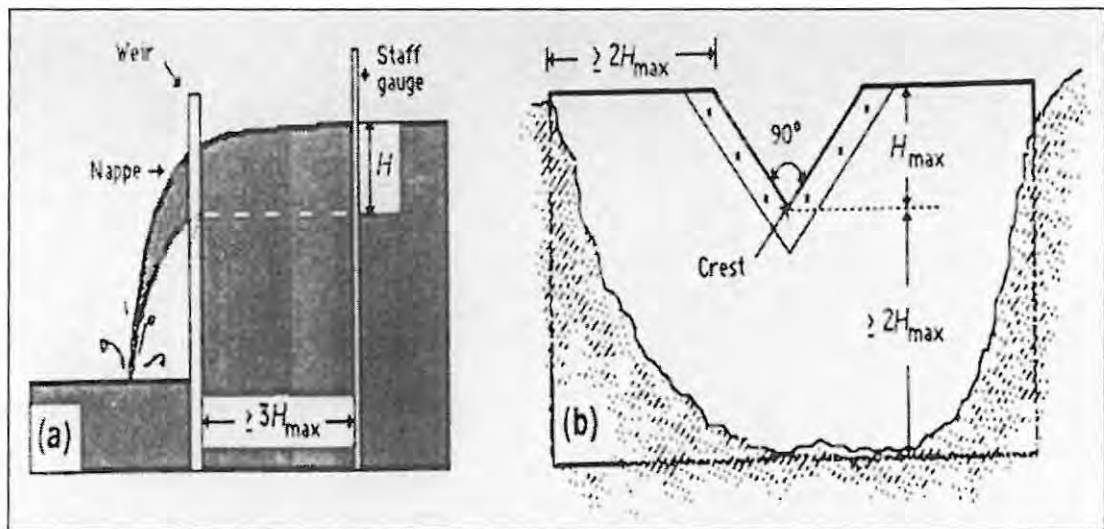


Figure 4.4: Dimensions associated with V-notch weirs: (a) side view and (b) front view. H_{max} is the maximum expected depth through the notch and H is the depth of water above the bottom of the “V”, as measured in the upstream pond (After Gordon et al., 1992).

Due to the smallness of flows, stage measurements in the weirs were not carried out; instead volumetric measurements were conducted in all cases. Gordon et al. (1992) recommends volumetric measurement as the most accurate method of measuring very small flows such as those from a spring. This kind of discharge measurement involves measuring the time taken to fill a container of known volume. In the case of this study, a five-litre container was employed and a stopwatch was used to monitor time taken by water to fill the container. Discharge figures were computed using the following formula:

$$Q = \frac{V}{t}$$

Where: Q = discharge in litres per second (l/s)

V = volume in litres (l)

t = time in seconds (s) (Gordon et al., 1992, p157).

Discharge monitoring halted on 09 September 2002 due to the disruption brought about by a destructive flood event that occurred on same date. The flood destroyed the lower weir that was used to monitor water outflow from the main wetland.

(iii) Rainfall

Initially, a rainguage was installed on site to monitor continuous rainfall, but the instrument experienced technical problems that led to its abandonment. The data collected could not be used due to high level of inconsistencies in recording. Such data were replaced with daily rainfall figures obtained from the Grey Dam located about 3km from the study site. The figures dated from January 1990 to September 2002. Another set of rainfall data was composed of historical monthly rainfall figures for the Grahamstown area dating from 1878 to 2000. They were obtained from the South African Weather Service, Pretoria. Such figures were used in the analysis of the historical geography of the study area.

(iv) Evaporation

An attempt was made to measure evaporation using an evaporation pan located at Rhodes University weather station. However, the data could not be used due to leakages that were discovered on the instrument. Regional daily figures were obtained from the Department of Water Affairs and Forestry based on the open pan evaporation records monitored at Loerie Dam some 200 km from the study site. The dam is in the same climatic region where the study site is located, and the use of regional evaporation figures is a well-accepted practice. The South African Weather Service is no longer recording evaporation at its weather stations.

4.2.5 Geomorphology

(i) Site survey and mapping

Small wetland sites present a number of challenges when it comes to their mapping. For example, they do not often appear in map scales such as 1:50 000 and 1:10 000, which are easily available in South Africa. Given that situation, a combination of survey methods was used for different purposes:

- At a broader catchment scale, aerial photographs were used to construct the map showing the location of the study area in relation to Grahamstown and broader catchment scale (Fig 3.2). The photographs were scanned and compiled into geo-referenced images using the Arcview Geographical Information Systems (GIS) package. Then, layers of other geographical features were added, including rivers and contour lines, to give a general view of the topography of the area.

- At a meso-catchment scale, where the experimentation site was located, a different method of compiling the map was used. Firstly, a desktop freehand sketching of the study area was done based on enlarged orthophoto maps. Features were added based on the knowledge of the site. The map was taken back to the field for verification. In the field, a Geo-Explorer Geographical Positioning System (GPS) instrument was used to note the relative heights and coordinates of selected points. This approach was proposed by Gordon et al. (1992, p150) when they argue that, “at an overview scale, copies of maps can be taken into the field and details such as location of sampling sites or unmarked features can be added in”. Based on that information, a sketch map of the study area was produced as shown in Figure 4.2. The information was also used to estimate the size of the catchment and its sub-catchments (i.e. GPS coordinates computed in GIS). It should be noted that this was not a very accurate map in terms of scale and height references, and as such it was not incorporated with the other data.
- At the wetland scale, a survey of the site was carried out using a surveyor’s level instrument (Total Station). Electronic Total Stations are normally used for measuring horizontal and vertical angles; recording measurements, computing by means of application software (details of the procedures employed for carrying out surveys using Total Stations are available in user-manuals that normally accompany them). In this case the instrument was used to compute x,y and z dimensions of the piezometers. The survey point was fixed on benchmarked areas at the top and bottom ends of the site. Given the problems about mapping the study area highlighted above, the survey data were used independently of other geo-referenced data like GPS coordinates. Therefore, it was deemed unnecessary to adjust the heights according to altitude. Instead, the benchmark at the far bottom end of the site was used as a reference datum. According to the data generated, as reflected in Appendix 4, the piezometer height refers to the ground level/wetland surface part of the piezometer (This wetland did not necessarily have water above ground level except for periods after significant rainfall). The data were used to draw the sketch template of the instrumented area as shown in Figure 4.3 (in Figure 4.3 only the dotted points showing piezometers and benchmarks represent surveyed parts, and not the lines). The data were incorporated with the measured water levels and soil stratigraphy.

(ii) Wetland soil characteristics

Wetlands are known for their role in sediment storage. The analysis of wetland soils was performed in order to characterise the wetland sediments. Wetland soils are sometimes used as tools to delineate various wetland hydrological zones. A preliminary analysis of soil samples taken from five transects to a depth of one meter (dotted lines 1 to 5 in Figure 4.3.) for purposes of delineating the wetland into various hydrological zones. The samples were analysed for their organic matter content, colour and mottle abundance. The organic matter content was measured through the combustion method and colour was determined using the soil colour chart.

A more extensive analysis of soil samples taken from the piezometer cores was done. Soil colour, mottle presence and soil texture analyses were carried out. A field method of identifying colour using the Munsell's Soil Colour Chart was employed. Regarding soil texture, a field method called "texture by feel" was employed. Gordon et al. (1992) describe the method as a low-effort method of analysing size composition of soils and finer sediments, which is defined as the relative proportions of sand, silt and clay as shown in Figure 4.5.

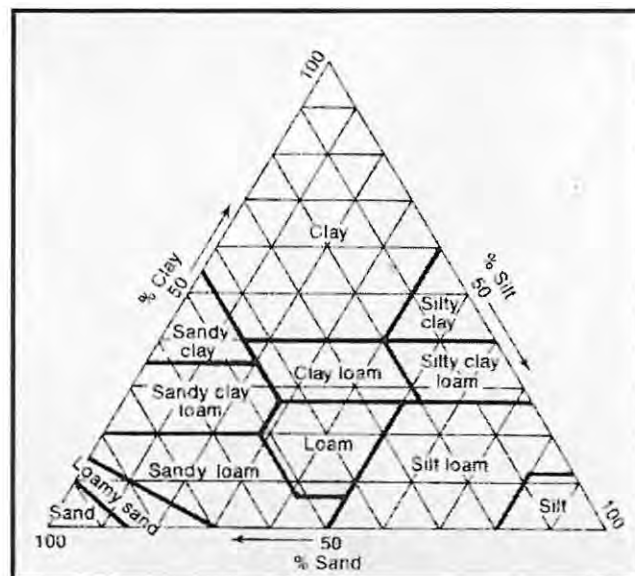


Figure 4.5: Standard US soil texture triangle (After Gordon et al., 1992)

The composition was estimated from the feel and malleability of the wetted sample (a “bolus”). By working the bolus between the thumb and forefinger a thin “ribbon” was created with more coherent soils, its length determined by the soil type. To detect the sand content by feel the samples were run under a stream of water. The data collected were used to construct soil stratigraphy diagrams.

Lastly, surface porosity was measured from nine samples taken from various points in the study site (three across the seep area and six from the main wetland). The total porosity method described by Danielson and Sutherland (1986, p444) was used. They state that total soil porosity may be calculated if the particle density and the dry bulk density are known. Therefore, the dry bulk density and the particle density of the samples were measured using the methods detailed by Blake and Hartge (1986 a and b). With respect to the bulk density, the core method was employed whereby a double-cylinder, hammer driven core sampler was pressed into the soil to a depth of 10cm. The sample was carefully removed to preserve it as it existed *in situ*. The procedure outlined in Blake and Hartge (1986a, p366) was then followed. The same samples were also tested for their particle density using the pycnometer method. A small volumetric flask of 50mL was used in place of a pycnometer because the samples were large enough to compensate for the decrease in precision of measuring fluid volume. The procedure outlined by Blake and Hartge (1986b, p378) was followed. From the results of dry bulk density and particle density, total soil porosity was calculated. Then, an average porosity figure for the whole wetland was derived. The figure was equal to 0.5 and was used as a porosity coefficient in the water balance calculations.

(iii) Wetland sedimentological history

The sedimentology of a wetland is a product of historical processes of aggradation and degradation. This wetland was also assessed for its sedimentological history using the radiocarbon dating technique. Two organic soil samples were taken from an organic soil layer on a cutting on the left bank of the wetland incision. One sample was taken from the bottom of the organic layer at a depth of 130cm and the second was taken from the top of the layer at a depth of 80cm. The samples were prepared through grinding using a pestle and mortar to avoid breaking the individual soil particles. They were also tested for their organic matter content using the combustion

method. Then, they were sent to the Quaternary Dating Research Unit (QUADRU), which is a Quaternary Period dating laboratory based at the Centre for Science and Industrial Research (CSIR), Pretoria.

The QUADRU (2003) website gives the following overview of the principles underlying the method:

“Radiocarbon dating is based on the radioactive decay of ^{14}C in organisms after their death. Under normal conditions the worldwide C cycle maintains a state of equilibrium in which the amount of ^{14}C that decays in a given time period is balanced by the amount that is produced in the upper atmosphere. Living organisms are a subsystem of the C cycle and the amount of ^{14}C that decays within the organism is balanced by the replacement rate [sic]. The result is that all living matter contains a more or less constant level of ^{14}C . After death the vital processes that control the C turnover in the organism cease to operate, and the replacement of ^{14}C ceases. Thereafter the ^{14}C decays at a well established rate. The radiocarbon age of a sample is calculated from the amount of ^{14}C it contains taking into account the known live ^{14}C content and the known decay rate. At QUADRU the samples are carefully pre-treated to exclude all C contamination introduced during or before collection. The sample treatment varies according to the material that is to be dated. The clean C is converted into ultra-pure CO_2 for ^{14}C detection. QUADRU uses high precision proportional counters to measure the β irradiation produced by ^{14}C decay. The counters are housed in a dedicated cellar 20 m underground where background radiation is minimal. This contributes to the high efficiency of the counters and allows a high degree of dating precision on samples that are as old as 50,000 years”.

The results are presented in Chapter 3, where the historical and spatial context of the study area is discussed

(iv) Catchment sediments

Various source areas, pathways, and accumulation areas of sediments were identified in the contributing catchment. In addition to the detailed surveys done on the wetland site, general field observations and measurements were conducted. Photographs of

identified areas were taken and data were used for constructing sketch diagrams and also presented as plates in the thesis. As Gordon et al. (1992, p76) put it, “photographs taken from hand-held cameras with ones feet firmly planted on *terra firma*... are of great value in environmental studies...[They] should be taken laterally upstream and downstream at a site for monitoring purposes or to provide historical record”. In the case of this study, such photographs were also useful for monitoring spatial and temporal changes of various areas in the wetland and its catchment, especially after significant flood events. An example is the erosion and deposition that occurred in the incision upstream of the wetland as presented in Figure 5.6. The diagram is schematic since it was not surveyed with more accurate instruments such as surveyors level used above. Instead long and cross section profiles were measured using measuring tape and meter rulers, and sketch diagrams were drawn on the field and refined on the desktop and digitised. They were not geo-referenced, and therefore should be interpreted separately from other survey data such as the one generated using the Total Station.

4.3 SUMMARY

In this chapter, the research design was presented. A flow chart summarising the design was presented, where the research context, aims and objectives were depicted as interacting with the research design and methods to inform the research content. The research implications, conclusions and recommendations were viewed as emanating from the research results, and also linking the findings with the initial purpose of the research. On research methods, the study site and monitoring instruments were described. Various hydrological and geomorphological research methods used were also detailed. The data sets obtained through various surveys could not be integrated due to the degree of differences between various methods used. This is one limitation of this research that should be borne in mind when reading the results presented [i.e. in all cases where diagrams are presented as schematic or sketches, that means they are not drawn to scale unless stated otherwise].

The greater part of the research data were based on primary sources and secondary sources were used for historical and regional information data. Table 4.1 summarises the various aspects of this research, the methods used in each case and the sources of data used.

Table 4.1: A summary of various aspects of the research, methods used and sources of data

| RESEARCH ASPECT | State of wetland knowledge | Historical and spatial context | Hydrology | Geomorphology |
|-----------------|----------------------------|---|--|---|
| METHODS | Literature review | <ul style="list-style-type: none"> • Literature review • Radiocarbon dating • Rainfall analysis | <ul style="list-style-type: none"> • Analysis of: <ul style="list-style-type: none"> ○ Rainfall ○ Evaporation ○ Discharge ○ Water table • Water balance calculation | <ul style="list-style-type: none"> • Analysis of: <ul style="list-style-type: none"> ○ Soil texture, ○ Colour ○ Mottles ○ Organic matter • Survey of: <ul style="list-style-type: none"> ○ Sediment erosion and deposition ○ Wetland topography |
| DATA SOURCES | Documents | <ul style="list-style-type: none"> • Documents • Fieldwork • Quaternary Dating Research Unit • SA Weather Service | <ul style="list-style-type: none"> • Grey Dam • SA weather service • Department of water Affairs & Forestry • Fieldwork | Fieldwork |

Chapter Five: RESULTS: THE RAINFALL SITUATION FOR THE DECADE OF 1991 TO 2001 AND THE IMPACT OF THE FLOOD EVENTS OF AUGUST/SEPTEMBER 2002

5.1 INTRODUCTION

Chapter three sheds light on the prehistorical and historical environmental changes that might have contributed to the current situation in the Featherstone Kloof Catchment. The medium-term climate change was assessed based on the analysis of the Grahamstown rainfall data from 1878 to 1990. In this chapter, a closer look at the rainfall situation for the last decade to the present (1991 to 2001) is done. Analysis of the frequency of storm events over the same period is performed. The rainfall situation during the monitoring period is presented, and the impact of the severe storm events of August/September 2002 is described.

5.2 METHODS

The rainfall data obtained from Grey Dam (about 3 km from the wetland site) was analysed for its trends and variability. A linear trend line was fitted on the rainfall results to show the general trend over the period. For small systems like the Featherstone Kloof Wetland, the long-term environmental change may have an influence on their existence on the landscape, but it is short-term events of high magnitude that influence their functioning and dynamism. Since wetlands are hydrological systems, flood events might be considered as very important in determining their short-term changes. Storm events of high magnitude were listed and their annual frequency compared. Such storms were determined using the approach adopted by Rowntree (1989), whereby events greater or equal to 10mm were selected – as it is generally accepted that 10mm or more is required before storm runoff is produced. The intention was determine how exceptional was the rainfall of the monitoring year (2001-2002) compared to the rest of the period. That context would assist in the interpretation of results, particularly the impact of the flood events of August and September 2002.

5.3 RESULTS

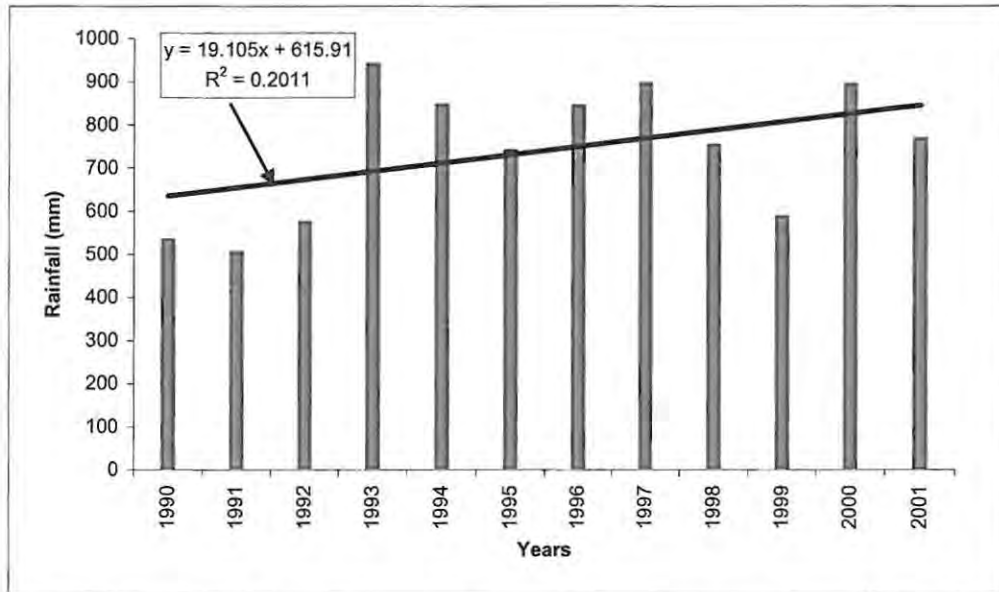


Figure 5.1: Annual rainfall totals plotted against time. The smooth line indicates the linear trend.

Figure 5.1 indicates that there was a general fluctuation in rainfall as shown by the annual totals. Years 1990, 1991, 1992 and 1999 were the driest, with their rainfall total below 600 mm. Only years 1993 and 2000 exceeded 9000 mm each. However, the trend indicates that there is a general increase in the monthly variability over the whole period (1990-2001)

Table 5.1: A list of the number of rainfall amounts of more than 10mm from 1991-2001

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| 1991 | 1 | 2 | 1 | 0 | 0 | 2 | 0 | 3 | 1 | 6 | 2 | 1 | 19 |
| 1992 | 1 | 1 | 3 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 4 | 0 | 13 |
| 1993 | 1 | 3 | 0 | 3 | 0 | 1 | 0 | 1 | 4 | 2 | 2 | 6 | 23 |
| 1994 | 3 | 3 | 3 | 1 | 0 | 2 | 1 | 4 | 0 | 3 | 0 | 4 | 24 |
| 1995 | 3 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | 2 | 3 | 2 | 4 | 21 |
| 1996 | 3 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 4 | 9 | 2 | 24 |
| 1997 | 2 | 3 | 2 | 6 | 2 | 4 | 1 | 1 | 3 | 2 | 1 | 2 | 29 |
| 1998 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 2 | 2 | 3 | 3 | 7 | 23 |
| 1999 | 1 | 0 | 4 | 4 | 1 | 0 | 3 | 1 | 3 | 5 | 1 | 2 | 25 |
| 2000 | 3 | 1 | 9 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 5 | 1 | 26 |
| 2001 | 3 | 3 | 2 | 3 | 1 | 1 | 2 | 3 | 4 | 1 | 2 | 2 | 27 |
| Sum | 22 | 20 | 29 | 24 | 7 | 11 | 9 | 17 | 20 | 33 | 31 | 31 | |

Table 5.1 shows that rainfall events of more than 10 mm were common in the area for the period 1991 to 2001. An illustration of the total for all the years and all the months of the period is given in Figure 2 (A and B). Figure 5.2a shows the total number of rainfall events above 10 mm for all the months for the period 1991 to 2001. According to the figure, storm events were more common during the months of March, April, October, November and December. The months of May, June and July recorded the lowest figures. Figure 5.2b shows the total number of rainfall events above 10 mm for all the years starting from 1991 to 2001. The year 1992 had the lowest number of storms (13) and 1997 had the highest (29). The most recent year, 2001 had had the second highest number of such events (27).

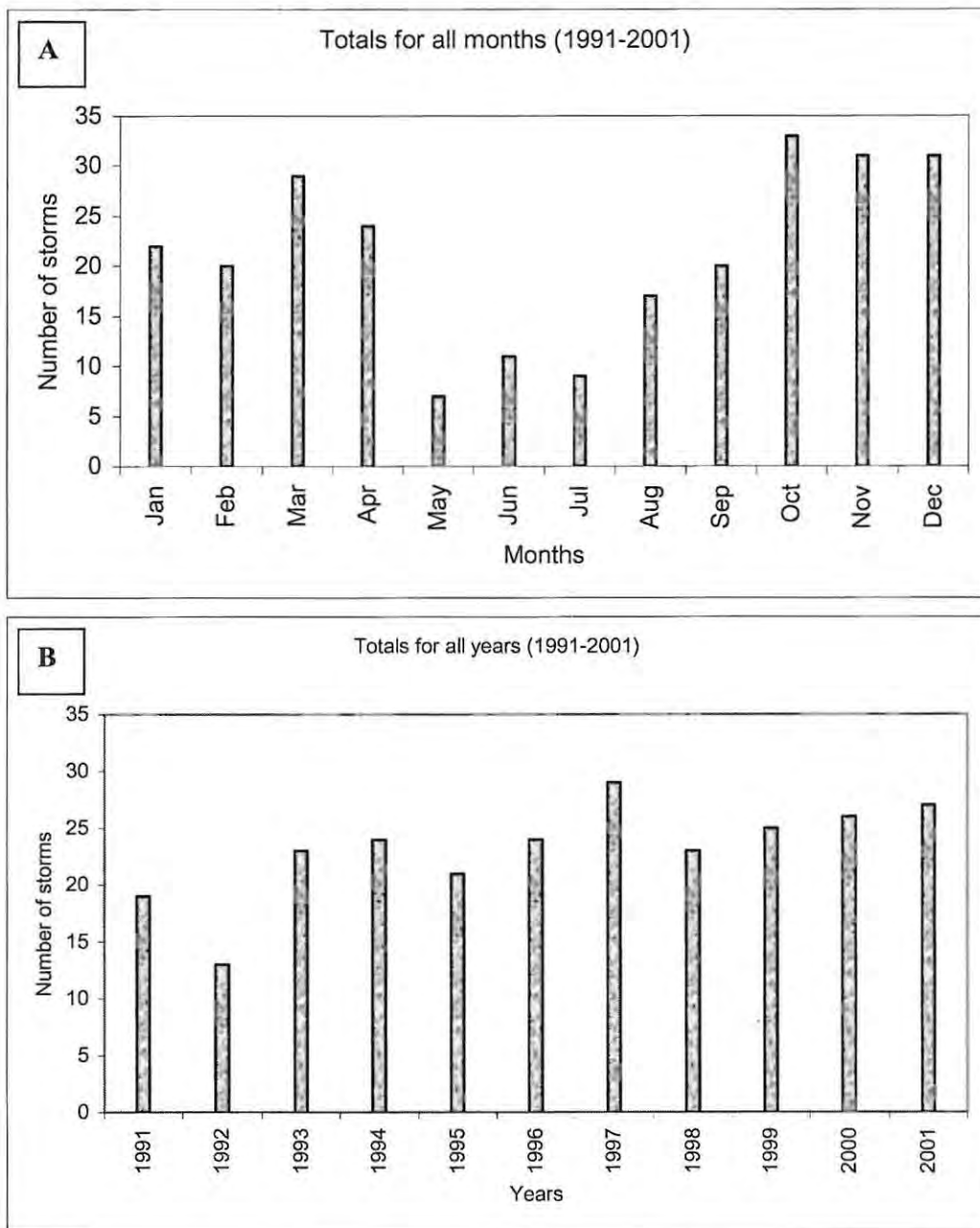


Figure 5.2 A and B: A graphical representation of the total number of storms events within and between years for the period 1991 to 2001.

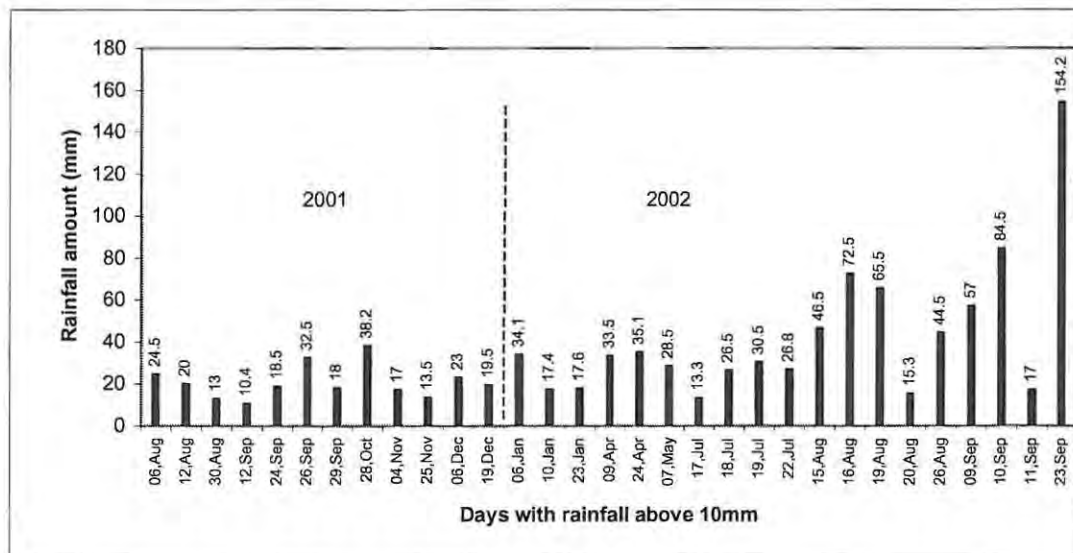


Figure 5.3: Rainfall events of more than 10 mm for the monitoring period (August 2001 to September 2002)

According to Figure 5.3, rainfall events of more than 10 mm were very common during the monitoring period (August 2001 to September 2002). Highest figures were recorded from the spring season of 2002 (46.5 mm on 15 August 2002) to the end of September (154.2 mm on 23 September 2002). The September figure of 154.2 mm was one of the few rainfall events that exceeded the 100 mm mark over the period 1991 to 2002 and was the highest over the whole period. Other events that exceeded the 100 mm mark were recorded during the following dates: 23 September 1993 = 113.1 mm; 18 November 1996 = 107.0 mm; and 16 April 2001 = 106.0 mm. Based on this evidence, it is concluded that the monitoring year of August 2001 to September 2002 was an exceptional one over a period of a decade in Grahamstown.

It was also deemed useful to compare the storm events of the monitoring period with those that occurred over the preceding century (1878 to 1989) that were presented in Table 3.4A. Such storms are recapped in Table 5.1, where only those that exceeded 100 mm are presented and compared with the annual figure of each year.

Table 5.2: Storm events above 100mm from 1878 to 1989 and the expression of their percentage from the annual figure of each year

| Date | Rainfall amount | As % of annual | Annual figure |
|-------------------|-----------------|----------------|---------------|
| 14 September 1879 | 141.5 | 18.6% | 760 |
| 19 December 1889 | 149.9 | 19.2% | 780 |
| 24 May 1910 | 184.9 | 22.8% | 812 |
| 4 November 1922 | 101.6 | 10.2% | 998 |
| 30 October 1941 | 124.0 | 19.9% | 624 |
| 19 April 1948 | 129.0 | 20.5% | 630 |
| 11 January 1951 | 106.7 | 18.4% | 579 |
| 25 December 1963 | 113.0 | 12.6% | 896 |
| 20 August 1979 | 175.0 | 15.4% | 1140 |
| 25 July 1983 | 155.0 | 20.9% | 741 |

According to Table 5.2, only ten storm events exceeded 100 mm over the period from 1878 to 1989. Most of the storms constituted about 20% of the total rainfall for each year. The storm event of September 2002 (154 mm) is therefore among the few storm events that exceeded 100 mm over a period of more than hundred years.

5.4. THE IMPACT OF FLOOD EVENTS OF AUGUST AND SEPTEMBER 2002

5.4.1 The rainfall situation

Extreme events such as floods are usually localised phenomena and as such they give a wealth of information on the hydrogeomorphic response of small systems like the Featherstone Kloof Wetland. Two floods occurred during the summer season of 2002 (15, 16 and 19 August, and 10 and 23 September). These flood events were associated with the cut-off low phenomenon that is common in the Grahamstown area (Figure 5.4 A and B).

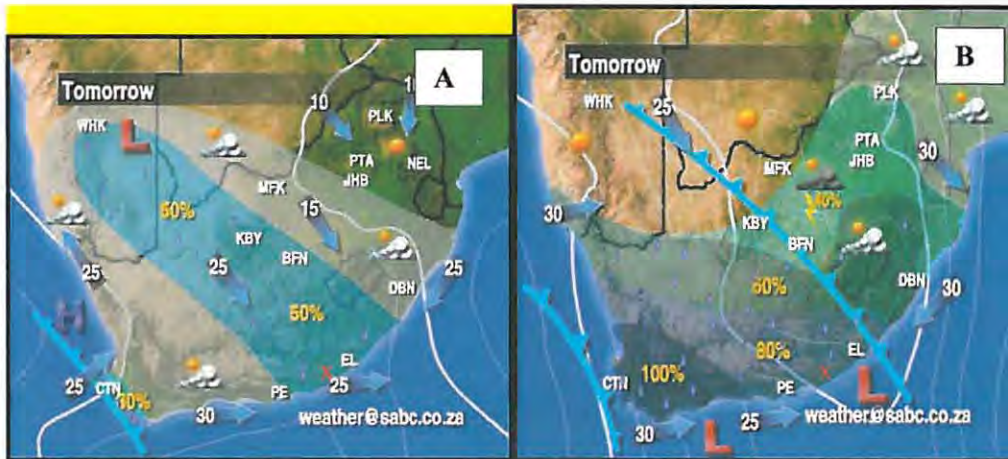


Figure 5.4: Shows weather forecast by the South African Broadcasting Corporation on the evenings preceding the days of the major storm events (09 and 22 September 2002). This summary is based on the information obtained from the South African Weather Service. Grahamstown is indicated by an X in the diagrams

In Figure 5.4 A., a cut-off low is illustrated by a blue patch wherein 50% rainfall probability was predicted. In Figure 5.4 B, the cut-off low is illustrated by a light-blue 'barbwire' line indicating a very strong cold front whereby 80% probability of rain was predicted for the Grahamstown area. In both instances there were converging winds blocking the eastward movement of the cold front, resulting in heavy rains falling on the same area for an extended period of time. According to Tyson (1986, p129), "cut-off lows are unstable, baroclinic systems which slope to the west with increasing height and are associated with strong convergence and vertical motion, particularly while they are deepening... They account for most of flood producing rains observed over South Africa... The frequency of cut-off lows producing heavy rains has a semi-annual variation with peaks in March-May and September-November". As indicated in Figure 5.2A, the heavy storms are common in the area during the same months.

5.4.2 Flood impact: Erosion

The impact of the flood events was felt in areas such as East London, where there was submergence of vehicles and buildings. On the study site, monitoring was disrupted due to the washing away of one of the gauging weirs and the complete inundation of the site itself. The most significant impact was felt during the second storm, which led to large-scale erosion of the incision area upstream of the wetland and the ultimate deposition of some of the eroded material on the wetland area. This could be attributed to antecedent soil moisture conditions as a result of the first storms, and such impact is illustrated in Figure 5.5.

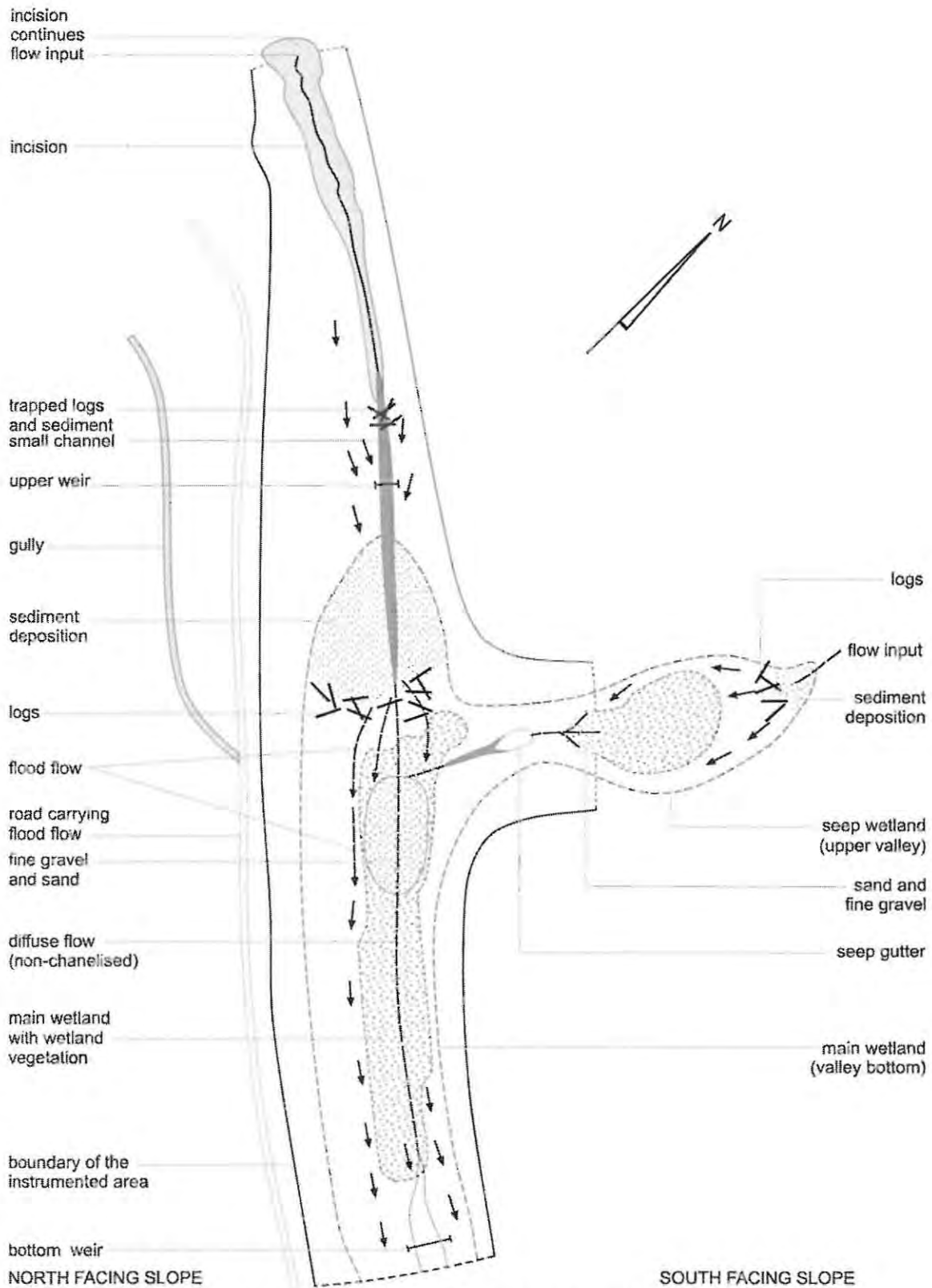


Figure 5.5: A sketch diagram showing the impact of August/September 2002 floods on the Featherstone Kloof Wetland

Floodwaters into the wetland came from the catchment area via the seep and the incision areas. The gravel road and a gully bypassing the wetland area took most of the floodwaters from the north-facing slope, resulting to extensive erosion as depicted in Plate 5.1



Plate 5.1: The extent of erosion on the road by-passing the wetland site (Courtesy of Kate Rowntree)

The wetland became completely inundated with most of the floodwaters flowing on the outside margin of the wetland where there was shorter ground cover. As it would be expected, floodwaters were carrying sediments from the upper catchment areas that acted as sediment source areas for the wetland area. A number of soil slumps were observed in the upper catchment as depicted in Plate 5.1.



Plate 5.2: Soil slumping on the catchment slopes

The soil slumping shown in Plate 5.2 covered an area of about 10m², and most of the soil was transported down the slope to the low-lying wetland area. Other similar cases were observed on many parts of the wetland catchment. However, the most prominent source of sediment to the wetland was the incised channel upstream of the wetland site as shown by large-scale erosion in Figure 5.6.

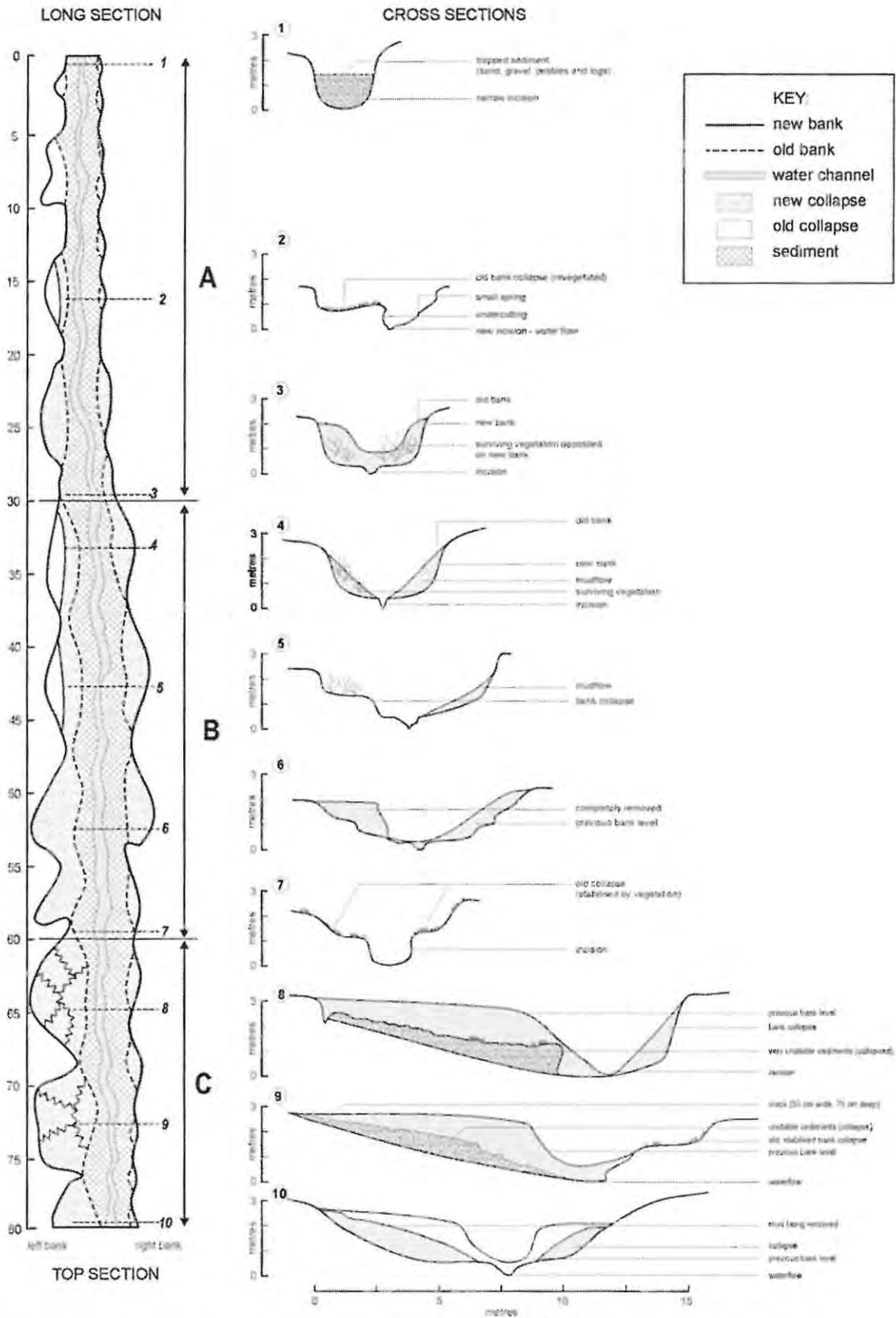


Figure 5.6: A schematic diagram of soil erosion that took place on the incision area after the flood events

According to Figure 5.6, erosion appeared to follow a particular pattern where there was deepening and widening of the gully through simultaneous slumping and down-cutting. The incision stretches for a distance of about 80m bordered by the wood patch on the top end and by the wetland area on the bottom end. Before the floods, the incision was narrower, slightly widening from the bottom to the top. The banks were covered in vegetation in the form of grasses at the lower sections and a mixture of small bushes and grasses as one moves up into the woody area. After the floods, certain erosion patterns were observed that warranted a convenient division of the incision into three sections: A, B and C.

Section A: represented the lower part of the incision where it joins the wetlands area. In this area the incision is quite narrow, with the width of about 1.5 m at the lowest end and 1.5m deep. It widens gradually towards the top area, with the width of about 2m and a depth of about 2m. The banks were covered in grasses on the top and partially bare on the insides. Due to its narrowness, the lowest part of the incision blocked bigger eroded material such as the wood logs, which also encouraged the accumulation of finer material due to their attenuation of flow velocity. The left bank is characterised with alternating areas of old slumping and steep banks. The old slumps continued to maintain the characteristics of the original bank in terms of relative angle and plant cover.



Plate 5.3 A and B: A. Shows the bottom end of the incision with blocked wood debris and other sediment materials. B. Shows an old slump which is characteristic of the lower section of the incision area

During the floods, this area was characterised with down-cutting and under-mining of the banks, which was a reworking of the old slumped banks. Despite this under-mining, there was no major slumping of the banks maybe due to stable conditions as an effect of the grasses covering the old slumps.

In area B: the incision was deeper and wider, with an average depth and width of three metres. The banks were covered in a mixture of grass and small bushes. There was evidence of an existence of bigger alien trees before as evidenced by tree stumps left along the banks. The area was characterised by slumping of both banks, with more slumping taking place on the right bank. This could be attributed to floodwaters that were entering the incision from upslope combined with the weight exerted by the bushes on the banks.



Plate 5.4 A and B: A. Slumping on the right bank, with soil moving down as bank collapse. B. Shows soil moving down as mudflow.

In area C: large scale slumping took place on the left bank which is below a steeper slope. The banks were covered in a fair mixture of grasses and small bushes. Some of the slumped soil was washed down in a form of mudflow. The vegetation was deposited into the bottom of the incision, with some bushes still maintaining their angle of growth. The soil slumping phenomenon terminated at the top end of the incision where it joins the forested Buchawe's wood patch

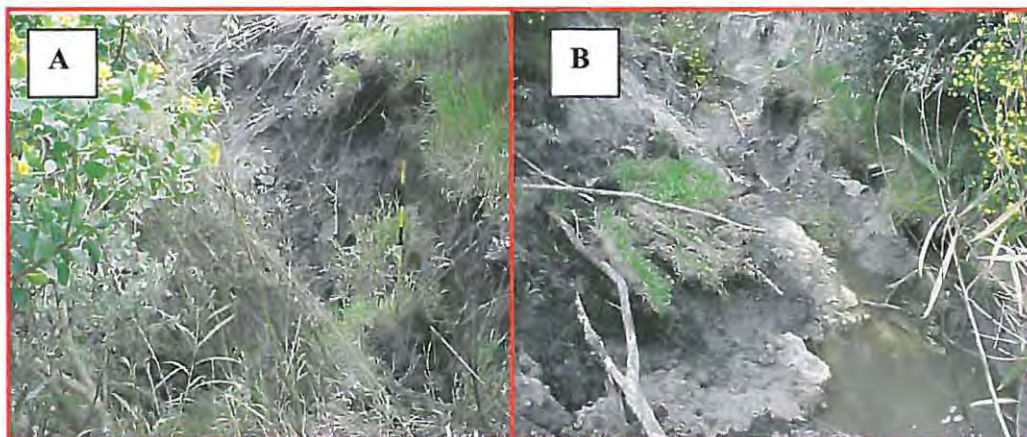


Plate 5.5 A and B: A. Shows a large crack about 8m from the left bank of the incision resulting from slumping. B. Shows the extent of slumping with a huge amount of soil having been washed away.

5.4.3 Flood impact: Deposition

The eroded material was deposited on top of the wetland area, downstream of the incision area. During the floods this deposition was promoted by the sudden drop in the flow velocity of floodwater, which might have been caused by the following factors:

- In the wetland area the slope is gentler and wider compared to the relatively steeper and narrower incision area;
- In the wetland area the channel gradually becomes shallow to being non-existent; and
- There is also the presence of wetland vegetation in the form of reeds and sedges.



Plate 5.6: The deposition of sediments of various sizes on the main wetland

According to Plate 5.5 sediments of various sizes were deposited on the wetland. They ranged from wood logs, smaller plant debris, pebbles, gavel and sands. The fate of finer sediment carried in suspension and solution is not known.

5.4.4 Post -flood conditions

The flood events of August/September 2002 led to a complete halt of the intensive monitoring since most of the hydrological equipment was destroyed. However, general monitoring of qualitative changes in the study site for the period after the floods have occurred led to some interesting observations as shown in Plate 5.6 A and B.



Plate 5.6 A and B: A. shows the incision area three days after the floods. B. shows the same area three months after the floods.

As stated before, wetland sediments also filled the lower parts of the incision and small channels in the wetland. After a period of few months, such sediments were colonised by vegetation. The flow of water into the wetland started dispersing further upstream compared to the conditions before the floods. In fact, the flow from the incision was generally intermittent, and that promoted the settling of water in stagnant pools, also creating saturated conditions conducive to the growth of hydrophytes.

5.5 CHAPTER SUMMARY

In this chapter a detailed analysis of the rainfall situation in the area during the decade preceding the monitoring period. A presentation of the rainfall situation during the monitoring period was also done. The results obtained from this analysis can be summarised as follows:

- The mean annual rainfall for the period 1990 to 2001 showed a general increase, with moderate variability. The increase was largely a result of three dry years at the beginning of the decade.
- The monitoring period (August 2001 to September 2002) was an exceptional one in terms of rainfall compared to the preceding decade. The storm event of 23 September 2002 was the highest over the period of 12 years. However, a comparison with the long-term trends, particularly the occurrence of storms of high magnitude, revealed that the monitoring year was similar to some few other years over the period of just over a hundred years.
- The severity of the flood events of August/September 2002 brought about a lot of changes on the nature of the wetland and its contributing catchment.
- Major soil erosion occurred on the incision area upstream of the wetland leading to the major changes on the wetland downstream where sediments were deposited.

The implications of these results will be dealt with in Chapter 7 on general discussion.

Chapter Six: RESULTS: THE HYDROGEOMORPHOLOGICAL CHARACTERISTICS AND FUNCTIONS OF THE FEATHERSTONE KLOOF WETLAND

6.1 INTRODUCTION

The preceding chapters have placed the wetland in the broad landscape context at both temporal and spatial scales. Chapter 5 gave a more focused analysis of the rainfall situation for the past decade and the observed impact of the flood events of August and September 2002. In this chapter, a presentation is given of the results of the data generated during hydrological and geomorphological monitoring.

6.2 WETLAND SOIL ANALYSIS

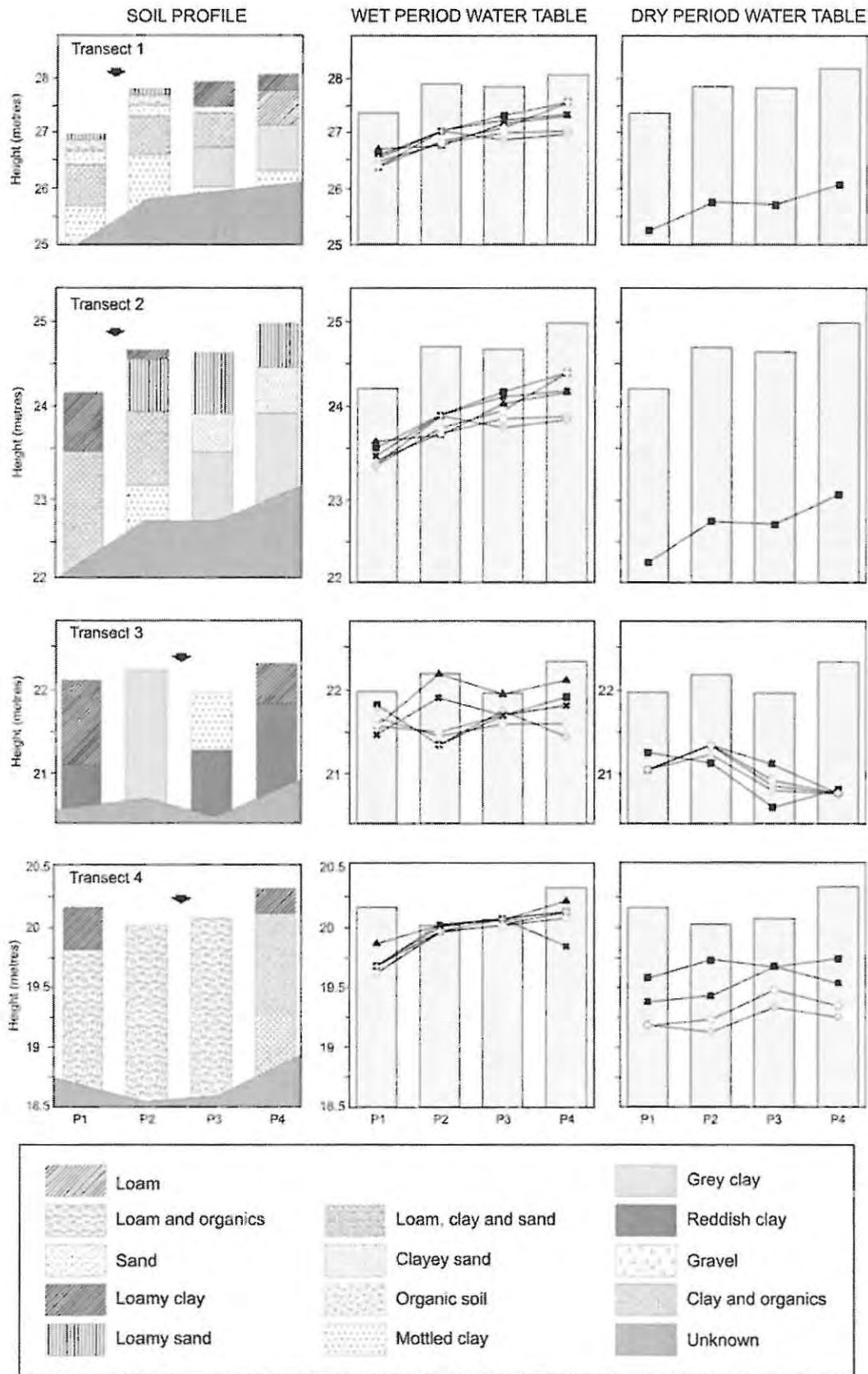
A description of wetland soils is important for understanding the physical nature of the wetland. It is common to use soil characteristics as the main indicator of wetland functioning, especially when conducting delineation of wetlands into various hydrological zones. An analysis of organic matter and soil colour was conducted on nineteen cores taken at approximately one-meter depths across a selection of five transects (i.e. four on the main wetland and one across the seep area). The results are presented in Appendix.

The results presented in Table 6.1 indicate that most of the wetland area to a depth of about 20 cm was dominated by brown to dark yellowish soils, that is, sandy loam soils with undecomposed organic matter. Lower layers from the depth of about 20cm to 1m were characterised by soils with low chromas ≥ 3 , and with colours ranging from greyish brown to black in the middle holes (Holes 2 and 3). Along the right hand margin of the wetland (Hole 4), soils had chromas of < 3 with colours ranging from brown to light yellowish brown. The abundance of redoximorphic features indicated the variable nature of saturation levels in this part of the wetland. However, these results did not help in delineating specific wetland zones based on colour and organic matter. In summary, this analysis indicates that the soil characteristics of the wetland are highly varied and they need to be related to other wetland variables to be

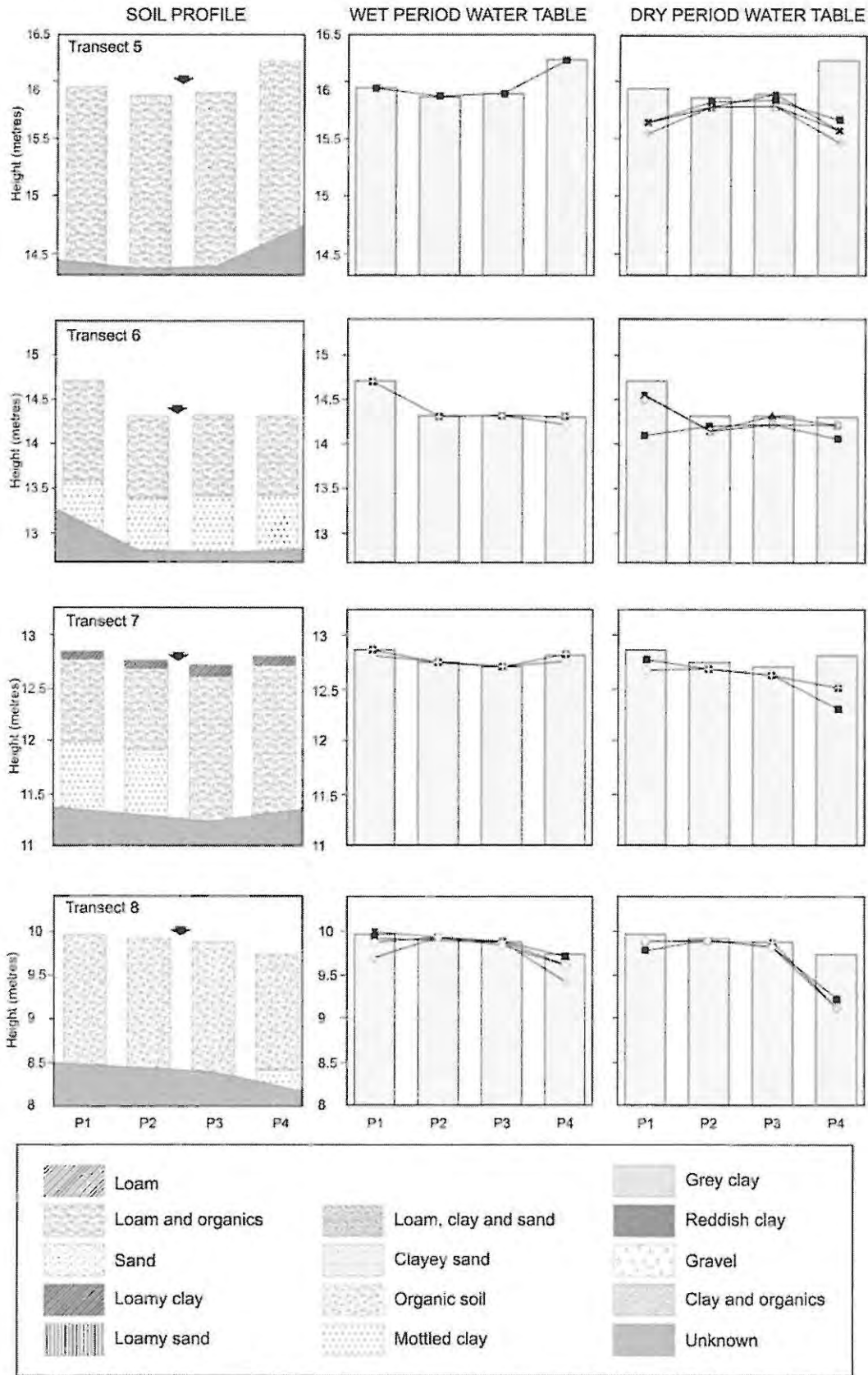
understood better. In the next section, the relationship between the wetland soils characteristics, wetland water-level regime and elevation is discussed.

6.3 THE WETLAND WATER LEVEL-REGIME VERSUS SOIL MORPHOLOGY AND ELEVATION

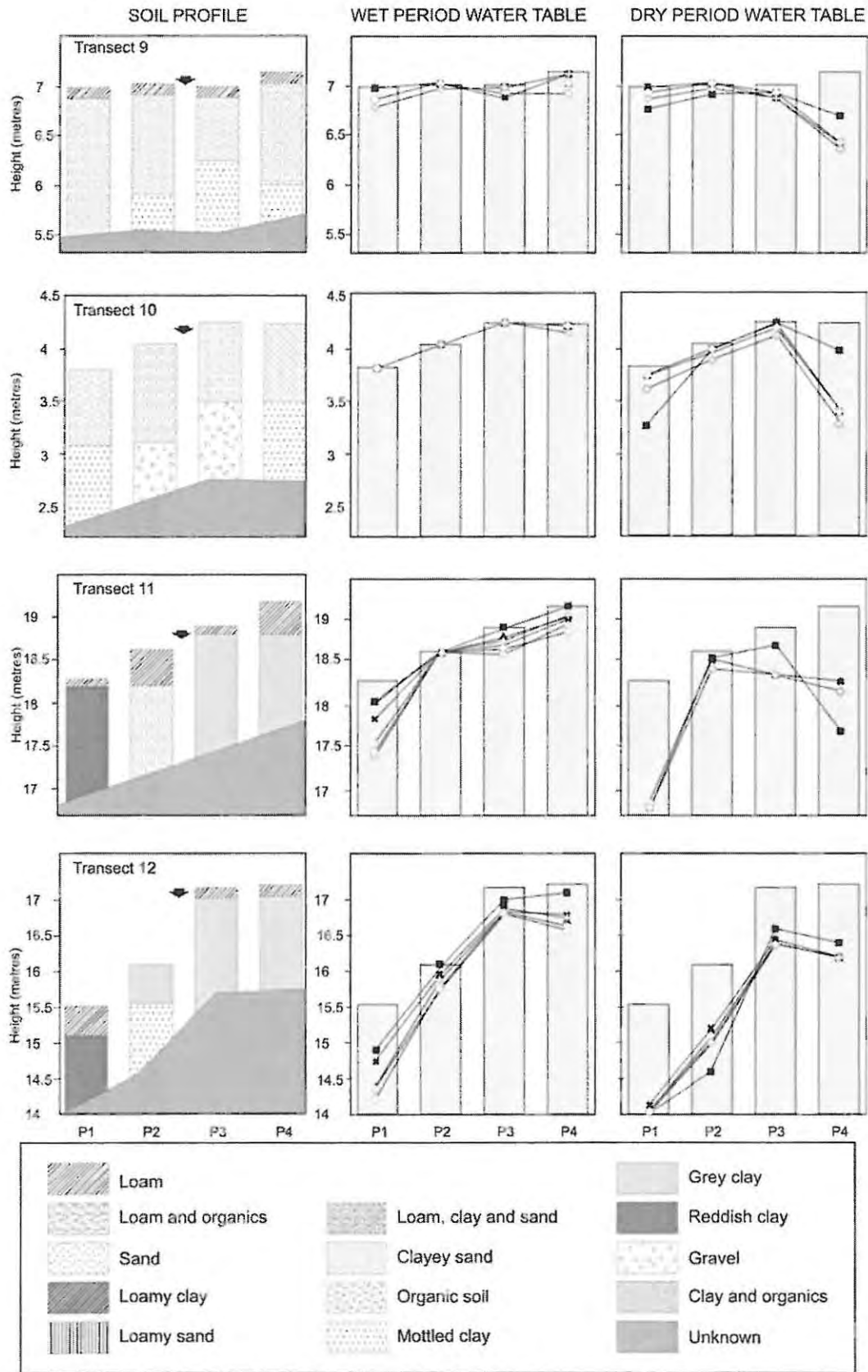
A more extensive analysis of wetland soil morphology (presence of mottles, soil colour and soil texture) was conducted from samples taken from forty-eight piezometer cores arranged in twelve transects of four. Results are presented in the form of diagrams (Figure 6.1 A, B, and C) showing change in soil characteristics with depth. The depth (presented as height in meters, the maximum being the soil/ground level) is based on the elevation calculated from the reference datum (the benchmark located at the lowest end of the wetland). The soil characteristics diagrams are juxtaposed with the wetland hydroperiod diagrams depicting wet and dry periods watertable levels, respectively.



...Figure 6.1 continues



...Figure 6.1 continues



...Figure 6.1 continues

Figure 6.1: The relationship between wetland water-level regime, soil morphology and wetland elevation. Both wet and dry period watertable levels are presented. The small arrows indicate the location of the stream channel, although it was not very distinct in the middle part of the wetland (From Transect 4 to Transect 9). P1 to P4 stand for piezometer cores, starting from the left hand side facing downstream

Figure 6.1 shows a complex relationship between wetland water-level regime, soil morphology and elevation as described for each transect in the next paragraphs.

6.3.1 Reflections on the relationship between wetland water-level regime, soil morphology and wetland elevation

Transect 1

This transect is in a non-wetland area along the incision upstream of the main wetland. The area is drained by an incision to a depth of about 1.5 m. The incision, where there is also intermittent flow of water, is located between P1 and P2. Soil properties are characterised by a mixture of loam, sand and clay, with relics of mottles in some places. Mottles dominate the bottom parts of the cores where there is great fluctuation of the watertable. The watertable is always below the surface, even during the wet season, to a depth of more than 20 cm. During the dry period, the area becomes completely dry and the watertable drops to below 2m.

Transect 2

This transect also belongs to the same area where there is an incision. Soil characteristics are also very variable. The watertable behaved in manner similar to Transect 1.

Transect 3

This is the top part of the wetland area, which is highly seasonal in nature. Loamy and clayey soils dominate. Both reddish and grey clays are found. The variability of soil properties could also be the reason for the variation in watertable levels. For instance, in clay soils water infiltrates slowly and is also retained for longer periods whereas in sandy and loam soils water infiltrates quickly and is also lost quickly. In the case of this transect, in some places the watertable remains very low despite the

wetness of the period and in some it continues to remain high. Even during the drier periods watertable fluctuations are highly variable. The elevation of different cores could also be a factor in watertable variability, although there appears to be no clear pattern.

Transect 4

In this transect soil properties start to show some uniformity. Cores P2 and P3 are completely dominated by organic soil. The two cores on the margin of the wetland, cores P1 and P4, are overlain by loam soil to a depth of about 10 cm. At the same time they are quite elevated in terms of height compared to P2 and P3. Cores P2 and P3 are completely inundated during the wet period. The watertable is just below the surface and the area does not become completely dry, whereas in cores P1 and P4 the watertable fluctuates and soil properties also vary.

Transect 5

This is the beginning of the wettest part of the wetland. The place is dominated by organic soils, which are the result of anaerobic conditions prevailing due to high watertable levels. The area is always wet for both seasons. On the wetland margins, cores P1 and P2, the watertable fluctuates a lot due to their higher elevation, but that does not necessarily affect the soil conditions.

Transect 6

This is the part where the seep starts joining the main wetland from the direction of P1. Soil characteristics depict mottled clay overlain by loam and organic soils. The area is always wet, both during the wet and the dry periods. The watertable fluctuates slightly during the dry period. There is one instance whereby the watertable dropped drastically, and that could be attributed to the sudden stoppage of flow from the seep during prolonged hot and dry periods. The most unusual thing about this area is the occurrence of mottles far below the perennial watertable level. This anomaly will be pursued later in the discussion.

Transect 7

This transect possesses similar characteristics to Transect 6 in terms of the watertable levels. However, soil characteristics are quite different. The top part of the cores is

made up of a layer of loamy clay to a depth of about 10 cm. Below the loamy clay layer, organic soil dominates in all the cores, except for cores P1 and P2 where mottled clay layer observed in Transect 6 occurs.

Transect 8

Loam soils with high organic content continue to dominate except for core P4, which has a layer of mottled clay overlain by loam and organic soils. The watertable in this area is always high both in wet and dry periods. In core P4 it is always very low – maybe due to higher elevation and distance from the stream.

Transect 9

In this transect all cores are overlain by a small layer of loamy surface. Below the loamy surface organic soils dominate, with mottled clay at the bottom of cores P2, P3 and P4. In terms of the watertable condition, the area is generally wet both in wet and dry periods. The right margin of the wetland (Core P4) is slightly drier, maybe due to higher elevation compared to other parts of the transect.

Transect 10

This transect marks the bottom end of the wetland, where the stream starts to be clearly defined. Like the previous transect, the area is dominated by organic soil to a depth of about a meter. The two middle cores, P2 and P3, are characterised by the presence of gravel. This may be a reflection of the deposition of coarser material during the stages of the wetland formation. The cores on the margins of the wetland, P1 and P4, are characterised by mottles below the depth of about 1m. The watertable is generally high, both during the wet and the dry periods. It tends only to fluctuate slightly at the margins of the wetland, something that was common with all other Transects discussed above.

Transect 11 and 12

These two transects are located on the seep area. They are characterised by steep gradients and variable soil properties. The seep cuts through the middle, between cores P2 and P3, and that results in the two cores being wetter for most of the time compared to the ones on the margin.

6.3.2 Summary

From this comparison of the wetland water-level regime, soil morphology and elevation a number of observations were made:

- The wetland has distinct hydrological zones based on the observation of the behaviour of the watertable over time (wet and dry periods). The top section (Transects 1 and 2) is the driest area of the site, due to the existence of the incision. The margins of the wetland (P1s and P4s) are drier than the middle of the wetland (P2s and P3s), with the exception of those transects that occur in the area where the seep area joins the main wetland. The seep area (Transects 11 and 12) is also characterised by high water table fluctuation.
- The observed hydrological zones also relate to the elevation of different parts of the wetland. Drier areas tend to be on a higher elevation to the wetter ones. The incision area as a zone is located at a higher elevation than the rest of the wetland. The margins, especially the right one (P4s) is also on a higher elevation than the middle part of the wetland.
- The wettest parts are also related to the presence of the stream.
- Soil morphology is highly variable across the whole wetland. For example, the presence of mottles and various soil textural characteristics does not show any particular pattern of distribution, except for the deep organic rich soils that tend to occur in association with saturated areas in the centre of the wetland. The dominance of mineral soils is very likely to be caused by the deposition of sediments eroded from the catchment.

The existence of the hydrological zones in the wetland is investigated further in the next discussion.

6.4 THE RELATIONSHIP BETWEEN RAINFALL, WATERTABLE LEVELS AND ELEVATION

A set of six diagrams is presented as a representative sample of the various parts of the wetland. They are based on a group of transects made up of four piezometric holes each used for observing the depth to the watertable. The holes are labelled P1 to P4 starting from the left hand side facing down stream. The maximum height of each hole is shown on the legend to assist in the interpretation of the water-table fluctuations. The diagrams relate two variables, namely, the depth to the watertable

and rainfall (Y-Axis) against time (X-Axis). Time is in weeks dating from 15 October 2001 to 26 August 2002.

6.4.1 Reflections on selected transects

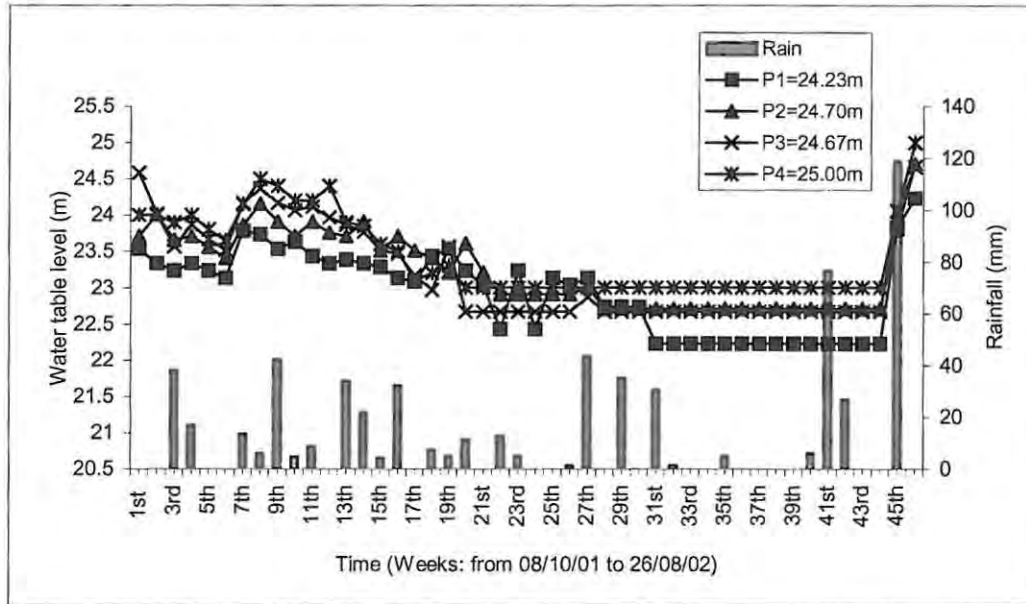


Figure 6.2: Transect 2

This transect represents the area across the incision, upstream of the wetland. The area was generally dry for most part of the monitoring period. From week 1 (15 October 2001) to week 25 (01 April 2002), there was general fluctuation of the watertable with a downward drying trend for all the holes. From week 26 (08 April 2002) to week 43 (12 August 2003) the area was completely dry. After week 43 the watertable rose to its maximum. In this part of the study site, the watertable appears not to be responding quickly to rainfall input. For example, there was significant rainfall input during week 41 (29 August 2002) but the area remained dry. The watertable only rose later and reached its maximum after the major rainfall input during week 45 (26 August 2002). The dryness of the area can be attributed to the presence of the incision, which may be draining most of the water except for times of complete inundation.

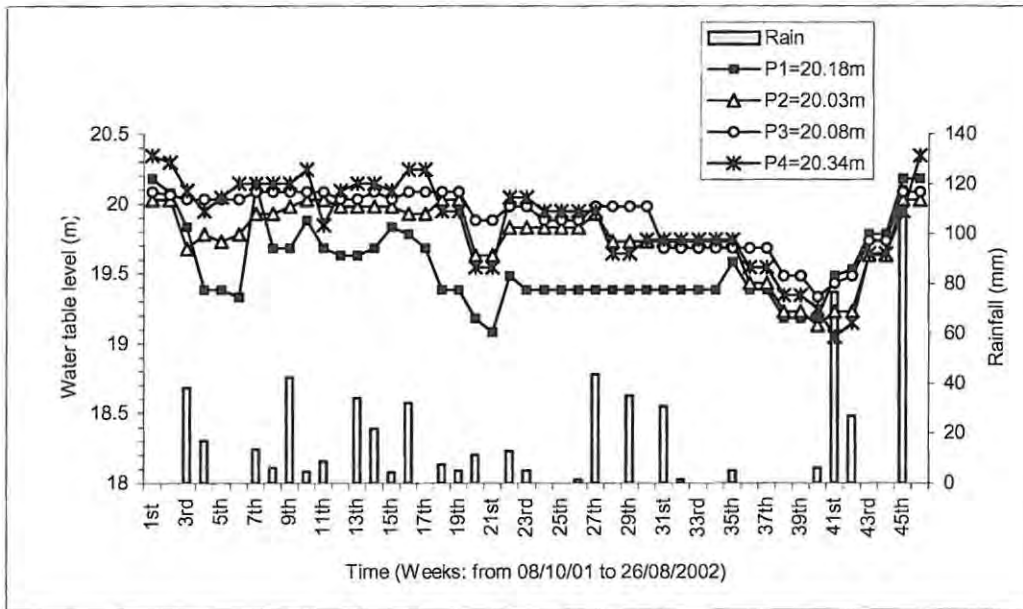


Figure 6.3: Transect 4

Transect 4 represents the top section of the main wetland area. The watertable fluctuation appears to be highly variable for the whole monitoring period. The watertable is mainly below the surface, except for the period after week 45. There is a weak relationship between the watertable fluctuation and rainfall input in the area.

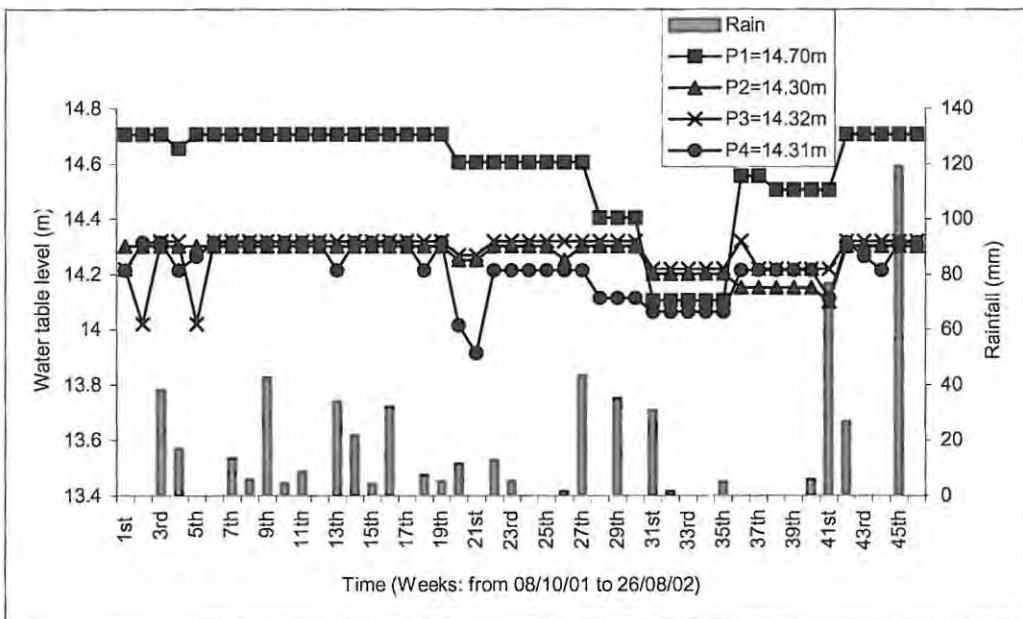


Figure 6.4: Transect 6

This transect represents the middle section of the wetland, just before the seep area. Hole P1 is located at a higher elevation to other holes, right at the bottom of the seep area. The water from the seep area maintains high watertable levels in the area, including middle holes, P2 and P3. Hole P4 is the drier than the rest of the transect. During the dry season the watertable drops sharply for the whole of transect. In contrast to the previous transects, the first significant storms of the new wet season (week 41) led to the rising of the watertable to very high levels – a condition that was sustained for the rest of the monitoring period.

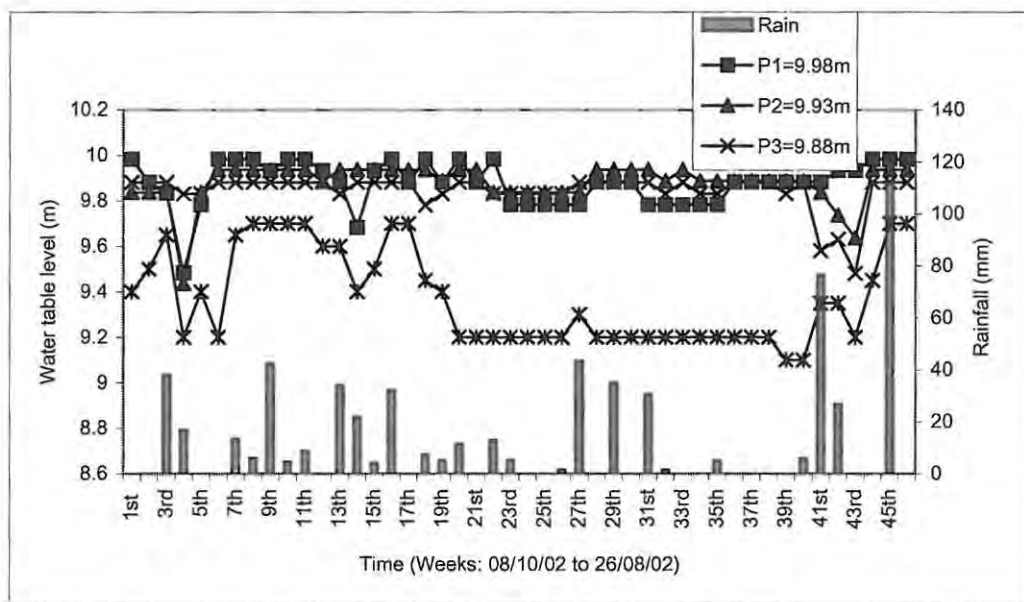


Figure 6.5: Transect 8

This transect is located on the lower sections of the wetland downstream of the area where the seep joins the main wetland. The watertable levels appear to be high for most of the period except for Hole P4 that is significantly drier. Hole P4 is also located at a higher elevation than other holes in the transect. This area is one of the wettest parts of the wetland, which could be as a result of the water input from both rainfall and the seep. The similar pattern prevails for the rest of the wetland down to Transect 10, which is at the bottom end of the wetland.

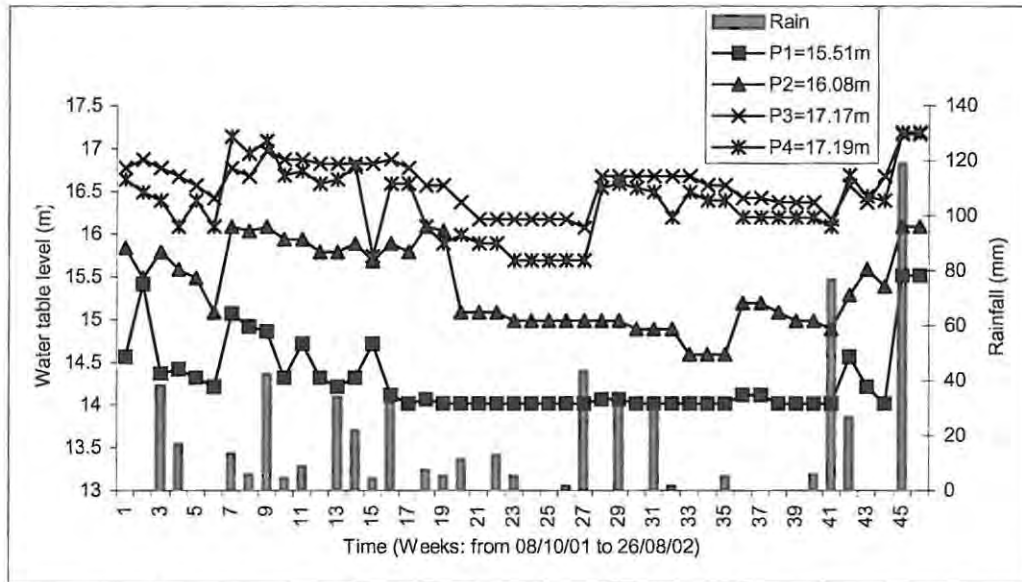


Figure 6.6: Transect 12

This transect is located across the seep area. There is quite a significant difference between the heights of various holes in this transect, with P1 located at the lowest elevation (15.51m) and P4 located at the highest elevation (17.19m). This leads to a situation whereby there is no similarity between watertable fluctuations in the area. The fluctuation seems not to be significantly affected by rainfall except for times of heavy rainfall such as in week 45.

6.4.2 Summary

This view of the wetland watertable situation as observed from each piezometer holes along the transects in relation to rainfall and elevation over the whole monitoring period of 45 weeks reveals that the site has four major hydrological zones:

- The incision area which is at a high elevation and also very dry
- The upper part of the wetland which is quite dry, especially on the margins
- The middle part of the wetland which is mainly wet with slight watertable recession during the drier periods;
- And the middle to the bottom part of the wetland which is very wet for most of the period, with the right hand margin (P4) significantly dry.

- Rainfall input appears to be a very important source of water for the wetland but does not automatically translate to the immediate rise in watertable levels in the wetland.
- The wetness of the middle to lower sections of the wetland appears to be more related to the input from the seep area and the lower elevation of the area in relation to the rest of the wetland.
- The existence of these hydrological zones confirms the findings made in 6.3 above.

The relationship between rainfall and discharge is investigated below.

6.5 THE RELATIONSHIP BETWEEN RAINFALL AND DISCHARGE

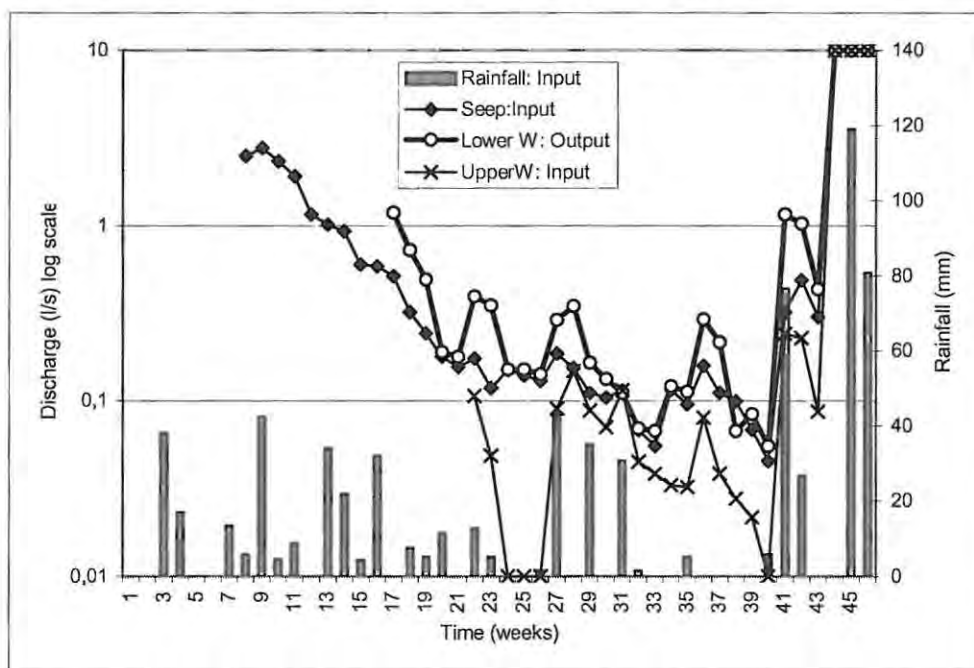


Figure 6.7: The relationship between rainfall and discharge over the monitoring period. Surface input is represented by the seep and upper weir inputs. The lower represented both surface and subsurface outputs from the wetland.

According to Figure 6.7, when the monitoring of wetland surface flows began on 29 November 2001, waterflow from the seep area was higher than the subsequent period. The rate of decline continued, with fluctuations, until it became very high again at the end of the monitoring period. The inflow from the seep was constant compared to the inflow from the upper weir, which was highly variable, with some periods of no

flow at all. Surface outflow through the lower weir was also variable. It appears that periods of higher inflow were followed by periods of higher outflow. The high discharge situation in the seep area during the start of the monitoring period relates well with frequent occurrence of rainfall that prevailed from the beginning of August 2001 (spring season) to December 2001 (summer season). However, the general decline in seep inflow does not correlate with the constant rainfall situation of that period. This could be attributed to high loss of water through its consumptive use by the wetland plants and the atmosphere. The validity of these observations will be investigated further by quantifying various wetland hydrological variables using the water balance method.

6.6 THE WETLAND WATER BALANCE

In this section an attempt is made to quantify the water balance in the wetland. To calculate the water balance, the water balance equation is employed:

$$\text{Input} = \text{output} \pm \Delta \text{ storage}$$

All figures will be given as volumes.

6.6.1 Methods used to calculate the figures

Inputs

Rainfall: The raingauge data from Grey Dam were used. Each rainfall figure in millimetres was converted into cubic metres. This was done by first dividing each figure by 1000 to convert it from millimetres to metres and then, multiplied by the wetland area of 9000m² to get cubic metres.

Seep and upper weir input: The original discharge figures were in litres per second. They were all converted into cubic meters accounting for each week. (It should be noted though that this conversion of an instantaneous measurement to a weekly value presents an inherent error in the water balance calculations because it assumes that discharge remains constant through the week, which is not representative of the real situation).

Outputs

Evapotranspiration: Original data were in the form of pan evaporation figures in millimetres obtained from the Loerie Dam. Each figure was divided by 1000 to convert from millimetres to metres, then multiplied by the wetland area of 9000 m² to get cubic meters. Since the pan evaporation figures represent the evaporation from a small pan, each figure was further multiplied by a standard pan coefficient figure of 0.7 to get corrected lake evaporation figures. This pan coefficient value is widely accepted, and according to Kadlec (1983, p225) it “has been used except in those few cases where it has been possible to approximate evapotranspiration by other techniques”.

Lower weir output: The procedure used to calculate seep and upper weir inputs was employed to get volume figures in cubic metres.

Change in storage

The watertable data was used to calculate change in wetland water storage. Original watertable figures were in centimetres, accounting for the depth to the watertable. To calculate the change in storage, a difference between two consecutive figures was derived, and divided by 100 to convert it to metres. To account for the porous medium in the form of the surrounding aquifer, each figure was multiplied by a porosity figure of 0.5. This value was derived as an average porosity figure for the wetland after direct porosity measurements and calculations were carried out. To get volumes in cubic metres, figures in meters were multiplied by the wetland area of 9000 m².

Determination of error

Error in the total water balance was calculated as the residual of (inputs-outputs) – change in storage, a method also used by Owen (1995).

6.6.2 Data evaluation

It is deemed important to put the results of water balance calculations into perspective by highlighting the potential limitations of the data used.

Rainfall data: Figures used were obtained from a site some 3 km away, not at the actual study site. This difference in location between the two areas (i.e. the study site and the Grey Dam) does not pose significant challenges in rainfall similarities in the long term, but differences are possible in as far as short-term storm values are concerned.

Stream-flow/discharge: The upper weir and the seep gutter were located in areas where there was recognisable surface-flow. The subsurface seepage input into the wetland could not be captured, but the evidence from the water-table data indicates that it was not significant since the piezometers upstream of the instruments did not show significant water changes, except after major rainfall events. The lower weir measuring output was constructed in such a manner that it could capture both surface

and subsurface outflows from the wetland. On both the input and output side, it is inevitable that flood peaks were missed because flows were not measured continuously. This would have been more so for the upper weir as the response was more flashy.

Evapotranspiration: Pan evaporation figures were obtained from the Loerie Dam, some 200km from the study site. However, this was not deemed to be a serious problem because it is common to utilise regional figures in the case of evaporation, especially that in this instance Featherstone Kloof Catchment lies in the same climatic region as the Loerie Dam. A potential error here is that pan evaporation gives potential evaporation from an open water surface, which is not the actual evapotranspiration from a vegetated surface. In the case of the wetland, this would depend on both the availability of water (which is high as most of the wetland is saturated) and the biomass of the vegetation, which is greatest during the summer. Thus winter figures may be overestimated whereas summer figures may be underestimated. As mentioned before, the pan coefficient of 0.7 was used to account for the fact that the measurements were taken from a small water surface, not a lake.

Watertable data: The depth to the watertable was measured over fixed periods, which could have missed some changes between the intervals. However, such changes were not significant, since there was an observed time lag between the time of rainfall and watertable response as demonstrated in section 6.4 above.

6.6.3 The water balance results

The results are presented in the form of a graph and a computed water balance equation.

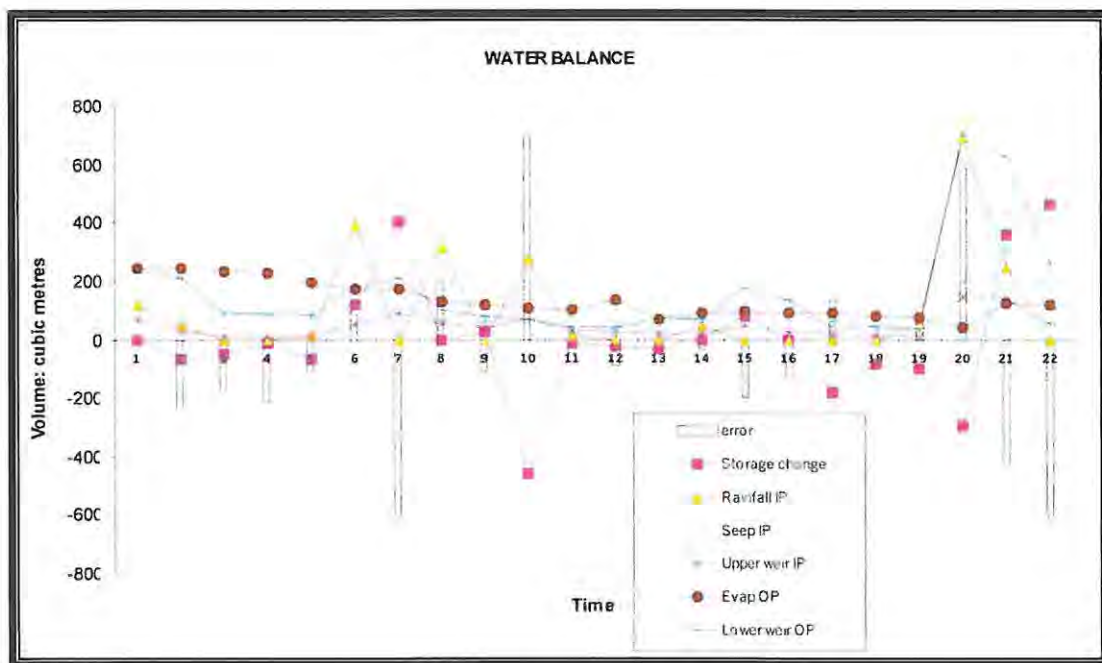


Figure 6.8: A graphical illustration of the wetland water balance

Figure 6.8 depicts the relationship between various wetland water balance variables, namely: change in wetland water storage, rainfall input, evapotranspiration output, stream-flow input and output. This is presented against time in weeks from 11 March 2002 to 05 July 2002. This is the period during which the data for all the variables was available, although monitoring itself commenced and ended at different times for the various variables. The diagram depicts a great fluctuation of the hydrological conditions over the period, with large error at times. Under normal circumstances the input is supposed to be equal to output without an error. An attempt is made to explain possible sources of this error and implications for the wetland water balance.

Possible sources of error

For the first five weeks (11 March to 08 April) all the variables do not show major fluctuation, and the storage change is generally very low. This is a generally dry period with little rainfall. The fact that changes in storage were very low is understandable because inputs in the form of rainfall and stream-flow were also low to nil. There is a small negative error which may be due to an over estimation of evapotranspiration.

During the sixth week (15 April) rainfall dramatically increases, leading to the attendant increase in stream-flow input and storage in the following weeks. The time lag between rainfall input and change in storage is very clear, whilst other variables seem not to follow the same pattern. The large negative error figure during the seventh week (22 April) might be caused by the flow estimates. However, given the dry conditions, the flow would change gradually so weekly measurements would give a reasonable representation. There would be no flood peaks to be missed.

After the ninth week (06 May), there is a general decrease in storage despite the fact that there was an increase in rainfall input during the previous week. This leads to a large positive error figure during the tenth week (13 May). The impact of rainfall of the tenth week is only realised during the following week when storage rose again.

From the eleventh week (20 May) to the sixteenth week (24 June) there is no major fluctuation in the hydrological variables. These are winter months, which are characterised by lack of heavy rain in the area. The error figures are also very close to nil. One significant thing about this period is that it is not only rainfall that is low, but also evapotranspiration is lower than during other weeks. Therefore, it is likely that it is not only rainfall and change in storage that contributed to the large error figures at other times, but also evapotranspiration.

From the sixteenth week, there is general decrease in storage until it rises again on the twentieth week (22 July) after the heavy rains of the previous week. The rainfall was so high that it managed to raise the storage to its highest levels during the monitoring period. There is no significant change in evapotranspiration, whilst stream flow both at input and output sides increases significantly. During this period, from the twentieth week to the twenty-second week (05 August) the error figures suddenly became very high at both positive and negative sides. It is likely that during this period all the variables contributed in various ways to the kind of the error displayed. The fact that rainfall occurred in the form of prolonged floods might have led to the missing of important peaks in stream-flow measurements. At the same time, observations were made that surface flows during flood events were not only confined to the channels where the discharge measuring instruments were located, but by-

passed them. (Details about the impact of those flood events on the wetland and its catchment were presented in section 5.4.)

Computed water balance for the period starting from March to July 2002

Gross figures in cubic metres:

- Rainfall input = 2087.10 (Ri)
- Seep input = 1905.12 (Si)
- Upper-weir input = 895.10 (Uwi)
- Total input = 4887.32 (Ti)

- Evapotranspiration = 2682.54 (ETo)
- Lower weir output = 3356.64 (LWo)
- Total output = 6039.18 (To)

- Volume storage change = 31.5 (ΔS)
- Error = 1183.4

Calculations:

- Input = output $\pm \Delta$ storage
- $Ri + Si + Uwi = Evo + Lwo \pm \Delta S$
- $2087.10 + 1905.12 + 895.10 = 2682.54 + 3356.64 + \Delta 31.5$

Therefore:

- $4887.32 = 6039.18 + \Delta 31.5$ error 1183.4

According to these results, the output is higher than the input and the net change in storage over the monitoring period is very small. A number of calibrations were performed in an attempt to present the likely water balance of the wetland. An investigation of the main source of water, as per water balance calculations in relation to the actual catchment, was done. The area of the catchment contributing to the wetland was calculated to be approximately 60 hectares (600 000 m²), whilst the size of the wetland itself was 9000 m² (0.9 hectares). Therefore, the wetland was about

1.5% the size of its contributing catchment. The total input from catchment B was estimated as 1905 m³ from an area of 240 000 m², that is 0.0079 m³ per m². This will probably be an underestimate due to the inability to measure flood peaks and some seepage. However given the seep's ability to store water, the flood effect will be minimised. The total input from catchment A was estimated as 895m³ from an area of 360 000 m², i.e. 0.0025 m³ per m². This is 1/3 of the runoff from catchment B, yet there is no apparent reason for this difference in yield per unit area as both catchments are essentially the same in terms of rainfall, vegetation cover and other attributes. Both should yield the same amount per unit area. This immediately points to an error and an under estimation of the flow at the upper weir. Given the flashy nature of flow observed at this weir, this makes sense. If you were to multiply the yield from A by the area of B you would get an input through the upper weir of 2844 m³, or 1949 m³ more than was measured. This more than accounts for the error in the water balance.

6.6.4 A reflection on the wetland water balance results

The water balance results provided an insight into the hydrological situation of the wetland. However, these results cannot be understood fully if they are treated in isolation. The geomorphological setting and other wetland characteristics will be taken into consideration. The water balance results indicate that the water input (4887.32 m³) was higher than the output (6039.18 m³). The possible scenarios are that, either the inputs were underestimated or outputs were overestimated. In addition to the possible limitations of the data highlighted above, the general characteristics of the contributing sub-catchments may have had an influence on the nature of the water balance of the wetland.

(i) The input side of the water balance

An attempt was made to estimate the size of the contributing sub-catchments in order to get an approximate amount of water input per unit area that is contributed by the each sub-catchment. The possible impact of the characteristics of each sub-catchment on wetland hydrology is investigated below.

The possible impact of sub-catchment A

Sub-catchment A has a seep wetland that is located at a higher elevation to the main wetland as illustrated in Figure 6.9.

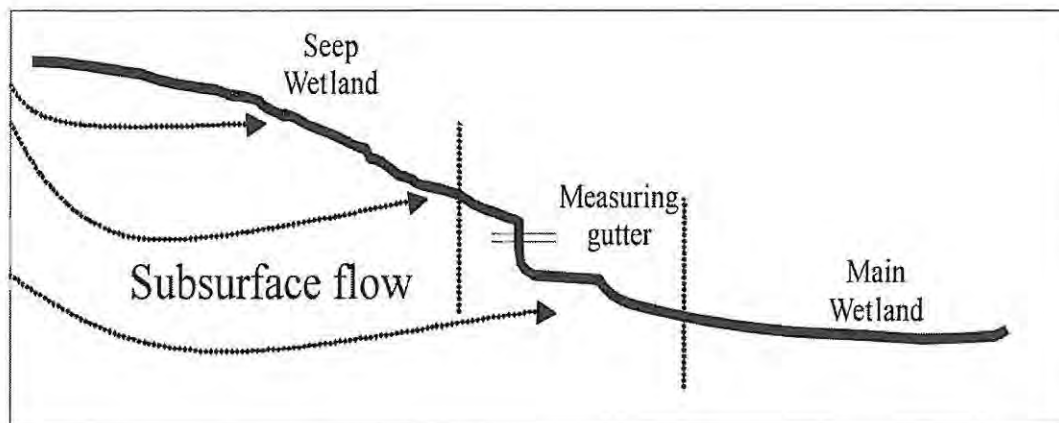


Figure 6.9: A side-view illustration of the location of the seep wetland in relation to the main wetland, and hypothetical subsurface flows. The dotted bars indicate the location of Transects 11 and 12 where piezometers for monitoring the watertable levels were installed

Figure 6.9 illustrates the difference in elevation between the two wetlands from a side view. This can be related back to the sketch map in Figure 4.1 where it was indicated that the seep wetland is located at an altitude of 550 metres above sea level, whereas the main wetland is located at 540 metres above sea level. This gives a difference of 10m between the two spot heights (The measurements were done using a GPS, which is not a very accurate instrument for measuring altitude – but can serve the purpose in this regard). On the basis of the topography of the area, the possible subsurface flows were hypothesised. It was hypothesised that subsurface flows from the seep wetland and the interfluvium followed the pattern depicted in the Figure 6.9. This hypothesis is also confirmed by the observation that surface input from the seep area was continuous even during drier periods, when the wetland itself appeared to be dry. This dryness was confirmed by watertable monitoring results obtained from piezometers located in Transects 11 and 12 at the lower end of the seep wetland. A tentative conclusion can be made that, despite the fact that the gutter managed to capture the continuous flow from the seep wetland area, some of the subsurface flow from the seep wetland and interfluvium could not have been accurately measured, thereby leading to the underestimation of the seep input.

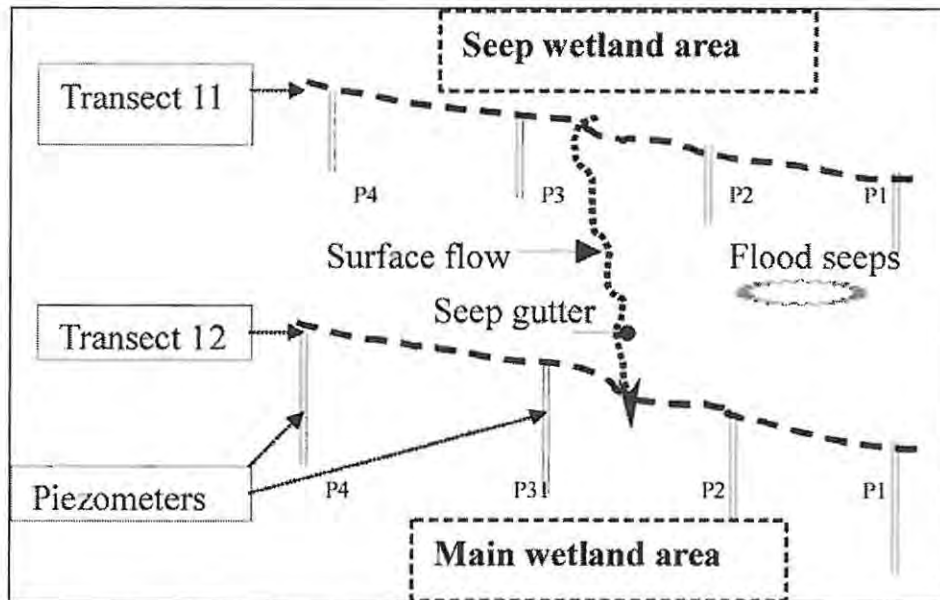


Figure 6.10: A plan view sketch diagram of the lower end of sub-catchment A, showing the location of piezometers and the gutter along Transects 11 and 12. The general surface flow to the gutter and ‘flood seeps’ are also shown

Figure 6.10 gives a plan view of the lower end of sub-catchment A and the location of the seep gutter and the piezometers. The gutter measured the main surface flow (as illustrated) from the seep wetland area, but some flows could have been missed during flood events, that is, high peaks or even surface flows that bypassed the gutter. Besides the surface losses, it was also observed that after prolonged rainfall events the watertable became high and some subsurface flows came out as small springs referred to as ‘flood seeps’ in Figure 6.10. The flood seeps continued to flow for some time after the rainfall has stopped as depicted in Plate 6.1.



Plate 6.1: A picture of one of the flood seeps that were observed on the lower end of sub-catchment A after the flood events of August/September 2002

The existence of these flood seeps confirms the fact that input from sub-catchment A could have been underestimated. The cause of the existence of these seeps is not well known. However, it is possible that water followed the areas where previously there were roots of trees that used to be in the area (alien tree species were removed from the area in the previous years), or maybe they were holes of burrowing animals like rats that were seen quite often in the area. Whilst the existence of these seeps is important for understanding the hydrological situation of the wetland, their cause is beyond the scope of this research.

The possible impact of sub-catchment B

The characteristics of Sub-catchment B (which does not include the north facing slope) are quite different from those of sub-catchment A as illustrated in Figure 6.11.

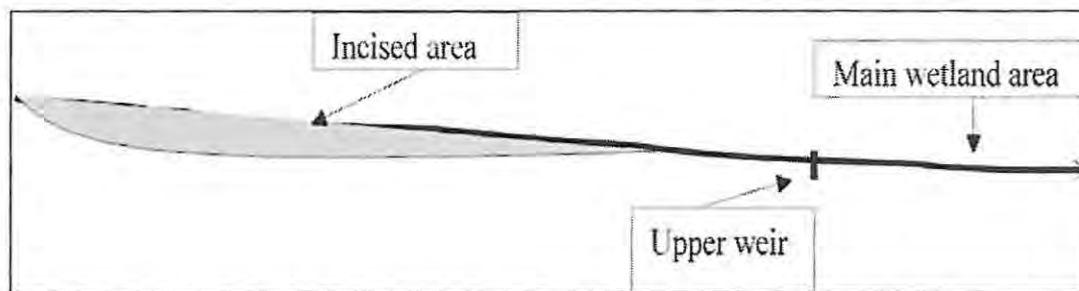


Figure 6.11: A sketch diagram illustrating the location of the upper weir in relation to the incised area and the main wetland

According to Figure 6.11, instead of having a wetland, sub-catchment B has an incision area upstream of the main wetland. The upper weir measuring input into the main wetland from sub-catchment B was installed between the incised area and the main wetland. In this way, the incised area helped in channelling flows from the upper catchment into the upper weir and the main wetland. The location of the incised area relative to the main wetland was not as high in elevation as the location of the seep wetland relative to the main wetland. The incision helped in channelling surface flows from sub-catchment B, thereby limiting chances of surface and subsurface flows bypassing the upper weir. This was also confirmed by the monitoring of the watertable through piezometers located in Transects 1 and 2 that were installed along the incised area. The watertable levels in those piezometers were the lowest over the monitoring period as mentioned before. However, during flood events sub-catchment B could have provided flashy flows because of its large size and lack of wetland vegetation to retard the flashiness of the floodwaters. Such floodwaters were observed to have been so high that they over-flooded the upper weir at times.

(ii) The output side of the water balance

As indicated in the results of water balance calculations, the output is significantly higher than the input. The output variables included in the calculations are evapotranspiration and lower weir output. The lower weir was located downstream of a headcut, on a lower elevation to the wetland – making it possible to measure both surface and subsurface outputs as depicted in Figure 6.12.

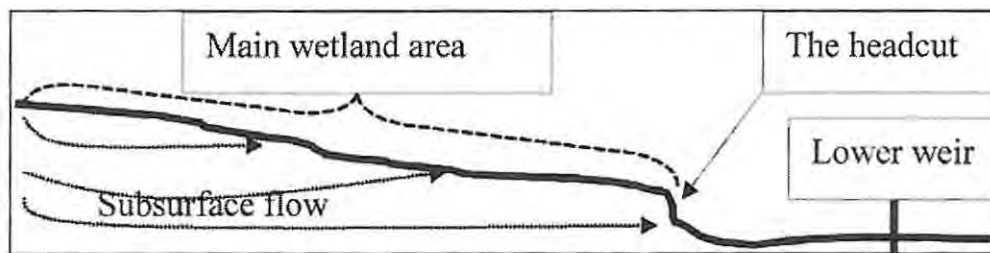


Figure 6.12: A sketch diagram depicting the location of the lower weir in relation to the main wetland.

In addition to the fact that the lower weir was located in a position whereby it could measure both subsurface and surface flows, it was also large enough in size not to be bypassed by high flows. Floodwaters were not flashy like the situation in the upper weir because the wetland absorbed surface-flows. The only flood event that had an impact on the lower weir was the one of August/September 2002, which destroyed the weir resulting the complete halt of monitoring. According to the results, the lower weir output was higher than the surface inputs, which might have been due to the contribution of the subsurface flows.

Evapotranspiration also contributed to the loss of water from the wetland, as shown in Figure 6.8, where it was high for most of the time. Evapotranspiration continued to take place even when all other variables were inactive, i.e. during the very dry periods when there is no rainfall and water flows (as observed from the seep, upper and lower weirs). Evapotranspiration is likely to be higher in the wetland itself than the surrounding catchment due to the presence of water and hydrophytes. Higher temperatures in the region, especially during summer months are likely to have contributed a lot to the increase the rate of evapotranspiration.

Based on such observations, it can be concluded that the high figure of output obtained from water balance calculations is a true reflection of the hydrological situation in the wetland, and the input underestimated.

6.6.4 Summary

The water balance situation of the Featherstone Kloof Wetland can be summarised as depicted Figure 6.13.

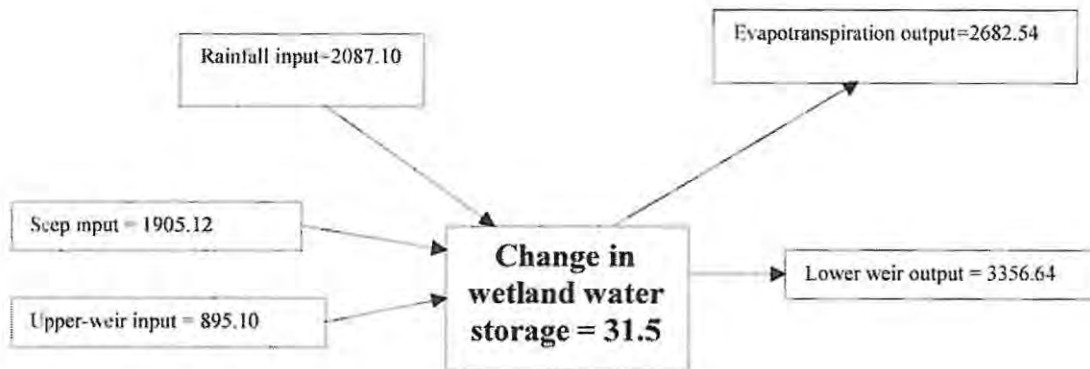


Figure 6.13: A summary of the water balance situation of the Featherstone Kloof Wetland for the period 05 March to 11 July 2002. All figures are presented as volumes in cubic metres

The water balance calculations and the subsequent reflections revealed that the gross water output was higher than input over the monitoring period. The input was almost certainly underestimated. The gross change in storage over the measurement period is small, and therefore it can be discounted leading to the conclusion that, water input into the wetland should have been equal to output, all other factors being equal. The implications of these results for the hydrogeomorphology of the Featherstone Kloof Wetland are discussed in Chapter 7.

Chapter Seven: GENERAL DISCUSSION

This research was based on the hypotheses that:

- Wetlands store sediments
- Wetlands attenuate floods
- Wetland have high water tables
- Wetlands prolong downstream flow

These hypotheses were seen as conventional wisdom that describes the hydrogeomorphological functions of wetlands – and the main aim of this research was to investigate the hydrogeomorphological functions of the Featherstone Kloof Wetland. To achieve that aim, a number of objectives put as key questions were stated. Extensive literature review was carried out and research results were presented. In this chapter, the implications of the various findings made will be discussed and related to existing literature.

The overview of the historical geography of the area where Featherstone Kloof Wetland is located gave an impression that a number of anthropogenic and natural factors have interacted to produce the kind of landscape existing in the area. After discussing a range of evidence from secondary sources, it was concluded that natural factors played a primary role in shaping the hydrogeomorphology of the Featherstone catchment whilst the anthropogenic ones acted as a secondary factor. Evidence from radiocarbon dating done on sediments taken from the study site revealed that the wetland has existed for quite a long time. The dates indicated that organic matter accumulation in the area occurred as early as 1850±50BP (252AD), which is about 2000 years ago. That falls within the Holocene in the geological timescale. The climatic change during the Holocene is known to have been very cyclic in nature, with alternating periods of high and low temperatures. That also resulted in oscillations in rainfall conditions, with dry periods alternating with wet periods. Such climate conditions were viewed as having had an impact on the geomorphology of the area, particularly to the hydrogeomorphological systems like the Featherstone Kloof Wetland. The influence of climate change on the natural aggradation and degradation of the landscape in the area is well documented.

It is against this background that rainfall was seen as probably the most important hydroclimatic variable that has an impact on the hydrogeomorphology Featherstone Kloof Catchment and the surrounding region. The Grahamstown region has one of the longest rainfall records in South Africa. The rainfall figures dating from 1878 to 2001 were used to analyse the extent and variability of rainfall in the area for the past century. The results showed a steady fluctuation of rainfall around the mean, with regular decadal cycles of wet and dry spells. The prevalence of flood events of high magnitude (above 100 mm/day) in the area was confirmed by both empirical and anecdotal evidence. That led to a question of how did the Featherstone Kloof Wetland respond to such flood events, bearing in mind that it was hypothesised that wetlands attenuate floods and act as sediment traps or sinks.

The rainfall events that occurred in August and September 2002 had a great impact on the nature and functioning of the Featherstone Kloof Wetland. After performing an analysis on the rainfall data, it was established that the flood event of 23 September 2002 was the highest (154.2 mm) over a period of about ten years, but was not necessarily exceptional when considering the long-term records of storms in the area. This condition had far reaching implications for the hydrogeomorphology of the Featherstone Kloof Wetland.

The flood events of August/September 2002 acted as an extrinsic factor and a triggering mechanism to rapid erosion/deposition cycle in the wetland. Extensive erosion occurred on the wetland catchment and the incised area upstream of the wetland, generating large amounts of sediments. According to the data obtained through field observations, sediments of different sizes were deposited on the wetland, especially wood debris, cobbles, pebbles, gravel and sand. However, the fate of the smaller sediments (clay and silt) held in suspension and solution is not known. But since it was observed that the wetland became over-flooded to the extent that the lower weir was destroyed, it could be deduced that most of such sediments was washed downstream. Therefore, if some of the large amount of soil that was eroded from the catchment and the incised area became part of the material held in solution and suspension, it goes without saying that the wetland failed to some extent to trap it.

The bigger sediment types that were trapped affected the geomorphological and hydrological characteristics of the wetland. The accumulation of sediments changed the wetland topography. The middle section of the wetland became elevated. Areas that used to be channels were filled up and raised into 'sediment piles'. Naturally, the deposited material resulted in new soil layers/horizons – as the original topsoil layers were buried. It was also observed that some wetland vegetation was buried under the deposited material, meaning that when such plant materials decompose they would form a buried organic matter. These observations gave insights into the possible effects of flood deposition on the wetland soil characteristics that will be discussed later.

From the foregoing discussion it is clear that the wetland did not really attenuate extreme floods. Inasmuch as the deposition of some sediments could be seen as an indicator of flood attenuation, the fact that flood waters were diverted to the margins of the wetland where there was little vegetation indicates otherwise. In fact, it was observed in the field during the floods that the flow of floodwaters was very high, to the extent that it destroyed the weir at the bottom-end of the wetland. Then a question arises as to why is it the case that the wetland did not perform its presumed function of flood attenuation.

In this case, it may be due to the fact that these flood events occurred after the end of a dry season, that is, at the beginning of spring (August/September). During this period the vegetation on the wetland (wetland biomass) is greatly reduced by the effects of the dry season. Wetland vegetation is the one that is known to trap sediments and attenuate floods. However, this limited amount of vegetation on the wetland during this period could not help in trapping sediments and attenuating floods. In addition to the role played by wetland vegetation in flood attenuation, the capacity of the wetland to store incoming floodwaters plays a significant role. The sequence of rainfall events over the period preceding the destructive flood event of September 2002 led to the inundation of the wetland and, therefore, the wetland could not store any more water; instead it acted as the source area for runoff. As it was noted before, the wetland was about 1.5% the size of its contributing catchment. This inability of wetlands to attenuate extreme floods is also confirmed by evidence from other studies. A study conducted by McCartney (1998) found that, once headwater

wetlands are saturated, the catchment response is sensitive to rainfall characteristics and they act as source of overland flow. This implies that headwater wetlands also contribute to floods. This runoff generation ability of wetlands in the catchments can also be associated with the use of Partial Area and Source Area models (Burt, 1989) by hydrologists to describe the storm runoff mechanisms in small catchments.

As mentioned before, the deposition of sediments on the wetland also affected its soils characteristics. Before the beginning of monitoring (July 2001), an analysis of soil characteristics (colour, organic matter and texture) was performed. The aim was to see if the wetland soil characteristics could be used as an indicator to delineate various hydrological zones of the wetland. The results did not show any particular pattern in the distribution of soil characteristics across the wetland as reported in the results in Chapter 6. When this condition is interpreted in light of the observations made during the flood events of August/September 2002, a number of deductions can be made:

- Firstly, the floodwaters deposited sediments on the wetland eroded from the upper catchments, which were made up of different soil types and materials. For example, the incision upstream of the wetland had an organic layer (where the organic soil samples that were radiocarbon-dated were obtained), whose erosion could have led to the deposition of the same material on the wetland downstream resulting in the existence of soil characteristics not normally expected to be found in those places - if one bases the argument on the conventional wisdom of the criteria that uses soil characteristics as the primary indicator for wetland delineation as discussed under soils in Chapter 2.
- Secondly, it was observed that the accumulation of sediments on the upper part of the wetland diverted the water-flow to the margins of the wetland where the vegetation was not high enough to continue trapping sediments. The fact that the accumulation of the deposited material diverted water-flows meant the change in the hydrodynamics of the wetland. That is, areas that used to have surface-flows no longer did and those that previously did not have such flows were now inundated with water. The shifting of hydrological regimes did not imply a similar change in the soil characteristics.

It is against that background it is concluded that the complexity of wetland soil characteristics based on soil analysis results may be due to the impact of natural events of extrinsic nature to the system similar to the floods events of August/September 2002, not necessarily the hydrological dynamics within the system.

From the observations made during the post-flood period, it was noticed that the characteristics of the wetland were quite different to those before the flood. Besides the change in the soil characteristics in the wetland itself, there were significant changes on the incised area upstream of the wetland. Some of the material in the form of plants and soil that came from the slumped banks remained on the channel bed. Such plants started growing in the channel, and due to poorly drained conditions created by the stagnant pools, hydrophytes also started to colonise the place. The growth of hydrophytes, that are typically adapted to wetland conditions, marked the upstream migration of the wetland and the stabilisation of the incision. Using the coupling concepts proposed by Harvey (2002), the system could be viewed as displaying both up-system and down-system coupling behaviour. On the down-system dimension, during the flood events, sediments were being transmitted from hill-slope and upstream incision onto the wetland downstream. Sediment deposition also brought about change in the base-levels. Up-system coupling ensued soon after the floods, when the propagation upstream of the base-level change became prominent as evidenced by the upstream migration of the wetland plants into the incised area. However, such processes need more elaborate investigation to be properly elucidated and that is beyond the scope of this research.

Regarding the hydrological functioning of the system, the monitoring of wetland watertable levels, water inputs and outputs was carried out. An analysis was performed to investigate possible relationships between various variables. The first analysis involved a comparison of the water-level regime with the wetland soil morphology and the wetland elevation. Given the fact that the initial analysis of soil alone as an indicator of the wetland hydrological regime did not yield expected results as stated before, the intention of the comparison with the water-level regime and elevation was to see if there were any observable patterns. The results indicated that the water-level regimes for both wet and dry periods helped in delineating the wetland into various wetland zones. That was easily related to elevation, whereby high-lying

areas tended to be drier than the low-lying parts of the wetland. Although there was no general observable pattern with regards to the distribution of soil characteristics in relation to the water-level regime and elevation, soil horizons with organic content tended to coincide with the wettest parts of the wetland. However, the distribution of mottles and soil texture in general did not really follow the expected patterns. For instance, in the middle of the wetland, where a perennial watertable existed, it was found that there was a layer of mottled clay buried under a layer of loam and organics. That was viewed as an anomalous condition because the existence of mottles is indicative of seasonal water-level regime.

The possible impact of events like flood deposition on the nature of the observed soil characteristics as discussed above cannot be ruled out. At the same time, a few years before the monitoring began, the Featherstone Kloof Wetland was infested with alien wood. It is possible that the parts of the wetland that maintained a perennial watertable during the monitoring year used to have a seasonal one before as a result of the consumptive use of water by the alien wood. Soil conditions reflect a long-term situation, which might not be directly linked to the monitoring year *per se*. Although it is well accepted that the existence of mottles is an indication of alternate wetting and drying (Mitsch & Gosselink, 2000), their lifespan under conditions of permanent inundation is not known. Although some commentators attempted to explain possible problems in using soil morphology as an indicator of hydric conditions (Kotze, 1994; Robenhorst and Pakish, 2000), as noted in literature review, they fall short of citing the possibility of sediment processes like deposition and erosion leaving anomalous imprints on wetland soil characteristics. The influence of geomorphological processes on pedology is well known, and wetlands as landscape features are no exception.

Regarding the relationship between various hydrological variables, time series analyses and the computation of the wetland water balance were performed on the data generated during monitoring. From the time series diagrams depicting the relationship between rainfall, watertable levels and elevation it was found that rainfall does not automatically translate to the rise in the watertable. Areas that maintained high watertables were those that received extra input from the seep area and were in gentle slopes (i.e., lower elevation than others). The relationship between rainfall and discharge (seep input, upper weir input and lower weir output) was also investigated.

The high discharge situation in the seep area during the start of the monitoring period was found to be related to the occurrence of rainfall at the beginning of August 2001 (spring season). However, the general decline in seep input during the summer months (late September to December) was found not to correlate with the constant rainfall situation of that period. This could be attributed to the possible loss of water through its consumptive use by the wetland plants and the atmosphere.

When looking at discharge alone, it was noted that the inflow from the seep was relatively constant compared to the inflow from the upper weir, which was highly variable, with some periods of no flow at all. Surface outflow through the lower weir was also highly variable. It was also observed that periods of higher inflow were followed by periods of higher outflow. However, when the inflow from the upper weir was nil, outflow at the lower weir remained high. This observation was further investigated through the use of water balance method whereby evapotranspiration was also included.

According to the results of the water balance calculations water input into the wetland was less than the output. The gross change in wetland water storage was very low. After investigating a number of factors that might have contributed to that state of affairs, it was noted that the low input value in the water balance was likely to be the reflection of the underestimation of the input from the upper weir. The influence of evaporation on the output side was noted, but not taken to be highly significant. Begg (1996) pointed out that wetlands can play a dualistic role in the environment. Their dense vegetation promotes high evaporation rates that lead to water loss whilst at the same time it contributes organic matter, which helps in increasing water storage in the wetland.

The continued flow of the seep and the lower weir even during periods of lack of rainfall was seen as being augmented by the subsurface input from the catchment slopes and the seep wetland. This observation is in line with the findings made by McCartney et al. (1998) that headwater wetlands mainly depend on water from the upland slopes, and instead of storing such water, they contribute it to downstream flow. In the case of this wetland, the evidence (periods of outflow in the lower weir

when there was no inflow from the upper weir) indicate that the wetland managed to store incoming water which was released slowly overtime as baseflows.

The general conclusions and recommendations are made in the next Chapter.

Chapter Eight: GENERAL CONCLUSION AND RECOMMENDATIONS

The foregoing chapters raised a number of issues regarding the hydrology and geomorphology of wetlands in general, and the situation in the Featherstone Kloof Wetland and its surrounding environment in particular. Chapter 2 on literature review emphasised a number of aspects, namely: wetland definition, functions and classification; the influence of climate, hydrology and geomorphology on the functioning of wetlands; the relationship between hydrology and wetland soil characteristics; and the impact of environmental extremes, especially flood events, on the nature and functioning of wetlands. Chapter 3 located the study area in the broader landscape context, taking into consideration the influence of environmental change. The results of radiocarbon dating done on the organic soil samples taken from the study site were also presented and discussed. Rainfall as a hydroclimatic variable was seen as exerting great influence on wetlands as hydrological phenomena. In addition to the analysis of the long-term rainfall data conducted in Chapter 3, a more focused analysis of the rainfall data for the period 1990 to 2002 was done in Chapter 5. The data generated during the monitoring period was presented in Chapters 5 and 6, showing possible relationships between various variables and the emerging patterns and their role in influencing the hydrogeomorphology of the wetland. Chapter 7 discussed the findings of the results and their implication for the hydrogeomorphological functioning of the Featherstone Kloof Wetland.

The key findings of the research were that:

- In the long-term past, climate; hydrology and geomorphology interacted to produce the current characteristics of the Featherstone Kloof Wetland. The radiocarbon dating of organic soils indicated that the wetland has existed for about 2000 years. The current degradation of the wetland as evidenced by the existence of the gully upstream is likely to be related to the influence of natural factors (particularly rainfall events of high magnitude) - with anthropogenic factors such as the introduction of alien vegetation acting as a secondary factor;
- In the contemporary period, the wetland maintained perennial waterlevels in some parts. That contributed to the fact that the wetland was able to store water and release it slowly during dry periods and prolong downstream flow. The water output from the wetland, as per water balance calculations, was higher than the

input over the monitoring period, implying gross errors that can be accounted for in terms of inflow measurements. The consumptive use of water by the wetland plants and the atmosphere due to higher biomass and temperatures in summer was seen as playing some role in contributing to water loss via evapotranspiration.

- Although the wetland did possess soil characteristics reminiscent of wetland conditions the distribution of such soil characteristics across the wetland, particularly the occurrence of mottles, was not necessarily linked to the existing wetland hydrological regime or showed any particular pattern to assist in the delineation of the wetland into various hydrological zones. However, the occurrence of deep organic rich soils did coincide with the wettest parts of the wetland. The complex nature of the wetland soils was seen to be related to the possible deposition of sediments from the wetland catchment by the flood events that are common in the area, and the possible impact of the earlier existence of alien vegetation.
- The wetland does serve its function of sediment trapping to some extent as evidenced by the deposition of large sediment types during floods, but the fate of the sediment types held in solution and suspension is not known.
- The wetland managed to attenuate floods to some extent as indicated by the limited impact of the first flood events of the spring season of 2002. However, the ability of the wetland to continue attenuating floods after attaining high levels of saturation is limited, as shown by the impact of the destructive flood events of September 2002. The limited surface roughness as a result of less vegetation after the winter dry season was also seen as another contributing factor.

Based on those findings, the following conclusions and recommendations are made:

- ⇒ It is important to locate wetlands within the broader context of environmental change in the regions where they are found in order to be able to interpret their current characteristics and predict possible scenarios about their existence and functioning in the future. It is acknowledged that wetland rehabilitation/restoration, conservation and management programmes do not usually have necessary resources to carry out such evaluations, but if their aim is to have long-term impact on the environment, attempts should be made to understand that context. Otherwise, they may not only fail, but may also

contribute to environmental degradation as demonstrated by the negative impact of the alien vegetation species that were introduced by our ancestors on the river catchments across South Africa's landscape.

- ⇒ Flood events can alter wetland soil characteristics through the erosion and deposition of sediments. The impact of other factors such as the drainage of the wetland by alien vegetation may lead to the existence of soil characteristics not linked to the existing hydrology. Therefore, wetland programmes that use soil morphology as an indicator should take such factors into consideration. It is possible that such conditions are common in South Africa, where flood events and alien vegetation continue to impact on the headwaters of catchments, implying that new wetland delineation methods may have to be designed. For example, according to the results of this study, the delineation of the wetland into various zones became possible after the assessment of the water-level regimes, which also correlated well with its topography, but not with the soil stratigraphy as such. Further research is needed on the time taken by wetland soil morphology to change after the wetland hydrology has been altered, particularly the duration of the existence of mottles under conditions of permanent inundation.
- ⇒ The view that wetlands act as sediment traps should also account for the sediments carried in suspension and solution during flood events. In some parts of South Africa, wetlands occur in areas dominated by dispersive soils, which are highly susceptible to transportation in solution. This is another area of future research.
- ⇒ The ability of headwater wetlands similar to the one under study to attenuate extreme floods remains questionable. However, the role played by wetland saturation levels prior to and during the event is very important. Floods also contribute to the change in wetland geomorphology and its hydrological functioning as shown by the development of new flow channels.

To what extent have the research objectives been met?

- The current state of knowledge regarding wetlands and wetland hydrogeomorphology*

Various definitions are getting acceptance in wetlands' research and practice, particularly the one adopted by the Ramsar Convention. There is burgeoning

literature on wetland classification systems, and almost all the systems recognise the importance of hydrology in understanding wetlands in general. There are also recent moves towards including geomorphology as the key factor in determining wetland functions. However, views on the climatic, hydrological and geomorphological controls on wetland functions are largely based on theory, rather than empirical studies. The impact of environmental extremes on wetlands, particularly flood events, was also acknowledged as very important.

□ *The historical events and processes at various spatial scales that might have led to the current characteristics of the Featherstone Kloof Wetland and its catchment*

The location of the study area was described. A review of the historical geography of the surrounding region, taking into consideration both natural and anthropogenic factors, was done and supplemented with the results of radiocarbon dating done on the wetland sediments. The approach proved very useful in understanding wetlands in their regional and historical context. An assessment of rainfall variability for the past century was also done and results demonstrated high annual variability of rainfall, and the prevalence of storm events of high magnitude. The analysis of the mean monthly distribution of rainfall indicated no strong seasonality of rainfall in the area, but the autumn months of March and April and the spring to early summer months of August to October tended to have higher rainfall peaks than other months, implying a bimodal mean monthly distribution of rainfall in the area. The general distribution of seasons in the area was illustrated using the evaporation time series.

□ *The recent and contemporary events and processes that have taken place in the Featherstone Kloof Catchment*

An analysis of the rainfall data of the decade preceding the monitoring period (1990 to 2000) was performed, paying particular attention to the frequency and magnitude of rainfall (storm) events. The results indicated that the monitoring period of August (2001) to September (2002) had an exceptional rainfall situation compared to the preceding ten to twelve years, particularly the storm event of 23 September 2002, which had a tremendous impact on the wetland. In the long-term scenario, the 2002 flood event was not seen as particularly exceptional, as there was considerable number of other storm events that occurred over the period 1878 to 1990 in the area.

□ *The hydrogeomorphological characteristics of the Featherstone Kloof Wetland*

Various wetland hydrological and geomorphological variables were monitored to characterise the system. Soils as surrogate for wetland sediments were analysed for their characteristics. The intention was to see if it was possible to use soil as an indicator for wetland hydrology and employ it in the delineation of various wetland hydrological zones. The results showed no relationship between the two in the case of this wetland, with the exception of some deep organic rich soils occurring on the wettest parts of the wetland. The relationship between wetland water-level regime and soil stratigraphy and elevation was investigated, and the results helped in delineating the wetland into various hydrological zones, but again, soil did not play any significant role. The relationship between various hydrological variables was investigated using time series diagrams and the water balance method.

□ *The implications of the characteristics of wetland and its surrounding catchment for its hydrogeomorphological functioning*

A discussion of the research results was done and related to the existing literature as a way of understanding whether the wetland performed the presumed hydrogeomorphological functions that: wetlands store sediments; attenuate floods; and store water and release it slowly during dry periods to prolong downstream flow.

It is against this background that it is concluded that climate, hydrology and geomorphology act as controlling factors to the functioning of wetlands. It is recommended that long-term and comparative studies should be carried out to investigate these issues further, particularly the quantification of various water balance components. There is still a gap in the research about wetland sediment budgets, and that would go a long way in clarifying the ability of wetlands to store sediments. The impact of flood events on wetland hydrogeomorphology requires special attention in wetlands' research. Although the implications of the findings of this research are sometimes globalised, the research itself remains a case study about the Featherstone Kloof Catchment and its wetland - and it should be understood within that context.

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APPENDICES

Appendix 1: The South African Wetlands Action Group and the Eastern Cape Wetlands Forum : A Narrative Of Events And Issues

1. Introduction

This appendix is a narrative of events and issues that the author observed over the period when the study was conducted. Such issues relate to wetland debates and developments at a non-academic level that had a tremendous influence on wetlands work in South Africa, in general and the Eastern Cape province, in particular. The focus will be on those events that the author managed to attend and the few that the author happened to have information about, particularly the activities of the South African Wetlands Action Group and the Eastern Cape Wetlands Forum.

2. The South African Wetlands Action Group

In South Africa, like in many other places in the world, wetlands work has always been the domain of scientists and environmental activists who did piecemeal work at different areas around the country. The developments that took place internationally, particularly the designation of many Wetlands as Ramsar sites¹ (prominent examples include the Okavango Delta in Botswana and the St Lucia Park in South Africa), encouraged individuals and groups from various backgrounds to take the wetlands issues seriously. Nongovernmental organisations, government departments, academics, environmental consultants, engineers, and many other interested individuals (colloquially known as Wetlanders) started communicating with each other about wetland issues. In South Africa, such conversations culminated in the establishment of the South African Wetlands Action Group (SAWAG)

One of the co-founders of SAWAG, Dr Donovan Kotze, gave the following summary² of its background at its sixth annual meeting held in Cape Town in 2002:

“...In early 1998, a field workshop was held in the KwaZulu-Natal Midlands in which fieldworkers active in wetland conservation and management contributed to field testing WETLAND-USE, a system for supporting wetland

¹ This is a designation that emanated from the Wetland Convention at a conference of the International Union for the Conservation of Nature and Natural Resources (IUCN) held in Ramsar in 1971.

² The summary forms an appendix to the minutes of the SAWAG meeting held in Rondevlei Nature Reserve on the 28th of September to the 31st of October 2002.

management decisions. The participants commented how getting together and learning from each other's experiences had been very beneficial. It was decided to continue and strengthen the group, and thus the South African Wetland Action Group (SAWAG) was born. The purpose of SAWAG is for field workers active in wetland conservation to maintain effective linkages, exchange ideas and experiences and co-operate on initiatives of common interest. The focus of the group is on palustrine (marsh/floodplain) wetlands, a wetland type which has generally been overlooked in the past.

A key emphasis of the Group is on actions in the field, rather than merely serving as a talk-shop. A further strength of the group is that researchers, local field workers and individuals from national organisations, notably the Department of Environmental Affairs and Tourism (DEA&T) and the National Department of Agriculture, are represented. Thus far the group has:

'Provided valuable comment in the refinement of WETLAND-USE, a system for promoting the sustainable use of wetlands. Increased the capacity of extension workers in promoting the sustainable use of wetlands. Conceptualised and is developing (sic) a tool, the "Vlei Lily Award", to give wetland users recognition for sustainable management practices and to promote their accountability in the management of their wetland by requiring that they develop their own measurable management goals for their wetland. Provided a forum (through meetings held approximately every 10 months and an E-mail network) for the exchange of information and experiences among members of different local Wetland Working Groups. These groups were initiated by the Mondi Wetlands Programme and each consists of field workers and volunteers involved in a particular area such as the KwaZulu-Natal midlands.

The first official SAWAG meeting was in Mpumalanga, and the theme was assessing impacts on wetlands. Particular attention was given to addressing cumulative impacts and field visits to an existing and a proposed dam site were undertaken. The issues surrounding wetland rehabilitation were also addressed. The second meeting was held in Pirie, Eastern Cape, with the

theme being wetlands in communal areas. The meeting provided a very valuable opportunity for field workers who had been working actively with communities and wetlands in KwaZulu-Natal to exchange their experiences with field workers from the Eastern Cape who had recently initiated projects in the King Williams Town and Port Elizabeth areas. Field visits were undertaken to two wetlands in the King Williams Town area that had been discussed in the meeting. The third meeting was held at Sterkfontein Nature Reserve. The meeting looked at catchment management issues and the direct links to wetland impacts and uses. The fourth meeting was held in Vryheid at the Vryheid Nature Reserve. The assessments of wetlands and the methodology was discussed and reviewed. The fifth meeting was held in the Northern Province at the Nylsvlei Nature Reserve, the main topic for discussion was wetland rehabilitation...'

From this summary, it is clear that the SAWAG has grown to be a very useful platform for exchanging ideas among Wetlanders. From its sixth meeting held in Cape Town, whereby the author also participated, a new and a very important item on its agenda was included regarding formal presentations of wetland research and activities taking place around the country. Although the presentations were not necessarily peer-reviewed, high scholarly standards were maintained. That tradition was carried on in its seventh meeting held in Barberspan Nature Reserve, North West province in 22 to 24 October 2003. Most importantly, the SAWAG led to the formation of wetlands forums in many provinces of South Africa. In the next section, focus will be on the Eastern Cape Wetlands Forum in which the author participated as a minute secretary.

3. The Eastern Wetlands Forum

The Eastern Cape Wetlands Forum, hereinafter referred to as the forum, was initiated on the instance of the recommendation of the Fifth SAWAG meeting of 2000, which mandated delegates to launch Wetlands Forums in their various provinces. In the Eastern Cape province the first meeting was a workshop held at Bisho on the 3rd of March 2001. The purpose of the workshop was to promote communication between stakeholders in the province, particularly various government departments; identify areas of responsibility for various stakeholders; establish consensus and cooperation;

and prioritise catchments in the province for rehabilitation. The workshop was well attended by a number of people including delegates from the national Department of Environmental Affairs and Tourism (DEAT); the provincial Department of Economic Affairs, Environment and Tourism (DEAE&T), Working for Water, Department of Water Affairs and Forestry (DWAf-Eastern Cape), NGOs and academic institutions. All the stakeholders were given a chance to briefly describe their role in wetlands. It is in that meeting that Mr Albert Mfenyana, who was a representative of the MEC³ for DEAE&T, announced that the department has appointed Mr Eric Qonya to be the 'wetland person' for the Eastern Cape province. The workshop marked the beginning of communication among wetlanders in the Eastern Cape Province.

A special meeting to officially launch the forum followed the Bisho workshop and was held in Van Stadens Wildflower Reserve, outside Port Elizabeth on the 30th of March 2001. The meeting dealt with the following issues, introduction to the Mondi Wetland Project⁴; Working for Water, introduction to wetland concepts (definitions, assessment, rehabilitation, classification, etc); current research in the province; current projects and few priorities and identification of the wetland expertise. The meeting also proposed that the forum should have its own Website, logo and constitution. It was also reported that a mailing list (list-server) was already in place and will be used as a communication platform for Wetlanders in South Africa and beyond. After noting that there was a general lack of wetlands awareness in the province, it was emphasised that more publicity of the current projects of Working for Water⁵ and activities of the forum should be done through media and other means as a way of conscientising people about the importance of wetlands. The Eastern Cape Wetlands Forum⁶ was officially launched.

³ An acronym for 'Member of the Executive Council', which is a provincial equivalent of a Cabinet Minister.

⁴ At that meeting David Lindley announced that the Rennies Wetland Project was in the process of changing its name to the Mondi Wetland Project, because of the major sponsorship it received from Mondi company.

⁵ By then, wetland rehabilitation programmes were an integrated part of Working for Water projects, before the official launch of the Working for Wetlands programme.

⁶ The forum was still known as the Eastern Cape Wetland Conservation Forum and the term "conservation" was subsequently dropped on the basis that it was too narrow as it did not necessarily encompass all wetland activities such as rehabilitation, use, and so on.

The next meeting was held in Rhodes University on the 11th of June 2001 as a follow-up on issues raised during the launch. A report was given on the Working for Water projects and the budgets allocated. The report noted that it was very difficult to prioritise wetlands for the province because they were not documented. Based on that, it was resolved that a special meeting to prioritise wetlands for the province and also initiate a process towards developing an inventory should be convened. The results of data collected would feed into the national inventory that was in the process of being developed by a consortium of experts appointed by the DEAT. Various individuals were delegated for specific tasks noted during the launch, namely, development of a Website, logo, constitution and the various means of publicising the forum, such as a video footage. It is in this meeting that it was announced that a first wetland in the Eastern Cape was nominated to be a Ramsar site⁷.

A special meeting which took the form of a workshop was convened in the Geography Department of Rhodes University on the 31st of July 2001 to conduct a desktop identification of wetlands from 1:50 000 topographic maps. A number of wetlands were identified and compiled into a Geographical Information Systems (GIS) map to be presented on the next meeting. In addition to that, various progress reports on issues raised in the previous meetings were given, including the fact that a straw-dog constitution was already drafted, a management plan for the Ntsikeni Ramsar site was being developed and the work on the National Wetland Inventory was already in progress.

On the 4th of September 2001, a meeting was held in Donne, Sturttheim, to present the preliminary wetland inventory for the Eastern Cape. Prof Kate Rowntree presented a GIS map reflecting the wetlands identified during the previous meeting. The map was seen as a good foundation for developing a detailed inventory for the province and assisting in the prioritisation of wetland areas for rehabilitation. It was noted that there was serious lack of information on the wetlands of Transkei. People were encouraged to ground-truth the wetlands compiled and note new ones as they travel across the province. It is in this meeting where it was reported that the forum Website was finished and hosted by the Institute for Water Research at Rhodes

⁷ Ntsikeni wetland in the Umzimkhulu area was nominated and subsequently approved as a wetland of international significance (Ramsar site).

University. The question of stakeholder participation came strongly in the meeting, particularly regarding the Department of Agriculture and Land Affairs (DALA). The few representatives of DALA present expressed their scepticism about their participation in the forum, which they viewed as putting more emphasis on rehabilitation and conservation whilst their mandate was mainly optimising food production in the country. After lengthy a discussion, it was resolved that a more holistic approach to wetlands discussions in the forum should be adopted, taking into consideration the interests of various stakeholders.

On the meeting of the 26th of November 2001 held in Bisho, the draft constitution of the forum was discussed. The constitution included issues of membership, office bearers, meetings, funding, and so on. A steering committee of two was appointed to facilitate the process of constituting office bearers and forum membership according to the constitution. An update on the national wetland inventory⁸ was given. Areas covered included data collection, field delineation of wetlands, stereotyping, desktop delineation, field verification, aerial photo analysis, satellite analysis and a system for serving data on the Web. Other issues discussed related to capacity building, publicity, fieldwork programme and preparations for the Wetlands Day of 2002.

On 17 September 2002, a meeting of the Forum was held in East London. It is on this meeting that the office bearers for the forum were formally elected. Progress reports on developments that occurred between the forum meetings were given. It was reported that the Wetlands Day celebrations were held in Hogsback and were very successful. It was also reported that for the first time in the history of the South African Society for Aquatic Scientists (SASAQS) conferences, in the 2002 meeting there was a whole session devoted to wetlands. Other reports included progress made in the area of wetland mapping in the province, WfW projects, and river rehabilitation research. The meeting also proposed that capacity should be built for surveying wetlands in the province, and subsequently a course was conducted in October 2002.

⁸ A document entitled "Wetlands Project to Establish the Most Appropriate Methodology for a South African Wetland Inventory" was circulated in the list-server and also made available in the Internet site: http://wetlands/csir.co.za/website/wetland_inventory/intro.htm

The last meeting of the forum before the writing of this review was held in East London on 08 May 2003. Eric Qonya reported about the tremendous success of the Wetlands Day celebrations that were held in the Ntsikeni Wetland in February 2003. More than 900 people attended, including dignitaries from various government departments and the DEAE&T MEC. An updates on budget allocations for the WfW projects, the work of the MWP and wetland surveys were given. The meeting also noted the fact that the local government structures, especially the municipalities, were not taken into consideration as important stakeholders, yet their actions have direct impact on wetlands in their spheres of influence. It was on this meeting that a logo for the forum was adopted.

4. Conclusion

The founding of the SAWAG marked a beginning of a new era in the area of wetlands work in South Africa. The level of wetlands work has increased tremendously over the years in the country. The activities of the Working for Water and Working for Wetlands programmes of the government continue to give practical meaning to wetlands debates in the country. Most importantly, these developments have stimulated new interest in wetland research. The provincial fora also provide valuable platforms for debates on wetland issues and practical implementation of wetland programmes as shown in the review of the activities of the Eastern Cape Wetlands Forum. From this review, it appears that stakeholder roles still need ironing out in order to have a united view of wetlands work in South Africa.

Appendix 2: Grahamstown monthly rainfall in millimetres (Figures were obtained from the South African Weather Service for the Grahamstown Weather Station)

| Year | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1878 | 12.1 | 59.9 | 71.8 | 29.2 | 25.0 | 33.0 | 15.3 | 54.0 | 14.5 | 72.1 | 45.5 | 0.0 |
| 1879 | 80.7 | 38.3 | 141.0 | 44.1 | 12.7 | 63.6 | 83.6 | 46.2 | 186.1 | 32.5 | 10.9 | 20.4 |
| 1880 | 63.3 | 187.5 | 174.0 | 32.4 | 60.1 | 8.6 | 0.8 | 60.0 | 15.0 | 117.7 | 146.0 | 64.8 |
| 1881 | 70.0 | 34.6 | 138.4 | 66.0 | 81.5 | 133.4 | 93.5 | 82.4 | 65.8 | 17.8 | 40.0 | 22.1 |
| 1882 | 43.5 | 93.4 | 86.6 | 70.4 | 91.7 | 2.0 | 37.7 | 65.7 | 60.4 | 47.8 | 0.0 | 0.0 |
| 1883 | 76.4 | 19.8 | 95.8 | 52.4 | 77.7 | 11.4 | 18.5 | 68.2 | 34.1 | 111.1 | 21.6 | 18.6 |
| 1884 | 74.3 | 70.9 | 49.7 | 32.0 | 58.7 | 89.3 | 11.1 | 13.8 | 39.6 | 79.2 | 125.4 | 17.1 |
| 1885 | 35.1 | 35.9 | 94.8 | 36.3 | 35.6 | 42.9 | 126.6 | 59.3 | 184.5 | 53.0 | 0.0 | 0.0 |
| 1886 | 92.7 | 108.0 | 102.3 | 160.7 | 35.9 | 0.3 | 232.0 | 10.5 | 19.3 | 129.2 | 49.1 | 140.1 |
| 1887 | 41.2 | 126.5 | 46.1 | 60.1 | 38.1 | 13.7 | 32.8 | 121.1 | 19.2 | 46.7 | 168.3 | 30.6 |
| 1888 | 62.7 | 61.7 | 136.0 | 52.4 | 121.0 | 8.9 | 14.7 | 199.7 | 89.6 | 68.9 | 49.1 | 35.5 |
| 1889 | 131.4 | 53.3 | 58.0 | 19.1 | 1.0 | 20.6 | 41.9 | 12.2 | 7.4 | 110.7 | 52.6 | 271.5 |
| 1890 | 35.2 | 191.2 | 17.0 | 61.7 | 26.4 | 31.5 | 13.0 | 3.6 | 35.1 | 57.3 | 75.3 | 58.2 |
| 1891 | 138.7 | 45.1 | 35.3 | 32.0 | 118.2 | 120.4 | 18.0 | 54.3 | 31.4 | 46.7 | 186.0 | 81.2 |
| 1892 | 14.3 | 67.1 | 123.9 | 102.2 | 30.2 | 11.4 | 16.5 | 9.2 | 238.7 | 87.3 | 23.0 | 24.3 |
| 1893 | 70.4 | 22.0 | 109.6 | 84.7 | 74.1 | 23.4 | 21.6 | 15.3 | 145.3 | 63.0 | 256.1 | 66.5 |
| 1894 | 132.3 | 20.8 | 162.5 | 85.6 | 55.5 | 4.8 | 26.2 | 38.6 | 35.8 | 120.7 | 48.6 | 43.0 |
| 1895 | 96.9 | 113.5 | 74.7 | 22.6 | 3.8 | 10.4 | 25.5 | 20.5 | 60.8 | 0.0 | 0.0 | 0.0 |
| 1896 | 57.4 | 46.2 | 36.9 | 52.9 | 19.8 | 30.0 | 16.2 | 62.5 | 71.1 | 68.4 | 172.1 | 75.4 |
| 1897 | 37.6 | 17.3 | 53.6 | 61.6 | 76.3 | 14.5 | 11.7 | 66.9 | 90.1 | 117.3 | 49.5 | 0.0 |
| 1898 | 116.0 | 16.2 | 32.8 | 43.2 | 14.2 | 26.4 | 18.3 | 21.1 | 124.2 | 42.4 | 48.2 | 0.0 |
| 1899 | 56.9 | 42.3 | 34.0 | 76.4 | 41.7 | 28.3 | 18.8 | 34.1 | 25.8 | 21.9 | 40.2 | 77.1 |
| 1900 | 51.3 | 30.4 | 89.7 | 53.9 | 22.1 | 5.8 | 8.1 | 72.4 | 18.8 | 41.2 | 22.8 | 199.6 |
| 1901 | 33.0 | 92.5 | 75.8 | 65.8 | 18.0 | 58.2 | 21.6 | 13.4 | 104.2 | 106.8 | 66.6 | 10.9 |
| 1902 | 33.6 | 83.0 | 99.6 | 26.7 | 13.0 | 110.7 | 18.9 | 82.1 | 113.4 | 38.2 | 56.4 | 66.8 |
| 1903 | 18.2 | 54.3 | 48.9 | 55.1 | 38.6 | 39.4 | 15.5 | 66.2 | 12.2 | 58.1 | 270.2 | 40.1 |
| 1904 | 61.0 | 98.8 | 92.5 | 7.6 | 15.2 | 14.7 | 21.6 | 16.6 | 49.1 | 14.0 | 33.3 | 0.0 |
| 1905 | 13.2 | 46.1 | 28.7 | 62.9 | 60.1 | 44.5 | 11.7 | 37.6 | 145.6 | 178.7 | 13.5 | 19.3 |
| 1906 | 20.4 | 74.8 | 142.8 | 77.7 | 40.0 | 70.3 | 0.0 | 59.5 | 83.1 | 205.0 | 0.0 | 0.0 |
| 1907 | 52.5 | 74.9 | 16.5 | 123.0 | 88.3 | 8.6 | 4.8 | 14.8 | 27.6 | 54.4 | 95.8 | 0.0 |
| 1908 | 31.2 | 41.7 | 84.9 | 119.0 | 20.7 | 30.7 | 9.6 | 31.0 | 52.6 | 172.6 | 112.2 | 42.3 |
| 1909 | 127.0 | 50.9 | 62.6 | 64.6 | 0.0 | 2.8 | 39.0 | 101.6 | 82.1 | 43.5 | 119.8 | 0.0 |
| 1910 | 27.7 | 165.1 | 69.2 | 12.3 | 217.2 | 19.6 | 8.6 | 2.8 | 35.9 | 108.8 | 45.0 | 99.3 |
| 1911 | 126.7 | 42.7 | 122.1 | 75.4 | 94.0 | 58.9 | 14.4 | 40.2 | 72.5 | 88.0 | 66.8 | 10.4 |
| 1912 | 105.2 | 59.3 | 49.0 | 98.5 | 15.0 | 49.1 | 21.4 | 25.7 | 53.8 | 56.6 | 18.3 | 56.3 |
| 1913 | 77.2 | 179.4 | 44.1 | 28.7 | 20.9 | 29.1 | 31.5 | 151.8 | 23.9 | 32.2 | 20.3 | 0.0 |
| 1914 | 101.1 | 82.6 | 44.6 | 25.2 | 55.6 | 63.5 | 14.5 | 50.1 | 22.6 | 44.8 | 94.2 | 75.8 |
| 1915 | 109.5 | 33.5 | 17.3 | 105.5 | 41.4 | 18.5 | 89.4 | 3.9 | 21.1 | 72.5 | 49.0 | 62.0 |
| 1916 | 59.7 | 20.4 | 51.0 | 25.4 | 102.9 | 14.4 | 31.0 | 6.4 | 34.0 | 33.3 | 0.0 | 0.0 |
| 1917 | 44.5 | 30.0 | 73.2 | 40.4 | 8.9 | 58.7 | 90.4 | 21.3 | 72.7 | 147.9 | 184.6 | 44.0 |
| 1918 | 75.3 | 48.3 | 114.5 | 27.9 | 42.9 | 29.7 | 8.7 | 31.8 | 89.3 | 55.5 | 19.0 | 45.5 |
| 1919 | 26.2 | 80.0 | 35.0 | 33.7 | 30.7 | 13.3 | 31.3 | 9.4 | 75.7 | 66.5 | 16.0 | 0.0 |
| 1920 | 51.8 | 73.8 | 52.0 | 29.7 | 25.1 | 13.4 | 17.3 | 14.3 | 13.7 | 37.7 | 65.4 | 97.1 |
| 1921 | 30.2 | 62.9 | 119.4 | 156.7 | 35.5 | 26.9 | 37.9 | 19.1 | 55.3 | 23.2 | 155.4 | 84.6 |
| 1922 | 68.0 | 44.6 | 38.6 | 57.2 | 78.0 | 124.4 | 106.7 | 31.0 | 56.4 | 42.4 | 307.7 | 43.3 |

...Appendix 2 continues

| | | | | | | | | | | | | |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1923 | 130.8 | 88.4 | 43.5 | 37.0 | 25.1 | 32.1 | 59.0 | 8.6 | 33.1 | 64.6 | 38.8 | 60.8 |
| 1924 | 63.7 | 66.3 | 68.1 | 26.7 | 39.5 | 18.0 | 9.4 | 47.9 | 41.1 | 47.0 | 69.5 | 0.0 |
| 1925 | 53.7 | 24.2 | 149.4 | 112.3 | 54.9 | 48.9 | 23.4 | 27.7 | 91.6 | 73.9 | 58.1 | 92.0 |
| 1926 | 40.2 | 64.4 | 100.5 | 22.7 | 37.6 | 48.5 | 18.4 | 15.9 | 65.2 | 93.2 | 104.9 | 29.0 |
| 1927 | 31.5 | 49.3 | 91.2 | 8.1 | 56.3 | 2.5 | 3.4 | 36.9 | 8.4 | 40.2 | 30.5 | 42.9 |
| 1928 | 36.3 | 47.8 | 234.8 | 32.3 | 16.4 | 33.1 | 6.1 | 43.4 | 58.9 | 95.0 | 70.6 | 68.8 |
| 1929 | 30.2 | 27.5 | 88.4 | 21.6 | 20.4 | 64.1 | 74.2 | 68.9 | 147.5 | 14.0 | 69.2 | 0.0 |
| 1930 | 65.8 | 166.4 | 32.2 | 33.3 | 75.7 | 18.3 | 84.6 | 83.5 | 136.2 | 5.7 | 0.0 | 0.0 |
| 1931 | 102.5 | 24.4 | 49.4 | 100.4 | 12.2 | 11.4 | 103.8 | 21.4 | 62.5 | 101.2 | 27.6 | 139.7 |
| 1932 | 96.7 | 47.2 | 50.0 | 2.0 | 43.0 | 16.3 | 49.5 | 12.9 | 198.2 | 78.6 | 94.1 | 30.0 |
| 1933 | 17.8 | 58.6 | 31.0 | 56.2 | 16.7 | 8.5 | 15.3 | 113.0 | 44.5 | 16.2 | 103.5 | 85.0 |
| 1934 | 104.7 | 119.7 | 121.0 | 43.0 | 20.5 | 22.1 | 106.4 | 22.4 | 19.8 | 86.9 | 88.1 | 33.7 |
| 1935 | 49.8 | 40.1 | 46.3 | 124.0 | 213.9 | 43.4 | 14.1 | 87.3 | 55.2 | 66.2 | 84.1 | 0.0 |
| 1936 | 29.1 | 62.4 | 79.6 | 7.0 | 59.5 | 11.4 | 47.5 | 1.6 | 36.4 | 118.7 | 175.4 | 46.5 |
| 1937 | 28.7 | 57.1 | 60.6 | 10.8 | 14.7 | 8.4 | 49.0 | 2.3 | 41.0 | 60.7 | 101.5 | 115.4 |
| 1938 | 86.6 | 71.9 | 77.0 | 78.1 | 25.7 | 34.0 | 3.0 | 44.7 | 23.6 | 70.8 | 143.6 | 55.5 |
| 1939 | 70.9 | 128.4 | 163.1 | 37.9 | 34.8 | 6.1 | 62.0 | 48.7 | 85.2 | 84.8 | 31.0 | 31.0 |
| 1940 | 29.7 | 113.1 | 139.8 | 19.9 | 35.6 | 4.8 | 26.2 | 3.3 | 67.6 | 47.5 | 67.8 | 20.6 |
| 1941 | 38.4 | 82.3 | 29.0 | 148.3 | 0.0 | 34.8 | 6.6 | 7.9 | 9.1 | 166.9 | 36.5 | 64.6 |
| 1942 | 85.3 | 23.4 | 50.7 | 17.0 | 45.0 | 28.0 | 15.8 | 28.9 | 22.6 | 104.1 | 43.2 | 58.1 |
| 1943 | 54.8 | 22.9 | 62.3 | 82.9 | 24.1 | 92.2 | 0.0 | 43.0 | 30.3 | 17.3 | 131.3 | 92.0 |
| 1944 | 36.9 | 87.0 | 159.2 | 20.6 | 135.3 | 45.7 | 36.1 | 0.0 | 126.3 | 52.5 | 20.6 | 16.8 |
| 1945 | 85.1 | 54.1 | 30.4 | 21.5 | 75.0 | 77.3 | 9.9 | 3.6 | 15.5 | 82.2 | 19.9 | 26.9 |
| 1946 | 26.1 | 49.6 | 108.4 | 33.0 | 16.5 | 19.5 | 20.9 | 11.7 | 84.8 | 43.3 | 53.7 | 0.0 |
| 1947 | 72.9 | 16.5 | 99.8 | 33.7 | 35.5 | 42.6 | 65.5 | 2.0 | 55.5 | 53.0 | 117.7 | 42.9 |
| 1948 | 38.7 | 109.4 | 53.3 | 189.3 | 3.0 | 6.1 | 36.7 | 6.3 | 41.9 | 88.4 | 36.9 | 20.0 |
| 1949 | 32.1 | 61.9 | 25.0 | 29.2 | 23.1 | 0.0 | 0.0 | 26.9 | 29.0 | 34.5 | 145.1 | 5.6 |
| 1950 | 76.6 | 34.0 | 57.7 | 17.4 | 106.9 | 0.0 | 43.0 | 46.0 | 10.1 | 139.7 | 104.1 | 0.0 |
| 1951 | 209.5 | 80.9 | 2.0 | 16.8 | 32.5 | 51.1 | 23.2 | 126.6 | 1.5 | 35.1 | 0.0 | 0.0 |
| 1952 | 69.4 | 100.6 | 31.5 | 39.3 | 30.3 | 15.0 | 28.0 | 34.5 | 231.2 | 25.4 | 37.6 | 30.3 |
| 1953 | 71.1 | 67.0 | 16.1 | 17.5 | 8.1 | 40.0 | 28.0 | 118.9 | 96.3 | 236.5 | 118.3 | 32.0 |
| 1954 | 17.5 | 35.5 | 148.0 | 42.5 | 79.5 | 24.5 | 41.5 | 52.5 | 46.0 | 27.7 | 72.0 | 15.0 |
| 1955 | 67.2 | 80.2 | 84.9 | 10.1 | 16.5 | 21.5 | 29.0 | 31.9 | 27.7 | 112.5 | 30.0 | 0.0 |
| 1956 | 21.6 | 29.0 | 41.4 | 26.0 | 57.9 | 15.0 | 14.5 | 31.5 | 151.0 | 63.5 | 105.8 | 89.0 |
| 1957 | 27.5 | 106.2 | 71.9 | 34.0 | 30.5 | 39.0 | 6.8 | 25.0 | 59.4 | 32.5 | 16.5 | 28.2 |
| 1958 | 49.0 | 39.5 | 55.3 | 35.7 | 157.0 | 11.5 | 9.5 | 31.0 | 78.2 | 52.3 | 96.5 | 0.0 |
| 1959 | 80.9 | 36.7 | 78.2 | 70.4 | 33.3 | 11.5 | 97.0 | 53.3 | 28.5 | 40.5 | 15.1 | 33.0 |
| 1960 | 87.5 | 7.0 | 41.4 | 58.7 | 64.6 | 19.3 | 23.5 | 13.5 | 76.0 | 66.5 | 58.0 | 32.5 |
| 1961 | 54.0 | 58.0 | 81.0 | 55.2 | 78.0 | 9.0 | 55.9 | 46.5 | 9.0 | 43.5 | 59.0 | 16.0 |
| 1962 | 33.5 | 67.0 | 155.3 | 62.5 | 24.0 | 4.0 | 15.0 | 14.0 | 17.0 | 94.5 | 60.0 | 10.0 |
| 1963 | 142.8 | 85.5 | 265.5 | 83.5 | 21.5 | 6.5 | 65.4 | 19.0 | 19.5 | 83.0 | 48.5 | 55.0 |
| 1964 | 43.5 | 121.5 | 34.0 | 9.5 | 15.7 | 98.0 | 14.5 | 57.8 | 108.5 | 25.6 | 20.7 | 43.0 |
| 1965 | 27.3 | 23.7 | 49.4 | 12.1 | 45.2 | 39.9 | 37.5 | 15.3 | 56.3 | 138.7 | 107.0 | 24.0 |
| 1966 | 66.5 | 22.0 | 47.9 | 19.5 | 47.0 | 9.3 | 10.8 | 59.9 | 47.3 | 37.2 | 92.1 | 37.2 |
| 1967 | 32.8 | 59.9 | 100.1 | 95.0 | 164.0 | 29.3 | 60.6 | 20.1 | 41.5 | 14.7 | 41.2 | 23.0 |
| 1968 | 17.2 | 23.2 | 87.4 | 93.1 | 28.0 | 125.9 | 12.8 | 37.5 | 94.5 | 25.8 | 34.1 | 38.7 |
| 1969 | 18.7 | 108.6 | 120.2 | 29.0 | 14.0 | 38.8 | 26.6 | 47.9 | 32.8 | 59.4 | 34.6 | 24.4 |
| 1970 | 29.2 | 63.6 | 25.0 | 21.4 | 18.3 | 28.8 | 9.6 | 233.2 | 20.6 | 123.4 | 22.1 | 194.6 |
| 1971 | 0.0 | 93.3 | 59.5 | 109.4 | 43.9 | 1.9 | 69.0 | 191.3 | 1.3 | 71.3 | 45.1 | 64.4 |

...Appendix 2 continues

| | | | | | | | | | | | | |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1972 | 72.7 | 62.6 | 58.2 | 32.0 | 16.0 | 35.9 | 8.1 | 28.7 | 64.1 | 22.1 | 95.6 | 16.5 |
| 1973 | 23.8 | 75.7 | 57.6 | 72.1 | 14.1 | 4.0 | 9.1 | 69.5 | 25.2 | 41.5 | 150.4 | 82.4 |
| 1974 | 126.2 | 104.4 | 270.6 | 25.7 | 97.3 | 62.3 | 5.9 | 150.6 | 67.3 | 16.6 | 79.8 | 27.4 |
| 1975 | 51.6 | 44.9 | 56.0 | 20.1 | 5.6 | 77.5 | 27.3 | 51.4 | 253.0 | 6.0 | 56.7 | 124.4 |
| 1976 | 33.6 | 89.4 | 183.6 | 26.6 | 61.2 | 16.7 | 112.5 | 18.5 | 17.7 | 141.4 | 81.2 | 56.8 |
| 1977 | 36.3 | 156.0 | 32.9 | 72.9 | 165.9 | 28.9 | 0.8 | 43.3 | 90.1 | 25.3 | 153.7 | 164.0 |
| 1978 | 42.5 | 22.6 | 55.6 | 162.0 | 49.3 | 45.2 | 10.1 | 27.8 | 34.2 | 154.0 | 63.4 | 89.3 |
| 1979 | 63.9 | 126.5 | 52.5 | 12.7 | 74.4 | 51.3 | 302.5 | 272.9 | 59.1 | 59.0 | 23.9 | 40.9 |
| 1980 | 62.0 | 57.5 | 44.5 | 60.2 | 3.8 | 54.8 | 6.7 | 46.8 | 74.1 | 79.7 | 88.1 | 80.0 |
| 1981 | 134.4 | 82.2 | 189.4 | 24.3 | 139.0 | 27.3 | 5.6 | 139.5 | 10.5 | 85.2 | 84.5 | 89.5 |
| 1982 | 26.0 | 59.9 | 55.0 | 77.3 | 6.0 | 52.5 | 35.7 | 27.3 | 67.0 | 61.5 | 32.2 | 22.2 |
| 1983 | 28.2 | 30.3 | 63.0 | 19.1 | 32.5 | 36.6 | 236.0 | 4.8 | 51.4 | 101.9 | 76.9 | 59.8 |
| 1984 | 38.2 | 86.6 | 72.5 | 35.5 | 8.0 | 58.0 | 43.4 | 10.5 | 25.3 | 52.5 | 83.1 | 36.3 |
| 1985 | 99.0 | 119.1 | 20.7 | 58.2 | 24.7 | 18.7 | 6.8 | 4.4 | 34.7 | 219.5 | 282.0 | 170.9 |
| 1986 | 82.9 | 40.5 | 68.7 | 15.5 | 3.5 | 41.7 | 10.5 | 70.3 | 78.5 | 151.6 | 92.1 | 40.2 |
| 1987 | 44.7 | 59.2 | 81.9 | 28.2 | 17.0 | 36.0 | 12.5 | 61.1 | 108.1 | 32.5 | 35.6 | 39.2 |
| 1988 | 43.6 | 174.5 | 53.6 | 80.1 | 14.9 | 15.2 | 24.0 | 25.5 | 61.7 | 56.8 | 88.9 | 103.7 |
| 1989 | 33.3 | 75.9 | 34.5 | 133.7 | 4.0 | 14.8 | 0.0 | 0.0 | 47.8 | 243.6 | 0.0 | 0.0 |
| 1990 | 99.8 | 76.5 | 94.6 | 43.3 | 12.1 | 36.0 | 0.0 | 27.0 | 53.0 | 91.6 | 34.7 | 0.0 |
| 1991 | 56.8 | 71.4 | 0.0 | 10.6 | 29.4 | 1.2 | 0.0 | 27.8 | 151.9 | 59.7 | 37.0 | 0.0 |
| 1992 | 29.6 | 30.8 | 57.0 | 29.8 | 7.1 | 28.7 | 21.0 | 0.0 | 41.8 | 88.9 | 83.3 | 12.7 |
| 1993 | 97.2 | 19.0 | 37.7 | 62.7 | 9.0 | 55.0 | 9.9 | 24.5 | 165.1 | 61.5 | 70.5 | 331.8 |
| 1994 | 95.0 | 127.6 | 62.7 | 21.1 | 16.8 | 21.5 | 35.5 | 118.8 | 29.3 | 77.5 | 4.1 | 271.0 |
| 1995 | 98.8 | 94.1 | 34.9 | 94.6 | 19.1 | 0.5 | 13.7 | 0.0 | 42.9 | 64.1 | 91.0 | 90.5 |
| 1996 | 59.0 | 46.0 | 24.5 | 31.2 | 7.5 | 0.0 | 17.1 | 34.0 | 16.5 | 70.6 | 256.2 | 71.9 |
| 1997 | 60.5 | 48.8 | 69.5 | 154.3 | 46.5 | 111.5 | 10.0 | 42.2 | 51.7 | 74.6 | 21.5 | 17.0 |
| 1998 | 43.5 | 81.0 | 48.5 | 39.0 | 23.0 | 0.0 | 3.0 | 41.3 | 46.0 | 46.0 | 59.1 | 118.1 |
| 1999 | 51.3 | 29.5 | 60.0 | 56.3 | 25.3 | 0.3 | 62.0 | 2.5 | 0.0 | 0.0 | 26.5 | 51.7 |
| 2000 | 23.5 | 17.3 | 90.5 | 122.0 | 11.0 | 25.0 | 3.7 | 0.0 | 108.0 | 123.4 | 151.7 | 36.0 |
| 2001 | 111.5 | 18.0 | 58.0 | 135.0 | 17.0 | 15.5 | 21.5 | 70.0 | 99.7 | 64.3 | 86.6 | 56.3 |

Appendix 3: Grey Dam monthly rainfall in millimetres (Figures were obtained from the Grey Dam offices of the Department of Water Affairs and Forestry)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------|-------|-------|-------|-------|------|-------|------|-------|-------|-------|-------|-------|
| 1990 | 49.9 | 86.4 | 99.5 | 36.2 | 19 | 46 | 0 | 24.3 | 56.8 | 63.2 | 31.4 | 21.8 |
| 1991 | 39.3 | 65.2 | 22.1 | 9.2 | 0 | 38 | 0 | 69.4 | 21.9 | 136.6 | 57.6 | 45.1 |
| 1992 | 110.1 | 30.9 | 67.8 | 27 | 4 | 23.4 | 16.2 | 80 | 16.4 | 85.1 | 97 | 16.9 |
| 1993 | 40.6 | 96.5 | 28.1 | 102.6 | 18.7 | 61.7 | 11.2 | 43.8 | 196.8 | 64.1 | 88.7 | 188 |
| 1994 | 74.9 | 111.4 | 77.8 | 23.8 | 15.5 | 34.8 | 28.9 | 112.5 | 28.7 | 91.9 | 8.1 | 238.1 |
| 1995 | 106.7 | 42.3 | 131.5 | 89.3 | 21.9 | 12.7 | 8.2 | 0 | 62 | 68.7 | 73 | 123.5 |
| 1996 | 75.2 | 62.3 | 83 | 42.4 | 9.6 | 0 | 22.9 | 42.1 | 18.1 | 95 | 316.5 | 76.7 |
| 1997 | 78 | 59.3 | 55.2 | 204.9 | 76.3 | 132.8 | 28.5 | 38.4 | 58.5 | 81.3 | 34.6 | 47.8 |
| 1998 | 48.8 | 55.9 | 107.7 | 43.2 | 13.8 | 0 | 27.4 | 50.9 | 65 | 70.7 | 88.2 | 181.1 |
| 1999 | 55.3 | 7.5 | 78 | 71.4 | 31 | 0 | 69.2 | 11.3 | 94.9 | 87.9 | 27.9 | 52.7 |
| 2000 | 98.8 | 38.2 | 224.6 | 65.5 | 31.6 | 6.6 | 0 | 5.4 | 79.9 | 56.5 | 271.3 | 15.2 |
| 2001 | 102.5 | 72.6 | 85 | 145.5 | 12 | 12.7 | 42.9 | 57.5 | 106.3 | 38.2 | 36.5 | 55.9 |

Appendix 4: Monthly evaporation for Loerie Dam in millimetres (Figures were obtained from the Department of Water Affairs and Forestry)

| Year | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | NOV | DEC |
|------|-------|-------|-------|-------|------|------|------|------|-------|-------|-------|-------|
| 2000 | 174.9 | 146.2 | 81 | 83.1 | 67.8 | 57 | 71.3 | 84.3 | 109.5 | 139.2 | 139.7 | 189.2 |
| 2001 | 169.2 | 155.3 | 152 | 75 | 91.5 | 59.9 | 71 | 78.1 | 83.6 | 123.6 | 114.8 | 178.9 |
| 2002 | 186.3 | 169.8 | 168.2 | 110.1 | 75.5 | 60.6 | 55.4 | 66.1 | 90 | 156.1 | 184 | 204.5 |

Appendix 5: Survey data of piezometer heights

| | | X | Y | Z | Adjusted Height |
|-----------|-------------------|--------------|----------------|--------------|-----------------|
| | Benchmarks | 0.672 | 151.623 | 9.166 | 29.166 |
| Transects | Piezometres | | | | |
| 1 | 1 | 25.183 | 150.451 | 7.002 | 27.002 |
| | 2 | 18.882 | 150.665 | 7.773 | 27.773 |
| | 3 | 12.464 | 150.226 | 7.881 | 27.881 |
| | 4 | 5.151 | 150.602 | 8.002 | 28.002 |
| 2 | 1 | 20.277 | 109.521 | 4.234 | 24.234 |
| | 2 | 14.22 | 109.287 | 4.709 | 24.709 |
| | 3 | 9.701 | 109.337 | 4.672 | 24.672 |
| | 4 | 5.882 | 109.678 | 5.003 | 25.003 |
| 3 | 1 | 26.085 | 76.113 | 1.989 | 22.1 |
| | 2 | 21.013 | 76.238 | 2.183 | 22.183 |
| | 3 | 17.063 | 75.911 | 1.976 | 21.976 |
| | 4 | 12.723 | 75.945 | 2.331 | 22.331 |
| 4 | 1 | 34.371 | 44.591 | 0.182 | 20.182 |
| | 2 | 28.539 | 44.975 | 0.03 | 20.03 |
| | 3 | 22.783 | 44.818 | 0.083 | 20.083 |
| | 4 | 17.335 | 44.956 | 0.345 | 20.345 |
| 5 | 1 | 46.163 | -12.675 | -0.057 | 15.943 |
| | 2 | 42.053 | -12.868 | -4.126 | 15.874 |
| | 3 | 36.592 | -12.55 | -4.111 | 15.889 |
| | 4 | 28.747 | -12.87 | -3.829 | 16.171 |
| 6 | 1 | 47.884 | -43.2 | -5.295 | 14.705 |
| | 2 | 39.313 | -43.933 | -5.698 | 14.302 |
| | 3 | 33.784 | -43.813 | -5.68 | 14.32 |
| | 4 | 27.481 | -43.568 | -5.685 | 14.315 |
| 7 | 1 | 47.143 | -74.278 | -7.137 | 12.863 |
| | 2 | 40.657 | -74.326 | -7.223 | 12.777 |
| | 3 | 34.572 | -74.156 | -7.285 | 12.715 |
| | 4 | 28.779 | -74.258 | -7.203 | 12.797 |
| 8 | 1 | 36.984 | -123.557 | -10.017 | 9.983 |
| | 2 | 31.236 | -123.835 | -10.063 | 9.937 |
| | 3 | 25.195 | -123.981 | -10.119 | 9.881 |
| | 4 | 19.521 | -123.896 | -9.842 | 9.7 |
| 9 | 1 | 34.385 | -172.642 | -13.013 | 6.987 |
| | 2 | 29.259 | -173.302 | -12.968 | 7.032 |

...Appendix 5 continues

| | | | | | |
|----|---|--------|----------|---------|--------|
| | 3 | 23.76 | -173.919 | -13.014 | 6.986 |
| | 4 | 18.595 | -173.86 | -12.867 | 7.133 |
| 10 | 1 | 41.837 | -224.27 | -15.714 | 3.8 |
| | 2 | 35.622 | -225.021 | -15.967 | 4.033 |
| | 3 | 30.121 | -224.679 | -15.758 | 4.242 |
| | 4 | 25.17 | -224.177 | -15.797 | 4.203 |
| 11 | 1 | 76.898 | -71.004 | -1.707 | 18.293 |
| | 2 | 73.818 | -55.118 | -1.377 | 18.623 |
| | 3 | 72.061 | -39.706 | -1.095 | 18.905 |
| | 4 | 71.545 | -25.464 | -0.831 | 19.169 |
| 12 | 1 | 61.606 | -72.758 | -4.482 | 15.518 |
| | 2 | 60.113 | -56.691 | -3.913 | 16.087 |
| | 3 | 60.663 | -41.19 | -2.829 | 17.171 |
| | 4 | 59.169 | -27.041 | -2.81 | 17.19 |

Appendix 6: Various soil characteristics observed in the wetland

| Table beginning | | | | Continuation | | | |
|-----------------|------------------|-------------------------|------|--------------|------------------|---------------------|------|
| Sample | Mottle abundance | Munsell Colour Name | %OM | Sample | Mottle Abundance | Munsell Colour Name | %OM |
| T1H1A | m | Brown | 2.25 | T3H4A | | Dark olive grey | 3.4 |
| B | c | Brownish yellow | 1.0 | B | | Olive | 4.2 |
| C | c | Brown | 2.7 | C | | Olive grey | 3.34 |
| D | | Black | 3.6 | | | | |
| | | | | T4H1A | | Black | 9.98 |
| T1H2A | | Dark grey | 2.6 | B | | Black | 4.59 |
| B | f | Very dark greyish brown | 3.8 | C | | Very dark grey | 4.66 |
| C | | Dark grey | 2.79 | D | | Dark greyish brown | 4.66 |
| D | c | Very dark grey | 3.51 | | | | |
| | | | | T4H2A | | Dark greyish brown | 2.65 |
| T1H3A | f | Dark greyish brown | 2.64 | B | f | Greyish brown | 2.56 |
| B | f | Very dark brown | 4.58 | C | | Greyish brown | 3.63 |
| C | c | Dark yellowish brown | 2.21 | D | | Greyish brown | 4.50 |

...Appendix 6 continues

| | | | | | | | |
|-------|---|-------------------------|------|-------|---|-------------------------|------|
| T2H1A | f | Very dark brown | 4.34 | T4H3A | | Grey | 4.64 |
| B | f | Very dark greyish brown | 2.38 | B | | Dark greyish brown | 7.08 |
| C | f | Dark brown | 2.21 | C | | Light olive brown | 2.07 |
| | | | | D | | Light olive brown | 4.53 |
| T2H2A | | Dark brown | 4.34 | | | | |
| B | | Black | 2.38 | T4H4A | | Very dark greyish brown | 4.58 |
| C | | Black | 1.99 | B | | Dark greyish brown | 2.59 |
| | | | | C | | Greyish brown | 2.57 |
| T2H3A | f | Very dark brown | 2.28 | D | | Olive brown | 1.90 |
| B | f | Very dark brown | 7.50 | | | | |
| C | c | Dark yellowish brown | 2.66 | T5H1A | f | Dark greyish brown | 1.6 |
| D | | Dark brown | 1.71 | B | f | Very dark greyish brown | 2.15 |
| | | | | C | | Yellowish brown | 4.02 |
| T2H4A | c | Strong brown | 3.91 | D | | Yellowish brown | 3.62 |

...Appendix 6 continues

| | | | | | | | |
|-------|---|--------------------|-------|-------|---|-----------------------|------|
| B | | Very dark grey | 8.18 | | | | |
| C | c | Strong brown | 8.18 | T5H2A | | Very dark grey | 2.71 |
| D | c | Strong brown | 3.98 | B | | Dark grey | 4.96 |
| | | | | C | | Olive brown | 3.34 |
| T3H1A | | Very dark grey | 4.87 | D | | Light olive brown | 3.39 |
| B | | Black | 12.12 | | | | |
| C | | Dark grey | 2.09 | T5H3A | m | Very dark grey | 3.21 |
| | | | | B | c | Very dark brown | 1.89 |
| T3H2A | | Very dark grey | 8.15 | C | | Olive brown | 3.49 |
| B | | Black | 3.18 | D | c | Dark grey | 5.3 |
| C | | Very dark grey | 4.70 | | | | |
| | | | | T5H4A | | Black | 5.58 |
| T3H3A | | Very dark grey | 4.68 | B | | Very dark grey | 2.43 |
| B | | Very dark grey | 4.18 | C | m | Light yellowish brown | 1.16 |
| C | | Dark greyish brown | 3.39 | D | c | Grey | 2.79 |

Key to the table

Sample: T = Transect number

H = Hole number

A; B; C & D = Sampling depth in each hole

Depths: A = 0-20cm ; B = 20 - 40cm; C = 40 - 60cm D = 60 - 100cm

Mottle abundance: (f = few, c = common & m = many)

% OM = Percentage organic matter.