THE GEOMORPHOLOGY OF WETLANDS IN THE UPPER MOOI RIVER CATCHMENT KWAZULU - NATAL

JENNIFER LYN LONGMORE

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Declaration

I wish to certify that the work reported in this project is the author's own unaided work except where acknowledgement is made of other sources. This project has not been submitted in any form for a degree to any other University.

J. Longmore
Jennifer Lyn Longmore
University of Natal, Pietermaritzburg
2001

Professor H.R. Beckedahl
Project Supervisor
University of Natal, Pietermaritzburg
2001

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Abstract

Wetlands are now recognized as being an integral component of the physical landscape. Geomorphology has recently been recognised by wetland scientists as being of fundamental importance in wetland genesis, maintenance and evolution, thereby providing the context for informed, effective wetland management and conservation. At present there exists a paucity of geomorphological wetland research in South Africa. A hydro-geomorphic approach was adopted to attain an understanding of wetland genesis, distribution and functioning of a range of different palustrine wetland systems in the upper Mooi-River Catchment of KwaZulu-Natal. The physical, chemical and landscape-morphological characteristics of wetland soils were investigated to interpret the processes operating within those wetland systems.

Both field and laboratory work suggest that wetland creation and maintenance in the upper Mooi River catchment may be attributed primarily to climatic factors, landscape position, landform and geological characteristics. These factors were found to cumulatively control the hydrological characteristics of wetlands, which impart an important influence on internal wetland conditions. While soil properties do not appear to be a primary factor in the establishment of these wetlands, they are nevertheless found to be important in the regulation of the hydrological dynamics of wetland systems. The close interdependence between wetlands and the surrounding landscape and the hydrological cycle is evident in the wetland systems investigated. Geomorphic processes within wetlands such as overbank flooding, overland flow, sedimentation, piping, leaching, soil swelling, shrinkage and cracking and channel incision and dynamics were found to be important variables in determining the nature and internal characteristics of wetland systems. In several of the systems investigated, all of the above mentioned processes were operative, while in other systems, a number of these processes were either insignificant or absent. Canonical Variate Analysis indicated that while commonalities exist between the palustrine wetland systems investigated in this study, significant differences were found between different groups. This supports the argument that a subclassification of the palustrine system into five different palustrine wetland types is warranted.

While the scope of the present research did not allow for an extensive investigation of suitable methods of rehabilitation, the study suggests that an understanding of geomorphic process and wetland dynamics will be beneficial to wetland management and conservation as a whole.

Preface

At an elementary level, wetlands are regions of the landscape/earth's surface with water tables at or near the surface either temporarily, seasonally or permanently. They are valuable habitats from both a physical and ecological perspective, providing a range of very important biophysical landscape functions.

Until relatively recently, wetlands were considered wastelands, occupying valuable land space, and were consequently drained, dredged and utilized for crops. This large scale destruction of habitat has resulted in few undisturbed wetlands remaining in South Africa. Over the last two decades, wetlands have gained much attention as a consequence of the growing appreciation of the natural functions they perform and their ecological value. Efforts are currently being made by government and non-government organisations to increase public awareness concerning the need for conservation of these important habitats. In addition, large sums of money are currently being directed into wetland restoration and rehabilitation initiatives.

It is now widely recognised by wetland scientists and practitioners alike, that the lack of geomorphological input into wetland studies has resulted in important deficiencies with regard to understanding of the origin, evolution, and long-term functioning of wetland systems; factors required if the long term management and restoration of wetlands is to be successful.

The present research was undertaken with the primary objective of addressing the paucity of geomorphological information available on South African wetlands, and to improve upon the general understanding of a range of different palustrine (non-tidal, fresh water) wetland systems in the upper Mooi River catchment, KwaZulu-Natal.The present mauscript has adopted the following format:

- ***Chapter one*** is divided into two primary sections. The first introduces the reader to the topic. Broad based definitions are included and methods of wetland identification outlined. The relationship of wetlands to the surrounding landscape and hydrological cycle is emphasized, and the important functions provided by these landscape features outlined. Problems associated with inconsistent terminology are discussed, together with the benefits of adopting a hydro-geomorphic approach. The scientific background and context makes up the second section of this chapter. Factors responsible for wetland genesis and maintenance are reviewed. This is followed by a brief review of hydric soil characteristics, and followed by a brief discussion on 'process' in a geomorphic context.

- ***Chapter two*** outlines the environmental setting of the study area and the specific topography, drainage, geomorphological, geological, climatic, soil and vegetative characteristics of the area.

- **Chapter three** discusses the materials and the methods adopted in this study. The experimental approach is discussed and the laboratory and field procedures are outlined.

- **Chapter four** investigates the factors responsible for the genesis and maintenance of the different wetlands systems in the Upper Mooi River catchment.

- **Chapter five** considers a number of dominant processes operative within the wetlands and their influence on wetland form, functioning and dynamics.

- **Chapter six** is concerned with the statistical determination of wetland variation. The similarities and/or differences of the palustrine wetland systems are investigated in an attempt to determine whether sub-classification of the 'palustrine' group of wetlands is justified.

- **Chapter seven** reviews the findings of this study and its implications in terms of wetland management and restoration. Areas requiring further research are highlighted, and the conclusions drawn from the study are presented.

Chapter I

1. Introduction

1.1 Literature Review

Although wetlands were once treated as transitional habitats in the succession from open water to land, they are now considered to be distinct ecosystems with specific ecological characteristics, functions and values (Mitsch and Gosselink, 1986). Wetlands are essentially lands with water-tables at or near the surface, either temporarily, seasonally or permanently (Mitsch and Gosselink, 1986; Hughes, 1999) (Figure1.1). According to Oates (1994), the most discernable wetlands in terms of diversity and biological productivity, are commonly those that dry out periodically.

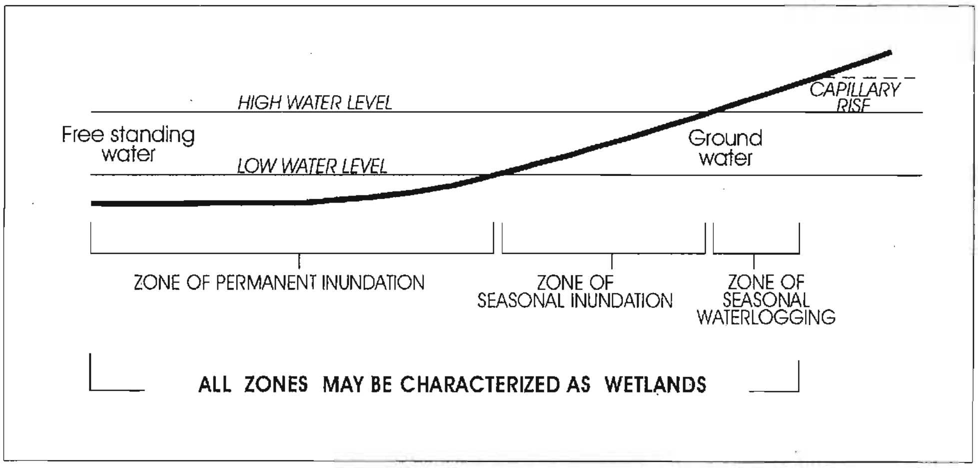

Figure 1.1 Potential zones which may be associated with wetlands. Each zone will develop its own unique characteristics over time.
(*Modified after:* Semeniuk and Semeniuk, 1995).

1.1.1 Wetland identification and definitions

A vast number of wetland definitions appear in the international literature, emphasizing the wide range of conditions that constitute wetlands. While definitions of wetlands vary, the consensus is that a wetland is a water-dominated area with impeded drainage where soils are saturated with water at least periodically, and where characteristic assemblages of flora and fauna occur (Mitsch and Gosselink, 1986). Two well known definitions are the Ramsar Convention on Wetlands of International Importance (1971) and the Cowardin *et al.*, (1979) definition. The Ramsar Convention defines wetlands as:

> *Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres.*

The Cowardin *et al.*, (1979) definition (regarded as one of the most comprehensive definitions used by wetland scientists), specifies that:

> *Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water...Wetlands must have at least one of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season each year.*

Mitsch and Gosselink (1986) highlight the problem that, since wetland characteristics grade continuously from aquatic to terrestrial, any definition is to some extent arbitrary. Begg (1986) suggested that the following criteria be used for wetland identification: a characteristic position in the landscape, a distinctive plant community, distinctive animal communities, impeded drainage, soil that is at least periodically saturated and soil within which reducing conditions prevail. Wetlands are currently being identified and delineated by wetland managers and extension officers, using four specific indicators, namely: (i) terrain morphological unit, (ii) vegetation, (iii) soil form and (iv) soil wetness factors (Gardiner, 1999). A brief outline of each indicator is summarized below.

(i) Morphological terrain unit

It is argued that the habitat must first qualify as a valley bottom unit, (defined by McVicar *et al.,* 1977). The valley bottom unit (unit 5, Fig. 1, Appendix 1) is shown as typically occurring in depression areas. It has been agreed, however, that unit 5 may occur as a depression on a crest, scarp, midslope or footslope.

(ii) Vegetation

Hydric soils create physical and chemical conditions in which most 'upland' plant species cannot survive. The composition of flora in wetlands is consequently very different from non-wetland areas. Plants adapted to live in wet environments are termed hydrophytes (Federal Interagency Stream Restoration Working Group, 1999). The basic identification of dominant hydrophytes can be used to identify wetlands and to provide indications of the nature or degree of wetness displayed, namely: non-wetland, seasonal, temporary or permanent (Kotze, 1999).

(iii) Soil form

Soil types typically belonging to permanent, seasonal and temporary wetland habitats have been identified by the Soil Classification Working Group (1991). Soil types belonging to these groups are outlined in Appendix 1.

(iv) Soil wetness factor

To be diagnostic, it is agreed that hydromorphic soils must have signs of wetness within 50 cm of the soil surface. Begg's (1990) provisional four class scheme for determining the relative wetness of wetland soils, i.e. hydroperiod determinations, is at present widely adopted by field practitioners (see Section 1.2.2).

1.1.2 Physical interactions between wetlands and the environment

There is currently a trend away from the old philosophy of conceptualizing wetlands as isolated landscape components. Wetlands are now recognized as being closely connected to the surrounding landscape and influenced by the hydrological cycle. Brinson (1988) emphasized that in order to assess the associated benefits of wetlands, wetlands should be considered in a broad landscape and catchment context, rather than being restricted solely to features of the particular site. According to Kotze (1999), wetland functioning is to a large extent determined by the properties and behaviour of the catchment. Winter and Llamas (1993), argue that, depending upon their physiographic position in the landscape and the climate of the setting, wetlands interact to varying degrees with all components of the catchment hydrological system. The hydrological cycle is discussed in numerous hydrological, geographical and geomorphological texts (see *inter alia* Selby, 1985; Farr and Henderson, 1986; Thompson *et al.*, 1986; Stone and Lindley Stone, 1994). The intimate connection of wetlands to the landscape, atmosphere, lithosphere, pedosphere and biosphere is illustrated in Figure 1.2.

1.1.3 The functions, values and benefits of wetlands

Wetland functions may be broadly categorized into physico-chemical functions, biological and socio-economic components. A brief overview of general wetland functions follows.

(i) Physico-chemical functions

Wetlands perform a number of physical functions, such as interception of run-off; attenuation of floods; groundwater recharge, discharge and storage; reduction in erosion (soil stabilization); and sediment retention (*inter alia* Erickson, 1979; Kadlec and Kadlec, 1979; Denny, 1985; Adamus *et al.,*1987; Schwabe, 1989; Mitsch and Gosselink, 1990 and Cowan, 1995a). It is generally acknowledged that wetlands perform a water purification role in the landscape, improving water quality by trapping a wide range of substances commonly considered to be pollutants.

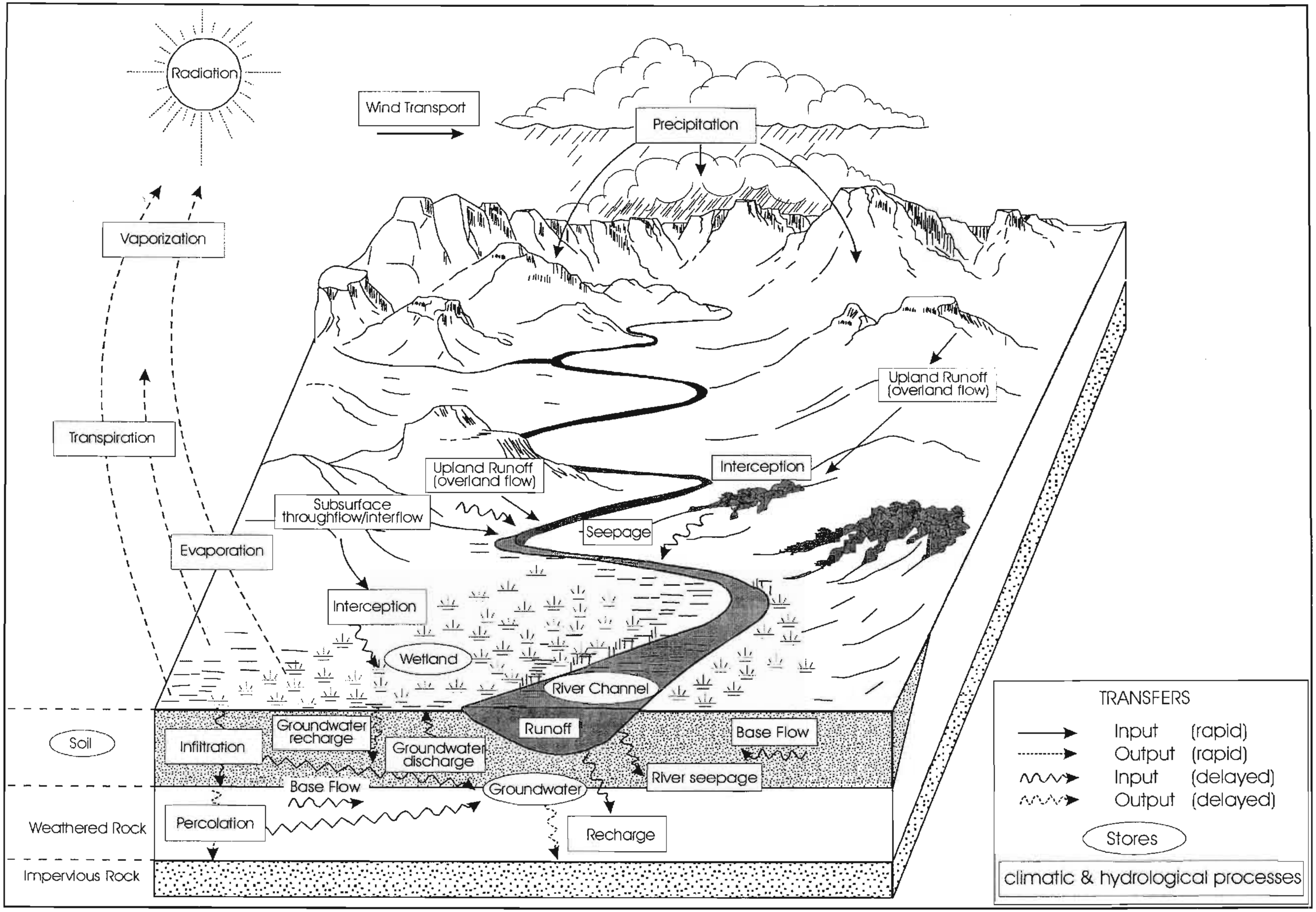

Figure 1.2 Systems diagram of the hydrological cycle operative in a typical wetland catchment. (*Modified after:* Schulze, 1979, Whitlow, 1983 and Begg 1986).

These include suspended sediment, excess nutrients (most importantly nitrogen and phosphorous) and toxicants (pesticides, herbicides and excess heavy metals) (Kadlec and Kadlec, 1979; Kotze, 1999). Chemical functions include the breakdown of toxins and their re-adsorption, as well as the recycling of nutrients (See for example: Erickson, 1979; Denny, 1985; Adamus *et al.,*1987; Schwabe, 1989; Cowan, 1995a; Rogers, 1995).

(ii) Biological functions

Wetlands frequently support a significant diversity of biota through the provision of habitat for wetland-dependent fauna and flora. Wetlands are areas where land and aquatic biota can live and interact. They are important as year-round habitats, breeding grounds and areas of wintering for migratory birds. Many species are endemic to wetlands (Preston and Bedford, 1988; Cowan, 1995a).

(iii) Socio-economic functions

Wetlands provide seasonal or year-round water, fodder and food, and are therefore particularly beneficial in a semi-arid climate such as South Africa. Wetland plants provide valued materials for construction and handcraft production, thereby benefiting local communities. The scenic beauty of their open landscapes as well as their wildlife, makes wetlands popular tourist and recreational destinations. This is beneficial to local economies and an integral part of South Africa's heritage. Wetlands can also reduce the probability of damage to man-made structures such as dams by decreasing the probability of damage by flood waters and the risk of becoming sediment laden (*inter alia* Mitsch and Gosselink, 1990; Adams, 1992; Cowan, 1995a and Hughes, 1999).

While the functions outlined above are very valuable from both a physico-chemical and biological perspective, it is important to realize that not all wetlands perform the full spectrum of functions, and that some perform functions better than others. In the context of groundwater for example, some wetlands are groundwater recharge areas, whereas others may be groundwater discharge areas, or may not interact with the groundwater system at all. While some wetlands may augment stream flow, others may decrease it. The functions performed will vary depending on the wetland type in question.

1.1.4 Wetland Classifications

The Ramsar and Cowardin wetland definitions, outlined in Section 1.1.1, group together a very diverse array of inland, coastal and marine ecosystems. Wetlands comprise a wide range of physical locations and characteristics, water regimes, chemistry and vegetation types (Orme, 1990). They consequently vary greatly in terms of landscape functioning. Semeniuk and Semeniuk (1995) emphasize that in the past, there was a tendency to aggregate all wetland systems under the single common term 'wetland', with the result that sometimes one system was chosen for conservation *in lieu* of another. The authors argue that there 'are wetlands and wetlands', with the implication being that preservation of diversity warrants conservation of each of the recognised types. While a number of more finely-tuned wetland classifications have been developed (see Table 1.1), the literature demonstrates an absence of consistent terminology with respect to wetland forms. Terms are frequently used interchangeably when they in fact refer to very different wetland systems with respect to functioning and morphology. Inconsistent terminology with respect to wetland forms is of major concern to wetland scientists and practitioners. Examples of commonly used wetland terms include: mire, marsh, swamp, bog, fen, carr, vlei and dambo. The need for accurate wetland definitions has been identified by Cowardin *et al.,* (1979) as not purely an academic exercise, but one of legal importance. In the United States especially, federal and state legislation is attempting to regulate wetland changes (Gosselink and Maltby, 1990). This is increasingly likely to be the case in South Africa too with the implementation of the National Environmental Management Act of 1998. Williams (1990) stresses that without commonly accepted and agreed upon terminology and definitions, there cannot be accurate mapping of wetlands nor can their area be adequately calculated. Inconsistent terminology has been recognised by Cowan (1995b) as being a significant weakness of the Agricultural Resources Act 43 of 1993, the terms vlei, marsh and sponge are used but are not defined.

Problems of inconsistent terminology are somewhat exacerbated in South Africa, with limited wetland work having been undertaken in this country compared with first world countries, and the United States in particular. This has promoted the adoption of terms, classifications and knowledge from other countries, often with very limited validation having been undertaken. Wetland classifications developed in South Africa have generally been devised to suit individual research projects. They are frequently restrictive in terms of the different types of wetlands classified, and thus tend to be highly specialized, severely limiting their use and applicability to other studies. Examples of a number of relatively well known wetland classification schemes in use in southern Africa, are outlined in Table 1.1.

The relatively restrictive nature of many of the South African wetland classification systems prompted the extensive use of the Cowardin *et al.*, (1979) classification system (developed by the U.S. Fish and Wildlife Service). Morant (1981) identified the Cowardin *et al.*, (1979) classification as being the most applicable for use in southern Africa. The Cowardin system was adopted for the South African wetland inventory in 1997. It is currently being used by organizations such as the Mondi Wetlands Project, (formerly known as the Rennies Wetland Project), which falls under the auspices of the Wildlife and Environment Society of southern Africa), and the South African Wetland Action Group (SAWAG). The Cowardin classification system has proved useful in that it was designed for application at all levels of data collection i.e. as the information on a wetland increases the classification may be refined so that two objectives are realised: (i) the wetland can be classified immediately within a regional framework, and (ii) the wetland can eventually be described and differentiated further on the basis of important individual characteristics (Semeniuk, 1987). The classification is hierarchical, based on different levels of taxonomic differentiation. At the outset, the classification denotes five systems of wetland (marine, estuarine, riverine, lacustrine and palustrine) each having certain key homogeneous natural attributes.

Table 1.1 Examples of classification systems developed to describe South African wetlands

author	classification framework
Nobel and Hemens (1978)	Divided inland water ecosystem types in South Africa into six broad groups using biotic and abiotic information provided in the literature. The groups include: Rivers; Vleis and Floodplains, which are subdivided into river source sponges, marshes, swamps and floodplains; Pans, divided into six types; Impoundments; Coastal and Estuarine lakes, which were subdivided according to water salinity and Estuaries and Estuarine lagoons, which are sub-divided into five types.
Breen and Begg (1989)	Developed a hierarchical classification largely based on a previous classification of Nobel and Hemens (1978). Wetlands were divided into exorheic vleis and floodplains, and endorheic pans. The former are further subdivided into river source sponges, marshes and swamps, and floodplains. Floodplains are further subdivided into Karoo salt flats, floodplain vleis and storage floodplains.
Schwabe (1989)	Wetlands in the Maluti/Drakensberg were ordinated using both biotic and abiotic data. Abiotic information included *inter alia* soil type, wetland condition, erosion status, water quality, altitude, and location within terrain. The following wetland types were identified: Mires, Bogs, Slope Bog, Raised Bog, Fens, Valley Head Fen, Slope Fen, Vleis/Marshes, Catchment Vleis and Seepage vleis.
Rowntree (1993)	Geomorphic classification based on: the position of the wetland in the hydrological network, the presence or absence of channelized drainage and the order of the stream feeding the wetland relative to those draining away from it. (Developed principally to describe wetlands in Eastern Cape).
Cowan (1995b)	Regional classification system of wetlands situated across southern Africa. Based primarily on topographic morphology and climate (temperature and the ratio of rainfall to potential evaporation). Twenty six subregions across southern Africa are recognised. This regional subdivision is cited as providing a basis for understanding the biological variability of southern African wetlands.
Rogers (1995)	Developed a riparian wetland classification; based primarily on hydrology and vegetation species distribution; included some geomorphological characteristics .
Rogers (1997)	Modified the classification of Breen and Begg (1989); proposed a four fold subdivision of wetlands into: vleis and floodplains, riparian fringes, endoreic pans and lakes; which are then themselves subdivided.
Hamer and Martens (1998)	Distinguished between rock pools and tarns (high altitude lakelets) in the uKhahlamba-Drakensberg Park. The following categories of tarns were identified: isolated tarns; series of tarns (two to over ten) in close proximity occurring on a single ridge or plateau, the tarns being separate from one another or interlinked; series of tarns with nearby rock pools.
Smuts (1998)	Proposed a geomorphological classification of southern African wetlands (mires). Aerial extent was used as the primary basis for sub-division. Two primary categories were proposed: Extensive mires (> 10000 ha) and Bound mires. The former is sub-divided into Coastal mires and Inland mires, the latter is sub-divided into Valley mires, Upland mires, Interdune mires, Pans and Springs.

Definitions of interior wetlands (riverine, lacustrine and palustrine systems), as defined by Cowardin *et al.* (1979) are outlined below.

❑ **riverine systems** include all non-tidal and tidal-freshwater wetlands contained within a channel, where a channel is defined as an open conduit, either natural or artificial, which periodically or continuously contains fresh, flowing water.

☐ **lacustrine systems** include non-tidal and tidal-freshwater wetlands within a lake or reservoir, covering more than eight hectares and being more than two metres deep.

☐ **palustrine systems** include all those non-marine wetlands outside of the river channel or of a large standing water body, where subsurface water is the major determinant of wetland characteristics. It also includes the small shallow, permanent or intermittent water bodies frequently referred to as ponds.

According to Orme (1990), the distinction between palustrine and other interior wetlands is frequently arbitrary since spatially these systems often merge laterally with one another, while in a temporal sense a certain category of wetland may eventually prograde into another type. Palustrine wetlands may, for example, develop from lacustrine wetlands following significant sediment deposition. This intergradational nature of wetland systems has been recognised by a number of other authors including Semenuik (1987). Contrary to the Cowardin classification system, Orme's (1990) categorisation considers annual floodplains to be part of the active fluvial system (riverine system). Gopal and Sah (1995) maintain that while floodplain wetlands may appear to be palustrine systems in different years or in different seasons, their functions and values are directly influenced by their riverine interactions, and should hence be considered a subsystem of the fluvial system. Dini and Cowan (2000) argue that non-wetland islands or palustrine islands may occur within the channel, or on adjacent flooded plains, but are not included within the riverine system. In addition, they argue that oxbow lakes may be placed within the lacustrine or palustrine systems, unless connected to a riverine system by an open channel at both ends, either permanently or intermittently.

While it may be argued that classifying river channels as wetlands is justifiable in that they are essentially wet habitats, the philosophy of the present study does not support the contention that all river channels are wetlands for a number of reasons. Firstly, the primary role of a river channel is generally to direct water from upland areas to the sea, a river's ultimate baselevel, as quickly and efficiently as possible. This does not conform with a number of accepted functions of wetland systems, namely their water attenuation role, their promotion of diffuse flow, reduced flow velocities and water retention. Furthermore, the fluvial system (encompassing rivers, streams and all other forms of established surface water flow), have been separated traditionally from other types of wet habitats. Fluvial systems have been extensively described and categorised according to geomorphic principles (see for example Leopold *et al.*, 1964; Chorley, 1969; Gregory and Walling, 1976; Schumm, 1977 and Bloom, 1978). While it is acknowledged that channel wetlands may arise where extensive, topographic floodplains exist and where a decrease in channel gradient results in a decease in transmission efficiency, promoting channel aggregation and the creation of wetlands, the above processes are not commonplace in the production or conveyance zone of river systems. This is particularly true on the eastern seaboard of southern Africa, where rivers are actively incising. It is therefore argued that fast flowing river channels be regarded as fluvial systems and not classical wetlands. However, where channel aggregation has occurred, and channels are characterized by very little flow for most of the hydrological year, resulting in the establishment of hydrophytes within the channel. Under these conditions it is argued that the channel may be justifiably incorporated within the riverine category of wetlands. The foregoing discussion emphasizes the potential difficulties of categorically placing a particular wetland system into one of the five wetland systems defined by Cowardin *et al.*, (1979).

1.1.5 The emergence of hydro-geomorphic classifications

At present an increasing emphasis is being placed on geomorphic and hydrological aspects of wetland classification in an effort to enhance the ability of the classification to provide information on the functional aspects, i.e. the physical processes, of wetland ecosystems (Brinson, 1993; Semenuik and Semenuik, 1995; Dini and Cowan, 2000). A hydro-geomorphic (HGM) approach is defined as a system that classifies wetlands into similar geomorphic units or groups for conducting functional assessments of wetlands (Federal Interagency Stream Restoration Working Group, 1999). A hydro-geomorphic classification is based upon three fundamental properties of wetlands - the geomorphic setting, water source and transport, and the hydrodynamics (Brinson *et al.*, 1995). According to Federal Interagency Stream Restoration Working Group (1999), this allows the focus to be placed on a functionally similar group of wetlands to a much greater extent than would be the case without such classification. A number of advantages of adopting a hydro-geomorphic approach include:

☐ in the absence of detailed studies (for example by using only aerial photographs), a given wetland can still be readily classified into landform categories (Semenuik and Semenuik, 1995);

☐ instead of relying on specification of hydroperiod or other hydrologic variables for individual wetlands, knowledge of landscape properties that control wetland hydrology and water chemistry can provide an idea of hydrological equivalence (Bedford, 1996);

☐ as additional detailed information becomes available, further discrimination of the individual wetland types is possible (Bedford, 1996; Dini and Cowan, 2000);

☐ it enables a wetland that has been substantially altered by vegetation-clearing and soil disturbance to be placed into the appropriate category provided the hydroperiod and basic landform geometry have not been destroyed (Semenuik and Semenuik, 1995);

☐ it potentially provides the means to distinguish between a wetland that has lost some function through alteration or degradation and a wetland that would never support that function in its pristine state due to properties inherent to its class (Bedford, 1996);

☐ it can be used as the basis for any wetland study regardless of the ultimate discipline of the study, be it hydrology, pedology, botany or zoology, and so circumvents the proliferation of nomenclature arising from other case specific studies (Semenuik and Semenuik, 1995);

☐ botanists, zoologists, recreation and landuse planners may be able to make preliminary assessments and inferences of the diversity, dependence and complexity of wetlands from the geomorphic class to which a wetland belongs (Semenuik and Semenuik, 1995); and,

☐ as broad patterns of landscape and landform are easier to observe than ecosystem processes, an understanding of how landforms affect the other processes offers some predictive capability for ecosystem behaviour (Swanson *et al.,* 1988).

Few geomorphologically based classifications exist at present. This has been emphasised by Semenuik (1987), Tooth *et al.,* (1999a) and McCarthy and Hancox (2000). Inconsistent terminology remains an important impediment of current geomorphic classifications. Semeniuk and Semeniuk's (1995) non-genetic classification system of inland wetlands based on landform type and water permanence, is an example of a relatively recent and well known geomorphic classification system. According to Dini (2000, Pers. Comm.) while Semeniuk and Semeniuk's (1995) geomorphic classification is commendable, the introduction of an array of additional terms such as sumpland, dampland and palusplain (corresponding to seasonally inundated basins, seasonally waterlogged basins and seasonally waterlogged flats respectively), is an adverse consequence of this classification, since the formulation of additional terms is likely to contribute to the existing problem of inconsistent wetland terminology.

The Cowardin *et al.*, (1979) classification system has recently been modified to better suit the wetland systems found in South Africa, and incorporate geomorphic and hydrological information in an attempt to improve the knowledge of the functional aspects of different wetland systems (Dini and Cowan, 2000). This modified version of the Cowardin classification has subdivided the palustrine system into the following subsystems: Slope, Pan, Basin, Floodplain, Flat and Fringe. The slope category includes wetlands occurring on sloping valley bottoms and wetlands commonly termed seeps or sponges. It is argued here that wetlands on valley side slopes and sloping valley bottoms should not be placed in the same category. The main reason for this is that sloped valley bottoms, in addition to receiving water inputs via groundwater discharge and direct precipitation, are frequently influenced by slope wash or runoff, toeslope seepage and overbank flooding of channels, i.e. they have a larger catchment area and generally greater volume of discharge exiting the system than the sideslope wetlands. Pans are defined by Dini and Cowan's classification as wetlands where water is contained in topographic depressions, displaying all of the following characteristics: closed/endoheric drainage (i.e. lacking any outlet), a flat basin floor, less than two metres deep when fully inundated, usually circular to oval in shape, but sometimes kidney shaped or lobed. Basins are defined as wetlands occurring in a distinct depression or concave landform, which may be either open (inflow or outflow), closed (inflow but no outflow), or isolated (no inflow or outflow drainage). The interchangeability of the term 'pan' and basin (pans described as having a flat basin floor) is problematic. In addition, Goudie's (1991) review of pans defines these features as: 'closed basins, characteristic of many dryland environments' (p 221). Tarns, commonly referred to as small mountain lakes, assume characteristics of both pans and basins, yet do not 'fit' into any of the above subsystems. It is argued that the distinction between floodplain systems and flats is again rather problematic, since floodplains are located on level land with little or no relief. The classification provides no indication in terms of the surrounding landscape, which is increasingly being recognised as being important in terms of wetland functioning. Fringe wetlands are defined as occurring within the banks of a river or along the shores of a lake or island in a river or lake. The statement that palustrine 'fringe' wetlands may occur within the bank of a river, is in direct contention with earlier statements, that 'all wetlands contained within a channel be termed riverine wetlands'. In addition, a 'fringe' is not a classical landform type. It is proposed that the narrow strip or fringe of hydromorphic soil and hydrophytes, associated with a river or lake, should rather be incorporated within the particular wetland with which it is associated. While Dini and Cowan's (2000) preliminary classification is an improvement on the Cowardin system, (which did not divide the palustrine system into any subsystems), it is argued that the approach used is somewhat arbitrary and lacking in foundation. It must be emphasized however that the Dini and Cowan (2000) classification system is still in its draft form, the Cowardin system being the accepted, contemporary classification in South Africa at present (Kotze, 2001, Pers. Comm.).

According to McCarthy and Hancox (2000), while the various classification systems have their individual merits, they all appear to fail with respect to considering the fundamental processes that give rise to the wetlands, and the processes which will most likely determine their future evolution. McCarthy and Hancox (2000) argue that as a direct result of this "oversight", many wetland classifications are suited to descriptive or only very short term analysis of wetland dynamics, and do not provide an adequate framework for the conceptual understanding of wetlands from a process perspective.

1.1.6 A review of wetland origin and status in South Africa

Southern Africa has relatively few wetlands (Cowan, 1995a). The limited wetland area has largely been attributed to: (i) tectonic activity of the sub-continent and (ii) climatic conditions. These two factors are briefly reviewed in turn.

(i) Tectonic activity

With some local exceptions, southern Africa has behaved as a single tectonic entity since the Cretaceous era. Geological activity has hence been limited to uplift of the sub-continent, with most of the interior lying at an elevation above 1000 m.a.s.l. (Partridge, 1997). According to King (1972) *in* Dardis *et al.*, (1988), drainage systems of the eastern escarpment are the direct consequence of post-Mesozoic tectonism. The high relief ratios on the eastern escarpment of southern Africa explains why the majority of rivers are in a state of active incision, and, therefore, not promoting diffuse flow and wetland creation.

(ii) Climatic conditions

The climate over most of southern Africa is semi-arid (Schulze, 1997; McCarthy and Hancox, 2000). Rainfall over most of the subcontinent is low and averages less than 490 mm for southern Africa as a whole. Potential evaporation ranges from 1100 mm to over 3000 mm, and generally exceeds rainfall by a substantial margin (Schulze, 1997).

Despite physical conditions not being ideal for the development and maintenance of wetland systems, southern Africa nevertheless hosts some important wetlands. A cause of concern to many environmentalists is the fact that very few undisturbed wetlands remain in South Africa. It has been estimated that over half of South Africa's wetlands have been destroyed by human interference, resulting in the many positive functions rendered by wetlands being minimized or lost (Begg, 1988; Kotze *et al.*, 1995; Kotze, 1999). Cox (1999) estimated that

40% of the wetlands in the upper Mooi River Catchment, KwaZulu-Natal have been lost. Field visits to the area suggest that this is a very conservative estimate. Problems of wetland loss are not restricted to South Africa, but is a serious problem globally. Wetlands are considered by many researchers to be the most threatened of all land elements (Maltby and Turner, 1983).

Man's previous negative perception of wetlands is believed to be the cause of much of the wetland loss in the past. Wetlands were viewed by many people as swampy, dank wastelands, harbouring snakes, insects and disease, as well as impenetrable reeds and scrub that cut and scratch (Oates, 1994). To farmers, wetlands were (and still are in many cases), viewed as unproductive wastelands, that harbour mosquitos and snakes, breed disease, bog livestock, choke up waterways and drains and occupy good grazing or cropping land (Oates, 1994). Wetlands were thus frequently drained for agricultural purposes, or filled for industrial, commercial, and residential development (Stone and Lindley Stone, 1994). According to Hill *et al.*, (1981), prior to the 1980's, extensive wetland areas in South Africa were converted to commercial cropland, in many cases with the support and advice of Government.

In recent decades wetlands have assumed a new attraction and value, with a new and growing appreciation of their natural functions (Naiman *et al.*,1992). While for much of this century the conservation of wetlands was motivated almost exclusively by concern for the conservation of wildlife and biodiversity, growing attention is now being focussed upon the many other values for which wetlands are important, such as flood attenuation and tourism. Williams (1990) has described the growth of knowledge concerning wetlands as 'explosive', and the change of attitudes to wetlands in the past few decades as 'radical'. The rise in environmental awareness in South Africa during the 1980s, led to a significant transformation in the South African government's position with respect to wetland transformation. The Conservation of Agricultural Resources Act 43 of 1993, makes provision for wetland protection, in requiring that a permit be obtained prior to cultivating or draining a wetland. The Mondi Wetlands Project has performed a pivotal role in increasing public awareness of wetlands in South Africa. Stone and Lindley Stone (1994) caution that public environmental concern is frequently not matched by equivalent levels of scientific understanding. This statement is pertinent in South Africa at present; even within the scientific community there are numerous 'vague areas' with respect to wetland functioning and dynamics.

While inadequate environmental education and poor appreciation of wetland values is believed to underlie much wetland loss, a disturbing characteristic is that wetland loss is continuing at present, despite the realization of the multitude of beneficial functions wetlands perform. Demographic growth, rising poverty, severe economic stress, and drought cumulatively place rising pressure on wetland resources (Dugan, 1990). The economic climate appears to be forcing farmers to make use of unsuitable, marginal land, despite the fact that the farmers may themselves know that their activities may not be beneficial to the environment scenario. Dugan (1990) argues that wetlands are lost because in the short term, farmers can expect to earn more from utilizing wetlands than from leaving them in their natural condition. Breen and Begg (1989) and Kotze *et al.*, (1995) argue that despite the high conservation priority wetlands are perceived to have in South Africa, there has been a deficiency in policy formulation. Cowan (1995b) emphasise that ineffective enforcement of the legislation is an important weakness of the Agricultural Resources Act 43 of 1993. While large wetland bodies such as the St. Lucia wetland system have received much media and public attention, smaller inland wetland systems have in the past been largely neglected. The destruction of smaller wetland systems has been occurring insidiously in South Africa over the last century. Dugan (1990) argues that man-induced loss of smaller, less conspicuous wetland systems is collectively no less important than the destruction or degradation of larger wetland systems.

The literature is consistent in identifying that human-induced disturbances, arising from landuse activities, have the greatest potential for influencing the structure and functioning of wetland ecosystems (Gosselink and Maltby,1990; Williams, 1990; Federal Interagency Stream Restoration Working Group, 1999). Landuse activities with the potential to disturb wetland function include agriculture, urban development and mining (Federal Interagency Stream Restoration Working Group, 1999). Worldwide, the conversion to agriculture appears to be the largest single cause of inland freshwater loss (Gosselink and Maltby,1990; Williams, 1990). The majority of South Africa's wetland area falls within the privately-owned, large scale commercial agricultural sector (Kotze, 1999), making these wetlands highly susceptible to modification by either direct or indirect farming activities. An overview of various forms of wetland disturbance and the expected environmental effects are outlined in Table 1.2.

Disturbances arising from many of the anthropogenic activities, are frequently cumulative or synergistic (Federal Interagency Stream Restoration Working Group, 1999). Impacts may vary spatially, from local to catchment impacts, to regional impacts in some cases (Gosselink and Maltby, 1990). The permanence of wetland impacts may vary from transient or temporary to irreversible (Finlayson and Moser, 1991). If the disturbance is severe enough, it can alter the structure and function of a wetland to a point where the dynamic equilibrium is disrupted. Generally, impacts that change wetland substrate or hydrology are more permanent than those that influence biota (Gosselink and Maltby, 1990; Finlayson and Moser, 1991). According to the Federal Interagency Stream Restoration Working Group (1999), the manner in which ecosystems respond to these disturbances vary in accordance with their relative stability, resistance, and resilience.

While human induced wetland loss appears to be responsible for much of the wetland loss globally, a relatively neglected concept in the wetland literature is the fact that geomorphologically, individual wetlands are ephemeral features of the earth's surface. Wetlands may evolve into dryland as a result of lowered water tables, sedimentation and plant succession, or alternatively be submerged by rising water-tables associated with relative sea level rise or climatic change (Gosselink and Maltby, 1990). Wetlands will hence be lost over time as a result of natural secessional processes and new ones created.

Examples of a number of natural disturbances which may potentially influence wetlands include floods, cyclones, landslides, temperature extremes and drought (Federal Interagency Stream Restoration Working Group, 1999). While such disturbances may alter the structure and functioning of wetland systems, wetlands generally appear to be better able to accommodate natural disturbances than anthropogenic disturbances. The Federal Interagency Stream Restoration Working Group (1999) argues that natural disturbances are frequently agents for regeneration and restoration. Certain species of riparian plants for example, have adapted their life cycles to include the occurrence of destructive high-energy disturbances, such as alternating floods and drought (Federal Interagency Stream Restoration Working Group, 1999).

Table 1.2 Simplified overview of the negative consequences of anthropogenic modifications in wetland ecosystems. (✱= probable environmental effect; **?** = possible probable environmental effect)

Expected environmental effect / Form of wetland disruption	Reduced interception	Less infiltration	Reduced winter flow	Increased run-off	Increased stream velocity / flood damage	Reduced run-off	Reduced water storage	Lowered water table	Elevated water table	Deterioration in water quality	Dessication	Substrate disruption	Soil loss (transport/erosion)	Bank erosion	Gully erosion	Wildlife disruption / habitat losses
Channelization / excavation	✱	✱	✱	✱	✱		✱	✱		✱	✱	✱	✱	?	✱	✱
Drainage (canals /pipes)	✱	✱	✱	✱	✱		✱	✱		✱	✱	✱	✱	✱	✱	✱
Crop production	✱	?	✱	✱	✱		✱	✱		✱	✱	✱	✱		✱	✱
Pasture production				✱	✱		✱			✱						✱
Over-grazing	✱	✱	✱	✱	✱		✱			✱	?	✱	✱	✱	✱	✱
Burning	✱	✱	✱	✱	✱		✱	✱			✱	✱	✱			✱
Afforestation	✱		✱	✱	?	✱	✱	✱			✱	✱	✱			✱
Road construction		✱							✱		✱	✱	✱		✱	✱
Dam construction			✱			✱			✱				✱			✱
Water abstraction			✱			✱	✱	✱			✱					✱
Waste disposal										✱		✱				✱

(*Modified after*: Begg, 1986, p 63).

Whether efforts should be made to restore wetlands undergoing natural adjustments and changes, such as gully initiation, is currently of concern to a number of wetland extension officers (Walters, 2001, Pers. Comm.). It is unfortunately, frequently very difficult to identify and isolate process-response mechanisms. Petts and Foster (1985) emphasise that anthropogenic adjustments may be superimposed on natural adjustments, contributing to the problems of identifying process-response mechanisms.

Concerns over the large proportion of wetlands that have been either lost or degraded, together with the realization that wetland utilization cannot be halted, has prompted scientists to investigate possibilities for creation and/or enhancement of wetlands. Possibilities for wetland creation is currently receiving considerable attention in the developed world in particular (Wolf *et al.*, 1986; Larson and Neill, 1987; Strickland, 1986 *in* Gosselink and Maltby, 1990). Gosselink and Maltby (1990) state that man's ability to 'create' artificial wetlands has led developers to argue against the unnecessary protection of natural wetlands where they can be replaced or re-created. This view was voiced by engineers and planners at Umgeni Water at a workshop attended by the author in 1999, concerning the proposed Mooi-Mgeni River Transfer scheme and wetland rehabilitation. Larson and Neill (1987) emphasise that the acceptability of mitigation or wetland creation lies in the ability (or lack thereof) of artificial wetlands to duplicate functions as well as appearance. Growing literature from the field of conservation ecology suggests that wetland scientists need to pay much more attention to the 'context of the wetland created', i.e. its role in the landscape, which according to Soulé and Wilcox (1980) *in* Gosselink and Maltby (1990), has been largely neglected in the past. Winter and Llamas (1993) maintain that the construction of wetlands to replace destroyed wetlands can be successful only if the replacement wetland has the same hydro-geologic and climatic setting as the destroyed wetland. For example, it would be illogical to construct a groundwater recharge-type wetland in a groundwater discharge area, and expect the constructed wetland to be an exact replacement of the natural wetland. Gosselink and Maltby (1990) argue that the same characteristics of wetlands that make them valuable, namely their ecotonal nature and critical hydrology, make them difficult to engineer and replace. The adoption of hydro-geomorphic concepts to design wetlands in Southern Virginia, was, however, found by Whittecar and Daniels (1999) to be valuable in wetland creation projects.

According to Brinson and Rheinhardt (1996), individual wetland scientists, regulators, and consultants frequently have their own perceptions of what constitute fully functioning wetlands. This prompted the development of 'reference' wetlands, which according to Brinson *et al.,* (1995), is the cornerstone of the hydro-geomorphic approach. Reference wetlands are defined as sites within a specified geographic region that are chosen for the purpose of functional assessment, to encompass the known variation of a group or class of wetlands (Brinson and Rheinhardt, 1996). Brinson and Rheinhardt (1996) further argue that the proper use of reference wetlands removes potential biases and provides the foundation for more objective, functional-assessment procedures. Despite the obvious positive attributes of reference wetland standards, Duthie *et al.,* (1999) emphasise that the level of understanding with respect to reference conditions of South African wetlands is very poor. They also stress that it is frequently not possible to find an unimpacted site that can be surveyed in order to accurately quantify reference conditions.

Wetland losses are clearly not easily reversible, there are no 'quick fix' solutions. This problem is exacerbated by inadequately understood process operation. Gosselink and Maltby (1990) maintain that this fact puts a premium on the conservation of the remaining wetland resources. McCarthy and Hancox (2000) emphasize that the rational conservation and use of wetlands requires an understanding of the geological and hydro-geomorphological controls, climatic variability, and natural and induced vegetational succession. Knowledge of the above factors is not well established in South Africa at present.

1.1.7 Rationale for the present study

The host of functions provided by wetlands, particularly their moderating influence on both the quality and quantity of water stressed several times before, are of vital importance in a semi-arid country such as South Africa, where the average annual rainfall is well below the world average and most of the rain is in the form of intense seasonal storms, promoting flooding and erosional problems. The limited wetland area in South Africa, in accordance with the important functions provided by wetlands, puts a premium on rehabilitating or restoring wetland systems which have been degraded, and conserving the remaining quasi pristine wetland sources. The current economic climate in South Africa, together with the largely ineffective implementation of wetland legislation, suggests that wetland utilization will continue, if not increase. Informed, effective wetland management appears to be at present, the only solution to constrain wetland loss and to maximize the natural benefits accrued by wetlands. While wetland management and rehabilitation efforts of government, non-government organisations and concerned individuals is exemplary, these are not, as previously noted, matched by equivalent levels of understanding in terms of genesis, maintenance and functioning.

As already indicated, despite the acknowledgement by many wetland scientists of the importance of geomorphology in wetland genesis, maintenance and evolution, geomorphological studies of wetland systems have received relatively little attention. According to Tooth *et al.,* (1999), the correct identification of factors giving rise to wetlands, and the geomorphological processes governing their development, provide the context for long-term ecological studies and management of such wetlands. This was reiterated by McCarthy and Hancox (2000) who argue that the lack of geomorphological input has resulted in important gaps in the understanding of the origin, evolution and long term fate of many wetlands, which if not rectified, may result in inappropriate conservation strategies being applied, and ultimately in the possible loss of wetlands. Relatively few studies have been undertaken in South Africa to examine the factors or processes giving rise to different wetland systems (Tooth *et al.,* 1999a&b; McCarthy and Hancox, 2000; Kotze *et al.*, 2001).

As already indicated, anthropogenic adjustment may be superimposed on natural adjustments, making it difficult to identify and isolate response mechanisms. For this reason, detailed investigations examining origin, evolution and processes operative within wetlands was restricted to the KwaZulu-Natal Drakensberg (uKhahlamba-Drakensberg Park), recently listed as one of 690 world heritage sites in November 2000 (Derwent, 2001). The uKhahlamba-Drakensberg Park is regarded as one of the most important high altitude catchment areas in South Africa in terms of water yield. The wetland systems in the uKhahlamba-Drakensberg Park have been classified as being in an 'unmodified, near-pristine condition' (Bainbridge, 1991 and Derwent, 2001). According to Kotze *et al.*, (1995) they are precious resources since very few undisturbed wetlands remain in South Africa. In January 1997, the wetlands of the KwaZulu-Natal Drakensberg Park were included to the list of Wetlands of International Importance, according to the Ramsar wetland descriptors (Kabbi, 1997).

It is advocated that by adopting a hydro-geomorphic approach, and investigating the physical, chemical and morphological soil properties of a range of relatively 'pristine'/ unaltered palustrine wetland systems in the uKhahlamba-Drakensberg Park, a fundamental understanding of the functioning and dynamics of various palustrine wetland 'types' can be ascertained. It is proposed that the information obtained from the different systems investigated in the uKhahlamba-Drakensberg Park, may be valuable as reference standards for degraded wetlands of similar types further down the catchment.

1.1.8 Aims and objectives of the present work

The aim of the present study is to address the paucity of geomorphological research undertaken on South African wetlands, and to increase the general understanding of a range of different palustrine systems. The present study supports Semeniuk and Semeniuk's (1995) philosophy that there 'are wetlands and wetlands', implying that preservation of diversity warrant conservation of each of the recognised types. It is proposed that the functioning and internal dynamics of specific wetland types need to be understood if wetland management and restoration initiatives are to be effective. The specific objectives of the present study are to:

☐ investigate the origin and maintenance of (seven) wetland systems in the upper Mooi River Catchment within the context of wetland process and dynamics;

☐ determine whether landscape position and landform characteristics are important with respect to internal wetland characteristics and wetland functioning;

☐ establish the homogeneity or heterogeneity of the wetlands studied, in terms of their geomorphology (pedology and hydrology, subsumed under geomorphology here); and to investigate whether the systems are significantly different from one another to warrant subclassification of the palustrine system; and

☐ provide reference/benchmark data which may be integrated into the management of palustrine wetlands with similar physical characteristics and in similar environments. This may then go some way towards assisting wetland managers and extension officers to predict the probable effect(s) of impacts induced by either natural and/or human influence.

In order to realize these objectives, it is necessary to first review the current state of knowledge pertaining to wetland formation, wetland soil and geomorphic processes.

1.2 Scientific Background

1.2.1 Variables controlling wetland genesis and characterisation

The significance and importance of hydrology in the genesis and characterisation of wetlands has been acknowledged by many scientists (Gosselink and Maltby, 1990, Thompson and Finlayson, 2001). Carter (1986) argues that water is the driving force in the formation and maintenance of wetlands. Mitsch and Gosselink (1993) have described the hydrology of a wetland as its 'life-blood', since it is largely responsible for the chemical and physical properties of a wetland. Williams (1990) argues that if hydrology is the key to the formation of wetlands, it is not necessarily the total explanation for their distinctiveness, in that a number of different processes are frequently involved in creating and maintaining wet conditions. Stone and Lindley Stone (1994) showed that differences in wetland characteristics appear to be the result of local and regional variations in climate, geology, soils and vegetation. McCarthy and Hancox (2000) later proposed that wetlands owe their origin primarily to geological, geomorphological and hydrological processes, and that the long term evolution of wetlands, on a scale of decades and more, is governed by these processes. Climate, geology, physiography, soils and vegetation of the Maluti/Drakensberg catchments are identified by Schwabe (1989) as playing an important part in the formation of the wetlands. He argues that wetland type and wetland maintenance are moulded by these factors. Factors and processes identified as being important in terms of wetland genesis, functioning and maintenance in the uKhahlamba-Drakensberg Park, are reviewed under the following headings: Climate, Topography / Landscape position / Micro-topography, Soil characteristics, Hydrology and Geology.

1.2.1.1 Climate

According to Semeniuk and Semeniuk (1995), the overall control of the distribution and abundance of wetlands globally, is climate. Naiman *et al.,* (1992), however, showed that unlike other landscapes, wetlands are not climatically induced and thus do not occupy large contiguous stretches of land. This apparent contradiction can be explained by the fact that while vegetation patterns broadly follow climatic and moisture regimes (Acocks, 1953), wetland location is generally more local. At a site specific level, local variation in topography, landform, hydrology, geology and soil, can override the climatic setting as a major factor of wetland development. Wetlands are nevertheless generally more numerous in humid environments, and become less numerous as the climate becomes drier. Wetlands are generally found in scattered locations, and are intermittent and local in their occurrence (Naiman *et al.,* 1992).

The variation of climate, particularly precipitation, across the globe, has led to the development of different types of wetlands, according to the endemic landform type and the availability of water (Semeniuk and Semeniuk, 1995). According to Richardson (1996), climate plays an important role in determining how soil and water interact to define wetlands. Watkeys *et al.*, (1993) found the rainfall gradient to be important in the formation of wetlands. They found that the high rainfall at the coast generally leads to leaching of the soil and the development of impermeable horizons within the soil profile, resulting in the formation of a complex array of seepage lines and wetlands (McCarthy and Hancox, 2000). In addition to rainfall influences, temperature is also of importance in wetland genesis, in that it influences the rate of chemical reactions and weathering. Higher temperatures generally promote more rapid weathering (Boul *et al.*, 1980). Temperature will also influence evaporation rates, and thus the water longevity of wetlands. Garland (1979) argues that wind is a frequently underrated form of soil erosion. Aeolian processes, principally deflation, has been identified by McCarthy and Hancox (2000) as initiating the genesis of wetlands in some areas. Wind also influences the vapour flux above wetlands, and consequently evaporation in wetland environments.

According to McCarthy and Hancox (2000), climate and climate change is also particularly important in determining the genesis and distribution of wetlands. A brief overview of both past and present climate is outlined below to demonstrate the transient nature of wetlands over geological time scales, and to provide a rough framework of when the majority of wetlands in existence today in southern Africa are likely to have originated.

The climatic history of Africa since the late quaternary is believed to have consisted of five predominant epochs (Thompson *et al.,*1983). During the first period (35 000 - 20 000 BP), the climate was cool and moist. A change to a cooler and more arid environment occurred during the second stage (20 000 -12 500 BP). The climate then passed through a transitional phase (12 500 - 10 000 BP) until it again reached a moist period which had fluctuating temperatures (10 000 - 4 000 BP). According to Thompson *et al.,*(1983), the climate up to the present has been much drier and more stable with regard to temperature. Pollen analyses conducted on the high altitude alpine bogs of Lesotho, indicate that the wetlands developed during the second climatic period (20 000 -12 500 BP) (Thompson *et al.,*1983). According to van Zinderen Bakker *et al.*, (1974), the occurrence of peat appears to be restricted to the fourth climatic period (10 000 - 4 000 BP), when climatic conditions favouring its production were favourable. Boast (1991), however, argues that caution must be exercised when trying to determine the paleo-environment of Southern Africa since the evidence of climatic change is frequently conflicting. (See paleo-environment interpretations of *inter alia* Street, 1981; Shore and Cooke, 1986 and Stager, 1988). Despite the uncertainty concerning the paleo-environment of Southern Africa, it is clearly established that while wetlands may survive different climatic conditions, the functioning and internal dynamics of the system may be altered significantly. Wetlands assume a new or different character in accordance with the prevailing climatic characteristics.

1.2.1.2 Topography, Landscape position, Micro-topography

The area and size, shape and pattern, relief and slope of drainage basins are regarded as salient topographic characteristics, which individually and collectively influence watershed processes (Selby, 1985). Wetlands are believed to maintain their moisture status as a result of their morphology, topographic setting and low relief (Gilman, 1994). Landforms are regarded by Semenuik and Semenuik (1995) as 'containers' or 'hosts' to wetlands. Landforms determine the size and shape of wetlands, as well as the depth (specifically in the case of basin wetlands). Five basic landform types, identified by Semenuik and Semenuik (1995), that may potentially retain water and hence promote wetland conditions are illustrated in Figure 1.3.

Semeniuk and Semeniuk (1995) argue that in more humid areas, a whole regional landscape may retain water and become a 'wetland', while in very arid areas, the majority of the terrain will be dry. The main landforms which host wetlands in a semi-arid climate (such as South Africa) include: basins, channels and flats. Semeniuk and Semeniuk (1995) argue that while slope wetlands are uncommon, local zones of marked seepage may develop some small scale slope wetlands. They nevertheless note, however, that slope wetlands remain inundated for only a very short period before runoff removes any free-standing water.

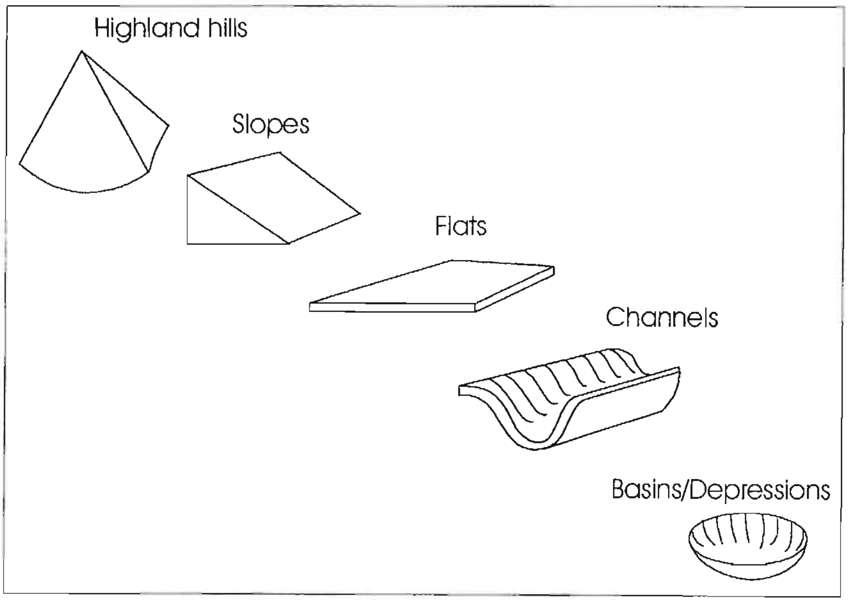

Figure 1.3 Five basic landform types, identified by Semenuik and Semenuik (1995), that may potentially retain water and hence promote wetland conditions.

The influence of hillslope morphology and landscape position on water movement across a hillslope, is recognised by Thompson *et al.*, (1997) as being very important in influencing the hydrological regime of soils and regulating hydric conditions. The form and functioning of a wetland will clearly be conditioned to a large extent by the character of the surrounding landscape, i.e. gradient, length of proximal slopes and size of catchment area, as well as the characteristics of the wetland surface itself. Steep, long slopes for example, potentially provide more available energy and hence promote rapid runoff downslope, than more subdued gentler relief (Selby, 1985). The topographic position and landform characteristics of wetlands will largely determine the nature and rate of water input and output. According to Daniels *et al.*, (1971), while surface form and position aid in predicting flow patterns, these features should be used as an initial estimate, the permeability of the underlying materials produces much of the wetland variability. Topography, in addition to influencing water paths and flow rates, may also influence the location and character of wetlands, by influencing local mesoscale and micro-climate.

1.2.1.3 Soil characteristics

Gregory and Walling (1973) argue that soil may be perceived statically and dynamically. The static influence derives from the water-holding capacity, which relates to the type and amount of water which can be contained by the soil, whereas the dynamic influence reflects the water-transmitting and sediment-bearing properties of the soil. Soil characteristics may thereby have a profound influence on the hydrology of wetland systems. A number of authors *inter alia* Mitsch and Gosselink (1986) and Naiman *et al.,* (1992), claim that wetlands are generally characterized by impeded drainage. According to Hardwick and Gunn (1995), thick, superficial cover deposits may hinder groundwater recharge processes. As already mentioned, Watkeys *et al.*, (1993) found that the location of impermeable horizons within a soil profile may result in a complex array of seepage lines.

Wetland water storage, while largely a function of the porosity of the soil, is dependent on the *in situ* water content i.e. the extent of saturation (Ingram, 1983; Backeus, 1988 and Schwabe, 1989). Wetlands which have a low saturation, store water as capillary water (Schwabe, 1989). Soils with low porosity store little capillary water. In instances where a wetland is totally saturated, additional water will not be stored (Jacot Guillarmod 1963; Schwabe, 1989). According to Hardwick and Gunn (1995), recharge that exceeds the groundwater storage capacity may give rise to small streams. Soil properties such as: texture, structure, organic matter content, horizon sequence and chemical composition will also influence the saturated water content, and thereby influence the water potential at a particular time (Gregory and Walling, 1973). Soils containing significant quantities of clay and organic matter for example, which have high water retention capacities, may be more effective in water retention than very sandy soils.The rate and pathways of soil-water movement are also greatly influenced by structure and porosity (Daniels *et al.*, 1971). The storage of water in wetland soils, and the slow release over a long period of time is largely responsible for these features being referred to as "sponges".

1.2.1.4 Hydrology

As already indicated, wetland hydrology is regarded by many wetland scientists as the single most important determinant in the establishment and maintenance of specific types of wetlands and wetland processes (Begg, 1986; Cowardin *et al.*, 1979; Denny, 1985; Scotney and Wilby, 1983; Mitsch and Gosselink, 1993). An overview of wetland water balance, wetland hydrological regimes and wetland groundwater interactions is presented below.

Wetland water balance

The extent and duration of saturation varies from one wetland to another. The general balance between water storage, inflows and outflows of a wetland system is referred to as the wetland hydrological mass balance. Water entering, stored in, and leaving a wetland can be considered within the context of a hydrological budget, in which the amount of water entering a wetland over a given period of time (a year is the usual period used for calculation), is approximately equal to the amount of water leaving the wetland (Figure 1.4). Hydrological budgets have been reviewed by *inter alia*, Huff and Young (1980); Kadlec (1983); LaBaugh (1986); Stone and Lindley Stone (1994) and Thompson and Finlayson (2001). Wetlands generally receive water from any one or a combination of four primary sources, namely: direct precipitation, sometimes termed "autogenic recharge", surface flow, ground water flow, and interflow or throughflow (Williams, 1990; Stone and Lindley Stone, 1994; Hardwick and Gunn, 1995; Thompson and Finlayson, 2001). Interflow or throughflow is a relatively neglected form of water input in the wetland literature. It may be defined as the sideways movement of water between soil layers located above the water table, generally occurring after heavy rains. Wetlands lose water through: evaporation, transpiration, surface flow (as overland flow or from a surface outlet), and subsurface seepage to the groundwater table (Stone and Lindley Stone, 1994).

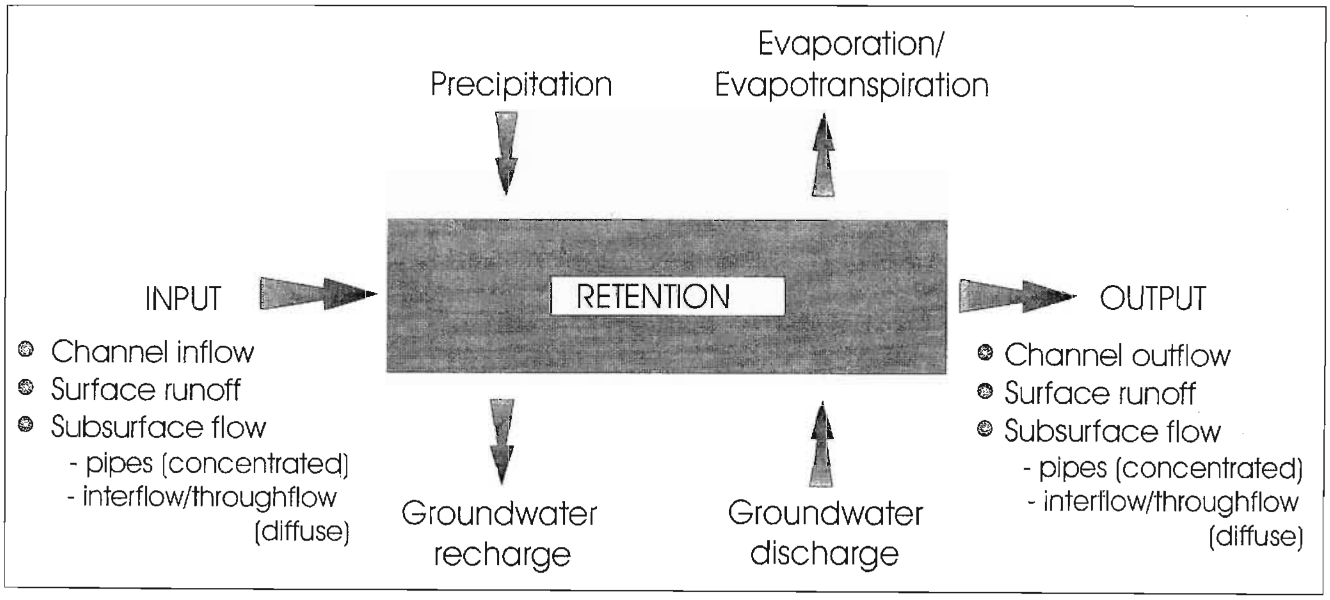

Figure 1.4 A summary (conceptual model) of the 'water balance' operative in a typical wetland. For a wetland to remain wet, inputs have to exceed outputs.

Wetlands associated with substantial river channels may be subject to water input via overbank flooding (Federal Interagency Stream Restoration Working Group, 1999). In addition to overbank flooding, complex hydrological processes may arise between the reach and the wetland soil matrix, i.e. the river/reach may lose water to the wetland, or may receive discharge from the river, as illustrated in Figure 1.5.

As previously indicated, Orme (1990) distinguished riverine wetlands on floodplains, whose moisture status is largely determined by inflow of water from upstream, from palustrine wetlands, whose moisture status is dominated by the local balance between precipitation and evaporation. While floodplain wetlands are relatively 'open systems' in terms of water exchanges with the surrounding landscape, other wetland types are relatively 'closed systems', being fed exclusively by precipitation.

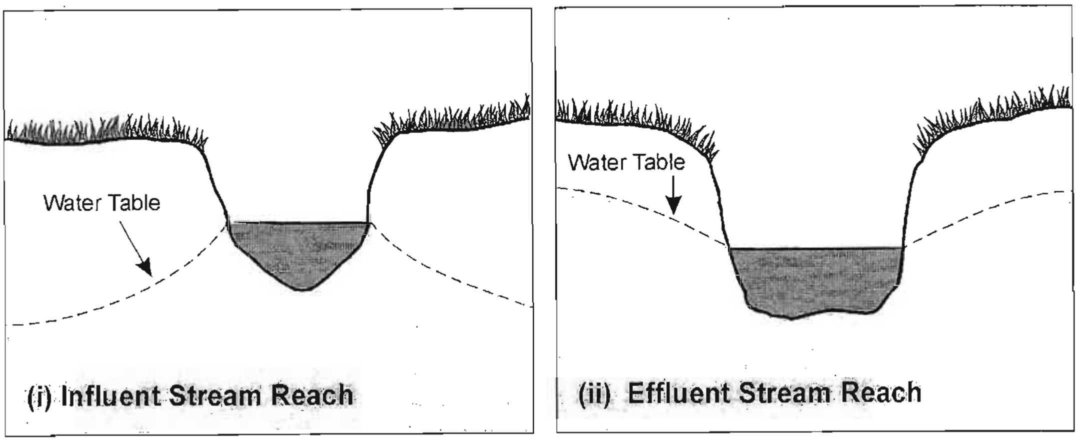

Figure 1.5 Cross sections of (i) influent and (ii) effluent stream reaches. Influent or 'losing' reaches lose stream water to the aquifer. Effluent or 'gaining' reaches receive discharges from the aquifer.
(*Modified after:* Federal Interagency Stream Restoration Working Group, 1999).

Such wetlands are termed ombrotrophic wetland features, since their water supply is derived from precipitation alone *(Gk. Ombros: a storm of rain, trophos: feeder)*. Ombrotrophic wetlands are generally characterized by very low nutrients, since the water contains no dissolved minerals that would have accumulated if it had passed over soil. Wetlands that receive nutrients entirely from precipitation, are referred to as oligotrophic or poorly fed wetlands (Mitsch and Gosselink, 1993).

Water storage can be considered as "savings" in the budget analogy. Storages may become depleted in dry years and increase in wetter conditions. Rowntree (1993) outlines that wetland storage is largely dependent on the morphology of the wetland and on vegetation which retards water flow. Soil characteristics may also influence wetland retention capacities.

Humans can affect the finely tuned hydrological balance of wetlands by: redirecting water or extracting water via boreholes and pumping for example (Williams, 1990). According to Stone and Lindley Stone (1994), an understanding of the hydrology of a wetland in terms of a water budget, may aid in estimating the relative contribution of any one of the components. It is proposed that an understanding of dominant water flow paths of a particular wetland system, may be instrumental in understanding wetland maintenance and functioning, and aid wetland managers to better predict possible consequences of hydrological interference.

Wetland hydroperiod / hydological regime

A wetlands hydroperiod is defined as the seasonal pattern of water level fluctuation (Mitsch and Gosselink, 1986). In other words it is the period of water availability, i.e. water permanence or intermittence. The hydroperiod can be summarized as being the result of the following factors:

- The balance between the inflows and the outflows
- Surface contours of the landscape
- Subsurface soil, geology and groundwater conditions

The first condition defines the water budget of the wetland (outlined above), while the second and third define the capacity of the wetland to store water (Mitsch and Gosselink, 1986). The hydrological regime of a wetland is defined by the depth, seasonal timing, frequency and duration of flooding (Rogers, 1995). Roggen (1995) maintains that these variations lie at the root of how all wetlands function. Long-term hydrological data should ideally be obtained when assessing the hydrological regime of wetlands. This is unfortunately lacking for most of the wetlands in South Africa. Wetland hydrological regimes are thus commonly determined using indirect soil morphological features. Four hydroperiod classes have been recognized by Begg (1990); namely permanently saturated, seasonally saturated, temporarily saturated and non wetland or upland. This provisional four class system, is discussed in Section 1.2.2.

Wetland-groundwater interaction

In certain circumstances groundwater may be an important component of wetland hydrology (Stone and Lindley Stone, 1994). According to Stone and Lindley Stone (1994), groundwater is frequently a topic of much misunderstanding. While all water beneath the surface of the ground that fills pores and cracks in the rock formations, is to all intents and purposes subsurface water, only the water found in the saturated zone is called groundwater (Stone and Lindley Stone, 1994). The upper limit of groundwater is the watertable. In any one place, the water table rises with increased recharge from precipitation and declines in response to seasonally dry weather, drought, or excessive pumping of water. The watertable is generally deeper beneath hills and shallower beneath valleys (Stone and Lindley Stone, 1994). The wetland-groundwater relationship is dynamic and site specific. Every site is different in terms of underlying geology and physiographic location, both of which are fundamental in the determination of groundwater flows (Donkin, 1994). The factors influencing groundwater flow to a wetland are related to recharge and storage in an area extending beyond the wetland itself (Stone and Lindley Stone, 1994).

The recharge/discharge function of wetlands is a controversial topic (Carter, 1989). According to Carter (1986), some wetlands in North Dakota, U.S.A. appear to recharge the groundwater flow system, while other wetlands have groundwater discharging on one side and recharging on the other side, while others are discharge sites only. Discharge, recharge and throughflow processes are briefly outlined below. The effects of these processes on wetland soil characteristics are briefly discussed in Section 1.2.2.

Groundwater recharge

The term 'recharge' refers to the replenishment of water in the groundwater stores (Stone and Lindley Stone, 1994). Groundwater recharge is that water flowing from the soil to the water table. Conditions controlling recharge are complex, the hydrological significance of wetlands varying greatly (Richardson *et al.*, 1992). Slow recharge involves rainfall seeping slowly through the soil profile, while rapid recharge comes from areas in the catchment where rainfall can move quickly to the water table via direct paths. Examples of preferential recharge areas include: fractures in rock outcrops, riparian zones, fault lines, very shallow soil profiles, and sandy soil profiles (Gardiner, 1999).

Groundwater discharge

Groundwater discharge is the upward or lateral movement of groundwater to the ground surface as springs or seepages (Stone and Lindley Stone, 1994). According to Stone and Lindley Stone (1994), the discharge or outflow of water from aquifers occurs as part of the natural movement of water in the hydrological system. Discharge is regarded to be predominant at the base of interfluves and along midsections of the valley backslope, proximal to the dissecting stream.

Stone and Lindley Stone (1994) argue that since rivers, lakes and wetlands occupy topographically low areas of the landscape, groundwater usually discharges into these water bodies. Stone and Lindley Stone (1994) further argue that discharge wetlands should have surface water for longer periods than either the recharge or flowthrough ponds.

Subsurface water throughflow

Throughflow conditions generally combine recharge and discharge with lateral flow between the discharge point that receives water, to the recharge point that yields water (Stone and Lindley Stone, 1994). In throughflow wetlands, most water moves laterally, not upwards nor downwards (Stone and Lindley Stone, 1994).

1.2.1.5 Geology

Rock type is frequently regarded as influencing the topographic characteristics of an area (discussed in Section 1.2.1), and dictating the character and rate of weathering, and hence the weathering products supplied to wetland systems (Gregory and Walling, 1973). Rock properties such as mineral composition and strength (compressive, shear and tensile), may influence an areas susceptibility to weathering and erosion (Lurie, 1977).

Hydro-geological controls have been found to play a predominant role in the development and distribution of wetlands in areas where atmospheric water inputs are not limited (Ugolini and Mann, 1979; Lapen *et al.*, 1996). The permeability and porosity of bedrock, as well as the likelihood of joint fractures, sills and dykes, together with variations in the dip and strike angles of inclined beds, may influence the level of the water-tables, and therefore assume an integral role in terms of wetland water budgets, hydrological regimes, recharge and discharge functions and the like (Hardwick and Gunn, 1995).

The term 'base level' is used to denote the effective limit to which fluvial erosional processes can operate (Selby, 1985). Zones where resistant rock outcrops forming a level which land upstream of the outcrop cannot be reduced, are termed 'temporary base levels'. The 'ultimate base level' is defined as an imaginary level surface in extension of that of the ocean surface (Selby, 1985). Resistant rock outcrops such as dykes or sills generally promote the accumulation of water behind these structures.

Bedrock accommodating joints, is frequently attributed to plate tectonics (Scheidegger, 2001). Joints may influence wetland hydrology by acting as preferential recharge or discharge sites as previously discussed. The location of joints within wetlands may hence influence wetland hydroperiods. Stone and Lindley Stone (1994) and Hardwick and Gunn (1995) argue that joints may act as conduits for water flow, promoting weathering and hence the establishment of deep profiles. According to Hardwick and Gunn (1995), groundwater storage is frequently located in joints, faults and steeply inclined bedding plane fissures. Hardwick and Gunn (1995) contend that joints are frequently enlarged by sulphuric acid dissolutions, following aerobic and anaerobic decomposition of sulphides and sulfates. Joint direction frequently correlates with geomorphological features such as rivers, gorges and ridges (Hardwick and Gunn, 1995), and has been implicated in the formation of depressional landscape features. Jointing is discussed further in Section 4.3.2.

The above discussion has emphasized the importance of: climate, topography/micro-topography, soil characteristics, hydrology and geology in wetland genesis and maintenance. These variables synergistically determine wetland location, internal characteristics and maintenance. While the above discussion has focussed on natural factors initiating wetland genesis, as mentioned in Section 1.1.6, anthropogenic wetland creation is currently receiving considerable attention. Wetlands may, however, not only arise via the intentional creation of wetlands, but may also arise unintentionally, via activities such as tillage, ploughing and grazing practices in wet, plastic soils, which may promote reduced infiltration properties, i.e. hardpan development (see discussion in Section 5.2.2.2), resulting in water accumulation and hence wetland formation. Wetlands may also be initiated as a result of man-made structures such as dams, weirs etc. which obstruct water flow and reduce water losses. The genesis and maintenance of wetland systems investigated in the present study is reviewed in Chapter 4.

1.2.2 Hydric soil characteristics

Wetland soils are described by Williams (1990) as being physically volatile in that they are in constant flux with the decomposition, erosion and deposition of sediments. Wetland soils vary widely in terms of texture (% clay, silt and sand), mineralogy, pH and organic carbon (O/C) content (Kotze, 1999). Two broad types of hydric soils have been identified, namely organic soils and mineral soils. In South Africa, the minimum organic carbon and minimum thickness limits for a soil to be classified as organic is 10 % and 200 mm respectively (Soil Classification Working Group, 1991). Soil material that has less organic carbon than the specified amounts given above, i.e. less than 10 % O/C and a surface thickness shallower than 200 mm, are termed mineral soils (Soil Classification Working Group, 1991). The limits specified above are less restrictive than those of the Soil Survey Staff (1975) and Avery (1980). The above definitions are at present tentative and may undergo refinement as additional information and knowledge are made available (South African Soil Classification Working Group, 1991). Daniels *et al.*, (1971) argue that while many factors affect soil development, none is more important than the abundance, flux, flow pathways, and seasonal distribution of water. The importance of water in directing soil development and in influencing chemical and physical characteristics of the soil body, while not restricted to wetland environments, is magnified in wetlands where water is plentiful. As already indicated, hydric (mineral) soils are distinguished from non-wetland soil by displaying redoximorphic features, such as: mottles and a low chroma matrix at less than or equal to 50 cm from the soil surface (Soil Survey Staff, 1975 & 1992). (The appropriateness of the 50 cm restriction, will be revisited later on in this manuscript). Begg's (1990) provisional four class scheme for determining the wetness/hydroperiod of soils, (Table 1.3), as previously discussed, is at present widely adopted by field practitioners. Soil is classified into: non-wetland and temporarily, seasonally, permanently saturated classes, based on: soil chroma and mottling evidence, the presence or absence of sulphidic smelling soil and organic carbon content.

Table 1.3 A provisional four class scheme for determining a soils wetness/hydroperiod.

	DEGREE OF WETNESS			
soil depth (mm)	non-wetland	temporary	seasonal	permanent/semi-permanent
0 - 100	matrix chroma: generally >1 generally no mottles generally low O/C non-sulphidic	matrix chroma: 0 - 3 usually 1 or 2 mottles few/nil low/intermediate O/C non-sulphidic	matrix chroma: 0 - 2 mottles common intermediate O/C seldom sulphidic	matrix chroma: 0 - 1 mottles nil/few high O/C often sulphidic
300 - 400	matrix chroma: > 2 mottles nil/few	matrix chroma: 0 - 2 mottles few	matrix chroma: 0 - 1 mottles common/many	matrix chroma: 0 - 1 mottles nil/few

(Begg, 1990)

A brief overview of processes involved in the development of characteristic wetland identifiers, namely: low chroma soil profiles and mottle development, iron ochre deposits, sulphidic smelling soil and methane gas emissions and high organic matter contents follows.

(i) Low chroma soil profiles and mottle development

Iron is a strongly coloured compound giving soils their characteristic colours. It is a good indicator of hydrological regimes, since its state changes according to the water status i.e. anerobic/aerobic status. Under aerobic conditions, iron in its ferric state (Fe^{3+}), which is sparingly soluble in water, is hence not leached out of the profile. The soil thereby acquires a red/brown colour. In Southern Africa, red colours are generally associated with well-drained aerated soils with high porosities, while yellow colours are frequently associated with slightly less freely drained conditions, and yellow-brown colours with a further reduction in drainage status. Bright orange (lepidocrocite) is an indicator of a temporary excess of water (Baize, 1993; Hughes, 1999). Prolonged wet, reducing conditions in mineral soils leads to Fe^{3+} being reduced to ferrous (Fe^{2+}), which is more soluble by many orders of magnitude. Fe^{2+} leaves the soil profile via infiltrating drainage water. With continued iron removal under reducing conditions, soil develops a 'gleyed' appearance, (frequently a grey-blue/ grey-green colour), indicative of very little ferric iron and the presence of the ferrous iron. Gleyed colouration is typical of a reducing (anaerobic) environment (Daniels *et al.*, 1971; Farr and Henderson, 1986). According to Daniels *et al.*, (1971), grey matrix colours generally result when soil is saturated for 50% of the year or more. Mottles (concentrations of material of which iron is one of the most important component) (Baize, 1993), frequently develop as a consequence of alternating anaerobic and aerobic states. When aerobic soil dries out, iron oxides are precipitated in small isolated patches.

Colour patterns develop slowly, thereby reflecting 'average' conditions over a long time (Mitsch and Gosselink, 1986). In addition, wet soil indicators remain in the soil profile for long periods of time (even after drainage), revealing the historical conditions which prevailed (Federal Interagency Stream Restoration Working Group, 1999). The interpretation of the area's colour pattern or 'signature', enables the water regime of a particular area to be ascertained. While soil morphology analyses are believed to provide one of the best methods for making hydroperiod approximations (*inter alia* Ponnamperuma, 1972; Richardson, 1996 and Kotze, 1999), cognisance must be made of the fact that colour may differ depending on bedrock type and the degree of weathering the bed has undergone (Allison *et al.,* 1974; Baize, 1993). In addition, colour depends on factors such as the thickness of the coatings, crystallinity and age (Baize, 1993).

(ii) Iron ochre deposition

Ferrous (Fe^{2+}) may be oxidized to ferric hydroxide when exposed to air. According to Greenland (1981), this generally results in the formation of 'rag-like ochre' - the result of oxidation by filamentous bacteria. Deposition of ochre in field drains and their subsequent blocking is a very common and serious agricultural problem (Bloomfield, 1972; Johnston, 2001, Pers. Comm.).

(iii) Sulphidic smelling soil and methane gas emissions

Following the depletion of iron oxides, sulfates may be reduced to sulphides, producing a sulphidic odour (Federal Interagency Stream Restoration Working Group, 1999). Prolonged waterlogged conditions may lead to carbon dioxide being reduced to methane (CH_4). Methane gas, also referred to as 'swamp gas' can be seen at night, as it fluoresces (Federal Interagency Stream Restoration Working Group, 1999).

(iv) Organic matter content

Wet or anaerobic soil conditions promote the accumulation of organic matter by impeding decomposition (Tiner and Veneman, 1988). Wetland zones subject to the longest wet periods generally have the highest organic matter content in a given wetland (Tiner and Veneman, 1988 and Kotze *et al.*, 1996). Organic carbon (O/C) has been identified by many researchers as being a very important constituent of the soil, in that it significantly influences a number of soil properties, such as: soil bulk density, matrix chroma, pH and total nitrogen (*inter alia* Farr and Henderson, 1986; Baize,1993).

1.2.3 Overview of soil development associated with aquic conditions

Four kinds of water movement dominate soil development in aquic conditions, namely: groundwater recharge or water movement to the water table, throughflow or lateral groundwater movement, groundwater discharge or movement from the water table either to or near the soil surface and stagnation or slow water movement creating water-table mounds (Stone and Lindley Stone, 1994). Richardson (1996) showed that soils in groundwater recharge type wetlands are characteristically leached, and may contain well developed soil profiles, with clay-enriched argillic horizons. In recharge wetlands subject to quick flooding and drying, surface soils tend to have ferric iron lining the pores around the roots. The root zone is generally gleyed (Stone and Lindley Stone, 1994; Richardson, 1996). Lateral water flow frequently changes the direction of most soil processes (Stone and Lindley Stone, 1994). It may result in the outwash of fine clay and silt particles, together with chemical constituents (Stone and Lindley Stone, 1994; Mitchell, 1998). Richardson *et al.,* (1992) notes that iron deposition is a common characteristic of discharge wetlands. This type of wetland is often enriched by iron, calcium, carbonate and various salts (Richardson, 1996). While in stagnant zones or zones characterized by slow water movement, very little movement or translocation of fine particles and chemicals occurs, anaerobic conditions are likely to develop profiles assuming reduced characteristics. A broad overview of the typical physical, chemical and soil morphological characteristics of seasonally and permanently saturated soil profiles is briefly given below.

(i) Seasonally saturated soils

Soils which are seasonally saturated or have a fluctuating water table, frequently display distinct horizonation within the profile (Federal Interagency Stream Restoration Working Group, 1999). As water drains through the profile, it translocates particles and transports soluble free ions from one layer to another, or entirely out of the profile (Federal Interagency Stream Restoration Working Group, 1999). Often these soils have surface horizons which are stripped of all soluble materials including iron, resulting in a "depleted matrix" (Federal Interagency Restoration Working Group, 1999). According to Kotze *et al.,* (1996), seasonally saturated soils are grey but may contain mottles, indicating a zone with a fluctuating water table. Seasonally saturated soils usually have substantial organic matter accumulated at the surface, which is generally black in colour (Federal Interagency Stream Restoration Working Group, 1999). The organic matter adds to the cation exchange capacity (CEC) (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+}, H^{+}) of the soil. The base saturation (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) however, is generally low due to stripping and the overabundance of hydrogen ions (Federal Interagency Stream Restoration Working Group, 1999). During dry periods, organic materials may be exposed to atmospheric oxygen, resulting in aerobic decomposition, and the massive liberation of hydrogen ions (Federal Interagency Stream Restoration Working Group, 1999). Seasonally wet soils do not as a rule retain base metals well, but may release high concentrations of metals in wet cycles following dry periods (Federal Interagency Stream Restoration Working Group, 1999).

(ii) Permanently saturated soils

In situations where soils are continually saturated throughout, i.e. in permanently wet zones, reactions can occur equally throughout the soil profile, as opposed to zones where the water level fluctuates. Federal Interagency Stream Restoration Working Group (1999) argues that this produces soils with little zonation, materials tending to be more uniform in these cases. Little translocation happens within the profile, as essentially no water moves through the soil to transport the particles. Owing to the reactivity of wet soils, clay formation tends to progress at a much faster rate than in adjacent uplands (Federal Interagency Stream Restoration Working Group, 1999). Mineral soils that are permanently saturated are usually uniformly gleyed throughout the saturated area and show less mottling development, usually only along root channels (Kotze *et al.,* 1996).

The above discussions illustrate that water plays an important role in dissolving and transporting materials within the soil column. Water not only adds and removes material from the soil, it rearranges the chemical and physical composition (Daniels *et al.*, 1971). An understanding of soil morphology and physical and chemical properties can, as shown above, be beneficial in terms of interpreting hydrological processes, both past and present. Knowledge of wetland soil characteristics may hence facilitate in the assessment and comprehension of wetland processes, and so promote a more comprehensive and accurate understanding of the functioning of wetland systems in the landscape.

1.2.4 Geomorphic process and wetland characteristics

In the foregoing discussions, mention has been made of the importance of 'process' in understanding wetland form and functioning, as well as soil development and characteristics. A brief review of exactly what 'process' refers to in the geomorphic context, is included here, since this is identified as a rather vague domain in the wetland fraternity at present (Lindley, 2000, Pers. Comm.). Application of knowledge about geomorphic process is regarded by Ritter (1986) as being of fundamental importance in the field of environmental science.

In geomorphology, the word 'process' is defined as the action produced when a force induces a change, either chemical or physical in the materials or forms of the earth surface (Ritter, 1986). It is a noun used to define the dynamic actions or events in geomorphological systems, which involve the applications of forces over gradients (Embleton and Thornes, 1979; Thorn, 1988). Where forces exceed the resistance(s) in natural systems, change occurs. Change may be in the form of deformation of a body, change in position, and change in chemical structure (Embleton and Thornes, 1979). Embleton and Thornes (1979) emphasize that while change in the form of the earth's surface indicates the operation of processes, the lack of observable change need not imply that no processes are operating. A lack of observable change may be attributed to the rate of operation of the process being small, i.e. the ratio of force to resistance is small, possibly resulting in the in the dissipation of energy in friction. Alternatively, the forces and resistances may be fairly balanced.

It is important to recognize that just as forms are influenced by process, so processes are influenced by form (Embleton and Thornes, 1979). Swanson *et al.,* (1988) outline that over the long term, geomorphic processes create landforms, while over a shorter term, landforms are boundary conditions, controlling the spatial arrangement and rates of geomorphic processes. A series of events when one change induces another, such that the result is to reinforce the initial change, is referred to as a positive feedback (Federal Interagency Stream Restoration Working Group, 1999). For example, while denudation processes (such as surficial sheet erosion) operating over a long period of time may erode landscapes, explaining many of the landforms in existence today, landforms themselves greatly influence water flow paths and hence flow velocities and the potential for erosion. Processes can be considered in relation to both space and time. Examples and a brief review of wetland processes from a spacial and temporal perspective are outlined below.

(i) Process in relation to space

Processes operate at various levels of spatial resolution. The filling of pore spaces in the soil by moving water is an example of a process operating at the finest level, while landscape denudation as a result of prolonged sheet erosion is an example of a process at a relatively coarse scale. Processes are understood by geomorphologists to be spatially nested (Embleton and Thornes, 1979; Thorn, 1988). For example, groundwater recharge may appear to be the most important wetland process maintaining a wetland at a scale of a few square metres, while at a broader scale of about 1 km^2, runoff from the surrounding upland areas may be considered the most important process. At a larger scale, covering several square kilometres, regional isostatic adjustment may be most important process in promoting and maintaining wetlands.

(ii) Process in relation to time

Processes occur at varying rates. The response may be instantaneous, for example when a large flood passes through a channel, while at other times the response may be fairly slow. Their may be 'dead time' when nothing happens to landforms to reveal the change in process. The time taken for the system to respond to externally imposed changes is called the reaction time (Embleton and Thornes, 1979; Federal Interagency Stream RestorationWorking Group, 1999).

Intricate interactions between geomorphic processes, landforms and biota occur at various temporal and spatial scales (Swanson *et al.,* 1988). For example, at a fine spatial scale, vegetation may retard soil erosion, or may be damaged by earth movement, while on a much larger scale, the geographic distribution and height of landmasses broadly control distributions of plants and animals, through influences of environmental gradients such as temperature and moisture (Swanson *et al.,* 1988).

An understanding of the principle of process linkage is important in understanding natural systems and in predicting possible responses. Process linkage operates on the 'domino principle' (Ritter, 1986). Alterations that occur in one process or landform during an adjustment period, often initiate subsequent responses in totally different processes and/or landforms. A myriad of different processes may hence be involved in the response to a single threshold-inducing force (Ritter, 1986).

A broad, yet by no means comprehensive overview of the types of processes one may expect to find operating within wetland systems is outlined in Table 1.4. The processes have been ranked into various categories, abbreviated in the table as 'Ctgry', namely: 1. Additions to wetland soil body; 2. Losses from the wetland soil body; 3. Translocation within the wetland soil body; 4. Chemical/physical transformation of material within the wetland soil body. It is important to recognize that in certain wetland systems, a particular suite of processes may be dominant, contributing significantly to the internal conditions and structure of wetlands, while in other systems, the same process may be absent or insignificant, posing minimal influence in terms of internal wetland conditions and functioning. Dominant processes occurring within the wetlands investigated in this study is discussed further in Chapter 5.

Table 1.4 An overview of characteristic processes operative within wetland systems

HYDROLOGICAL PROCESSES	Ctgry	BRIEF DEFINITION(S) (*inter alia* Boul, *et al.*, 1989; Farr and Henderson, 1986; Stone and Lindley Stone, 1994).
infiltration	1	Process by which water enters the surface horizon of the soil. Controlled by a number of factors, including: intensity of precipitation; surface soil porosity and cracks.
groundwater discharge	1	The upward or lateral movement of groundwater to the ground surface as springs or seepages.
overbank flooding	1	A high water level along a river channel that leads to inundation of land which is not normally submerged.
sedimentation	1	The deposition of entrained sediment load carried by either wind or water.
enrichment	1	General term for addition of material to a soil body.
littering	1	The accumulation on the mineral soil surface or organic litter and associated humus to a depth of less than 30 cm.
evaporation	2	The return of water vapour to the atmosphere by evaporation from land and water surfaces and by the transpiration of vegetation.
groundwater recharge	2	Groundwater recharge is that water flowing from the soil to the water table, i.e. refers to the replenishment of water in the ground water stores.
surficial soil erosion	2	Removal of material from the surface layer of a soil.
leaching (depletion)	2	General term for washing out or elevating soluble materials from the solum.
elluviation	2	Movement of material out of a portion of the soil profile.
interflow	1, 2	Frequently used interchangeably with subsurface soil flow or throughflow; distinguished from throughflow by a greater lagtime.
overland flow	1, 2	The visible flow of water over the ground surface.
capillarity	3	The rise of moisture towards the soil surface. This process takes place spasmodically in all but waterlogged soil.
illuviation	3	Movement of material into a portion of the soil profile (as in an argillic or spodic horizon).
dealkalization (solodization)	3	Leaching of sodium ions and salts from natric horizons.
lessivage	3	Mechanical migration of small mineral particles from the A to the B horizons of a soil, producing in B horizons relative enrichment in clay (argillic horizons).
pedoturbation	3	Biologic, physical (freeze-thaw and wet-dry cycles) churning and cycling of soil materials, thereby homogenizing the solum in varying degrees.
melanization	3	The darkening of light-coloured mineral initial unconsolidated materials by admixture of organic matter (as in dark A1 or mollic or umbric horizon).
throughflow (subsurface flow)	1, 2, 3	Lateral water flow in a soil body. Infiltrated water is deflected by an impeding horizon, where it is diverted laterally as saturated throughflow. (Impedance may be due to saturation or reduction in permeability).
slumping/landslides	1, 3	The movement downslope under the influence of gravity of a mass of rock or earth.
channel incision	4	Downward cutting of channel floor by flowing water, i.e. erosion potential > channel resistance.
channel meandering	4	The sinuous winding of a river, frequently the result of outer-bank erosion and inner-bank deposition on channel beds.
swelling, shrinkage and cracking	4	Processes arising from moisture content changes and consequent changes in soil properties, namely: expansion, contraction and deformation.
decomposition	4	The breakdown of mineral and organic materials.
humification	4	The transformation of raw organic material into humus.
paludization	4	The accumulation of deep (> 30 cm) deposits of organic matter as in peats (Histosols).
ripening	4	Chemical, biological and physical changes in organic matter after air penetrates previously waterlogged
mineralization	4	The release of oxide solids through decomposition of organic matter.
gleization	4	The reduction of iron under anaerobic 'waterlogged' soil conditions, with the production of bluish to greenish
subsurface erosion	2, 4	Removal of material from the subsurface soil layers, also referred to as suffosion.
piping	2, 4	Removal of material from the surface layer of a soil, resulting in the formation of a subsurface channel.

Chapter 2

2. Environmental Setting

2.1 Location of study area

Wetland systems in the upper Mooi River catchment were investigated in this study. While a number of wetlands located on private farmlands were visited and assessed, intensive investigations were restricted to the KwaZulu-Natal Drakensberg (uKhahlamba-Drakensberg Park) (Figure 2.1). The KwaZulu-Natal Drakensberg is physiographically part of the main escarpment, which extends from the Northern Province near the Tropic of Capricorn across a distance of approximately 960 km to the Stormberg range at a latitude of approximately 31°30'S in the Eastern Cape Province, South Africa. The KwaZulu-Natal Drakensberg section is crescent-shaped, stretching from latitude 20°05' to 29°55' South, and longitude 29°45' to 29°44' East, and covers approximately 242 800 ha.

Wetland systems in the Highmoor, Kamberg and Impofana Nature Reserves, all located in the Southern KwaZulu-Natal Drakensberg, form part of the present study. Detailed study site locations are indicated in Figure 2.2. The approximate geographic locations (topographic map and GPS readings) of the respective wetlands are listed in Table 2.1.

Table 2.1 Approximate location of the primary wetland study sites

WETLAND LOCATION	LONGITUDE	LATITUDE	NAME OF WETLAND	SITE NAME *
Highmoor Nature Reserve	29°35'15" S	29°17'28" E	Highmoor 1	H1
Highmoor Nature Reserve	29°36'17" S	29°18'17" E	Highmoor 2	H2
Highmoor Nature Reserve	29°36'52" S	29°20'45" E	Highmoor 4	H4
Highmoor Nature Reserve	29°36'42" S	29°19'42" E	Highmoor 5	H5
Kamberg Nature Reserve	29°43'45" S	29°22'53" E	Stillerust	S
Impofana Nature Reserve	29°25'04" S	29°43'05" E	Impofana 1 (Tarn 1)	T1
Impofana Nature Reserve	29°25'06" S	29°41'53" E	Impofana 2 (Tarn 2)	T2

* The site names will be used predominantly in this manuscript to identify the respective wetland systems.

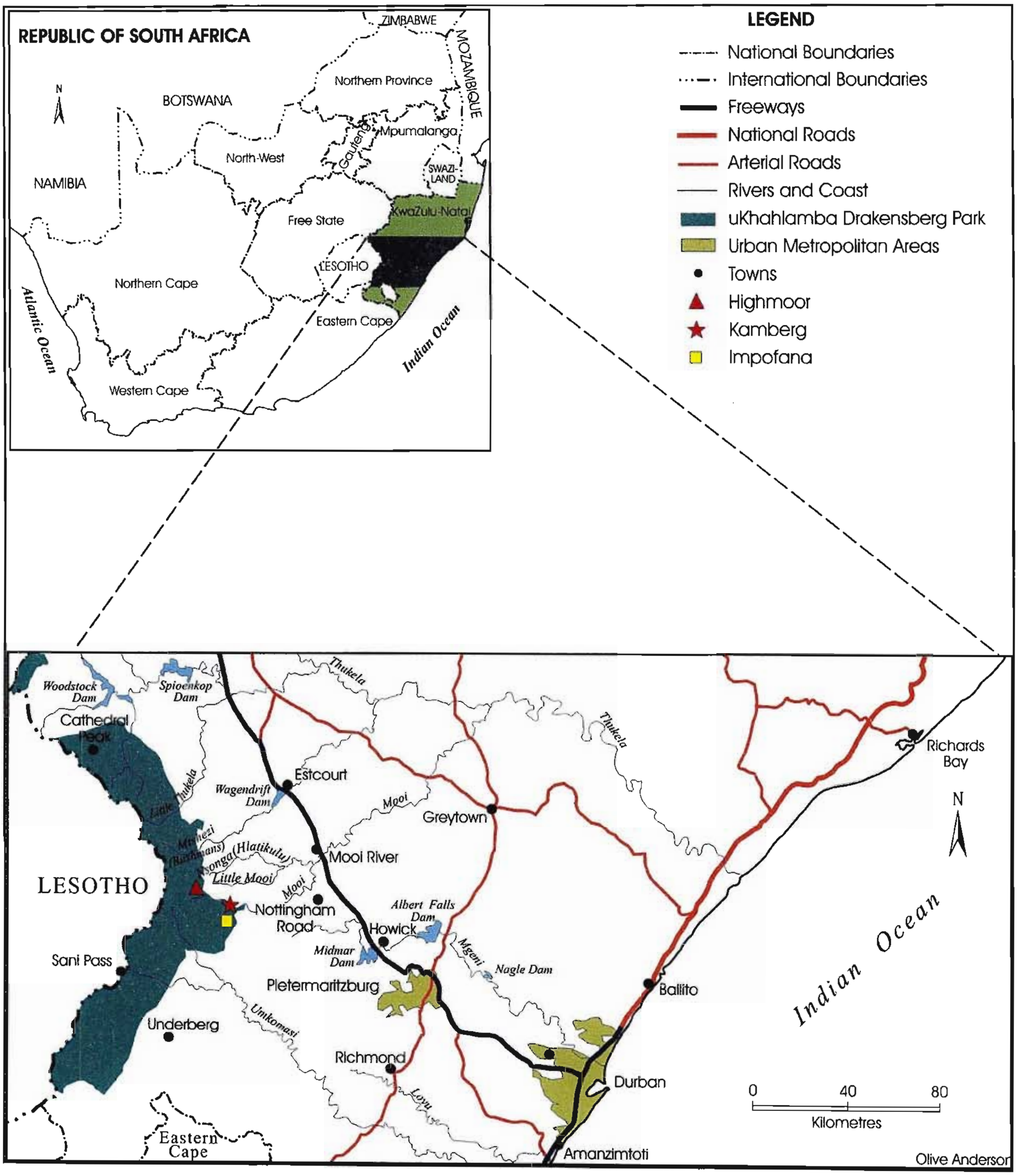

Figure 2.1 Location of the uKhahlamba Drakensberg Park and upper Mooi River catchment.

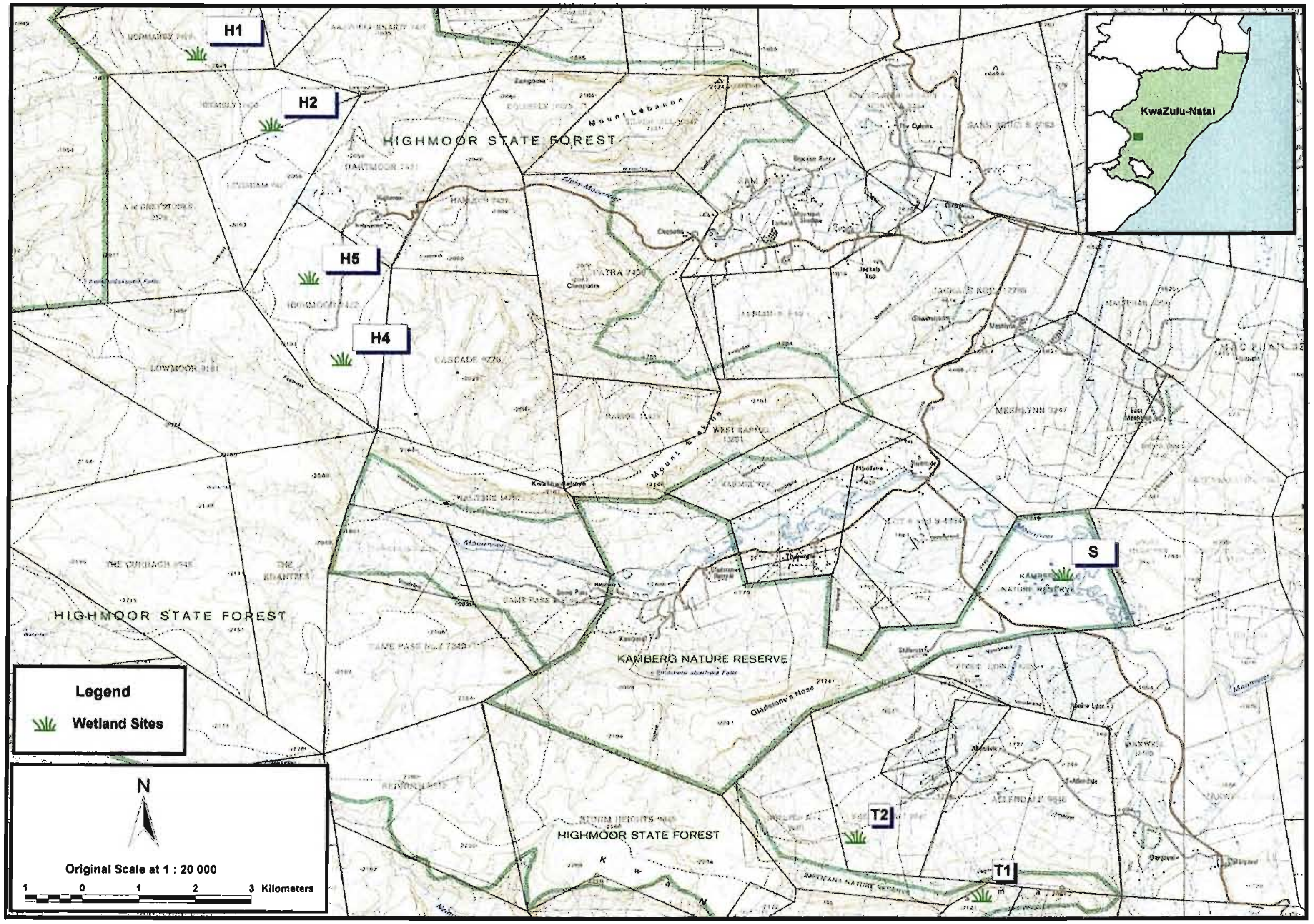

Figure 2.2 Portion of a 1 : 50 000 topographic map (2929BC Kamberg) showing the location of wetland study sites and their relative landscape positions and relation to fluvial systems.

2.2 Topography and drainage

The KwaZulu-Natal Drakensberg has been described as the most prominent physiographic feature of eastern South Africa (Pearse, 1989). It consists of three very distinct steps, the Main Escarpment, the Little Berg and the foothills (Killick, 1961, Irwin and Irwin, 1992). The southern section of the KwaZulu-Natal Drakensberg is more extensive and its topography more diverse than in the northern and central Drakensberg (Irwin and Irwin, 1992). While the valleys tend to be broader and longer, with a gentler gradient, many parts are nonetheless rugged and broken (Irwin and Irwin, 1992). The study area is characterized by stepped terrain, typical of the Drakensberg, with undulating plateaux, valley-side benches and associated scarp slopes at about 1670 m (Garland, 1987). The Highmoor area (as the name implies) is characterized by a range of undulating hills providing a typical “moorland” setting.

As previously mentioned, the KwaZulu-Natal Drakensberg is considered the most important high altitude watershed in southern Africa in terms of water yield. The catchment consists of an intricate network of streams, river courses and wetlands (Bainbridge, 1991). The wetland systems occupy variable positions in the landscape, from small wetlands on valley sides, to extensive watercourses (Cowan and Marneweck,1995). These wetlands are present throughout the altitudinal gradient of the mountains (Bainbridge, 1991) and have been identified as playing a significant role in the maintenance of regular stream flow patterns and high water quality levels.

The KwaZulu-Natal Drakensberg forms the headwater catchment area of the three major rivers in KwaZulu-Natal, namely the Thukela (Tugela), Umkhomazi and Mzimkulu rivers (Bainbridge, 1991). The Mooi River is one of the major tributaries of the Tugela River, joining it from the south (Thorrington-Smith, 1953). The Mooi River catchment area, from its source to its confluence with the Tugela is approximately 1865 km^2 (Thorrington-Smith, 1953). The Mooi River arises in the Kamberg Nature Reserve, while the source of the Little Mooi, a major tributary of the Mooi, rises in the Highmoor reserve. The Mooi River is located in an east-west orientated valley, running between two spurs of the Little ‘Berg (Garland, 1987).

Fluvial processes were noted by Garland (1987) as constituting a powerful geomorphological force in the area. The study area can be divided into three main landforms: older weathered valleys which have formed plains, younger U-shaped valleys, and steep V-shaped valleys. While these landforms are evenly distributed throughout the study area, V-shaped valleys are the most dominant. Minor watersheds are also abundant (Garland, 1987). Mathews (1969) argues that the Mooi River catchment is a very good example of a catchment showing a systematic but asymmetrical pattern. According to Garland (1979) the Mooi River valley is typical of the distinctly asymmetrical valleys in the Southern Drakensberg. Sparrow (1965) has argued that this asymmetry can most likely be attributed to a periglacial phase in the Pleistocene. Garland (1979) and Meiklejohn (1992) however, argue that supporting evidence suggests that the influence of aspect is more plausible. The north facing valley side is drier, more eroded and has gentler slopes than the south facing side. In addition, it is postulated that the regional tilt in the dolerite base may explain the valley asymmetry.

Mathews (1969) attributes the uneven or step-like character of the longitudinal profile of the Mooi River to resistant rock barriers of dolerite. This occurs in the form of extensive sills or slightly inclined sheets, with a component of dip in the upstream direction, resulting in major steps, i.e. waterfalls or steep sectors/rapids. Mathews (1969) argues that the pronounced steps in the river profile is clear evidence that the associated river barriers of dolerite are acting as local, structurally controlled base levels.

2.3 Macro-Geomorphological evolution

The geomorphological history of the Drakensberg Zone has been strongly debated since the late nineteenth century. Over the years, numerous interpretations of the geomorphological evolution of the Main Escarpment (the dominant feature of the Drakensberg) have emerged. Well known interpretations and reviews include those of: Suess (1904); Penck (1908); King (1963, 1972); Birkenhauer (1985). In response to the confusion and apparent conflicting geomorphological interpretation, there has been a re-evaluation of the geomorphological history of the subcontinent by Partridge and Maud (1987). Partridge and Maud (1987) interpreted the mountainous regions above the Great Escarpment as being unrelated to particular phases of erosion, in contrast to King's reference to a Gondwana surface, instead generally discrete phases of erosion were identified. The oldest surface identified by Partridge and Maud (1987), the "African surface", coincides with the African surface described by King (1967). Two surfaces of the Post-African age were identified, and are referred to as the Post-African I and the more recent Post-African II surface. The relationship between surfaces and stages is hypothesized as being indicative of landform development by progressive backwearing and downwearing, where existing surfaces continue to develop at the expense of higher-lying areas (Partridge and Maud, 1987). Few broad-based geomorphic studies of the sub-continent have arisen in the past few decades. While much controversy still surrounds this topic, for the purpose of this study it is sufficient to recognize that, with some local exceptions, southern Africa as a whole has functioned as a single tectonic entity since the Cretaceous. Geological activity has been limited to gentle uplift of the sub-continent (Partridge 1997 and 1998). This has resulted in the majority of the rivers (particularly in the high lying areas of the KwaZulu-Natal Drakensberg) attaining a state of active incision.

2.4 Geology

Fieldwork as well as recent wetland literature (*inter alia* McCarthy and Hancox, 2000; Tooth *et al.*, 2000 a&b) have highlighted the importance of geology in determining wetland location, functioning and dynamics. It is proposed that a basic knowledge of the underlying geology of wetlands is essential if questions of causality, maintenance and functioning of wetlands are to be adequately addressed (as illustrated in the discussion pertaining to the importance of geology in wetland genesis and maintenance, presented in Section 1.2.1).

The geology of the study area consists entirely of lithologies belonging to the Karoo Supergroup; containing strata of the Drakensberg Group as well as the Clarens, Elliot, Molteno and Tarkastad formations. The Highmoor wetlands (H2, H4 and H5) are located on Dolerite. Wetland H1, while underlain predominantly by dolerite, also overlies the Elliot and Clarens formations. Stillerust (S) and Tarn 2 (T2) are both located on the Tarkastad formation, while Tarn 1 (T1) is situated on the Elliot formation. A brief description of the geological history of the area, followed by a précis of the lithological characteristics of the subgroups on which the wetlands are situated is incorporated below. The geological stratigraphy of the upper Mooi River catchment region is summarized in Table 2.2.

2.4.1 Geological history of the Upper Mooi River catchment

The deposition of Karoo sediments was halted approximately 190 million years ago prior to the division of the Gondwana Pangaeae (Haskins and Bell, 1995). During the Jurassic period, massive outpourings of flood basalts occurred in the Karoo basin as a consequence of continental breakup (Haskins and Bell, 1995). While the extent of these flows suggests that they were erupted as low-viscosity flood basalts which flowed from fissures without a great deal of associated explosive activity, tuffaceous layers and volcanic agglomerates are present. According to Haskins and Bell (1995) this indicates that some localized explosive activity did occur. It is believed that the individual lava flows must have been laid down in fairly rapid succession, since according to Haskins and Bell (1995) there is a lack of highly weathered flow contacts. The basalts of the Lesotho Formation mark the final and main stage which consisted of thoheiitic flows with pipe amygdales forming at their bases (Lock *et al.*, 1974 *in* Haskins and Bell, 1995). The pipe amygdales were produced by the movement of gas bubbles through the viscous, cooling material (Haughton, 1969). At some places Clarens sandstones have been found to merge with the lower larva beds (Haughton, 1969). It has been suggested that this feature may be due to continued deposition and reworking of aeolian sands during the volcanic eruptions (Schmitz and Rooyani, 1987).

Thick layers of Drakensberg basalt, which covered the horizontal to sub-horizontal sedimentary units, was forced into cracks, fissures and other discontinuities in both the basalts and underlying sediments, creating a lattice of dolerite sills and dykes (Garland, 1987). According to King (1967), flows have maintained their thickness over great distances, so that the precipices of the Drakensberg exhibit pronounced stratification. Thicknesses of up to 1400 m have been recorded in places (Haskins and Bell, 1995).

2.4.2 Karoo dolerites

Dolerite is a dark-coloured, crystalline igneous rock, which frequently displays a mottled black and tan appearance in the KwaZulu-Natal Drakensberg (Irwin and Irwin, 1992, Pers. Obs). It is similar in chemical composition to basalt, but having cooled more slowly, is characterized by larger crystals than those found in basalt (Irwin and Irwin, 1992). As in basalt, amygdales may be associated with dolerite (Irwin and Irwin, 1992). Amygdales are formed when secondary products of zeolite, chalcedonic silica or quartz percolate into gas cavities and then crystalize.

Dolerite frequently intruded the sediments of the Karoo sequence. Evidence of this phenomenon is commonly observed as flat-topped hills (Kent,1980). According to Humphrey (1983), dolerite outcrops in the sandstone formations are usually evident as loose boulder slopes. According to Bester (2000, Pers. Comm.) dolerite frequently appears as either dykes or sills in the KwaZulu-Natal Drakensberg. A dolerite sill forms the valley base along which the Mooi River flows (Begg, 1988).

2.4.3 Clarens formation

Sandstones of the Clarens formation, formally referred to as the Cave Sandstone, form the massive, buff coloured, often sheer cliffs, normally located at an altitude just below 2 000 m (Garland, 1987). The Clarens formation forms vertical rock walls twenty to forty metres high, which mark the edge of the Little Berg and the transition between the Wilderness Heart Zone and the Landslide Zone (Humphrey, 1983). The contact of the Clarens formation with the overlying Drakensberg volcanics is generally sharp. Nevertheless, small and irregularly-shaped extrusions of basalt below the contact suggest that minor volcanism took place prior to the cessation of sedimentation (Eriksson, 1981).

In the Natal Drakensberg, the Clarens formation is approximately 145 m thick. The formation dips slightly to the south-west, which is thought to be related to the morphology of the depositional basin (Eriksson, 1981). While the Clarens formation frequently appears massive, according to Eriksson (1981) these deposits exhibit a broad spectrum of sedimentary structures, planar cross-bedding of different set thickness being the most important, followed by planar stratification, channels and trough cross-bedding. The Clarens formation in the study area consists of fine-grained sandstones, sandy siltstones and mudstones (Eriksson, 1981). Four lithofacies have been defined in the study area (see Eriksson (1981) for a detailed description). Eriksson (1981) hypothesizes that the four lithofacies point to deposition of sediments in playa lakes by sheetflow, fluvial and aeolian processes. (The above point illustrates how processes active in the geological past can have a profound impact on structure and morphology of the landscape many epochs later, and thus indirectly determine the processes operative today).

The contact between the Clarens and the underlying Elliot formation is generally gradational. This gradation is according to Eriksson (1981), characterized by the interfingering of lenses of the Clarens formation sediments with the Elliot formation strata.

2.4.4 Elliot formation

The Elliot formation (formerly referred to as the Red Beds), is characterized by red and purple massive argillaceous sediments, containing occasional subordinate lenses of fine to coarse sandstone (Eriksson, 1983 *in* Boelhouwers, 1988). The subordinate lenses exhibit mainly planar and trough cross-stratification. The argillaceous sediments are reported to range from mudstone to very-fine grained sandstone. Arenaceous lenses occur in certain parts of the study area, while other regions are apparently devoid of these features (Eriksson, 1983 *in* Boelhouwers, 1988). Of the three lithofacies identified by Eriksson (1983), only facies one and two are documented in the Highmoor and Kamberg regions, namely: massive argillite facies and laterally restricted sandstone lens facies. According to Eriksson (1983), the only conspicuous feature displayed by the sediments of facies one is their massive outcrops, thus obviating interpretation of sedimentary structures, while the sediments found in facies two, vary from fine to coarse in grain size, but are predominantly coarse to very coarse-grained (King, 1967 *in* Eriksson, 1983).

2.4.5 Beaufort group: Tarkastad subgroup

The Beaufort group consists of mudstones with interbedded sandstones (Lurie, 1977). It has been subdivided lithostratigraphically into (i) the upper Tarkastad subgroup, and (ii) the lower Adelaide Subgroup (Lurie, 1977), the Estcourt formation is also included under the Beaufort group.

The upper Tarkastad Subgroup is distinguished from the lower Adelaide Subgroup by possessing a greater abundance of both sandstone and red mudstone (Kent, 1980). According to Garland (1987), Tarkastad sediments occasionally outcrop at the topographically lowest points in the area, i.e. below 1800 m.

Table 2.2 Characteristics of the dominant stratigraphic sequences of the Karoo Supergroup found in the study area

SUPER-GROUP	GROUP	SUBGROUP/ FORMATION	LITHOLOGY	THICKNESS (m)	ALTITUDE (m)	AGE	
						PERIOD	APPOX. YRS
KAROO	Drakensberg (volcanics)	-	basalt dolerite	1350	>1880	Jurassic	180ka
	Stormberg	Clarens	sandstones, siltstones with subordinate mudstones	120	1720-1880	Upper Triassic	200ka
		Elliot	red-colored mudstone, shale and siltstones with subordinate sandstones	50-80	1630-1720	Upper Triassic	215ka
		Molteno	sandstones with interbedded shale and mudstone	50	1600	Middle Triassic	235ka
	Beaufort	Tarkastad Subgroup	sandstone, siltstone and mudstone	100-1000	1800	Permo-Triassic	250ka

(*modified after*: Kent, 1980; Eriksson, 1981 and Boelhouwers,1992).

2.4.6 Geomorphic resistance of Karoo Dolerites and Sandstones

Dolerite has a silica content of about 50%. It is a very hard rock and highly resistant to erosion, yet is very susceptible to chemical weathering (Beckedahl, 1986; Irwin and Irwin, 1992). Brink (1983) quote that Unconfined Compressive Stress (UCS) values for fresh dolerite frequently exceed 400 MPa. A detailed account of the factors promoting the rapid deterioration and slaking of volcanic rock is given in Haskins and Bell (1995).

According to Brink (1983), well sorted fine to medium grained clastic rocks, low in clays, exhibit variable strength. While sandstones consist dominantly of quartz which is highly resistant to weathering, the various cementing materials which hold the grains together may differ in resistance (Lurie, 1977). If siliceous, the rock is particularly resistant, however if ferruginous or calcareous, the rock is susceptible to chemical attack (Lurie, 1977). According to Bester (2000, Pers. Comm.), sandstones in the study area are generally more resistant to erosion than the volcanic geologies, as a result of highly resistant, siliceous cementing material. UCS values are unavailable for the Drakensberg area (Garland, 1987).

2.5 Climate

As discussed in Section 1.2.1, climate is an important factor in terms of wetland genesis, distribution and functioning. The KwaZulu-Natal Drakensberg currently experiences hot, wet summers and cool, dry winters (Garland, 1987). The variables of precipitation (rainfall and snow), wind, temperature and evaporation/evapotranspiration for the study area are presented below.

2.5.1 Precipitation

2.5.1.1 Rainfall

The KwaZulu-Natal Drakensberg lies in the summer rainfall area of South Africa, and is one of the wettest areas in the country (Killick, 1961; Schulze, 1970), which may possibly explain the large areal coverage of wetlands in this bioclimatic zone. The mean annual rainfall for Highmoor and Kamberg over the past 44 and 46 years is 1248 mm and 1073 mm respectively, with 76% and 75% of the annual rainfall falling in the summer months between October and April (Table 2.3, Figure 2.3). The highest maximum rainfall figures over a 24 hour period for Highmoor and Kamberg are 184.5 mm and 149.5mm, which occurred in March and September respectively, accounting for 14.78 and 13.92% of the total annual rainfall. Despite the almost rainless dry season, occasional heavy storms are possible between May and September (Tyson *et al.*, 1976).

The Drakensberg derives its rain mainly from oceanic air-streams entering from east coast highs (Tyson *et al.*, 1976). At the beginning of summer, the rainfall is predominantly orographic in nature, later on however thunderstorm frequency increases (Tyson *et al.*, 1976). Thunderstorms are almost entirely a summer phenomenon (Tyson *et al.*, 1976). This form of precipitation provides approximately 50% of the total rainfall in this region (Tyson *et al.*, 1976). Thunderstorms occur either along organized squall-lines which sweep coastwards from the escarpment, or as orographically-induced storms (Tyson *et al.*, 1976). Plain-mountain winds play an important role in the latter case. Killick (1961) emphasized that given the characteristics of rainstorms (short, intense downpours, with a high eroding capacity), wetlands in the Drakensberg render an important role in intercepting both the rainfall and sediment laden runoff. The water which is temporarily stored, is released slowly, thereby creating a more even supply of water throughout the year.

Topography has been identified as exerting a powerful influence on Drakensberg rainfall. This was demonstrated by Schulze (1979) in a cross-section from Bergville to Mothelsassanne (Lesotho), where Bergville (800 m.a.s.l.) receives approximately 750 mm p.a., the annual total increasing to a maximum of 1 650 mm at 2 400 m.a.s.l., just below the top of the Escarpment at 3 000 m.a.s.l. This spatial variability in relation to altitude was also evident in the present study. Mean annual totals vary from 1073 mm at Kamberg (1525 m.a.s.l.) to 1248 mm at Highmoor (1981 m.a.s.l.).

Table 2.3 Monthly and annual means, average number of rain days per month, and maximum 24 hour intensities in the Highmoor and Kamberg Reserves

	HIGHMOOR (1981 m.a.s.l.) **1955 - 1999**			**KAMBERG** (1525 m.a.s.l.) **1953 - 1999**		
Month	**Mean** (mm)	**No. rain days/mo**	**Max in 24 hrs** (mm)	**Mean** (mm)	**No. rain days/mo**	**Max in 24 hrs** (mm)
Jan	232.1	16.7	100	199.1	17.2	122
Feb	196.4	14	87	171	15.2	93
Mar	168.4	13.4	184.5	143.1	14.6	89.5
Apr	64.8	6.8	65	61	8.4	67.2
May	21.8	2.5	70	23.7	3.6	106
Jun	12.8	1.5	92	13.3	1.9	36
Jul	9.4	1.3	26	12.8	2	98
Aug	26.3	3	108.5	16.7	4.2	113.2
Sep	54.9	6.2	175	47.9	6.3	149.5
Oct	110.8	12.1	60	85	12.6	61
Nov	157.4	14.4	93	117.2	15.1	104.5
Dec	192.9	16.2	135.5	172.9	17.8	79.5
Tot	1248.1	108.2		1073.7	119	

(data obtained from the South African Weather Bureau, Pretoria, 2001)

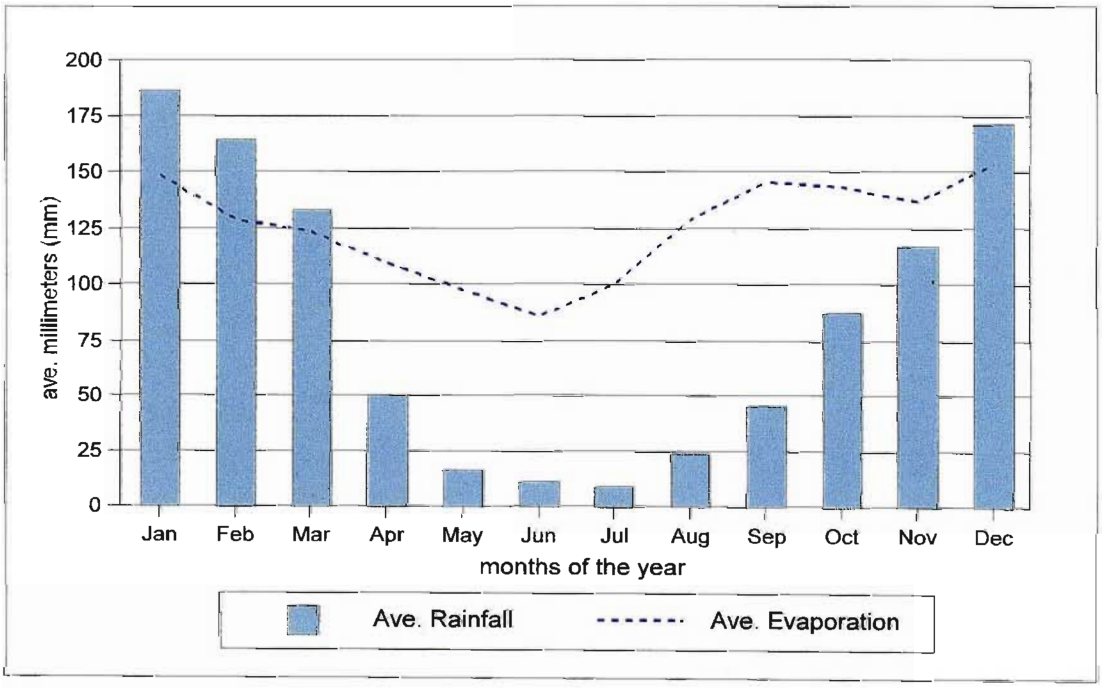

Figure 2.3 Longterm summary of rainfall and evaporation data for the Mooiriver district. Meshlynn, Kamberg Station, (1979 - 2000).

2.5.1.2 Snow

Snow can generally be expected between April and September, but occurs mainly in July (Killick, 1961). An approximate average of eight falls are reported along the Drakensberg annually (Tyson *et al.*, 1976). Sunshine soon follows the snowfalls, resulting in the snow seldom remaining for any significant period of time. Snow nevertheless substantially increases the soil moisture during winter when present, it also prevents the ground beneath from freezing (Killick, 1961).

2.5.2 Wind

The airflow of the Drakensberg is influenced by the presence of the Main Escarpment and the deeply-dissected terrain of the Little Berg (Tyson *et al.*, 1976). Under clear, fine weather conditions, airflow patterns near the ground are completely dominated by topographically-induced local winds (Tyson *et al.*, 1976). These are formed on a variety of scales by solar heating of the ground during the day and radiation cooling by night (Tyson *et al.*, 1976). Anabatic and katabatic winds may drain warm and cool air on slopes by day and night respectively (Tyson *et al.*, 1976). While strong winds generally accompany thunderstorms, they seldom last for long periods (Preston-Whyte and Tyson, 1988). Strong pressure gradients are usually associated with the passage of frontal systems. 'Berg Wind' conditions generally precede a cold front, wind speeds are high and humidity is low (Hurry and van Heerden, 1981; Preston-Whyte and Tyson, 1988).

2.5.3 Temperature

In the KwaZulu-Natal Drakensberg, the mean maximum daily temperature for January, the hottest month, ranges from 23°C (at 800 m), to 21°C (above 2 400m). Corresponding values for July, normally one of the coldest months are 15°C and 12°C (Tyson *et al.*, 1976). Frost is common in the winter months. Nottingham Road, located approximately 55 km south of the study area (Figure 2.1) has an average of 72 days of frost each year (Tyson *et al.*, 1976). Minimum, maximum and average temperatures for the Highmoor and Kamberg Reserves are given in Figure 2.4.

2.5.4 Evaporation and evapotranspiration

The loss of water to the atmosphere, either in the form of evaporation from a free-water surface, or from evapotranspiration from vegetated surfaces, is difficult to measure accurately (Tyson *et al.*, 1976). Average evaporation figures for the Highmoor and Kamberg area are nevertheless indicated in Figure 2.3.

Microclimate, in particular temperature and evaporation, has been related to slope aspect. North-facing slopes generally receive a greater amount of incoming radiation, and consequently experience higher evaporation and evapotranspiration (Garland, 1987). The limited distribution of recording stations has rendered detailed climatic analysis virtually impossible (Garland, 1987).

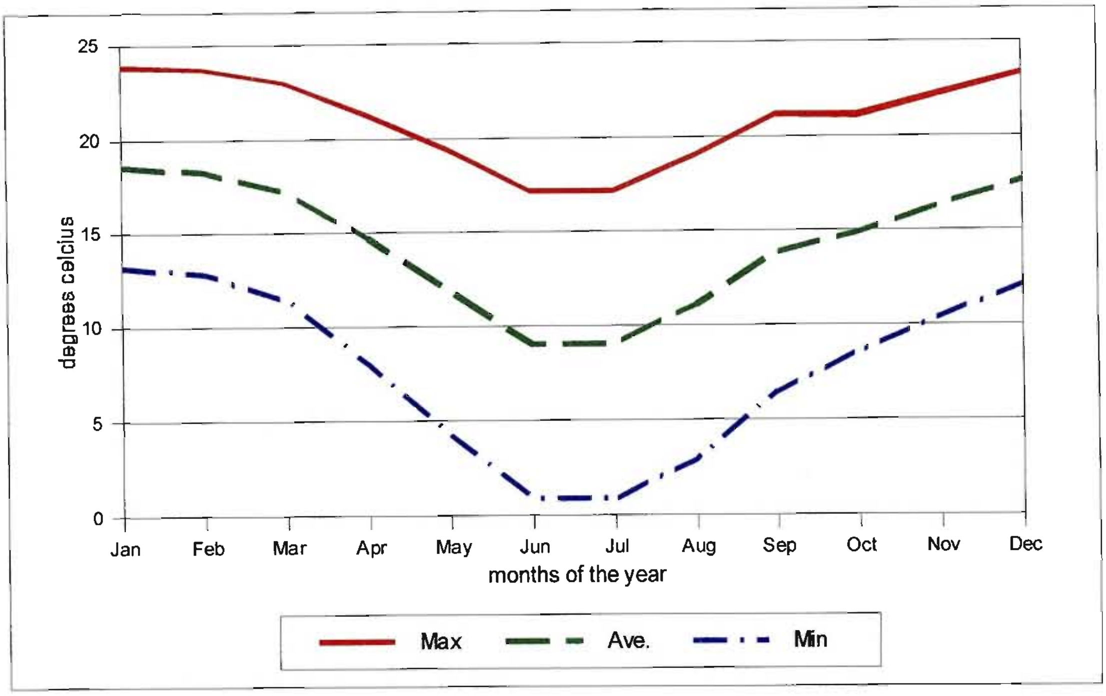

Figure 2.4 Longterm summary of temperature data for the Mooi River district. Meshlynn, Kamberg Station, (1979 - 2000).

2.6 Soils

While a few small-scale soil surveys of the Cathedral Peak area have been performed (Schultze, 1974; Granger 1976), a comprehensive soil survey for the KwaZulu-Natal Drakensberg has not as yet been undertaken (Sumner, 1995). Soil associations of a small part of the study area were mapped at a scale of 1: 100 000 by Van der Eyk *et al.*, (1969). Much of the area is however classified under mapping unit N, outlined as: 'Mountainous land, mostly steep, but including inaccessible land of the high plateaux', with no further information provided (Garland, 1987).

The combined effects of high summer rainfall and low dry season temperatures and the long exposure to weathering are instrumental in the genesis of the general acidic, highly leached, highly weathered and structureless characteristics of the Little 'Berg soils (Schulze, 1974; Granger, 1976; Bainbridge, 1987 and Boelhouwers, 1988).

In general, the Drakensberg soils are shallow, with skeletal soils on the mountain slopes and deeper soils in the valley bottoms (Killick, 1978; Irwin and Irwin, 1992; Grab, 1997 and Pers. Obs.). The shallow soils of the high Drakensberg slopes, in the order of 0.15 m in depth, are referred to as "lithosols", while valley floors and heads are represented by *mollisols.* Mollisols are usually deeper and darker soil than that found on the slopes above (Grab, 1997). Dominant soil forms found in the upper reaches of the Mooi River catchment are given in Table 2.2.

Table 2.4 Soil forms found in the upper reaches of the Mooi River catchment

FORM	DIAGNOSTIC HORIZONS	LOCATION
Clovelly	orthic A / yellow-brown apedal B	steep and/or south-facing slopes
Griffin	orthic A / yellow-brown B / red apedal B	low gradient moist conditions on cooler slopes
Hutton	orthic A / red apedal B	low gradient moist conditions on cooler slopes
Katspruit	orthic A / firm gley	poorly drained valley floors and in narrow strips along streams
Mispah	orthic A over rock	dolerite outcrops and along scarp edges

(Modified after: Van der Eyk *et al.*, 1969; Garland, 1987b; Boelhouwers, 1988 and the Soil Classification Working Group, 1991).

2.7 Vegetation

The distribution of plant species in the Drakensberg is determined primarily by altitude, aspect and soil (Irwin and Irwin,1992). Topographic position is believed to have a considerable influence on plant distribution and colonization (Granger 1976). According to Granger (1976) topographically-induced variations in radiant energy will lead to corresponding variations in soil moisture status, and thereby cause alterations in the plant environment. A long history of controlled burning is also believed to have influenced vegetation in the Drakensberg (Garland, 1987).

Three altitude belts: Montane (1280-1829 m.a.s.l), Subalpine (1829 - 2865 m.a.s.l) and Alpine (12865-3353 m.a.s.l) were identified by Killick (1963) and used to describe the vegetation belts of the Drakensberg and Maluti mountains. While the composition of flora varies slightly in different areas of the Drakensberg, for general purposes it is regarded as ecologically fairly homogeneous from north to south (Irwin and Irwin, 1992). Edwards (1967) included the Tugela Basin in his study of the plant ecology of the Central Drakensberg. He recognized altitudinal zones similar to those proposed by Killick, which he termed Upland (Killick's Montane), Subalpine and Alpine Belts (Garland, 1987).

The Kamberg Nature Reserve falls within the Montane belt, while Highmoor Nature Reserve and the Impofana Nature Reserve fall within what Killick (1963) terms the Subalpine belt. The dominant plant communities supported in these respective altitudinal belts, as identified by Killick (1963) are outlined below.

2.7.1 Montane belt (1280 - 1829 m.a.s.l)

Most of the upland Belt supports the *Themeda-Trachypogon* sub-climax community. It is dominated by *Themeda trianda* and *Trachypogon spicatus* grassland and is interspersed with small communities of *Protea* savanna in favourable sites. Pockets of evergreen shrub and woodland with *Leucosidea sericea* and *Buddleja salvifolia* occur on streambanks, in kloofs and on rocky soils (Garland, 1987). Patches of *Podocarpus* forest are sparsely distributed on steep, normally south-facing slopes (Granger, 1976).

2.7.2 Subalpine belt (1829 - 2865 m.a.s.l)

The most extensive plant association in this belt is *Themeda-Festuca* grassland. *Themeda trianda* is common, particularly on north-facing slopes, and *Festuca costata* is common on south-facing slopes. Small shrub communities dominated by *Leucosidea sericea* may be found following gullies and streams. Subalpine fynbos, consisting of a variety of small leaved shrubs, one to three metres in height, exist only where there is some measure of protection from fire i.e. along streams and gullies, and on steep slopes and rock outcrops (Granger, 1976). Both the Montane and Subalpine belts are characterized by tussock grassland (Granger, 1976).

As discussed in Section 1.1.1, the vegetative characteristics and composition of wetlands differ from upland vegetation. The vegetative characteristics of the Stillerust wetland (S), is described by Begg (1989) as a 'mixed hygrophilous grassland-sedge community'. Dominant plant species are given in Table 2.5. Additional "families" noted by the author include: (i) *Juncaceae* (rushes) - *Juncus effusus; (ii) Typhaceae* - *Typha capensis*; (iii) *Amaryllidaceae* - "vlei lilies" and (iv) *Potamogetonaceae* - "pondweeds". Additional species are included in bold type. Dominant hydrophytes found in the Highmoor wetlands, are outlined in Table 2.6. The tarns did not support a high diversity of Hydrophytes. Tarn 1 (T1) supports *Ilysanthes bolusii* (floating vegetation), while tarn T2 is characterized by a dense, homogenous stand of *Cyperus fastigiatus*. Within the wetlands several 'dryland' vegetation associations occur. These communities most likely exist as a result of micro- and macro-topographic variations within the wetland.

Table 2.5 Dominant grasses, forbs and sedges found in the Stillerust wetland, Kamberg

GRAMINEAE (GRASSES)	FORBS	CYPERACEAE (SEDGES)
Festuca caprina	*Gerbera ambigua*	*Carex cernua*
Poa binata	*Senecio sp.*	***Carex cognata***
Setaria obscura	*Tulbaghia acutiloba*	*Bulbostylis schoenoides*
S. sphacelata	*Ranunculus multifidis*	*Pycreus oakfortensis*
Harpechloa falx	*Aponogeton jinceus*	*Ascolepis capensis*
Miscanthus capensis	***Mentha aquatica***	*Schoenoplectus corymbosus*
Phragmites australis	***Crinum spp.***	*Kyllinga erecta*
Phragmites mauritianus		***Cyperus fastigiatus***
		Cyperus sexamgularis

(*Modified after:* Begg, 1989)

Table 2.6 Some hydrophytes common in the Highmoor wetlands

FAMILY	SPECIES				
GRAMINEAE (GRASSES)	*Pennisetum thunbergii*				
CYPERACEAE (SEDGES)	*Carex cognata*	*Kyllinga erecta*	*Cyperus fastigiatus*	*Cyperus sexamgularis*	*Xyris capensis*
POTAMOGETONACEAE	*Potamogeton thunbergii*				
AMARYLLIDACEAE	*Crinum spp.*				
FORBS	*Mentha aquatica*	*Gunnera perpensa*			

The materials and methods adopted in an effort to achieve the objectives of this study follows in Chapter 3.

Chapter 3

3. Materials and methods

3.1 Experimental approach

The present study comprised both field and laboratory work. Inductive, deductive, qualitative and quantitative approaches were synthesized in an effort to meet the aims and objectives of this study, outlined in Section 1.1.8. Prior to any field visits, wetlands located in the upper-Mooi River catchment were delineated from 1:10 000 ortho-photographs. The following features were noted:

- ☐ approximate altitude (m);
- ☐ terrain position;
- ☐ landform type;
- ☐ proximity of wetland to river channel;
- ☐ size (km^2);
- ☐ wetland shape;
- ☐ location of wetlands with respect to other wetland systems; and
- ☐ underlying geology.

This procedure was undertaken to gain an understanding of the location and diversity of wetlands in the study area. Numerous sites representative of dominant physical characteristics of the area as identified from the ortho-photos were then visited. Reconnaissance visits revealed that the wetlands located on private farmlands were subjected to a range of anthropic disturbances such as afforestation, overgrazing, drains and dams. As outlined in Section 1.1.6, anthropic activities may adjust natural wetland processes and disrupt wetland soil, thereby altering the natural functioning of the wetland. This makes the identification of natural processes and response mechanisms very difficult. Intensive investigations were therefore restricted to pristine wetland systems in the uKhahlamba-Drakensberg Park, the premise being that they may be used as reference wetlands, i.e. be used to develop reference standards against which similar wetlands can be evaluated. While the focus of this study was not on anthropogenically modified wetlands, a number of degraded or anthropogenically modified wetlands lower down in the catchment were assessed. Anthropic activities were documented, and the negative ramifications associated with these activities in terms of wetland functioning were qualitatively evaluated and discussed.

As outlined in Section 1.1.8, the research reported here has adopted a geomorphic/hydro-geomorphic approach in an attempt to identify and understand wetland genesis, wetland distribution, processes operative within wetlands as well as the likely evolution of different wetland systems.

Preliminary investigations indicated that water source and hydrodynamics were not always easily and correctly identified by field/map interpretation. Many processes operative within wetlands are very difficult to determine directly. The determination of how and where soil water moves in the field has been highlighted by Daniels *et al.*, (1971) as being labour and time intensive, and very difficult to measure. For this reason, wetland soils were investigated. As discussed in Section 1.2.2, soils reflect the historical hydrological condition of an area, and thereby may assist researchers in tracing the active, rapidly developing processes that maintain wetland functioning and dynamics (Richardson, 1996).

Variables and sub-variables considered to be important in driving wetland genesis, maintenance and functioning and investigated in the present study, are outlined in Table 3.1, together with a brief summary of the methods used. A detailed account of the field and laboratory and procedure undertaken in the present study is outlined in Section 3.2 and Section 3.3 respectively.

The statistical techniques adopted in this study, namely: Pearson Product Moment Correlation (PPMC), Principal Component Analysis, Canonical Variate Analyses, Monte Carlo tests, Analysis of Variances (ANOVA's) and the post hoc Tukey tests, are discussed where they are used in data interpretation in Chapter 5.

3.2 Field procedure

3.2.1 Broad geomorphic description

Each wetland was described in terms of its topographic position (using the 9-unit landscape model (Dalrymple *et al.*, 1968), (Fig. 1, Appendix 1), landform type and position relative to the overall drainage network. The hypothetical nine-unit landsurface model was adopted in this study in preference to the five unit terrain model as per the forest soils Database (1993), since it shows the relationship between slope position and dominant soil and land forming processes. A field sketch of each wetland was drawn from a vantage point (see Figures 4.1.5 - 4.1.8, 4.2.2, 4.3.3 and 4.3.4).

3.2.2 Sampling procedure and sampling sites

Most of the wetlands were large and complex, frequently displaying numerous arms. The wetlands were thus initially surveyed to ensure a fundamental understanding of the area of interest prior to choosing an appropriate sampling strategy and specific sample sites. Owing to the considerable size of most of the wetlands studied and the impracticalities of undertaking intensive grid sampling, sites were selected to provide information representative of conditions throughout a particular mosaic. Where feasible, transect sampling was adopted. Transect sampling is considered by many field scientists to be advantageous in that it has the potential to show progressive changes along a landscape segment, and quickly establish the local stratigraphic and geomorphic relations (Daniels and Hammer, 1992). Changes in elevation, hydrology and vegetation patterns largely determined the sample site locations, as suggested by Reese and Moorhead (1996). Sample site positions are indicated on filed maps.

Table 3.1 Variables and sub-variables investigated, overview of methods adopted

VARIABLE	SUB-VARIABLE(S)	METHOD
CLIMATE	→**temperature** →**evaporation/ evapotranspiration** →**rainfall timing, amount and intensity**	Indirect - Weather Station data analysis
GEOLOGY	→**rock type and structure** →**location of joints, strikes, dykes, sills etc.**	geological maps (Council for Geo-Sciences); literature; field examination
GEOMORPHOLOGY	→**topographic position**	field/map assessment: 9-point slope model
	→**landform assessment**	5 basic landform types identified by: Semenuik and Semenuik (1995), Figure 1.3; general geomorphic literature
	→**inclination, aspect and length of slopes**	measuring rod and abney level field and topographic map assessment / measurement
	→**relation of site to drainage line / river channel**	assessment of the nature of the wetland surface, i.e. presence/ absence of: hummocks, mounds, rock outcrops, pools etc.
SOIL	→**colour** (soil body, mottles)	munsell soil chart
	→**mottling abundance**	field assessment, see **Section 3.2.5**
	→**moisture content**	three class classification: dry, moist, saturated (**Section 3.2.5**)
	→pH	laboratory pH meter (KCL; H_2O)
	→**texture** % sand, silt and clay % coarse, medium and fine sand	pipette method; standard sieve stack method
	→**shrink, swell and flow potential**	Atterberg Limits
	→**organic matter content**	Walkley Black Method
	→**exchangeable bases**	atomic absorption and flame spectroscopy
	→**exchangeable acidity**	determination by titration
	→**cation exchange capacity**	calculated (sum of the exchangeable cations and exchangeable acidity)
	→**degree of o/m decomposition** (Fibric, Mesic or Sapric)	Farr and Henderson's (1987) classification
HYDROLOGY	→**primary input(s)** e.g. precipitation; surface runoff; g.w discharge; overbank flooding) →**nature of throughput(s)** e.g. surface runoff; matrix through flow; piping; channel flow →**primary output(s)** e.g. evaporation; infiltration/g.w.recharge; surface runoff; channel flow	direct and indirect assessment: - geological type: permeability, location of joints etc. (geological maps) - field indicators (e.g. iron ochre indicates g.w. discharge) - soil data information (e.g. soil texture, base concentration etc.)
	→**hydroperiod** (general hydrological regime)	wetness classes (permanent, temporary, seasonal) (Table 3.2)
	→**depth of standing water**	ranging rod
	→**depth to the water table**	auger whole method
	→**channel velocity / discharge**	floats, ranging rod and stopwatch
VEGETATION	→**effective cover** (density, height)	field estimation (%); ranging rod
	→**dominant hydrophyte identification**	field identification; sample collection - consultation with wetland specialist: Donovan Kotze.

3.2.3 Micro-topography, vegetation and organic matter assessment

A brief description of the surrounding micro-topography was recorded at each sample site, since in many instances it determines whether a site receives run-on or is contributing run-off, and may hence influence soil and vegetation characteristics. Vegetative characteristics such as: species composition, percentage cover and height were documented. The nature of the organic layer was determined in the field using the nomenclature of organic horizons outlined in Dackombe and Gardiner (1983).

3.2.4 Soil sampling procedure

While extremely wet samples were extracted using a bucket auger, in most instances a Dutch screw auger, with a diameter of five centimetres was used, as it posed minimum soil destruction. Soil samples were collected when a change in colour and/or texture was noticeable until bed rock was reached, or, in some cases to a depth of 220 cm (the maximum length of a standard auger plus extension).

3.2.5 Field assessment of wetland hydroperiod

3.2.5.1 Modified version of Begg's (1990) morphological criteria

The hydroperiod of wetland sample sites was indirectly determined using soil morphological criteria, discussed in Section 1.2.2. Beggs (1990) provisional four class system for determining the degree of wetness of soils by using soil morphological criteria (Table 1.3, Section 1.2.2), was modified slightly. While assessing soil morphology to a depth of 40 cm (Begg's 1990 system) or 50 cm (Soil Survey Staff, 1975), is adequate for wetland delineation and rapid assessment of wetland hydroperiod, the entire profile was investigated in this study in an effort to obtain a holistic picture of the driving processes causing the wet, waterlogged conditions. By investigating the entire profile, it is argued that reasons for wetness can be ascertained. For example, wet conditions may be the result of an impermeable surface layer, restricting infiltration and promoting water accumulation, or alternatively the result of groundwater recharge. The specified depths i.e. 0 -10 cm and 30 - 40 cm was found to be too fine/arbitrary in this study. There was frequently only a difference in soil morphology at the 0 - 20 cm - 20 - 40 cm interface.

Table 3.2 A provisional four class system based on soil morphology for determining the degree of wetness of wetland soils

	Degree of wetness			
	Non - wetland	**Temporary**	**Seasonal**	**Permanent / semi-permanent**
Matrix chroma	> 3	1 - 3	0 - 2	0 - 1
mottle abundance	few / no mottles	no / few / common	many mottles	no mottles
organic matter content	low / medium organic matter	low / medium organic matter	medium organic matter	high organic matter

(*Modified after:* Begg,1990)

Soil/mottling colour

The hue, value and chroma of the soil matrix and mottles were described in the field with reference to Munsell notations. While every effort was taken to ensure accurate documentation of soil colour, potential problem areas are outlined below:

- the probability of having a perfect match of the sample colour is less than one in one hundred (Munsell Soil Colour Chart, 1992). Difficulties were frequently experienced when trying to determine colours that were intermediate between hues in the chart.

- The Munsell Soil Colour Chart (1992) does not include some extreme dark and strong (low value, high chroma) colours, frequently encountered in wetland environments. (This potential difficulty is also recognized in the Munsell Soil Colour Chart, 1992).

Mottling abundance

A four class system for estimating relative mottling abundance was adapted from the Munsell soil book. (None = 0 %; few = 0 -1 %; common = 2 - 3 %; many = 4 -10 %).

3.2.5.2 Moisture content

The *in situ* moisture content of the soil was classified according to three broad moisture classes, defined in this study as:

- **dry:** soil was friable, crumbled easily between fingers.
- **moist:** soil was pliable. When squeezed in hand, soil deformed, but did not discharge water.
- **saturated:** when squeezed in hand, a soil/water slurry passed through ones fingers.

Water content was not determined in the laboratory owing to the delay period before samples could be analyzed; prolonged storage is understood to be far from ideal in the case of soil moisture determination (Curtis and Trudgill, 1974). According to Curtis and Trudgill (1974), should storage be necessary, each sample would require an airtight container (corked and sealed glass tubes/ aluminum foil containers), and in addition, low storage temperatures (8°C - 10°C). These basic requirements were beyond the financial and human resources available. The use of a Speedy Moisture Meter (Ashworth Speedy Moisture Tester) to determine *in situ* water contents in the field was investigated, but proved impractical because of the bulk and weight of the equipment. More importantly, it is not sensitive enough given the high water contents of wetlands.

The three broad classes defined above, while crude, were used to simply provide a relative idea of soil wetness at different sites. Accurate soil moisture measurements were not deemed necessary since monitoring was not undertaken throughout the hydrological year, and would hence be virtually meaningless considering that water content can fluctuate greatly over a 24-hour period.

3.2.5.3 Indicators used to determine discharge sites

Indicators used in this study to identify groundwater discharge sites include: (i) an oily covering on the surface of standing water (Fig. 2.1, Appendix 2); (ii) iron orchre deposits (Fig.

2.2, Appendix 2); (iii) exceptionally cold water regions compared to surrounding ponded water - all other variables constant; (iv) permanently wet conditions (direct field evidence - vegetation and soil indicative of permanent saturation); and (v) soil/sediment displaying a characteristic sulphur smell, indicative of anoxic, permanently wet conditions. These indicators were identified through field investigations, the general wetland literature and consultation with *inter alia*: Hughes (2000) and Beckedahl (2001).

3.3 Laboratory procedure

3.3.1 Pretreatment for analysis

Soil samples were air dried as opposed to oven-dried, since in many cases the samples were high in clay and organic carbon, and hence regarded as particularly vulnerable to organic and/or mineral transformations (Baize, 1988). Once the soil samples were completely dry, samples were disaggregated using a ceramic mortar and pestle. Care was taken not to pulverise or grind the primary particles. The soil was then passed through a 2 mm sieve and stored in sealed labelled bags for further laboratory analyses.

3.3.2 Textural analysis (< 2mm)

3.3.2.1 Pipette method

The pipette method was used to determine particle size and hence textural characteristics of wetland soil. This method is based on the measurement of the weight of sediment retained in the suspension after a known time. As with the hydrometer method, the pipette method depends on Stoke's Law governing settling velocities of particles in a liquid medium. (See standard soil texts for a detailed account of this method, *inter alia* Goudie *et al.*, 1981).

Air-dried samples (10g) were treated with 50 g of sodium hexametaphosphate (Calgon), an effective dispersing agent, and subjected to an ultrasound (20kHz at 350 Watts) for five minutes using a probe sonicator (Braun Ultrasonic-Homogenizer Labsonic U), to ensure thorough dispersion, i.e. overcome the effect of bonding materials such as organic matter and oxides. Clay (< 2 µm settling diameter) and silt (2-20 µm) fractions were determined by sedimentation and pipette sampling, and expressed as a percentage of oven-dried soil. The sand fraction (0.02 - 2 mm) was calculated by difference.

Despite the numerous assumptions of Stoke's Law which are generally difficult to satisfy in the laboratory (outlined in *inter alia* Briggs, 1997), this method is still recognized as providing very accurate results (Briggs, 1997). The main disadvantages of the pipette method is that it requires very precise weighing of fractions retrieved from suspension (Briggs, 1997). Every effort was taken to ensure accurate results: (i) beakers were oven dried and then cooled in a desiccator (to prevent variation in mass due to humidity), and (ii) a three point balance was used to ensure accurate mass determinations.

3.3.2.2 Vibrating sieve stack

The separation of the sand fraction was achieved by dry sieving, using standard 200 mm star screen test sieves with aperture sizes of 500, 250, 106 and < 106 µm. A vibrating sieve stack (Endecotts: model E.V.L.1) was used. The shaking frequency was set at 60 Hz to minimize the chance of loss of finer particles by percolation through the sieve contacts (Briggs, 1997). A sieving time of nine minutes was used. The sieves were weighed on a three point balance and cleaned with a brush between sample analyses.

While McTainish and Duhaylungsond (1989) caution that this method may introduce slight inaccuracies as a result of a limited range of sieve sizes not adequately representing the broad distribution of particle sizes in many soils, it is argued that the standard sieve stack method offers a simple, inexpensive means of providing relatively accurate sediment size distributions. More importantly, with the same method having been used for all samples, the results are certainly useable for comparative purposes.

3.3.3 Physical properties of wetland soils

3.3.3.1 Atterberg limits

Atterberg limits provide indications of three soil states, namely: solid, plastic and liquid. The three states of the soil are determined by the liquid limit (LL), shrinkage limit (SL), and plastic limit (PL) respectively.

☐ **The Liquid limit (LL)** indicates the moisture content at which the transition from plastic to liquid states occurs. It is commonly defined as the moisture content at which a soil paste will flow under the pressure of a small force (Smith and Atkinson, 1975). Carter and Bentley (1991) define the LL to be the minimum moisture content at which the shear strength of the soil approximates zero. The shear strength of soil is progressively reduced by increasing the moisture content until a specific energy input causes a failure (Cooke and Doornkamp, 1990).

☐ **The shrinkage limit (SL)** is defined as the moisture content of the soil at which the volume remains constant upon drying (Smith and Atkinson, 1975).

☐ **The Plastic limit (PL)**

The plastic limit is defined as the water content at which the soil begins to crumble when being rolled into a thread three millimetres in diameter (Sowers, 1961). According to Carter and Bentley (1991), the plastic limit test should be regarded as a measure of the energy required to fracture soil, which is also related to shear strength, despite the fact that there are no obvious analogies for the mechanism of failure. It has been found that all soils at the plastic limit exhibit similar values of undrained shear strength, reported by a number of researchers as being 100-200 Nm^{-2} (Carter and Bentley, 1991). The plastic limit is a useful measure of the minimum water content at which soil can be deformed readily without failure (cracking) (Sowers, 1961), or the minimum content at which the sample shows plastic behaviour (Smith and Atkinson, 1975).

The liquid and plastic limits are expressed as the moisture content percent of the dry weight. The shrinkage limit is expressed as a percentage, using equation 3.1 (Whalley, 1976 and Goudie, 1981).

$$SL = (1 - (\text{length after drying} / \text{initial length})) \times 100 \quad \text{equation 3.1}$$

Standard methods (*inter alia* Goudie *et al.,*1981) were followed. The above procedures were replicated three times on each sample, and the average value recorded. Atterberg limit determinations are extremely time consuming, and were therefore conducted on only a small sub-sample of the sites investigated.

Two potential limitations of Atterberg limits are (i) that limit tests are performed on material finer than 425µm. The degree to which this fraction reflects the properties of the soil will depend on the proportion of coarse material present and the precise grading of the soil; and (ii) limit tests are performed on remoulded soils and the correlations may not be valid for undisturbed soils unless the soil properties do not change substantially during rebounding. The above limitations are not deemed problematic in this study, since the majority of soil samples collected were comprised of particles finer than 425µm, the samples displayed limited coarse particles. Furthermore, the wetland soils are not cemented, but generally wet and pliable, suggesting that the Atterberg limits provide a fairly good estimate of field conditions. According to Whalley (1976), the plastic limit is influenced by both the skill and experience of the operator, and is hence regarded as a subjective parameter. The drop cone penetrometer (Farnell Testing machine, Civil Engineering Test Equipment, Hatfield, England, 10ths m/m) was used to determine liquid limits, as it is regarded as simple, reproducible, and not particularly sensitive to operator bias (Sowers, 1961). According to Davidson (1983), however, the degree of remolding and the time period over which the samples are tested, as well as wetting and drying cycles during the testing period, may have major effects on the liquid limit values as determined by this method. While the potential problems indicated by Davidson (1983) warrant consideration, the liquid limit results appeared to provide a fairly good indication of the susceptibility of soil to flowage. Care was taken to ensure that the water content of the soil paste used in the shrinkage limit tests was constant, since according to Carter and Bentley (1991), shrinkage limit results may vary depending on the initial moisture content of the test specimen.

3.3.3.2 Plasticity index (PI)

The plasticity index (PI) reflects the ratio of clay minerals to the silt and fine sand in a soil (Carter and Bentley, 1991). Carter and Bentley (1991) define the PI as the change in water content required to bring about a strength change of roughly one hundred-fold, within the plastic range of the soil. The PI of soils is essentially a function of the Atterberg Limit results, as illustrated in equation 3.2.

$$PI = LL - PL \quad \text{equation 3.2}$$

3.3.3.3 Soil activity (A_c) and swelling potentials

The ratio of the PI to percentage of material finer than 2µm, can, according to Skemton (1953) give an indication of the plasticity of the purely clay-sized portion of the soil which is termed 'activity'. The 'activity' of a soil is a measure of the propensity of clay to swell in the presence of water. A high activity is associated with those clay minerals that can adsorb large amounts of water within their mineral lattice. Penetration of the clay minerals by water molecules, causes an increase in volume of the clay minerals, so that the soil swells. Soil activity is traditionally calculated using equation 3.3.

$A_c = PI/C$ ....equation 3.3

C = the percentage material finer than 0.002mm)

The swelling potential of soil was determined using equation 3.4.

$S = 60K\,(PI)^{2.44}$ .... equation 3.4

(K is a constant equal to 3.6×10^{-5})

3.3.4 Clay mineralogy

Clay mineralogy was indirectly determined with reference to typical Plastic and Liquid limit ranges, in association with dominant pore water cation (Ca^{2+}) (outlined in Carter and Bentley (1991, p.106, Table 8.2). Reference was also made to Carter and Bentley's (1991) outline of clay types and associated/predicted activity values (Table 1.1, Appendix 1).

3.3.5 Soil pH

Soil pH was determined electrometrically using a laboratory pH meter (PHM 80 Portable pH Meter, Radiometer A/S Copenhagen, 64R70N07). pH analyses were conducted in both water and KCL solutions, since water pH frequently does not take into account all of the acid ions (protons and aluminum ions). In each case 10g of soil was shaken in a stoppered vial with 25 ml of the equilibrating solution, giving a soil:solution ratio of 1:2.5.

3.3.6 Organic carbon

Total organic carbon contents (O/C) were obtained using the Walkley Black method (1934). This method is based on wet oxidation (potassium dichromate in a sulphuric medium), as discussed in many introductory soil texts (see *inter alia* Baize, 1993). The high organic matter contents of these wetland soils, necessitated the use of 0.5 g of soil, as opposed to the standard 1.0 g of air-dried soil in these analyses.

The ash content was not adopted in this study since despite the soils containing relatively high organic matter contents, soils are largely mineral, with significant clay contents. Baize (1993) and Rowell (1994) maintain that when the loss on ignition method is conducted on heavy textured soils such as clay, values may be out by up to two times the organic matter content, as a result of clay and sesquioxides losing 'structural' water (generally at between 109 and 500°C) (Rowell, 1994).

The organic carbon results were not used to determine organic matter values, as the soil samples showed substantial ranges in both organic carbon content and the degree of humification. The choice of an appropriate ratio was hence difficult. French analytical laboratories multiply by a factor of 1.72 or 2.0 (Baize, 1993); while Avery (1990) recommends the value 1.9 for well-humified mineral surface horizons, which is not considered appropriate by a number of authors. It was hence decided to work with O/C values as opposed to organic matter values, since the latter is in effect an approximation.

3.3.7 Exchangeable acidity

Exchangeable acidity was assessed by the displacement of exchangeable and solution acidity (H^+ + Al^{3+} ions), and their determination by titration with a base. Soil samples were equilibrated with an unbuffered 1N potassium chloride solution, which was centrifuged at 3000 rpm (Hettich Universal centrifuge, type: 1-200), and then filtered through Whatman 41 filter paper. An aliquot of filtrate was titrated against a standardized NaOH solution using a burette. Exchangeable acidity was then expressed in terms of $cmol_c\ kg^{-1}$.

3.3.8 Exchangeable bases

Soil samples were equilibrated with 1M neutral ammonium acetate (CH_3COONH_4) for 10 minutes in stoppered centrifuge bottles on a tumbler. The resulting slurry was then centrifuged to 3000 rpm and then filtered through Whatman 41 filter paper. The filtrate was suitably diluted and appropriate iodization suppressants were added. The extracts were stored in a cold room prior to analysis to avoid modifications in concentration caused by: high ambient temperatures or alternating heating and cooling. The basic cations in solution, namely: sodium (Na) and potassium (K), and the alkali earths, magnesium (Mg) and calcium (Ca), were determined using atomic absorption and flame spectroscopy (Varian AA 10B instrument). Exchangeable bases were then expressed in $cmol_c\ kg^{-1}$ soil.

The sum of the exchangeable basic cations is known as the S-value, and is calculated using the following formula:

S-value = $\sum$ exchangeable (Ca^{2+} + Mg^{2+} + K^++ Na^+) $cmol_c\ kg^{-1}$ soil ....equation 3.5

The Effective Cation Exchange Capacity (ECEC) was calculated as the sum of the exchangeable cations and the exchangeable acidity:

ECEC = $\sum$ exchangeable (Ca^{2+} + Mg^{2+} + K^++ Na^+ + H^+ + Al^{3+}) $cmol_c\ kg^{-1}$ soil ....equation 3.6

The Base Saturation Percentage was calculated as the proportion of the effective cation exchange capacity occupied by the basic cations, expressed as a percentage.

Base saturation % = S-value x 100% / ECEC ....equation 3.7

3.3.9 Leaching determination

In addition to field observations of soil chroma, and wetland soil pH analyses; two leaching indices were used, namely the: S-value per unit mass of clay (equation 3.8) and the Ca:Mg ratio (discussed in Donkin, 1991).

S-value per unit mass of clay = S-value x 100/clay % ($\mathrm{cmol_c kg^{-1}}$ soil).............equation 3.8

The genesis and maintenance of the wetlands investigated in the Highmoor, Kamberg and Impofana Nature Reserves are discussed in the following chapter.

Chapter 4

4. The geomorphology, dynamics and maintenance of wetlands

Climate, geomorphology, soil characteristics, hydrology and geology, all contribute to wetland origin as already indicated. Wetland functioning, maintenance and long term evolution are also governed by these factors. The weather and climatic conditions experienced in the Highmoor, Kamberg and Impofana reserves are essentially similar. It is postulated that the high rainfall, relatively low temperatures and evaporation in comparison to figures characteristic over most of the subcontinent, may largely account for the relatively common occurrence of highland wetland systems. High rainfall also promotes high groundwater tables, which cumulatively promote 'wet land' conditions (Carter, 1986; Stone and Lindley Stone, 1994).

The other factors believed to promote wetland genesis and maintenance *viz.* the geomorphology (topography, landscape position, micro-topography) of the wetland itself and surrounding zones, soil characteristics, hydrology and geology, differ between sites. The physical characteristics and attributes of the wetlands and proximal 'upland' areas of the Highmoor, Kamberg and Impofana reserves were hence investigated individually, and their probable influence on wetland origin and maintenance assessed.

4.1 The Highmoor wetlands

4.1.1 Relief

The Highmoor wetlands are mainly located within positions six and seven of the nine-unit landsurface model (Dalyrymple *et al.*, 1968). The wetland zone does, in some instances, extend from position four to seven, i.e. incorporating what may be termed slope wetlands. These areas are termed 'source seepage zones' in this study, and represent zones of ground or slope water seepage. While the Highmoor wetlands all occupy the headward reaches of river valleys, the nature of the physical terrain i.e. valley dimensions, length and gradient of bordering valley slopes, and the gradient of the valley bottom location itself differ. For example, wetland H1 is located in a very steep sided, narrow wetland setting, while wetland H2 is found in a basinal setting. The Highmoor wetlands, particularly wetlands H2 and H4, also located in basinal settings, may be comparable to what Semenuik and Semenuik (1995) refer to as 'containers' within the landscape. The geomorphology and morphometry of the wetlands are summarized in Table 4.1. Figures 4.1.1 - 4.1.4 illustrate the landform characteristics and the nature of the wetland systems found at Highmoor. A detailed sketch map of each wetland (Figures 4.1.5 - 4.1.8), illustrates the approximate shape and form of each wetland.

The wetland side slopes, while varying in length and gradient, all promote runoff into bottom-land positions. The characteristic low gradients of these wetland systems attenuate runoff velocities, and thereby promote water accumulation. Macro-topographical irregularities of wetlands, frequently in the form of 'lobes' or mounds, were found to be important in obstructing or deflecting water flow paths, and thereby reducing flow velocities and promoting water accumulation. Micro-topographical variations include abandoned or ephemeral channels, circular pools and depressions, hummocks (ranging from 30 cm to 100 cm+), and isolated rock outcrops. Apart from increasing surface roughness and reducing flow velocities, interhummock hollows and pools are important water storage sites. The storage capacity of wetland pools and depressional areas are, in most cases, in the order of 20 to 25 cm. While the effectiveness of the depressions in reducing runoff velocity and retaining water may be compromised when depressions are filled with water, (effectively creating a relatively smooth surface, which promotes water runoff), the depressions only reached maximum storage capacity following exceptionally heavy precipitation events. The ponded water depth in these depressional areas over the wet months fluctuated between five and 15 cm. Surface irregularities varied across the wetland surfaces, suggesting that certain zones within the wetlands may be more effective at retaining water than other positions; cumulatively however, the wetlands appear to be effective in slowing down water flow and promoting water storage.

In addition to these wetland systems acting as reservoirs, retaining water inputs via direct precipitation and runoff, the groundwater table is generally closer to the surface beneath valleys (Daniels and Hammer, 1992), and thereby contributes to wet conditions by means of capillary seepage. The watertable may also intercept the surface and thereby result in wet, waterlogged conditions. Field evidence indicates that toe-slope seepage and groundwater discharge are dominant processes in these wetland systems, contributing significantly to wet conditions.

4.1.2 Geology

The geology of the valley in which wetland H1 is situated, comprises four different lithologies. The wetland overlies dolerite in the headward zone, and then intrudes the Clarens, Elliot and Molteno formations. The majority of the wetland area however, is underlain by dolerite. The basal and proximal areas of wetlands H2, H4 and H5 are all situated on a dolerite base. Dolerite is relatively impermeable (Brink, 1981), and is hence effective in impeding local drainage.

The 'upland lobes' found within these wetlands, can probably be attributed to resistant rock outcrops that influence water flow paths and promote water accumulation. Knick points, identified in the field as micro-waterfall features, are found at the base of all the Highmoor wetlands, and sometimes within the wetland itself (as was the case in wetlands H4 and H5), appear to be the result of a band of resistant rock being breached. Field evidence suggests that these small knick points or resistant dolerite dykes or sills, promote the accumulation of water behind these structures. The location of waterfalls at the base of all the Highmoor Source seepage wetlands, including other Highmoor wetlands not directly investigated in this study, and source seepage wetlands located on private farmland), suggest that the origin and maintenance of wetlands in this area are strongly geologically controlled.

Table 4.1 Summary of the geomorphology and morphometry of the Highmoor wetlands investigated in this study

WL	landform setting	wetland geomorphology (landform characteristics)	approx. area (km^2)	shape
H1	very steep upland valley (U-shaped)	GRADIENT: not greater than 1%. SIDESLOPE CHARACTERISTICS: very steep, ranging from: 25 - 40°. SURFACE IRREGULARITIES (ROUGHNESS): low to moderate.	0.23	elongate (seepages extending from valley sides are indicated in Figure 4.1.5 as minor arm-like extensions)
H2	basinal setting	GRADIENT: not greater than 1%. SIDESLOPE CHARACTERISTICS: relatively steep. Slope lengths varied quite substantially; slope angles ranged from > 5° to < 21°. SURFACE IRREGULARITIES (ROUGHNESS): moderate to high	0.63	irregular (arm-like extensions present)
H4	complex valley / basinal setting (comprised of two distinct levels. The upper wetland area is very much smaller than the lower portion)	GRADIENT: variable, majority of wetland not greater than 1%. SIDESLOPE CHARACTERISTICS: ranging from: 5 - 30°. SURFACE IRREGULARITIES (ROUGHNESS): moderate to high [hummocks, inter-hummock hollows, pools and isolated rock outcrops]. GENERAL CHARACTERISTICS: A minor watershed was present in this wetland, the relative location is indicated in Figure 4.1.3; in this zone, water was noted flowing left and right around the large upland area. The meso- and macro- topography was noted to be very important in influencing/ directing preferential flow paths. The upper level of this wetland is an important feeder to the large wetland portion below.	0.25	oval (no arm-like extensions are present)
H5	steep upland valley (the main body of the wetland is situated at the bottom of a U-shaped upland valley).	GRADIENT: variable, generally in the order of 1%. H5 has an altitudinal range of 60 m, the headward reaches of the arms are situated at 2080 m.a.s.l., the base of the wetland at 2020 m. SIDESLOPE CHARACTERISTICS: sideslope characteristics of arms A and B are gentle, in the order of 3°. Long and steep side slopes bordered arm C; slope length: 70m ; slope $\angle$ 22 °. SURFACE IRREGULARITIES (ROUGHNESS): High. [Hummocks, ranging from 30cm to 100cm+, inter-hummock hollows, a maize of pools and waterfall features].	0.75	irregular (arm-like extensions present)

Figure 4.1.1 An oblique view of wetland H1. Note the very steep adjacent side-slopes of this valley bottom wetland. Wetland areas are characterized by darker green vegetation.

Figure 4.1.2 An oblique view of a characteristic section of wetland H2. Note the gentle basinal landform characteristics of this wetland.

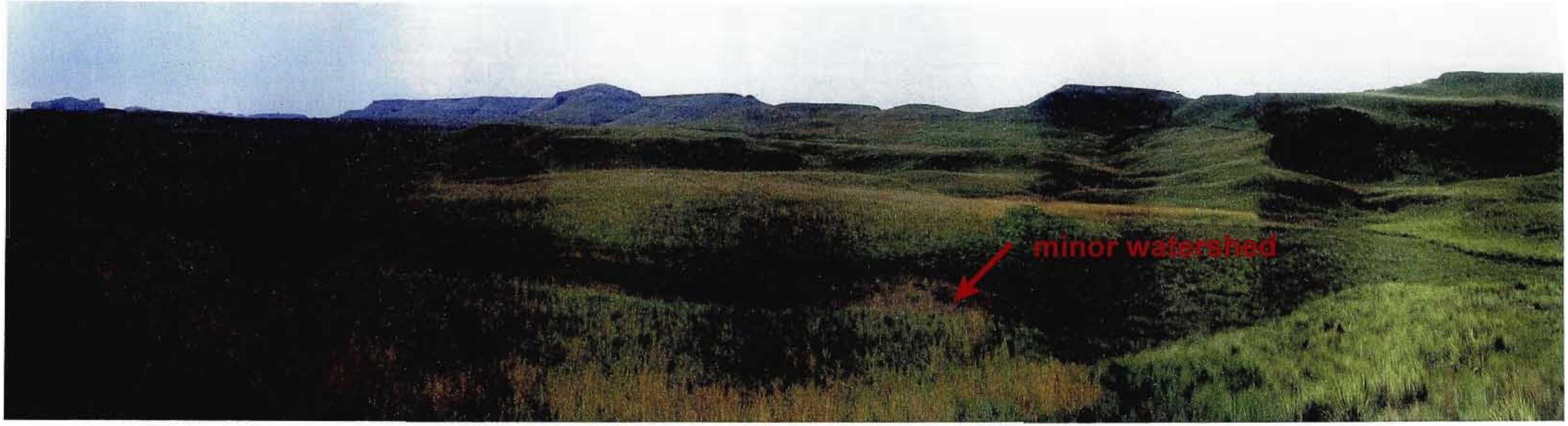

Figure 4.1.3 An oblique view of a typical section of wetland H4. Note the gentle topography and basinal setting of this wetland.

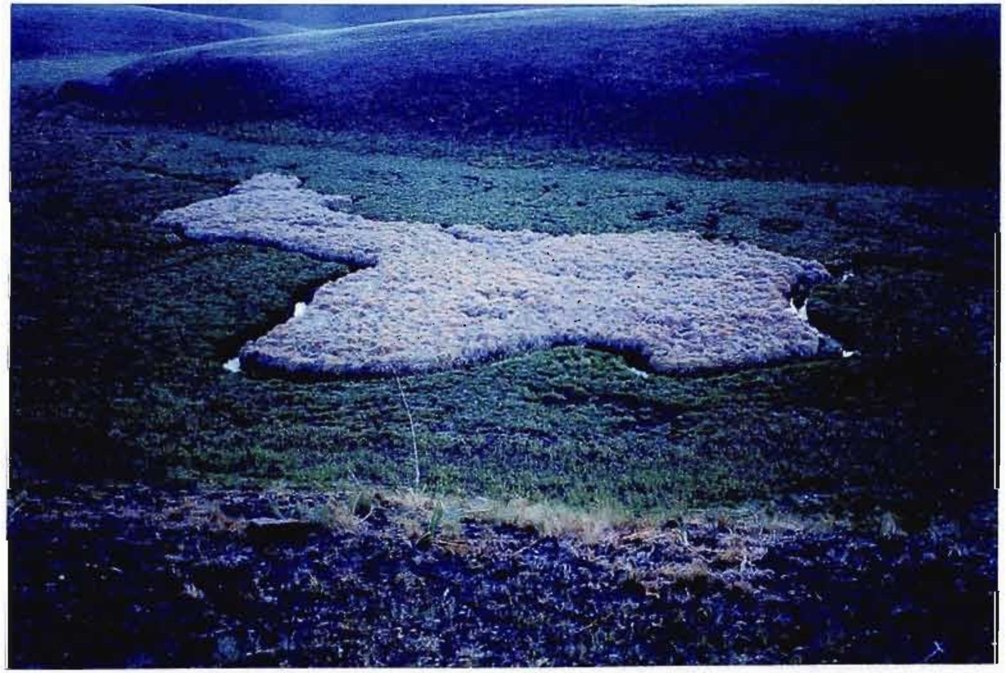

Figure 4.1.4 Wetland H5. Note the steep adjacent side-slopes of this flat, valley bottom wetland

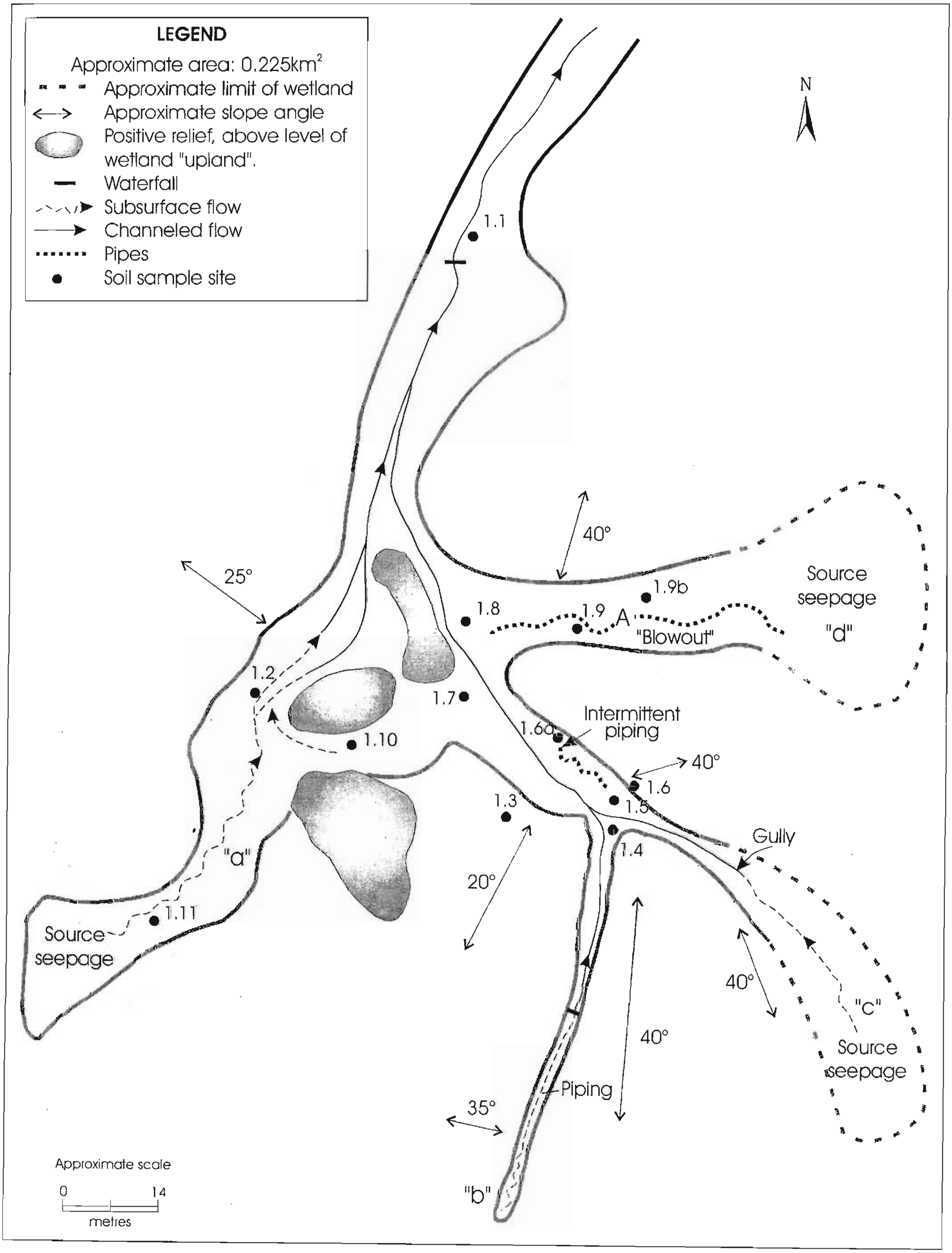

Figure 4.1.5 Field map of wetland H1.

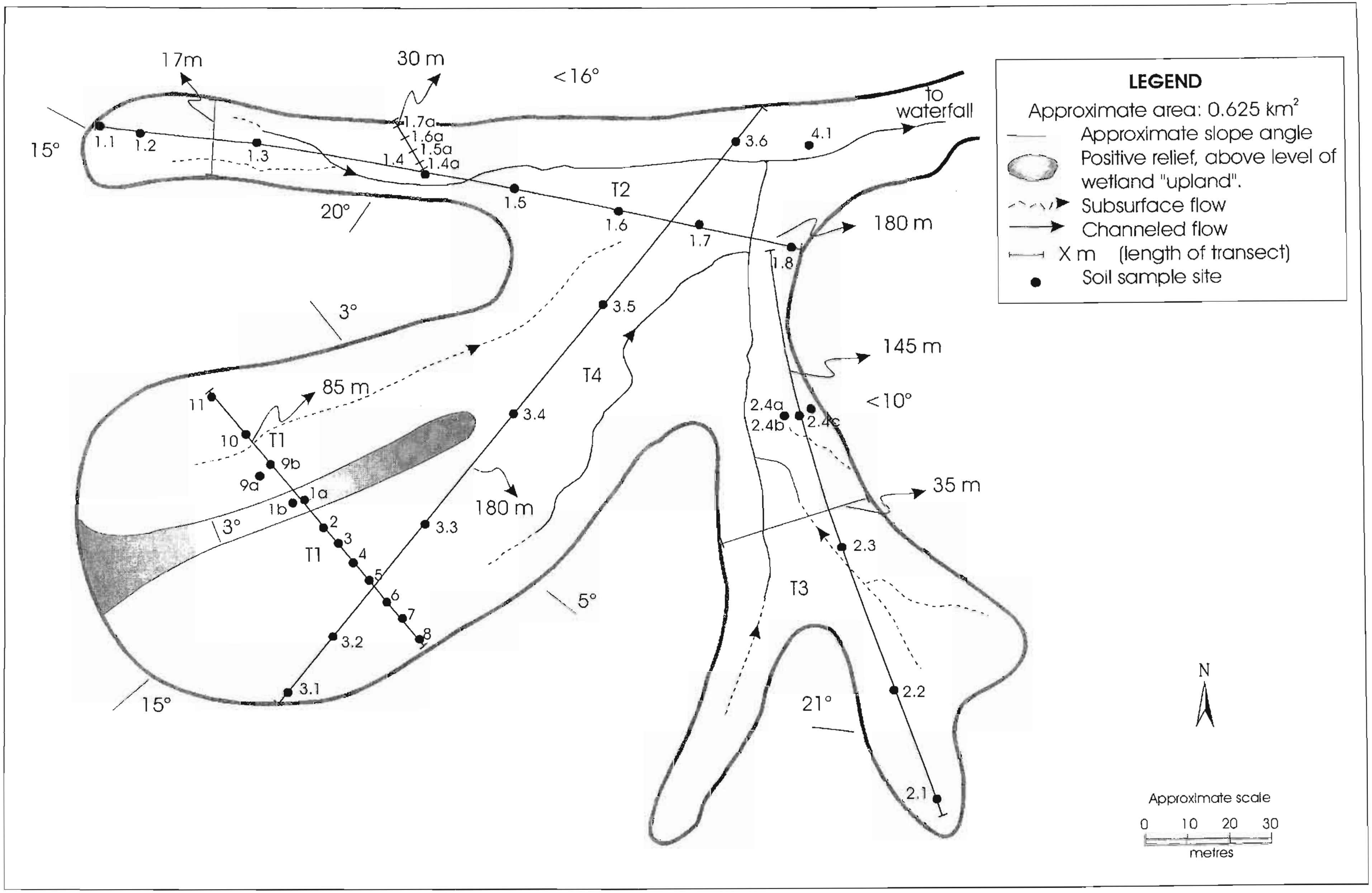

Figure 4.1.6 Field map of wetland H2.

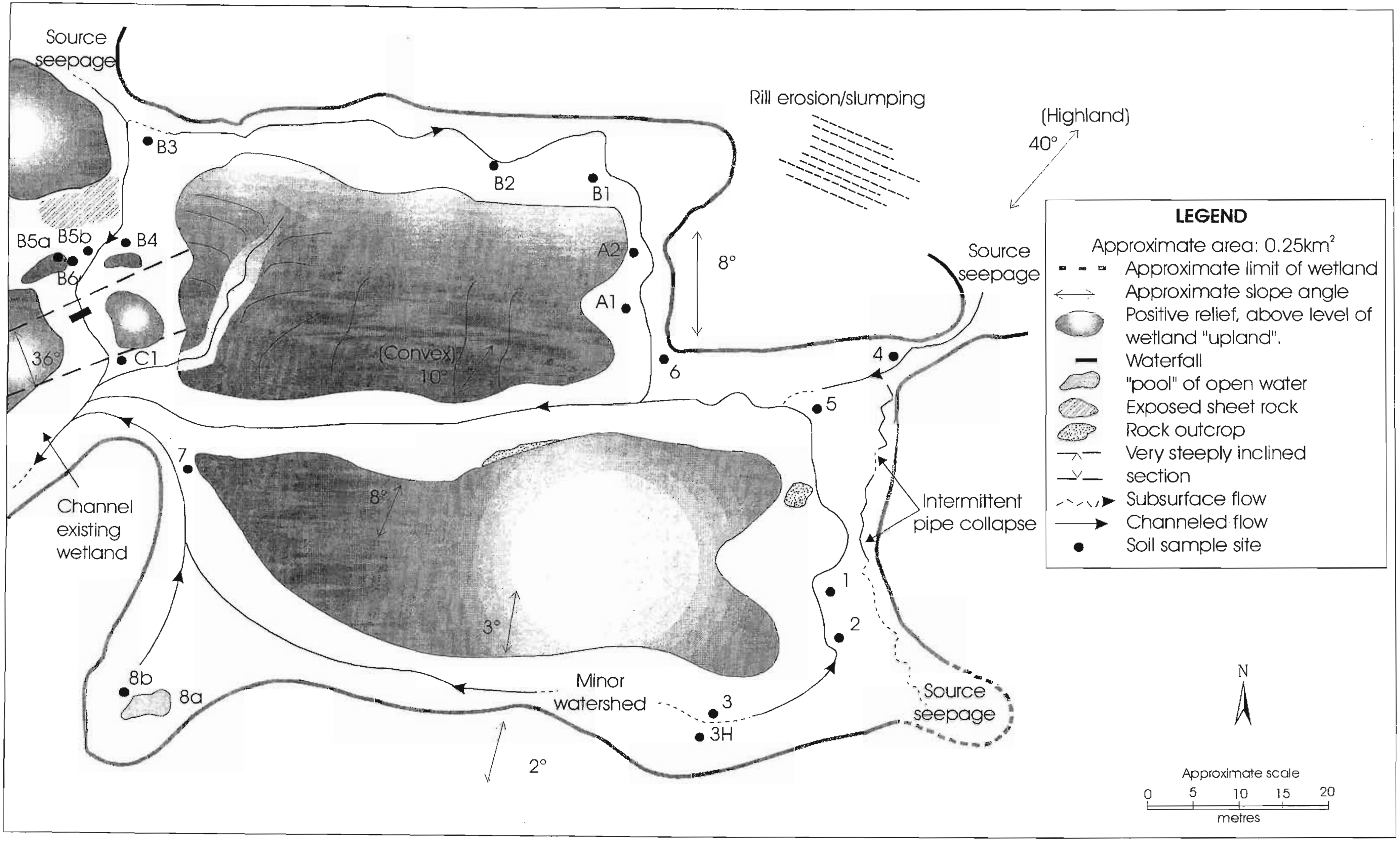

Figure 4.1.7 Field map of wetland H4.

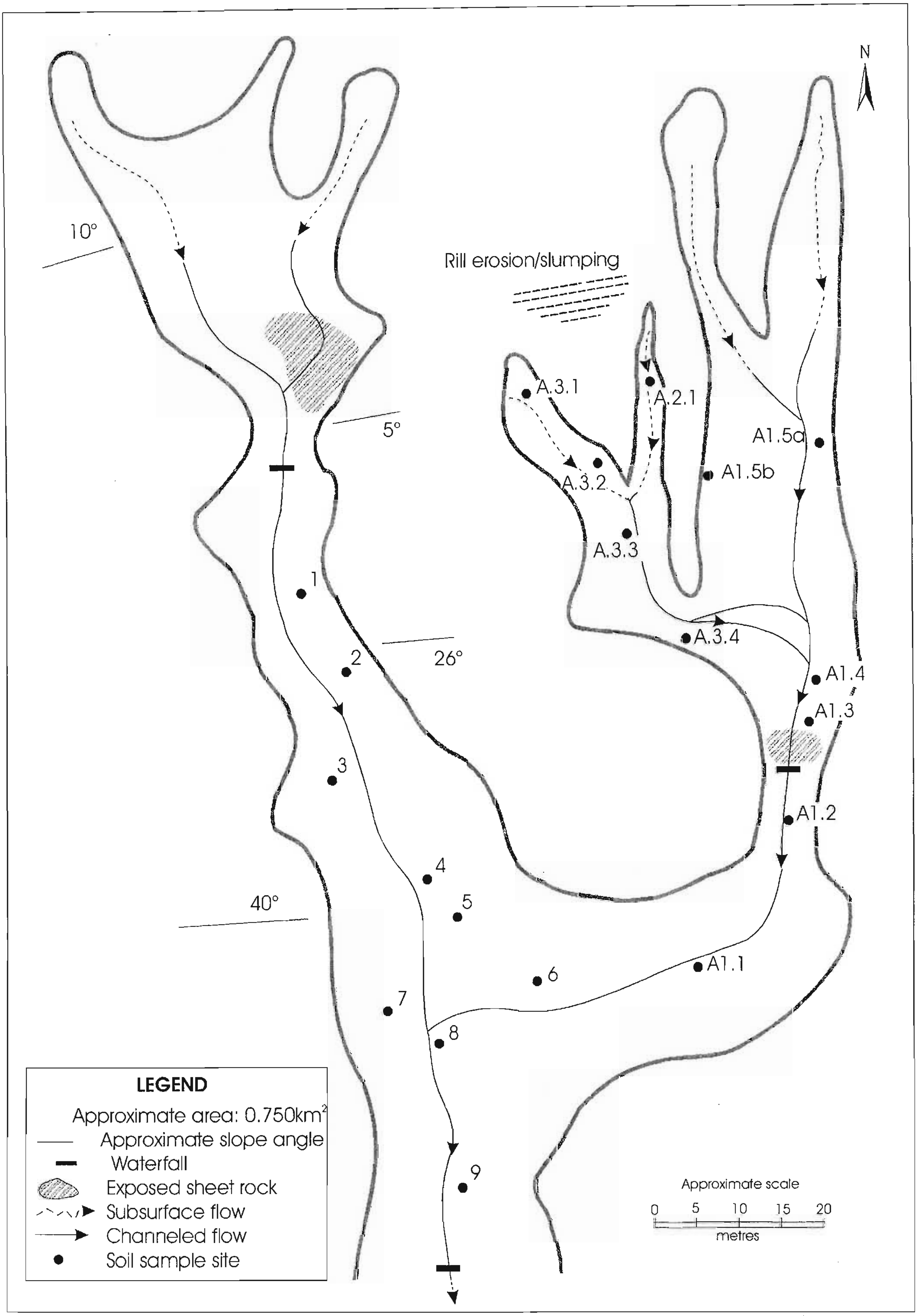

Figure 4.1.8 Field map of wetland H5.

Slight jointing activity was noted on exposed bedrock in the vicinity of the wetland systems. While no direct evidence of jointing within the Highmoor wetlands was obtained, exceptionally deep and wet zones in relation to surrounding areas were noted in wetlands H2 and H4. In wetland H2 for example, site H2.3.3 and H2.1.2 were characterized by deep, permanently wet profiles (130 and 150 cm's respectively), and were very different from proximal areas. These sites correspond to the dominant dyke direction in the area. It is probable that the deep soil profiles and permanently wet conditions may be the consequence of joints acting as conduits for water flow, promoting weathering and hence deep, well developed profiles. According to McFarlane (1989), an increased concentration of fractures, faults and joints in the bedrock, allows deeper or more advanced weathering; the same occurs however, where the rock is composed of minerals more susceptible to chemical breakdown. More intensive field investigations are required, before any definitive conclusions on the role of joints within these wetland systems can be attained. It is proposed that an appreciation of jointing extent and location would be beneficial in terms of understanding wetland processes and dynamics operative within these wetland systems, since as previously outlined, joints have an important influence on wetland hydrology, by acting as conduits for water flow, either to or from the watertable.

4.1.3 Hydrology

As indicated in Chapter 2, Figure 2.3, the study area experiences a moisture deficit (i.e. evaporation exceeds precipitation) from April to November. Although substantial areas of the wetlands investigated were assigned as temporarily and seasonally wet zones (according to soil morphology criteria), substantial areas remained saturated over winter. Ponded water was even present in places, albeit slightly shallower than depths recorded in summer. For example at site H2.3.3, standing water attained a depth of 35 cm during the summer period, while over the winter months, the depth was reduced to 10 cm. The surprisingly high water content of the Highmoor wetlands over winter, suggests that the wet conditions of these palustrine systems are not dominated by the local balance between precipitation and evaporation as outlined by Orme (1990), but may very likely be sustained by groundwater discharge. A number of factors support suggestions that groundwater discharge may be operative within these wetlands. Leaching indices indicate that leaching is not a dominant wetland process, as discussed in Section 5.5. An oily covering on standing water and iron ochre was noted at certain sites, which according to Hughes (2000, Pers. Comm.) is indicative of groundwater discharge. Estimates of the relative importance of different water input sources in maintaining these wetlands is outlined in Table 4.9. Further factors which may contribute to wet conditions during winter are outlined below.

(i) Customary fog and mist patches in this area over winter

The Drakensberg region is prone to frequent and heavy mist/fog patches as a result of orographic influences. It is proposed that fog and mist may account for the wetlands in this area not experiencing a moisture deficit over the dry winter months. According to Chapman (2001, Pers. Comm.), the significant water contribution of low cloud cover is frequently overlooked.

(ii) Snow melt

As discussed in Section 2.5.1.2, approximately eight snowfalls are reported in the Drakensberg annually. While snow melt may contribute to wet conditions after cold winters, this contribution is possibly the most variable and least significant of the water input sources, when compared with that of rainfall.

(iii) Dense vegetative cover and organic matter accumulation

The characteristically dense nature of hydrophytes as well as mats of decaying vegetative matter frequently found on wetland surfaces, may protect the wetland surface from evaporation.

(iv) Moribund/dormant wetland vegetation, characteristic of wetlands in winter

According to Winter and Woo (1988) plants do not transpire at maximum potential in winter. Evapotranspiration is hence likely to be very much reduced.

4.1.4 Soil characteristics

Mean soil depths within the Highmoor wetland systems ranged from 47 cm in wetland H2 to 100 cm in wetland H1 (see Table 4.2). While the relatively extensive shallow soil zones may not be particularly effective in storing large quantities of water, Gardiner (1999) argues that very shallow soil profiles frequently correspond to recharge sites. The high standard error (SE) readings and substantial ranges between minimum and maximum values suggest that the 'sponge' effect of wetland soil may vary spatially within wetlands.

Table 4.2 Summary of soil depths (cm) of the Highmoor wetlands

descriptive stats.	**wetland H1** (n = 20)	**wetland H2** (n = 69)	**wetland H4** (n = 28)	**wetland H5** (n = 38)
$\bar{X}$ **± S.E**	100.00 ± 17.92	47.24 ± 7.56	51.25 ± 12.53	82.61 ± 12.53
min	20	5	5	10
max	100	200	> 200	200

The soils within the Highmoor wetlands are composed mainly of silt fractions, followed by clay and sand (See Table 4.4). The fairly high clay contents and relatively heavy textured soils of these wetlands, may be effective in retaining water during drier periods. Despite the fact that the organic carbon contents of most wetland sites could rarely be classified as peat (i.e. was not > 10% O/C), the relatively high proportion of organic matter in these wetland systems is nevertheless likely to be effective in water retention. This preliminary investigation indicated that the water retention ability of organic carbon will not only depend exclusively on the quantity of organic carbon present, but also on its composition and degree of decay. Further investigations of the relative water retention capabilities of organic matter in wetland systems are required.

Despite the general tendency being an increase in clay content with depth (Table 4.3), no conclusive trends between soil texture and wetness/hydrological variations were obtained in this study.

Table 4.3 Clay content variations with depth (H1, H2, H4, H5)

clay content as a *f(x)* depth	**WL**	**wetland sites**
clay content ∝ depth	**H1**	H1.6; H1.7; H1.8
	H2	H2.1b; H2.6; H2.1.2; H2.1.3; H2.1.4A; H2.1.7A; H2.2.4 (c)
	H4	H4.2; H4.3; H4.4; H4.5; H4B3
	H5	H5.2; H5.3; H5.5; H5.5 B; H5.A1.5; H5.A2..1; H5.A3.2
clay content 1/∝ depth	**H1**	H1.5
	H2	H2.9.9; H2.1.6; H2.1.8
	H5	H5.5A; H5A1.3; H5.6; H5.7
no apparent trend of clay with depth	**H1**	H1.1; H1.2
	H2	H2.1a; H2.8; H2.10; H2.11; H2.2.2; H2.3.3
	H5	H5 A1.1; H5 A1.4

(Restricted to sample sites where > 2 samples were taken down the profile).

Clay contents in basal positions are not very much higher than in surface horizons, suggesting that water retention and maintenance within these wetlands is unlikely to be a function of indurated horizons. For example, a number of sites characterized by high sand content were found to be temporarily wet (as may be expected considering the high porosities and high saturated hydraulic conductivity), while other sites displaying high sand content were saturated in winter.

These findings are in disagreement with statements made by *inter alia* Gosselink (1986) and Naiman *et al.,* (1992), who argue that wetlands are generally characterized by impeded drainage.

The apparent lack of correlation between soil texture and moisture content is contrary to findings of Kotze (1999), who found wetland soil texture to be positively correlated with wetness. The lack of correlation between texture and wetness found in this study may be attributed to the complex hydrology of these wetland systems; discharge, recharge and throughflow processes all appear to operate within the wetland systems investigated. In addition, the relatively high rainfall of the area, together with the fairly level gradient and relatively impermeable bedrock base, will enhance water retention regardless of the sediment characteristics.

Table 4.4 Summary statistics of clay, silt, sand and O/C contents of the Highmoor wetlands

Wetland H1

(n = 20)	clay (%)			silt (%)			sand (%)			O/C (%)		
statistic	topsoil	subsoil	top & subsoil	topsoil	subsoil	top & subsoil	topsoil	subsoil	top & subsoil	topsoil	subsoil	top & subsoil
$\bar{x}$	29.35	38.74	34.04	40.78	39.11	39.95	29.87	22.15	26.01	5.66	3.50	4.77
SE	3.31	4.07	2.38	2.03	2.28	1.38	2.53	3.49	1.88	0.61	0.52	0.46

Wetland H2

(n = 69)	clay (%)			silt (%)			sand (%)			O/C (%)		
statistic	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil
$\bar{x}$	23.74	31.91	26.79	37.77	37.10	37.48	38.49	31.09	35.73	5.65	3.52	4.85
SE	1.38	1.91	1.21	1.23	1.39	0.92	1.62	2.30	1.39	0.24	0.39	0.24

Wetland H4

(n = 28)	clay (%)			silt (%)			sand (%)			O/C (%)		
statistic	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil
$\bar{x}$	32.51	49.34	36.12	38.16	29.78	36.37	29.32	20.88	27.51	7.71	3.73	6.86
SE	2.26	2.38	2.26	1.55	1.38	1.41	1.44	2.73	1.42	0.76	1.02	0.70

Wetland H5

(n = 38)	clay (%)			silt (%)			sand (%)			O/C (%)		
statistic	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil	topsoil	subsoil	top & sub soil
$\bar{x}$	31.86	35.87	33.3	39.24	35.36	37.89	28.91	28.76	28.81	8.93	6.60	7.99
SE	1.89	1.96	1.37	1.54	1.39	1.10	2.42	1.91	1.57	0.68	0.59	0.49

4.1.5 Highmoor's source seepage wetlands

It is argued that the location of the Highmoor wetlands in a high rainfall area explains the relatively extensive number of wetland systems in the study area. In addition to water input via direct precipitation and runoff, the abundant rain will promote high water tables. Evidence of groundwater discharge was noted within these wetland systems. In addition to ample water supplies, the Highmoor area, as already indicated, provides a typical moorland setting, with relatively gentle, undulating topography and numerous small valleys promoting water accumulation. The landform and topographic characteristics of the Highmoor wetlands, together with impermeable geologies and soils of relatively high retention capacities, synergistically promote wet land conditions.

These source seepage wetlands were found to initiate a fairly significant river/stream channel (see Section 5.4), suggesting that they are effective 'sponges' in the landscape. Figure 4.1.9 illustrates a first order river channel emerging from wetland H2. This channel is typical of all the source seepage wetlands investigated. It is proposed that they could perhaps be viewed as an extension of the fluvial network.

Figure 4.1.9 A relatively substantial first order river channel emerging from wetland H2.

The relatively deep, well established valley systems of H1 and H5 in particular, suggest that in the geological past, rivers may have eroded these head valley positions. Periods of reduced downcutting, in accordance with channel avulsion and sediment infill by slope wash and colluviation, may have occurred. These valleys may then have been subjected to both surface and subsurface erosion/suffosion, lowering the sediment deposits, and explaining the relatively shallow sediment depths found today. The imperfect paleo-environmental records in South Africa make assigning different processes to specific time periods fairly problematic. Elements of this discussion are in accordance with Mäckel's (1974) hypothesis on dambo formation. He hypothesized that rivers erode the head valleys which may be subsequently infilled by slope colluviation and by channel alluviation. Further research is required to validate the above assumptions. Regardless of the landscape genesis, the small valleys are ideal water containers, retaining water inputs and hence resulting in wetland development.

It is proposed that the complex basinal morphology of wetlands H2 and H4, points to chemical and biochemical weathering, as opposed to mechanical/fluvial erosion as the main agent to wetland landform development. The upland lobes and mounds in these wetlands are very likely the consequence of differential weathering rates, controlled by the geology and the availability of water. The above sentiments parallel a number of ideas proposed by McFarlane (1989) on dambo development. She advocates chemical and biochemical corrosion instead of mechanical or fluviatile erosion as the main agents in dambo development. According to McFarlane (1989), by the processes of chemical and biochemical alteration, minerals are prepared for removal. Lateral subsurface flows move them towards streams, and in this way the land surface is lowered, with areas of more advanced weathering lowering at faster rates, so producing a relief of highs and lows.

While more detailed research is required before any unequivocal conclusions can be drawn on the origin of the Highmoor wetlands, this preliminary study has highlighted that the genesis of landform formation and wetland geomorphology is complex and that the evidence is frequently confounding and contradictory. Regardless of landform genesis, the landforms in which the wetlands are found do appear to be effective water 'containers'. In addition, the *in situ* micro-topographical /physical characteristics of the wetlands all appear to be operative in water retention and hence wetland genesis and maintenance. In addition to being influenced by climatic changes, catchment alterations and so forth, the close connection of these wetland systems to the channel network, implies that the long term maintenance of these wetlands is intimately associated with fluvial conditions. Rejuvenation of the fluvial network resulting in headward extension will increase the potential for water evacuation from these wetland systems. This may consequently result in lowering of the water table, and hence the conversion of wetland to dryland. A similar argument is postulated by McFarlane (1989) in her study of dambos. These wetland systems are hence susceptible to alteration or change as physical conditions are altered over geological time frames. Wetland conditions are clearly not static, but continually altering as physical conditions change.

4.2 The Stillerust wetland

4.2.1 Relief

The Stillerust wetland is a typical floodplain wetland, located at a bottom of a relatively wide, U-shaped valley, (position 7 and 8 of the 9-unit landscape model, Dalrymple *et al.*, 1968), on a fairly wide, flat section of the Mooi River floodplain (Figure 4.2.1). When looking up the valley, the section of floodplain bordering the channel on the left hand side is substantially wider than the section on the right hand side, which is restricted by the valley side slopes (Figure 4.2.2). The low, flat relief of floodplains is conducive to the reduction in water flow and water accumulation. Flow attenuation and storage are assisted by the wide assemblage of micro-topographic features, some of which are fluviatile in origin. Examples of micro-topographical irregularities include: hummocks, interhummock hollows, deposition mounds, leveés and oxbow lakes. Despite the absence of very well defined levées, the slight increase in elevation towards the channel banks may explain the genesis of the marshy, backswamp area - water becoming ponded between the relatively elevated alluvial sediments and the valley side slopes. Oxbow lakes appeared to be particularly substantial topographic irregularities of this floodplain, and were found to be a particularly important water storage component, confirmed by significant standing water depths, hydrophytes (indicative of permanent wetness) and a sulphur smell. Similar sentiments are expressed by Rogers (1997) and Tooth *et al.*, (1999a). Physical characteristics of three representative oxbow lakes are given in Table 4.5.

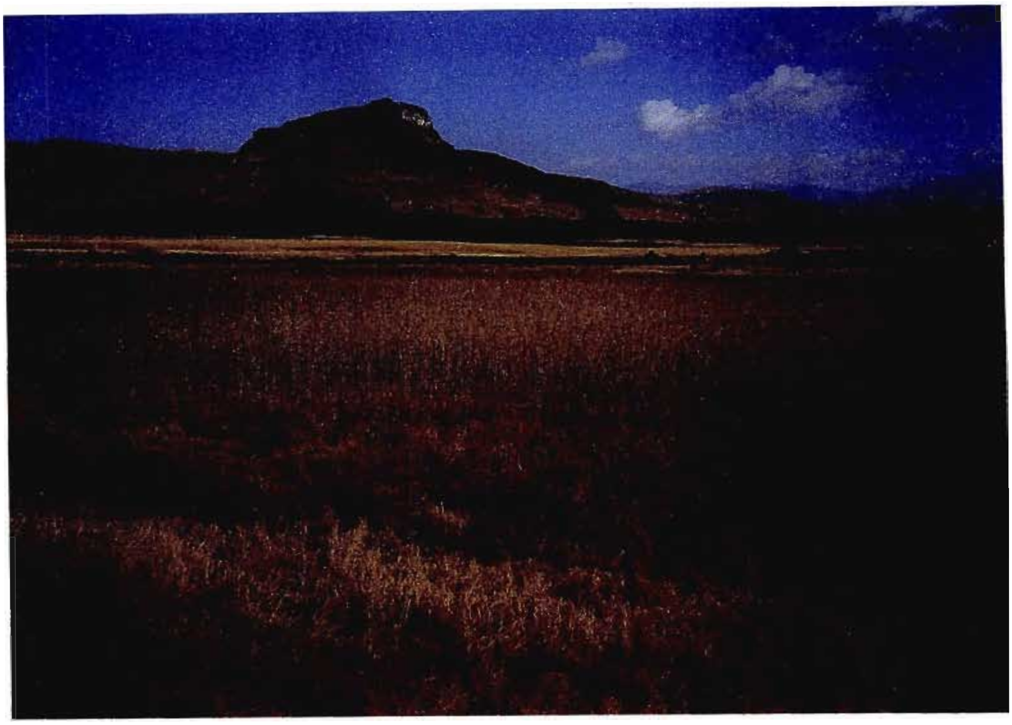

Figure 4.2.1 Oblique view of the Stillerust Floodplain. Note the flat gradient, extensive vegetative cover and diversity of vegetational mosaics.

Table 4.5 Physical characteristics of three oxbow lakes located on the Stillerust Floodplain

site	depth (m)	standing water depth (m)	dominant vegetation	additional characteristics
1.2	1.5	0.7	*Typha capensa*	sulphur smell
15	1.5 - 2.0	1	*Cyperus fastigiatus*	v. strong sulphur smell
16	1.5 - 2.0	1.5	*Cyperus fastigiatus* (perimeter of oxbow)	v. strong sulphur smell

4.2.2 Geology

The Stillerust wetland is situated on a relatively impermeable and resistant sandstone base of the Tarkastad subgroup. This relatively impermeable base rock restricts the infiltration of water. Water infiltrating through the solum layer is hence halted at the bedrock/solum interface, thereby promoting water accumulation and development of wetland conditions. As is the case in the Highmoor wetlands, Begg (1988) identified a resistant dolerite sill or dyke, located at the base/southernmost position of the Stillerust wetland, expressed as an impressive waterfall (Figure 4.2.3).

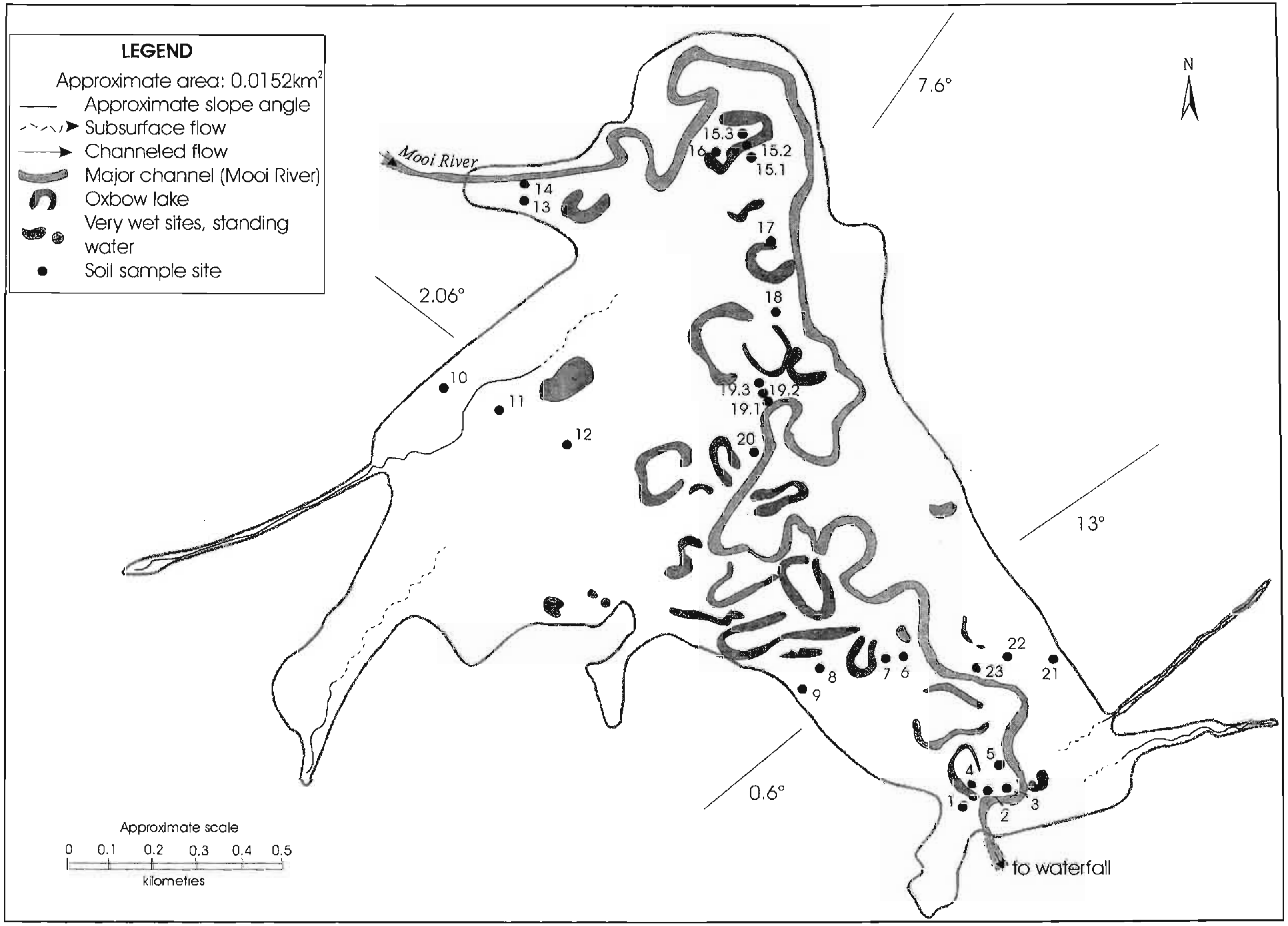

Figure 4.2.2 Field map of wetland S (Stillerust).

Figure 4.2.3 The significant sill/dyke waterfall feature found at the base of Stillerust.

Begg (1988) makes mention that the resistant dolerite sill/dyke may offer an explanation for the existence and maintenance of this wetland. As already discussed, a dyke traversing a valley setting is likely to promote water accumulation behind this resistant structure. It is proposed that the complex, extensive meandering of the Mooi River in this zone may be attributed to the location of this waterfall feature - the waterfall acting as a local base level. According to Tooth *et al.*, (1999a), vertical erosion rates are frequently controlled by erosion of the more resistant dolerites downstream. The resistant sandstone base may limit down-cutting, resulting in the energy being transferred into lateral meanders. Discussions pertaining to the influence of geological obstructions and fluvial dynamics are deliberated further in McCarthy and Hancox (2000) and Tooth *et al.*, (1999a). Complex meandering patterns contribute greatly to the dynamics and complexity of this floodplain wetland, by exerting considerable local instability and natural cycles of wetland formation and destruction. As some areas dry up, others are inundated, new land is formed and old land erodes. This not only influences biological and topographical irregularities, but also contributes to sediment complexity, which then influences wetland hydrology by influencing preferential water flow paths. The influence of pedological properties in water flow paths is discussed below in Section 4.2.4.

4.2.3 Hydrology

As in the Highmoor wetlands, water input via runoff from valley side slopes and toeslope seepage is operative in Stillerust. Water contribution via these input modes will, however, only be of significance on the right hand side of this floodplain (when looking up the valley), since as already documented, the Mooi River and hence floodplain is situated a substantial distance from the left hand side of this valley (Figure 4.2.2). Groundwater discharge also appeared to be a significant form of water input, many zones depicted 'discharge' characteristics outlined in Section 3.2.5.3. A fundamental difference between the Stillerust wetland and the Highmoor wetlands and tarns of the Impofana Nature Reserve, is the fact that this wetland receives water input in the form of overbank flooding. It must be noted however, that inputs from flooding are infrequent and variable. Field visits throughout the hydrological year indicated that there is a close relationship between the stage of river water flow and adjacent floodplain sediment (influent and effluent seepage appeared to be operative). Water input from smaller tributaries leading across the floodplain is a further form of water input. The complex and varied input of water into this floodplain wetland corresponds to findings made by Rowntree (1993), in her investigation of wetlands in the Eastern Cape. The relative importance of identified input sources is outlined in Table 4.9. As previously discussed, micro-topographical irregularities, particularly oxbow lakes, were found to provide an important water store function.

While small tributaries are frequently an important mode of water input into floodplain settings, the small channel (yazoo stream) located on the right hand side of the Stillerust floodplain, appeared to intercept both surface and subsurface flow, and thereby explain the dry conditions of the oxbow lake situated adjacent to the Mooi River (Figure 4.2.4).

Figure 4.2.4 A relatively dry oxbow lake situated adjacent to the Mooi River. The yazoo stream was located approximately five metres from this oxbow lake.

4.2.4 Soil characteristics/pedological properties

Field and laboratory investigations both indicate the complexity of the sediment deposits of Stillerust (Table 4.9 and 4.10, Appendix 4). Soil profile depths ranged from 50 cm at site S15.2, to > 200 cm at a number of sites, namely: 2, 6, 8, 9, 15.1, 17, 19.1, 19.2, 19.3 and 22. Seven textural classes were identified in this wetland. The clay loam textures were dominant (30.61% of the samples), followed by sandy loam (22,45%) and clay (18.37%). Fine sand was found in all sites, with the exception of sample S19.3 (100 - 200 cm+) where medium sand was dominant. As discussed above, the complex meandering patterns greatly contribute to the complexity of the floodplain sediment. Both lateral accretion (the deposition of sediment on point bars on the inside of river bends), and vertical accretion, (the deposition of sediment on flooded surfaces), appeared to be operative in building this floodplain and in accounting for the complex sediment and micro-topographic characteristics of this zone. Evidence of vertical accretion was noted adjacent to the banks of the Mooi River, this is illustrated in Figure 4.2.5.

The variation of textural characteristics both laterally and vertically, as well as the complex array of oxbow lakes, some attaining brimfull water while others were relatively dry suggests that this floodplain is very likely composed of a complex mosaic of sediment characteristics that influence water flowpaths, recharge and discharge processes. An open pool of water, dimensions (6 X 3 m), with a depth in the order of one metre (Figure 4.2.6), was found in the vicinity of site S22. This particular pool located on the edge of the floodplain did not appear to have arisen from a cut-off meander neck, i.e. was not a classical oxbow lake. This pool emphasizes the complex relationship between wetland sediment and hydrology of this floodplain wetland. According to Hardwick and Gunn (1995), at many sites drainage may be impeded by large amounts of clastic sediment, creating temporary, localized, and "perched" water tables. Of the profiles examined, only 35.29% showed an increase in clay content with depth. Clay content decreased with depth in 52.94% of the profiles, while no trend was apparent in 11.77% of the profiles (Table 4.6).

Table 4.6 Clay content variations with depth in Stillerust

clay content as a *f(x)* depth	**wetland sites**
clay content $\propto$ depth	S4; S6; S12; S17; S20; S21
clay content 1/$\propto$ depth	S1; S2; S8; S10; S11; S18; S19.1; S19.2; S19.3
no apparent trend of clay with depth	S3; S15.1

(Restricted to sample sites where > 2 samples were taken down the profile).

Clay content variations with depth are not restricted to particular zones within Stillerust (Table 4.6, Figure 4.2.2), which emphasizes the complexity of floodplain sediments. It also suggests that different processes (i.e. leaching, weathering, deposition etc.) are operative at different positions within the wetland. While sites showing an increase in clay content with depth, were all saturated during the wet, summer months suggesting that a clay liner effect may be operative (Tables 4.9 and 4.10, Appendix 4), permanently wet conditions were not restricted to sites displaying indurated horizons. Three of the sites showing a decrease in clay with depth, namely: S1; S10 and S11, also showed signs of permanent wetness in the field. Wet sites, as discussed in Section 1.2.2, need not necessarily be the result of water infiltrating down through the profile, but may be the result of groundwater discharge. Groundwater discharge appeared to be operative at a number of sites within Stillerust. Sample sites 8, 10, 12 and 21 all displayed two or more features identified in this study as indicating groundwater discharge (outlined in Section 3.2.5.3).

While the mean organic carbon content of Stillerust was not very substantial (4.34%), certain sites displayed very high organic carbon values, a maximum value of 39.90% was recorded. High organic carbon contents and water retention and maintenance may be regarded as a positive feedback process. Wet sites reduce organic carbon decomposition and therefore organic carbon accumulation. Organic carbon then enhances the retentive capacity of the soil, and aids wet conditions.

The best example of iron ochre deposition was noted within Stillerust (Figure 2.2, Appendix 2). This site was located in the vicinity of an underground pipe installed to drain the road. It is likely that iron ochre deposition within this pipe may lead to pipe blockage. Blockage of pipes will result in the wetland drainage function being minimized or lost. This is an example of how a wetland, left to its own devices, may in fact 'restore' itself over time.

Figure 4.2.5 Evidence of vertical accretion processes operative in Stillerust. Vertical accretion is most likely restricted to high flow periods, when overbank flooding and deposition is possible.

Figure 4.2.6 An open pool of water located on the edge of the floodplain, emphasizing the complex relationship between sediment characteristics and hydrology.

4.2.5 Genesis of the Stillerust floodplain wetland

The climate, topography, microtopography, geology, hydrology and soil characteristics of Stillerust were all found to contribute towards water retention, and hence wetland conditions. As emphasized in the preceding discussion, while overbank flooding is a distinctive and significant water input of floodplain wetland systems, it is not the only, or most significant form of water input. The fluvial system is, nevertheless, critical in explaining many characteristics of this wetland system.

As already mentioned, fluvial systems are subject to change in both time and space (Dardis *et al.*, 1988). Erosional and depositional components may evolve progressively over significant periods of time, with major morphological changes resulting from tectonism or climate change (Schumm, 1977 *in* Dardis *et al.*, 1988). Changes in channel morphology and riverine characteristics may result from changes in base level and variations in discharge, which will also very likely influence the form, functioning and maintenance of floodplain wetlands (Dardis *et al.*, 1988). For example, while at present lateral fluvial erosion is dominant, and may continue to be dominant in the short- to medium-term, in the longer term, vertical erosion may occur in this sandstone valley as downstream resistant dykes and sills are lowered by erosion. This will most likely result in the Mooi River assuming a more direct, straight form, and thereby reduce the intimate connection of the channel with the floodplain. According to Daniels and Hammer (1992), stream dissection can change the oxidation-reduction and leaching regimes of landscapes. Dissecting streams also have the potential to alter the drainage of the soil landscape. Dissection increases water movement through the sediment, deep leaching and enhanced soil formation are then possible. The water table is also likely to be lowered, which may result in floodplain wetlands such as Stillerust being converted to dryland conditions over time.

The genesis and maintenance of Stillerust is clearly closely linked to the dynamics of the fluvial system; since the fluvial system controls the quantity and timing of overbank flooding, and hence water input, topographical variations and complexity, sediment fluxes and the nature of the sediment. The inherent dynamics of fluvial systems appearing to be superimposed on wetland maintenance and functioning, making this wetland type very susceptible to change in internal characteristics and functioning.

4.3 Origin and maintenance of tarns

4.3.1 Relief

Tarns, frequently referred to as high altitude lakelets (Hamer and Martens, 1998), are bodies of still water occupying depressions in the ground, and having no direct opening. While tarns are documented as predominantly occurring on flat ridgetops (position one of the 9-unit landsurface model) (Killick, 1961; Hamer and Martens, 1998), field investigations revealed that this is not always the case. A tarn was found in position five on the steep sloping sides of the Pholela valley (Cobham), and in position seven in the Impofana Nature Reserve. Tarn locations away from ridgetop/interfluve positions however appear to be the exception rather than the rule.

Tarns T1 and T2 are both located in position one of the 9-unit landsurface model (see Figure 3.1, Appendix 3). While the bench on which tarn T1 is situated is relatively flat, suggesting that runoff will not be of great significance, proximal areas of T2 are clearly not flat, with slope angles ranging from 3° - 30°. Runoff into this tarn is thus likely to be more substantial than that of T1. Figure 4.3.1 and 4.3.2, illustrate the tarns' position in relation to the adjacent landscape. Schematic illustrations of tarns T1 and T2 are indicated in Figures 4.3.3 and 4.3.4. Cross profiles through tarn T1 (Figure 4.3.5), illustrate the significant depressional nature of this wetland body.

Figure 4.3.1 Tarn T1, photographed in winter (July). Note the gentle topography of this plateau.

Figure 4.3.2 Tarn T_2, photographed in Summer (November), Note the dense stands of *Cyperus Fastigiatus* and gentle proximal sideslopes of this wetland.

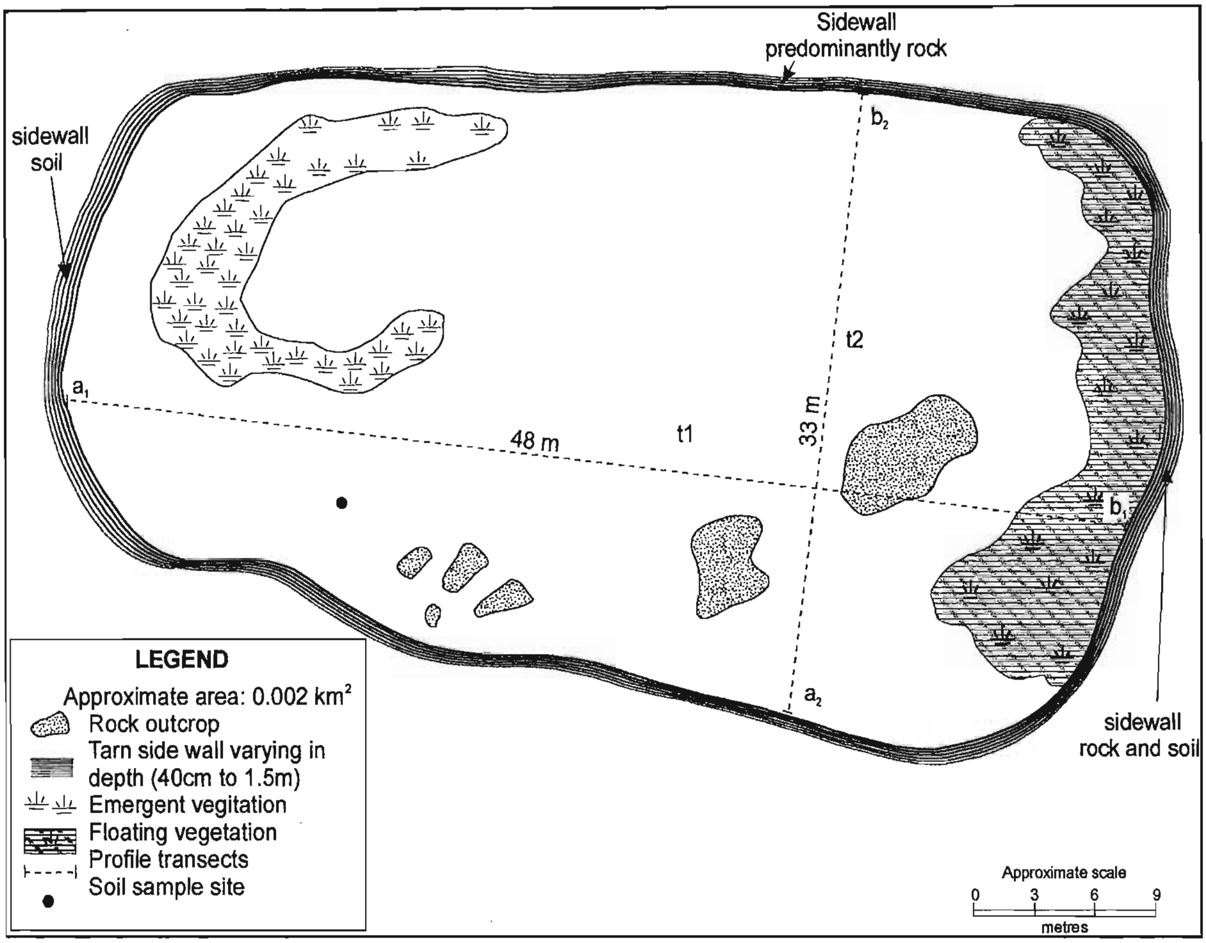

Figure 4.3.3 Field map of tarn T1.

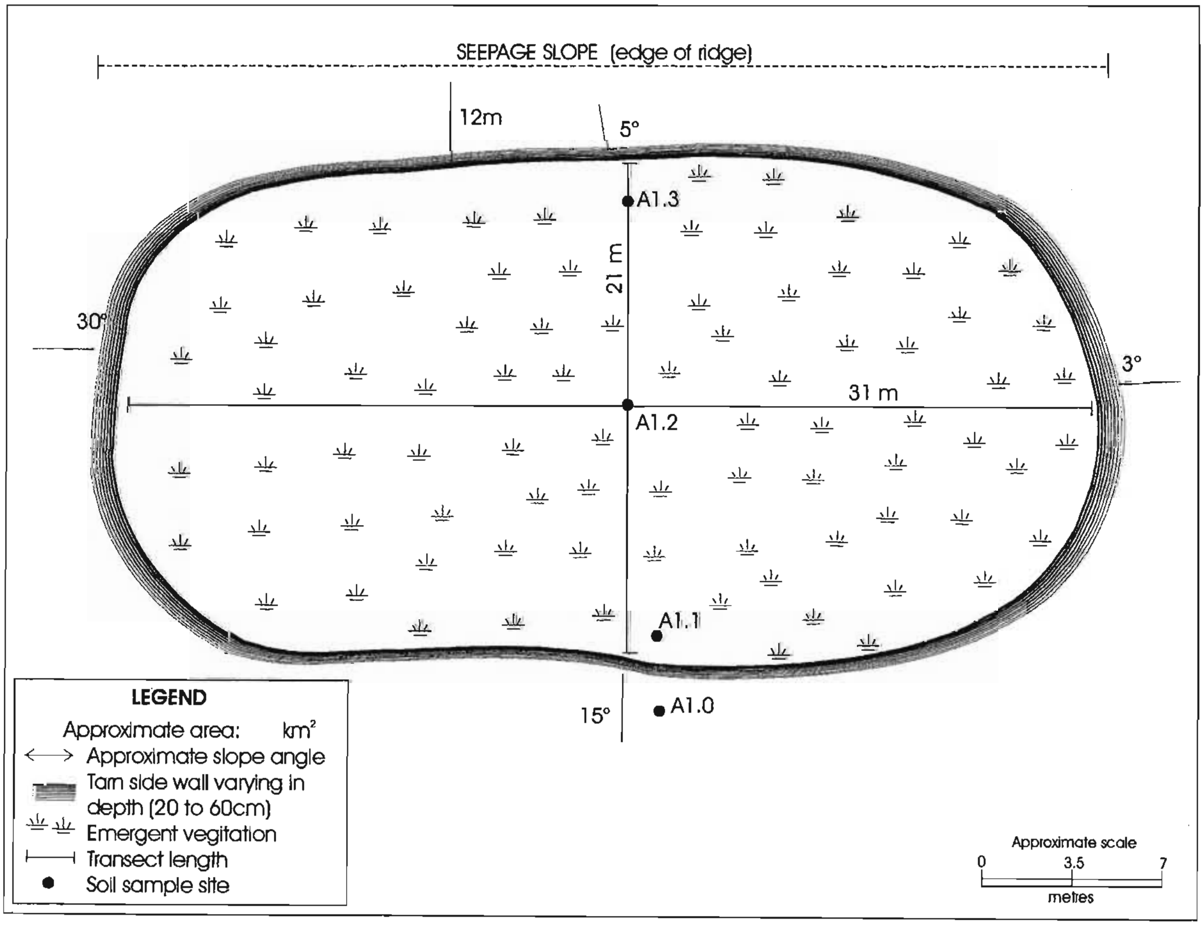

Figure 4.3.4 Field map of tarn T2.

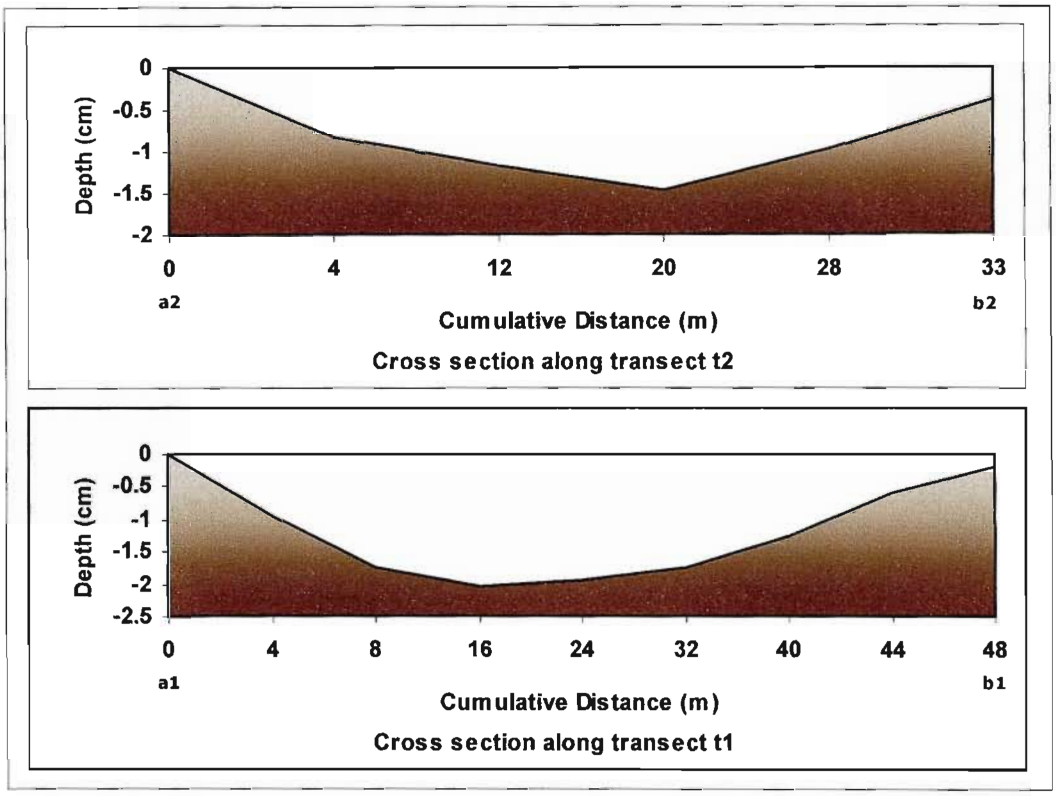

Figure 4.3.5 Cross Sections through tarn 1 (T1).

Two additional tarns, termed T3 and T4 are illustrated in Figures 4.3.6 and 4.3.7. The bench on which T3 is located is not as flat/uniform as is the vicinity of tarn T1. This suggests that input via overland flow may be a significant input source into this wetland. Tarn T4 is located in a valley bottom setting, and is hence likely to be subject to significantly larger volumes of runoff from adjacent valley sides, than the other tarns investigated.

Figure 4.3.6 Oblique view of Tarn T3, photographed in winter (July) when the tarn was completely dry. Note the relatively gentle surrounding topography.

Figure 4.3.7 Tarn T4, note the uncharacteristic landscape location, i.e. valley bottom setting.

4.3.2 Geology

Tarns T1 and T2 are situated on Elliot and Tarkastad sandstones respectively. While not as impermeable as dolerite or granite, these sandstones are nevertheless relatively impermeable. Jointing activity, in the form of fine cracks, was observed on exposed bedrock on the plateau on which tarn T1 is situated. A substantial joint (> 35 cm) was noted a few metres from this tarn. The orientation of T1 appeared to correspond to the dominant joint direction in the area. Prolonged seepage via joints/cracks on the base of the tarn is likely to promote intense chemical weathering along these zones of weakness. Prolonged weathering along joint lines may hence explain the origin of tarn T1. Similar findings are documented by Shaw (1988) and Hardwick and Gunn (1995) with respect to pan and turlough lake genesis. According to Shaw (1988), seepage from the groundwater body may be of local significance in pan initiation. Deep weathering by groundwater for example has been cited as a potential mechanism in the evolution of the Kalahari fluvio-lacustrine landforms (Shaw, 1988). Hardwick and Gunn (1995) hypothesized that in the case of turlough lakes, water may rise from fissures, gradually increasing the size of the lake.

While it is questionable whether the precise location of small dyke features can be obtained from 1: 50 000 geological maps, the geological map of the area (Council for Geosciences), indicates that tarn T2 may be located adjacent to, or on a dyke. According to Shaw (1988), dolerite sills in areas of the Beaufort group tend to be resistant to weathering, and may thereby contribute towards pan formation by forming surface barriers to groundwater movement. This may very well be a probable hypothesis of tarn formation, although further investigations are required to determine the precise locality of the dyke. The very deep soil profiles and permanently wet conditions of tarn T2, suggest that jointing activity (discussed above), may also offer a possible explanation for the existence and characteristics of tarn T2. Stone and Lindley Stone (1994), argue that joints may act as conduits for water flow by promoting weathering and hence the establishment/creation of deep profiles.

4.3.3 Hydrology

The maximum water depth of tarn T1 during the winter season was 90 cm, while the average depth was in the order of 60 cm. While this water depth is very much lower than it is during the wet season, where depths of at least one and a half metres may occur (Campbell, 2000, Pers. Comm.), the significant volume of water found in T1 over winter suggests that groundwater discharge (through joints/cracks on the base of this tarn) is very likely to be operative. In the wet summer months, standing water attained a depth in the order of approximately 60 cm in Tarn T2. While Tarn T2 does not contain standing water during winter, it nevertheless remains saturated. (Note the between season contrast of T2 in Figures 4.3.2 and 4.3.8). This suggests that while direct precipitation, and associated runoff is most likely a dominant input mechanism, groundwater discharge may also be operative. Factors outlined in Section 4.1.3, explaining the high water content of the Highmoor wetlands may also account for the wet conditions found in tarn T2. Tarn T3, also a rock based tarn (Figure 4.3.6), was completely dry in winter, indicating that subsurface discharge is probably not operative at this site. Owing to the relative inaccessibility of tarn T4, it was not revisited in winter, standing water did, however, appear to be present when viewed from the plateau.

The occurrence of water within tarn T1 in particular, but also tarns T2 and T4 during the winter season, when areas adjacent to the tarns are very dry, indicates that these wetlands are not ombrotrophic (Gk. *Ombros* = a storm of rain, *trophos* = feeder) as previously thought, i.e. the water supply is not derived from precipitation alone. Groundwater discharge can hence be a potential mechanism in maintaining the wet conditions. Despite the dry conditions of T3 in winter, this tarn is not a true ombrotrophic wetland, in that the adjacent areas are characterized by a slight gradient, which will in all probability promote input via runoff. Tarn T4, located on the base of the valley, receives water not only from precipitation, but also runoff, groundwater seepage and pipe flow input. The pipe system found entering T4 as well as the pipe found exiting a tarn on the Siphongweni Plateau (Cobham), indicates that tarns may not be hydrologically isolated as previously documented in the literature; i.e. precipitation and evaporation are not the only factors influencing the water budget of these wetlands. Tarns are nevertheless not associated with the fluvial system, and are hence more hydrologically isolated than most other wetland systems. While not truly ombrotrophic, water input via precipitation does appear to be a dominant input mechanism. See Table 4.9 for an overview of the relative dominance of different forms of water input.

Figure 4.3.8 Tarn T2, photographed in winter. While no standing water is present, note that the profile is saturated.

4.3.4 Soil characteristics

Sediment deposits of tarn T1 (a rock based tarn), attain a thickness of 16 cm. The texture is defined as "loam", with the fine sand grade dominating (Table 4.7). The low proportion of clay and dominance of sand (with a high permeability), suggests that this sediment deposit is not effective in retaining water. Water maintenance within this tarn is hence most likely a functioning of the underlying bedrock. Water maintenance throughout the hydrological year, together with low leaching indices (S-values per unit mass of clay, see Section 5.5.2), suggest that the wet conditions of tarn T1 be primarily attributed to groundwater discharge. The same property of sand, that does not promote water retention, (i.e. high porosity and permeability), will promote groundwater discharge into this depressional wetland feature. In addition, the relatively high organic matter content (Table 4.7) may influence factors such as bulk density and promote water retention.

Table 4.7 Textural characteristics and organic carbon content of tarn T1

WL T1	clay	silt	c. sand	m. sand	f. sand	total sand	O/C
%	11.55	42.5	2.6	9.4	33.95	45.95	7.01

Tarn T2, a soil based tarn, is characterized by a very deep solum layer (in excess of two metres in places). Both clay and silt fractions are dominant in deeper horizons (Table 4.8). As already discussed, clay accumulation in basal horizons may act as a 'plug' i.e. clay liner effect, preventing water from infiltrating into groundwater storage, and thereby accentuating waterlogging. Indurated horizons are likely to become more defined over time, since clay contents in the surface horizons are still relatively high, ranging from 26 - 32%. The relatively high clay, silt and organic carbon content of T2 is also likely to impart an important water retention role.

Table 4.8 Textural characteristics and organic carbon content for T2

Site	% clay	% silt	% c. sand	% m.	% f. sand	% tot.	% O/C
T2 1.1							
0 - 20	26.62	57.48	1.1	2.3	12.5	15.9	7.25
20 - 40	23.4	59.25	1.4	3.05	12.9	17.35	9.27
40 - 200	34.49	47.36	3.3	4.3	10.45	18.05	10.08*
T2 1.2							
0 - 100	32.89	42.66	1.55	5.45	17.45	24.45	18.94*
100 - 200	36.22	41.18	3.85	5.1	13.65	22.6	19.75*
T2 1.3							
0 - 100	28.29	45.26	3.25	4.85	18.35	26.45	9.75
100 - 200	31.96	36.49	4.7	8.95	17.9	31.55	4.23

* classified as peat when O/C > 10%

4.3.5 The genesis of tarns

Tarns are clearly fairly diverse in terms of: landscape position, hydrology, geology and solum characteristics. The diversity of physical characteristics associated with tarns suggests that these features may arise from very different processes of formation. Probable hypotheses of tarn genesis in the study area include:

- ☐ weathering along joint lines (discussed above in geology section);
- ☐ hollow in the toeslope of a paleo-landslip/slump. (Suggested by the smooth, rounded topography at the edge of the interfluve in the vicinity of T2, as well as the deep solum profile); and
- ☐ differential erosion and groundwater obstructions by a dolerite sill or dyke, acting as a barrier to groundwater movement.

Further investigations are required to evaluate the above hypotheses. According to Campbell (2000, Pers. Comm.), the local/indigenous people believe that these water containing depressions are remnants of elephant activity in the past. Interestingly, the earliest studies of pan origin (Alison, 1899 and Passarge, 1904 *in* Shaw, 1988) was attributed to faunal influence. Shaw (1988) outlines that animals may concentrate around pans to utilize water, and in the process may disturb ground, reduce vegetative cover and set up a cycle for enlargement. The low ungulate numbers and relative abundance of water in this high altitude zone, suggests that tarn formation by faunal processes is not likely in the uKhahlamba-Drakensberg Park. Evidence attained in this study supports a hydro-geological origin. Despite evidence in this study being contrary to indigenous beliefs, it is submitted that local knowledge is frequently very valuable, and should not be dismissed posthaste.

Field and laboratory evidence indicate that apart from variable processes initiating tarn genesis, i.e. landform development, the tarns appear to be maintained by different processes. The tarns are clearly not as hydrologically 'isolated' as once thought; this study has shown that they are influenced by a number of landscape process, i.e. they may be fed by: surface runoff, piping and groundwater discharge, see Table 4.9. The relatively close connection with the surrounding landscape and landscape processes suggests that the maintenance of these features is closely connected to conditions in proximal upland areas. It also suggests that these features may be temporary, in that they may be converted to dryland following prolonged sedimentation.

4.4 Wetland genesis and maintenance

The plentiful rainfall and high water tables in the uKhahlamba-Drakensberg Park largely explains the common occurrence of wetlands in this area. A summary of dominant mechanisms promoting wetland development and maintenance in the study area is illustrated in Figure 4.4.1. An overview of the relative importance of different water input sources in maintaining wetland conditions is outlined in Table 4.9.

Table 4.9 Relative importance of different water inputs in maintaining wetland conditions

wetland	direct ppt.	tributary/ seepages	runoff / sheetwash	subsurface discharge	overbank flooding	influent seepage
H1	✦✦✦✦	✦✦✦	✦✦✦✦	✦✦	✦	✦
H2	✦✦✦✦	✦	✦✦✦	✦✦✦✦	-	-
H4	✦✦✦✦	✦✦	✦✦✦	✦✦✦✦	-	-
H5	✦✦✦✦	✦✦	✦✦✦✦	✦✦✦✦	-	-
S	✦✦✦✦	✦✦✦	✦✦✦	✦✦✦	✦✦	✦✦
T1	✦✦✦✦	-	✦	✦✦✦	-	-
T2	✦✦✦✦	-	✦✦	✦✦	-	-

✦✦✦✦	✦✦✦	✦✦	✦	-
v. important input	important input	moderate input	negligible input	input not present/significant

As emphasized throughout this document, while water is a fundamental component of wetlands (Stone and Lindley Stone, 1994); water input, throughput, output and storage is in most cases largely conditioned by the:

- ☐ **topography:** gradient and landscape position;
- ☐ **micro-topography:** storage hollows, pools etc.;

- ☐ **geology:** relative permeability of bedrock, resistence to weathering, location of joints, dykes etc.;
- ☐ **hydrology:** depth of the water table; and
- ☐ **soil/sediment characteristics:** such as porosity, and horizon induration.

It is argued that wetland type, internal wetland functioning and maintenance are largely moulded by these physical factors of the wetland catchment.

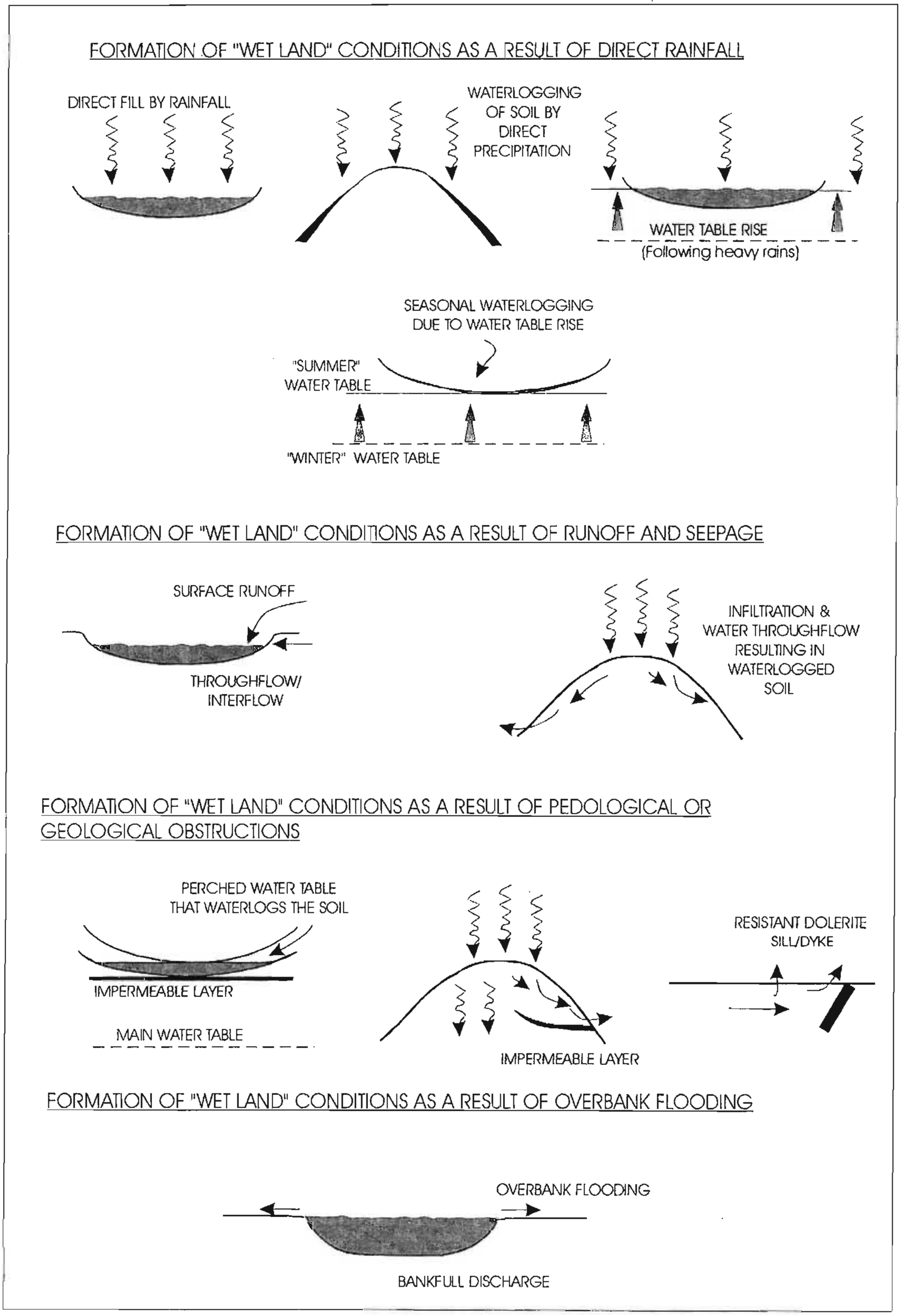

Figure 4.4.1 Summary of the dominant mechanisms resulting in ' wet land ' conditions.

This chapter has investigated the dominant factors contributing to and sustaining 'wet land' conditions, i.e. the reasons for wetland distribution and maintenance have been investigated. This manuscript has attempted thus far to introduce the concept that wetlands are not static systems, but are dynamic, in that they are particularly receptive to conditions in the surrounding catchment. Wetland form and functioning may hence alter over the short, medium and long term. They are not only dynamic, but also transient, in that as physical conditions are altered over geological time frames, wetlands may be converted to dryland or be submerged by rising water tables.

A number of dominant processes operative within the wetlands investigated is the focus of the following chapter.

Chapter 5

5. Processes operating within wetlands

An overview of what constitutes a 'process' in a geomorphic context is outlined in Section 1.2.4. As previously emphasized, there is a growing recognition of the importance of understanding wetland process, especially with respect to the management and restoration of wetland systems. A number of dominant processes found operative both within and adjacent to wetland systems in the study area are outlined in Table 5.1.

Table 5.1 Dominant processes found within different wetlands

PROCESS	WETLAND(S) IN WHICH PROCESS WAS IDENTIFIED
overbank flooding	S (H1, H2, H4, H5)
overland flow	H1, H2, H4, H5, S, T1, T2
sedimentation	H1, H2, H4, H5, S, T1, T2
piping	H1, H4, H5, S (T4)
leaching	H1, H2, H4, H5, S, T1, T2
soil swelling, shrinkage and cracking	H1, H2, H4, H5, S, T1
channeling (channel incision)	H1, H2, H4, H5, S

Both field and laboratory investigations were undertaken in an attempt to obtain an insight into the above processes, and to try and establish the influence of these processes on wetland functioning and dynamics. A number of physical and chemical soil variables (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} concentrations; pH; exchangeable acidity; particle size fractions i.e. % clay, silt and sand and % coarse, medium and fine sand and organic carbon (O/C) concentrations) were investigated in the present study in an effort to: support field findings, and facilitate field intuition, i.e. identify additional processes not directly visible in the field.

The strength of statistical association between dominant pedological variables was established, so as to evaluate the dependence or independence of physical variables, and thereby attempt to answer questions of causality. The strength of statistical association was achieved by using the Pearson Product Moment Correlation Coefficient (PPMC), 'r', which is a descriptive statistic used to describe the degree of association between two variables (Manly, 1986). PPMC was calculated using the Quattro Pro Program (Corel Suite, version 9). The PPMC results of the soil variables measured from all seven wetlands investigated in this study, are outlined in Table 5.2. Of the variables investigated, 45% are either positively or negatively correlated at the 95% confidence level, while 33% are correlated, either positively or negatively at the 99% confidence level. Many of the correlation coefficients while significant, are rather weak. A number of associations are obvious, such as: the associations between particle size fractions, pH and exchangeable acidity. Strong correlations imply that there is a relatively strong interdependence between variables, i.e. variables may be functions of other variables, or alternatively, may be conditioned by the same process. A number of associations expected to be fairly strong, such as the relationship between exchangeable bases and clay, or O/C content and clay, were surprisingly weak or non-existent. The overall predominance of weak associations may be attributed to a multitude of variables working together simultaneously to produce the inherent internal conditions. Explanations for the associations as well as lack of associations between the variables investigated in this study, proved difficult in many instances, highlighting the complexity of wetland environments - a multitude of variables appear to be working simultaneously to produce inherent internal conditions. While PPMC results are instrumental in providing an initial indication of the relationships between variables in the field, the results are limiting in that the correlations are pairwise. Principle Component Analysis (PCA) was hence conducted in an effort to obtain an indication of the overall correlation structure and to identify dominant trends in association (Manly, 1986). An elemental objective of PCA is to reduce the data set to a number of principal components, and thereby make the interpretation of the relationships that exist between the parameters easier (Manly, 1986).

The Principle Component Analysis results are illustrated in Figure 5.1. The arrow lengths (variables plotted in the PCA diagram), represent the rate of change of variables across theoretical gradients. Angles between arrows indicate the correlation: < 90° represents a positive correlation, 90° indicates no correlation (i.e. independence), > 90° represents a negative correlation (ter Braak, 1987, 1990). The first axis of the PCA accounted for 19.5% of the total variation. Geology and soil texture are dominant on this axis, particularly sandstone, dolerite, coarse sand, silt and clay. Dolerite and coarse sand show a strong positive correlation (angle < 90°). Sandstone, clay and fine sand are also correlated (angle < 90°), however, the correlation is not as strong as the relationship between dolerite and coarse sand. The second axis accounts for 14.6 % variation, the acidity gradient is dominant on this axis. The identification of pH as an important wetland variable is not limited to this study, but has been identified by *inter alia* Mitsch and Gosselink (1986) and Bridgham and Richardson (1993).

As previously outlined, one objective of the PCA is to reduce the data set, i.e. to reduce redundancy and promote easier interpretation in succeeding analyses. It is submitted that the inability to substantially reduce the number of variables may not highlight redundancy, but rather highlights the extreme complexity of wetland environments, a plethora of interlinked variables work together in maintaining the unique and complex conditions found within wetland systems.

Table 5.2 Pearson Product Moment Correlation between soil variables investigated in the seven wetland systems studied (n = 205)

	Ca	Mg	Na	K	pH	Ex. acid	% clay	% silt	c. sand	m. sand	f. sand	t. sand	% O/C	Geol.
Ca	1													
Mg	0.658**	1												
Na	0.158*	0.064^{NS}	1											
K	0.031^{NS}	0.035^{NS}	0.004^{NS}	1										
pH	0.425**	0.249**	0.024^{NS}	0.030^{NS}	1									
Ex. acid	-0.212**	-0.180*	0.108^{NS}	-0.025^{NS}	-0.269**	1								
clay	0.015^{NS}	0.124^{NS}	0.141*	-0.055^{NS}	-0.419**	0.059^{NS}	1							
silt	0.044^{NS}	-0.013^{NS}	0.077^{NS}	0.066^{NS}	-0.046^{NS}	0.085^{NS}	-0.048^{NS}	1						
c. sand	-0.152*	-0.088^{NS}	-0.053^{NS}	0.009^{NS}	0.195**	-0.122*	-0.287**	-0.110^{NS}	1					
m. sand	-0.141*	-0.173*	-0.080^{NS}	0.002^{NS}	0.205**	0.009^{NS}	-0.570**	-0.503**	0.221**	1				
f. sand	0.101^{NS}	0.011^{NS}	-0.135^{NS}	-0.006^{NS}	0.240**	-0.049^{NS}	-0.534**	-0.500**	-0.371**	0.446**	1			
t. sand	-0.041^{NS}	-0.089	-0.162*	0.001^{NS}	0.361**	-0.102^{NS}	-0.758**	-0.615**	0.299**	0.778**	0.748**	1		
% O/C	-0.086^{NS}	-0.278**	0.015^{NS}	-0.009^{NS}	0.041^{NS}	0.060^{NS}	-0.086^{NS}	0.225**	0.030^{NS}	0.249**	-0.207**	-0.079^{NS}	1	
Geol.	0.204**	-0.057^{NS}	0.108*	-0.171*	0.071^{NS}	0.129^{NS}	0.003^{NS}	0.041^{NS}	-0.384**	-0.037^{NS}	0.230**	-0.029^{NS}	-0.151*	1

Ex.acid = exchangeable acidity; **c. sand** = coarse sand; **m. sand** = medium sand; **f. sand** = fine sand;
t. sand = total sand; **Geol.** = geology

NS P $>$ 0.05)
* (P $\leq$ 0.05)
** (P $\leq$ 0.01)

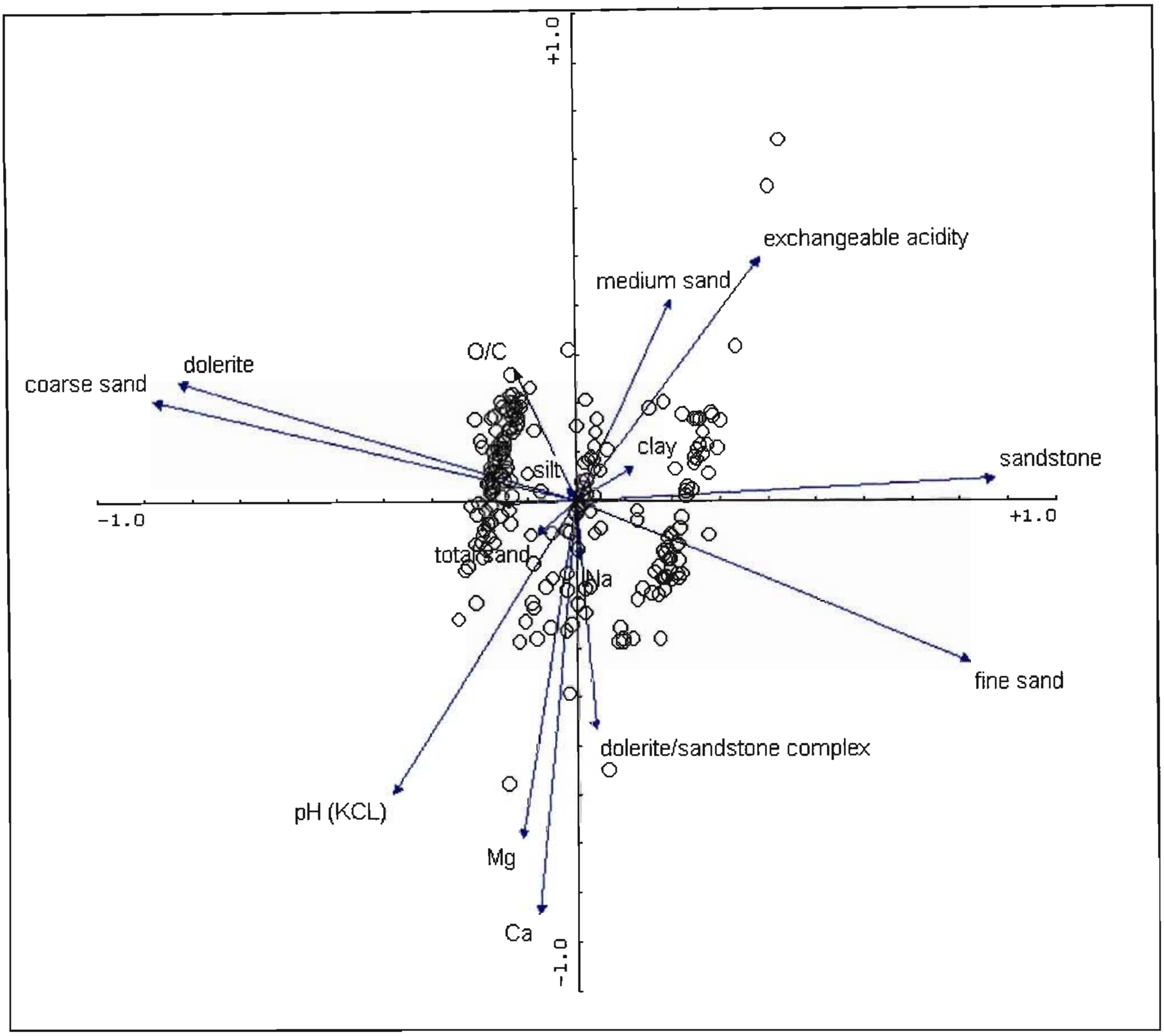

Figure 5.1 Principal Component Analysis (PCA) plot of axis one (horizontal) and axis two (vertical) showing pedological variables. Eigenvalues for axis one and two are 0.195 and 0.146 respectively, representing 19.5% and 14.6% of the total variability respectively.

The PPMC and PCA results are incorporated into the preceding discussions of processes identified as being relatively dominant both within the wetlands investigated and in proximal wetland areas (See Table 5.1). Wetland processes will be discussed under the following headings:

5.1 Wetlands as accreting systems

5.2 Susceptibility of wetland soil to change

5.3 Soil piping

5.4 Channeling

5.5 Leaching

Factors initiating the respective processes will be discussed. The influence of each process with respect to wetland functioning will be outlined, and possible implications for wetland management/restoration will be discussed where relevant.

5.1 Wetlands as accreting systems

The three primary geomorphic processes associated with flowing water are erosion, sediment transport or entrainment and sediment deposition. Precipitation provides the runoff necessary to transport inorganic sediments to wetlands. Sediment yield from a catchment is recognized as a dynamic process which varies in both time and space (Furness, 1983). The rate, volume and mechanism of sediment input into wetland systems is likely to vary, depending on the physical characteristics of the surrounding upland areas. A number of physical factors which control erosion and deposition include climate, angle and length of slope, hydraulic flow characteristics, soil type, geology, nature of vegetative cover, antecedent water content and surface irregularities.

Wetlands are well known not only for their flood attenuating role in the landscape, but also for improving the quality of river water by trapping sediments and filtering out pollutants (see *inter alia* Kadlec and Kadlec, 1979; Denny, 1985; Federal Interagency Stream Restoration Working Group, 1999). Wetlands are commonly referred to as 'sinks', in that the inflow of energy and sediments into wetland systems is generally greater than the energy and sediments exiting wetlands. Factors which encourage the deposition of sediments are generally the inverse of the factors promoting erosion and transportation. The ability of a particular wetland to dissipate erosion and effectively stabilize soils is, however, largely dependent on the erosive forces present (Schwabe, 1989). Rowntree (1993) describes wetlands as sensitive geomorphic features that may be defined according to geomorphic criteria. The presence and extent of wetlands are both a reflection and determinant of the magnitude of sedimentation and water storage within a drainage basin. The influence of rock type on soil properties is well established. Buol *et al.*, (1980) argues that in general, soils formed from clastic sedimentary rocks are of coarse texture. According to Buol *et al.*, (1880) and Brink (1981), dolerite rock types generally yield a substantial quantity of clay on weathering. The quartz content of mafic igneous rocks is generally very low. Little sand is consequently found in soils derived from dolerite (Buol *et al.*, 1880; Brink, 1981).

While monitoring of incoming and outgoing sediment loads over a significant time period is beyond the scope of the present project, the sediment trapping function of the wetlands investigated was indirectly assessed by considering landscape position, the physical characteristics of the catchment, and the geological and pedological characteristics. Pearson Product Moment Correlation (PPMC) and Principal Component Analysis (PCA) were used in an effort to assess whether the *in situ* wetland soil and/or sediment, has arisen from sedimentation as opposed to *in situ* weathering of the wetland base rock. Soil depth variations within the respective wetland systems were also assessed in an effort to determine whether the wetlands investigated act as effective sediment traps within the landscape.

5.1.1 Principal Component Analysis of wetland soils

The PCA plot (Figure 5.1) does not reflect accepted geological/textural associations. Dolerite and coarse sand are strongly correlated. Sandstone, while only slightly correlated to fine and medium sand fractions, was correlated to clay. It is proposed that the apparent anomalies can be explained by the well documented sediment trapping or accreting function of wetlands, i.e. wetland textural conditions may be a function of erosion and deposition, rather than *in situ* weathering of the geological base.

Under identical conditions, clay will be entrained further than fine sand, fine sand further than medium sand, i.e. according to grain size (Hjulström, 1935 *in* Thompson *et al.,* 1993). The strong negative correlation between clay and sand (coarse, medium, fine and total sand) may be explained by the fact that clay and sand fractions are likely to differ in the field with respect to its susceptibility to erosion, entrainment and deposition. Coarse and medium sand are positively correlated ($p < 0.01$, $r = 0.221$), as are medium and fine sand ($p < 0.01$, $r = 0.446$). Positive associations suggest that these fractions function similarly in the field with respect to overland flow and deposition processes.

In light of the fact that the PPMC and PCA results suggest that the wetlands do function as sediment traps, the relative effectiveness of each wetland type investigated in acting as a potential sediment trap in the landscape, are individually investigated and discussed below.

5.1.2 Highmoor source seepage wetlands as sediment traps

The Highmoor wetlands, located in a high energy environment, and situated at the bottom of valleys or in basinal landforms, suggests that these wetlands are highly susceptible to receiving sediment loads from the surrounding upland zones. Upland wetland side-slopes displayed numerous characteristics suggesting that overland flow rates and associated erosion may be substantial. In many places, slopes were steep and long. According to Granger (1978), it is reasonable to expect slope to be positively related to the amount of erosion that takes place. North facing slopes were characterized by a reduced vegetal canopy. Tufaceous vegetation appeared to fall below 70% cover in certain localities. The fairly shallow solum layer of the wetland side-slopes (approximately 20 cm), overlying relatively impermeable geologies, suggests that the saturation of soil layers may be rapid, promoting saturated overland flow and hence erosion. Soils that have a higher than usual water content at the beginning of a storm, are generally characterized by greater runoff amounts than the same soils with average or below average antecedent conditions (Schwabe *et al.*, 1996). Gregory (1981) argues that saturation may weaken the surface soil, making it more susceptible to splash discrete particles into the air. While the thin sola of the convex, upland slopes suggests that sediment entrainment downslope may be active, a number of authors (McCracken *et al.,* 1989 *in* Daniels and Hammer, 1992) have proposed that low moisture in comparison to surrounding areas, may account for thin soils on slopes. Reynolds and Froude indices (indicators of flow turbulence and velocity), were not derived in this study. Direct measurements of overland flow were not undertaken, since flow characteristics were found to vary both spatially and temporarily, thereby requiring intensive investigations over a long time period. Field observations during two substantial thunderstorms, however, indicated that water moving downslope approximates sheetflow conditions. Threads of deeper flow were noted in places, particularly where sheetflow was broken up by large stones and tufts of grass, resulting in substantial eddying and so promoting erosion. Terracing, slumping, shallow landslides and rill erosion were observed at isolated positions on wetland valley side slopes (Figures 5.2 and 5.3), suggesting that these processes may significantly contribute to sediment input. Similar findings and deductions were made by Rowntree (1993). Wetland sediments may also be of colluvial origin, having entered the wetland as a result of gravitational forces.

Figure 5.2 Rill erosion and terracing found on the valley side slopes above Highmoor 1, (wetland H1).

Figure 5.3 Terracing and slumping on the sideslopes of Highmoor 5, (wetland H5).

Apart from the physical location of these wetlands in the landscape, and their respective landform characteristics and morphology, the deposition of sediments is promoted by a number of physical characteristics of the wetlands themselves. These are briefly discussed below.

- ☐ **Gentle gradients**: not conducive to high flow velocity (Morgan, 1980).

- ☐ **High surface irregularities**: these increase surface roughness and assist in breaking up flow and decreasing flow velocities. Surface irregularities in wetlands such as: hummocks, inter-hummock hollows, pools etc., are frequently more pronounced than in upland areas (Figure 5.4). According to Schwabe *et al.*, (1996), wetland surface roughness assists in regulating the flow of water. The uneven surface of wetlands is likely to disrupt overland flow resulting in the capacity for entrainment being very much reduced. Water is frequently stored in the inter-hummock hollows before being released from the wetland as sheetflow, but at a slower rate than when it entered the system (Schwabe, 1989).

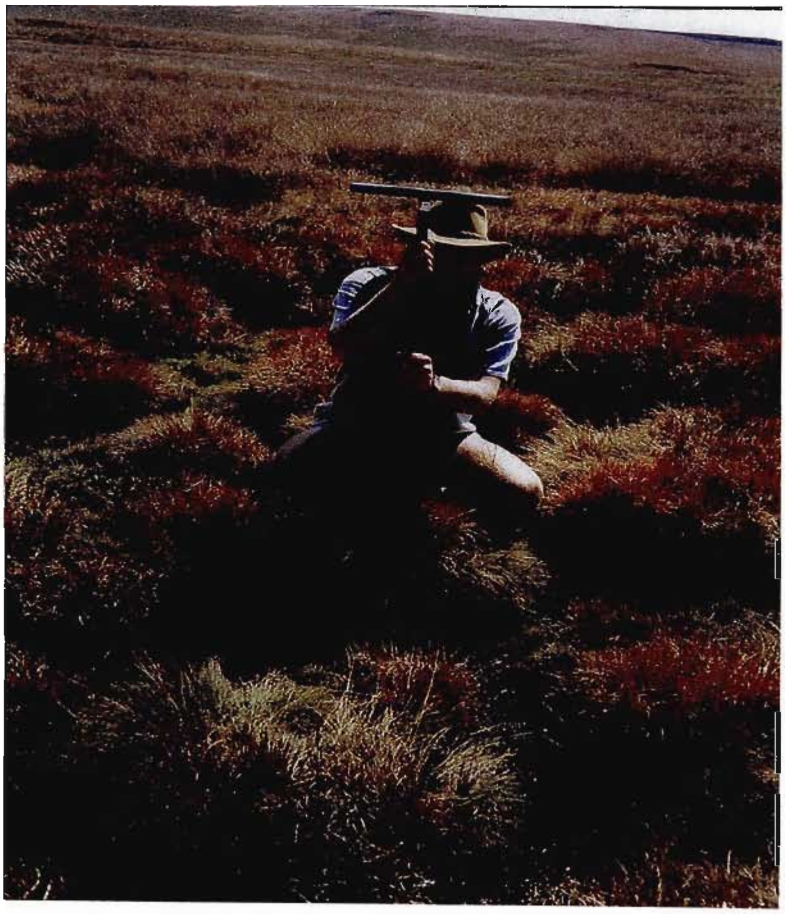

Figure 5.4 Typical example of the irregular nature of the wetland surface, dominated by hummocks, inter-hummock zones and depressions.

- ☐ **Vegetative characteristics**: wetlands are characterized by tall, dense vegetation, which greatly reduces flow velocity and hence promotes infiltration and deposition. In addition, wetlands are frequently characterized by a mat of decaying organic matter (peat), which according to Jacot Guillarmod (1962) and Schwabe (1989), also regulates the flow of water across its surface, and restricts erosion of the wetland surface itself. Distillation of certain organic carbons may be deposited on soil particles and aggregates to produce non wettable surfaces, which may affect infiltration and runoff (Cass *et al.,* 1984). Creation of water-repellent soils can occur either on the surface or at depth, and consequently modify the type and amount of erosion which takes place.

☐ **Agate (stone layer) covering**: in a number of localities (particularly in wetlands H2, H4 and H5), the wetland surface was covered with agates (Figure 5.5). Rock fragments at the soil surface have been found by *inter alia* Poesen and Lavee (1994) and Valentin (1994), to protect the soil surface against the physical dispersion of soil aggregates by raindrop impact, and thereby inhibit aggregate breakdown, surface sealing and crusting. According to Poesen and Lavee (1994), rock fragments may alter soil properties such as bulk density, water-holding capacity, infiltrability, erodibility, soil temperature and rooting volume. These factors affect the hydrological response of soil and hence the susceptibility to erosion. Further investigations are, however, required to determine the specific influence of high agate concentrations on wetland functioning.

Figure 5.5 Agate layer found armouring the wetland surface. These are frequently concentrated within first order channels.

The dominance of silt provides further emphasis that these wetland systems are effective sediment traps, since silt is the particle size fraction preferentially eroded and entrained. These wetlands do, however, contain a relatively high clay and sand proportion. This may be attributed to the frequent, high intensity rainfalls, characteristic of the uKhahlamba-Drakensberg Park (discussed in Section 2.5.1). According to Morgan (1995), erosion and particle size entrainment is likely to be less size selective under high-intensity rains than with low-intensity rains.

Cognisance must be made of the fact that sediment contained within wetlands need not necessarily be attributed solely to sediment deposition, but may also have arisen as a result of *in situ* bedrock weathering.

The physical characteristics of wetland side-slopes and the nature of the wetland surface, suggests that runoff velocities may be substantially reduced on entering wetland settings. Reduced water flow velocity substantially reduces entrainment capacity (see Hjulström's (1935) graph of velocity against particle size), leading to the deposition of sediments entrained in runoff (Thompson *et al.,* 1993). Substantial reductions in flow velocities on entering wetland environments, suggest that wetland perimeters should be characterized by relatively deep profiles. While in many instances comparatively deep profiles were located at the base of wetland slopes, this was not always the case. Figure 5.6 (a - e), illustrates the complex spatial variation in solum depth of a number of cross-sectional profiles taken within wetland H2. The varying and complex solum depths may be attributed to the fact that once deposited, sediments do not remain undisturbed. Resuspension and redistribution occurs. Furness (1983) indicates that sediment reworking occurs as a result of water movement/turbulence within the wetland itself and biotic activities at the sediment-water interface. The high concentration of agates on the base of the first order tributaries is evidence of clastic sediment reworking and movement within the wetlands. Varying soil depths may also be attributed to an uneven bedrock base, resulting from localized geologic characteristics and preferential weathering. For example, the weathering of sites H2.3.3 and H2.1.2 may be explained by the likely existence of a joint running through this wetland system. Jointing is discussed in Section 4.1.2. Extensive weathering at these sites of weakness, promotes the development of deep soil profiles. Continuous descriptions of the spatial variability of subsurface bedrock using ground-penetrating radar would be beneficial in a study of this nature (Lapen *et al.*, 1996), since soil coring provides an incomplete characterization of the subsurface.

While water runoff within the wetlands themselves was not appreciable during field visits, indirect field evidence in the form of flattened vegetation and deposited sediment mounds was observed in isolated positions. While flattened vegetation was found in all the Highmoor wetlands visited, it was most prominent in wetland H1. Flattened vegetation below seepage sites "a", "b" and "c", suggests that a large volume of fast flowing water had entered the wetland at these sites in particular. Figure 5.7 was taken below seepage zones "b" and "c", at the confluence of two first order channels at site H1.4. Large clumps of soil had been deposited along this flowline, some of which can be seen in the forefront of this figure. (Soil peds appeared to have originated from gully wall slumping, located a few metres above this site). Dense wetland vegetation clearly plays an important role in reducing runoff velocity and promoting deposition.

Water flow, both concentrated and diffuse, was generally of a high clarity in the source seepage wetlands investigated. While turbid water was observed in isolated positions within the wetlands following heavy thundershowers, water exiting these source seepage wetlands was exceptionally clear, indicating the effective filtering and accreting function of this wetland type.

The close proximity of the Highmoor wetlands and similar landscape positions, suggests that these wetland systems are likely to have arisen during the same epoch, and may hence have been subject to similar processes. The identical geological base and climate of these wetlands suggests that sediment depth and textural variations may be related to the relative size of the surrounding catchment and differential surficial erosion and sediment entrainment. Average soil depths of the Highmoor wetlands (Table 4.2), appeared to be strongly correlated to the length and gradient of wetland side-slopes.

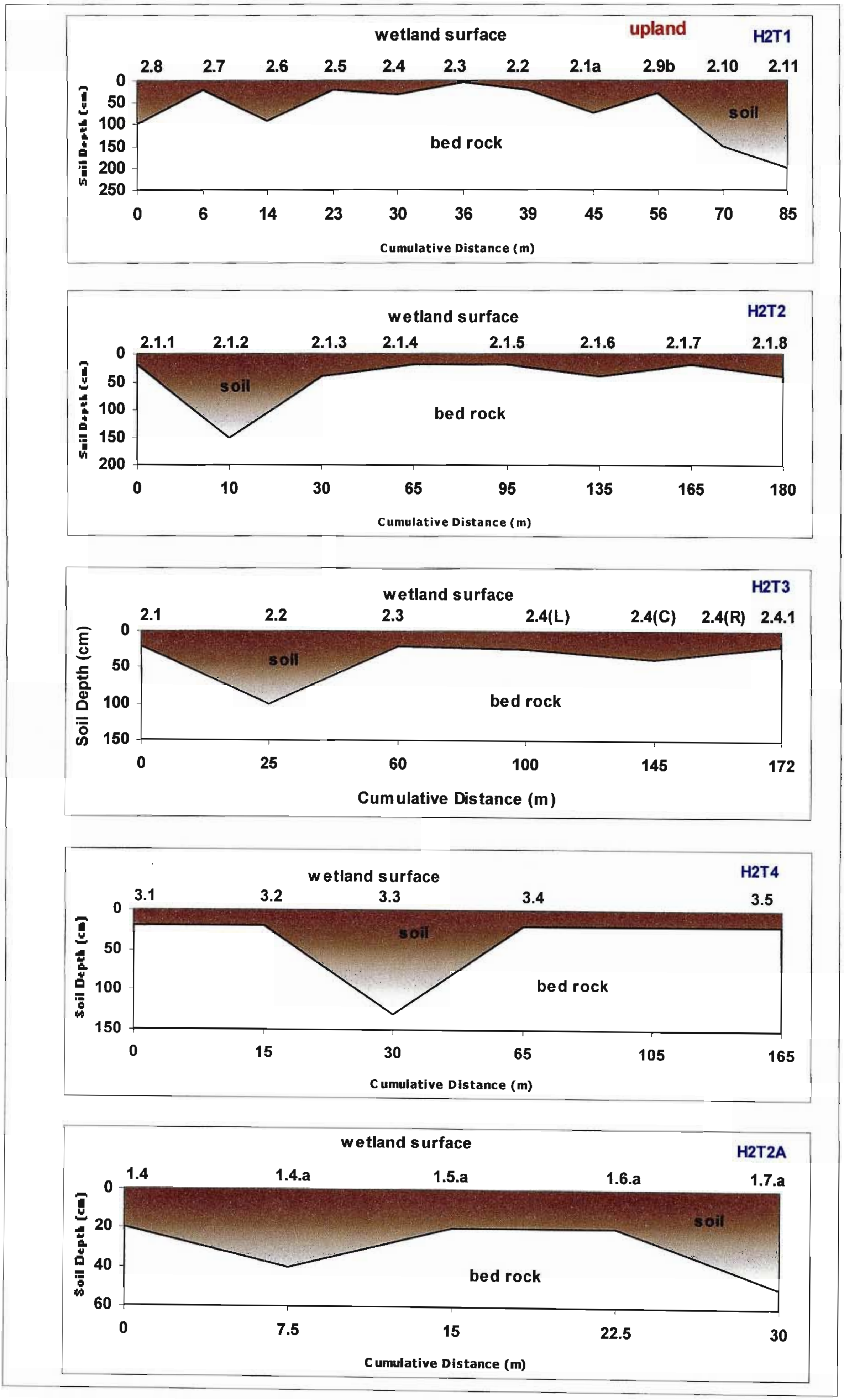

Figure 5.6 (a - e) Profiles illustrate the complex spatial variation in solum depth of a number of cross-sectional profiles taken within wetland H2.

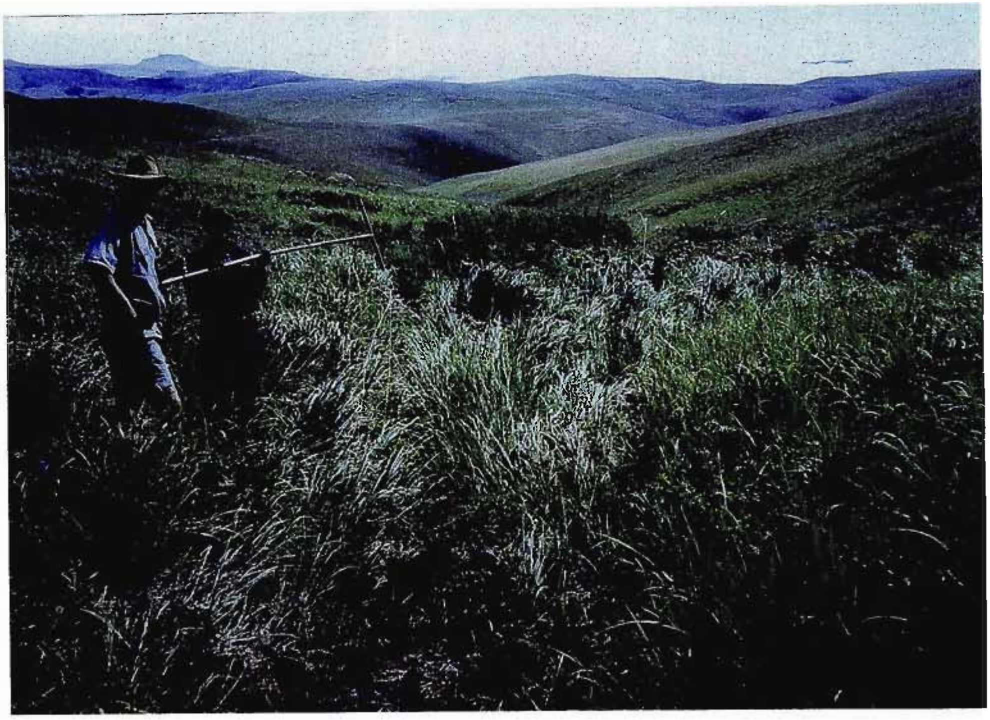

Figure 5.7 The flattened vegetation highlights the force of flowing water. The dense stands of vegetation are clearly effective at slowing down water runoff, and trapping entrained sediments. In the forefront of the photograph fairly large clumps of soil are visible.

H1 for example, characterized by the steepest and longest side-slopes, was also characterized by the greatest mean sediment depth (100 cm). Wetlands H2 and H4, characterized by gentler slopes i.e. occupying a basinal landform position, displayed substantially shallower mean solum depths (47 cm and 51 cm) respectively.

The sediment depths of these wetland systems are rather shallow, considering the geomorphology of the proximal upland areas and the wetlands themselves, i.e. the steep adjacent side-slopes, and internal wetland characteristics conducive to sediment deposition, and minimal sediment removal or loss from these wetland systems. The relatively shallow profiles may be attributed to the:

❑ ‘thatching effect of thick mats of grass which may prevent rainfall from actually reaching the soil surface (Granger, 1987). Overland flow may hence be low in sediment;

❑ mechanically stable geology of the Drakensberg Stage, as discussed in Keulder (1974); and,

❑ small catchment area relative to the size of these wetland features.

Provided climatic, isostic and fluvial conditions remain uniform, these wetlands may over time develop deeper soil profiles, and may eventually be converted to dryland. These processes may be accelerated should the surrounding catchment activities change. A number of activities in the study area, which may enhance the erosion and entrainment of sediment, is discussed in Section 5.1.5.

5.1.3 Sediment trapping of floodplain wetlands

Stillerust wetland differs from the other wetlands investigated in this study in that in addition to sediment input from valley side-slopes (discussed above), it is subject to deposition from overbank flooding. During times of overbank flooding, sediment entrained by river flow will be deposited on this floodplain wetland. Fluvial deposition of fine sediments i.e. vertical accretion, is recognised as being the dominant sediment input source of active floodplains, generally prone to flooding, every two out of three years (Federal Interagency Stream Restoration Working Group, 1999). Field evidence of active sedimentation was noted on the banks of the Mooi River (Figure 4.2.5).

This wetland was characterized by deep profiles, characteristic of floodplain wetlands (see Table 4.10, Appendix 4). A mean depth of 150 cm ± 10.26 cm was recorded. Physical characteristics of the Stillerust floodplain wetland, namely gentle gradients, high surface irregularities and dense vegetative cover, applicable to most wetland systems, reduce runoff velocity and hence promote sedimentation. The shallow depth of the oxbow lakes relative to the sidebanks of the Mooi River appears to be attributed primarily to sedimentation within these depressional features. As outlined in Section 4.2.4, clay loam textures were dominant, followed by sandy loam and clay. The continual deposition and reworking of sediment offers an explanation for the apparent absence of well defined soil profile development in the Stillerust wetland.

The landscape position of this wetland i.e. located at the bottom of a U-shaped valley, together with the gentle gradient of this floodplain wetland and characteristic micro-topographical irregularities, cumulatively encourage sediment deposition i.e. wetland accretion from either overland flow processes or overbank flooding.

Floodplain wetland systems are generally subject to significantly greater energy fluxes and sediment reworking than the other palustrine wetland systems discussed above. In addition, floodplain wetlands are generally more 'open' than the other wetland systems discussed in this manuscript. Moore (1990) argues that sediment retention times are generally least in floodplain wetlands, in that sediment contained within these systems may be 'flushed out' during flood events.

Floodplain wetlands, by virtue of the fact that they are generally restricted to lower positions in the catchment and associated with fairly significant high order channels, are characterized by a large catchment area and are consequently particularly susceptible to flood events, changes in fluvial dynamics and anthropogenic influences.

5.1.4 The sediment trapping ability of tarns

Tarns, as already discussed are depressional landscape features not characterized by an inlet or outlet, i.e. they are essentially closed systems. Figure 4.3.5 illustrates that wetland T1 is a substantial depression in the landscape, with the potential to trap and retain sediment entering this depression via overland flow, or tarn-wall slumping processes. Despite the potential for this tarn to be an effective sediment trap, T1 is characterized by a shallow sediment layer, in the order of 16 cm. The sand fraction was most dominant in this wetland (45.95%), followed by silt (42.50%) (Table 4.7). The shallow sediment deposits of T1 indicate that erosion, entrainment and deposition of sediments by overland flow processes is not particularly active on this plateau. The effectiveness of tarns in acting as sediment traps in the landscape, is largely a function of the nature and characteristics of the proximal upland area. The influence relief exercises on runoff and sediment production is widely discussed in the literature (Selby, 1985). Erosion is generally expected to increase with an increase in slope steepness and slope length, as a result of respective increases in the velocity and volume of surface runoff (Bryan, 1979; Morgan, 1995). The relatively flat proximal areas of T1 are hence unlikely to facilitate erosion and entrainment on the plateau, as discussed in Section 4.3.1. In addition, the plateau is characterized by sandy soils. According to Schwabe *et al.*, (1996), soils higher in clay will have a greater runoff, while sandy soils have less runoff. The most erodible soil particles by overland flow are in the range of 100 - 300 μm (Morgan, 1995). Sand or particles larger than 1.0 mm, are therefore unlikely to be easily entrained in runoff or sheetwash processes on the plateau. Sediment was, however, generally deepest on the perimeter of the tarn base, suggesting that sediments contained within this tarn feature may be attributed to deposition as opposed to *in situ* weathering of the bedrock base. Field investigation of exposed sections of bedrock on the outer rim of the tarn, showed advanced weathering, a small force resulted in the disintegration/crumbling of the sandstone. This suggests that weathered material adjacent to the tarn may be available for transport. As already indicated, sediment contained in T1 may not be attributed solely to input via overland flow processes, but may also have arisen via tarn wall slumping processes. Deeper sediment deposits were noted where the tarn side wall was composed predominantly of soil, in comparison to sections composed predominantly of rock.

Wetland T2, as already indicated, is fundamentally different from wetland T1, in that it is a soil based tarn. This tarn is characterized by deep profiles, in the order of 175 cm. The silt fraction was dominant at all sample sites, and in all layers/horizons, the dominance of silt suggests that much of the sediment contained within T2 may be attributed to overland flow and deposition. Despite proximal areas to T2 displaying a more significant gradient than the plateau on which T1 is situated (Figures 4.3.2 and 4.3.1 respectively), the dense vegetation cover (in excess of 70 %) on the gentle and short slopes is not likely to produce large volumes of sediment. Most authorities agree that vegetal canopy cover in excess of 70% is sufficient to protect land from sheet erosion (Morgan, 1995). The energy of the raindrop is absorbed by vegetation and the direct splashing of the soil particles into the air is reduced. In addition, vegetation limits the action of overland flow by increasing surface roughness. Water is often diverted around plant stems and roots, which decreases the velocity of the runoff, and the capacity to entrain sediment and cause erosion. Roots provide added shear strength to soil, binding the sediments and decreasing the extent of resuspension.The deep solum layer of T2, suggests that either this tarn feature is much older than T1, i.e. deposition may have operated over a longer time period, or alternatively, it may be attributed to tarn genesis, this tarn feature may have arisen from a hollow/toe-slope depression in a paleo-landslip/slump (see hypotheses of formation Section 4.3.5). Sidewall slumping was again noted to be a potential sediment input source. In the vicinity of site A1.1, a heavy clay layer was found overlying an organic topsoil layer.

While sediment input into these wetland systems is largely seasonal and generally not substantial, especially when located on a bench/interfluve terrain setting; once sediment has entered these essentially closed, low energy, depressional features; limited reworking and removal occurs. Insignificant removal of sediment may, however, occur via entrapment under animal hooves, tarn-bank flooding and deflation during dry periods. Continued input over geological time frames with limited removal, suggests that these particular wetland bodies are susceptible to in-filling and hence conversion to dryland.

5.1.5 Catchment activities promoting sediment mobility

While the wetland systems located in the protected uKhahlamba-Drakensberg park, are not subjected to the same degree of anthropic influence/interference as wetlands located on farmlands lower down in the catchment, a brief overview of activities which may potentially increase sediment input into the wetland systems of the Highmoor and Kamberg areas specifically, are identified and discussed below.

The Highmoor Reserve

Factors which may potentially increase sediment production and hence input into wetland systems in the Highmoor area include: Road/path cuttings and burning of valley side-slopes and wetland systems themselves. These factors are discussed below.

☐ Road and path cuttings were found to be generally devoid of vegetation. The exposed soil was highly compacted and relatively smooth (roughness elements having been removed). According to Moodley (1997), the above features, together with a decrease in organic matter, aggregate stability and infiltration rates, are characteristic features of road/path cuttings. These zones often favour accelerated soil erosion. Much of the rill erosion located on wetland side-slopes was attributed to former road/path cuttings.

☐ Fire break burning, practised on the steep, adjacent wetland side-slopes is likely to result in marked increases in sediment yield, as a result of increased soil exposure. Burning, in addition to reducing groundcover, may increase the susceptibility of the soil surface to erosion by altering soil properties (Morgan, 1979). Hot fires for example, can 'bake' the soil, leaving the soil surface hard and brittle, which negatively influences the infiltration of water into the soil. The infiltration capacity of the soil surface has a considerable control on runoff generation, and therefore on the rate of transport of entrained soil particles. Cass and Collins (1984) have recorded a decrease in infiltration rates in burnt areas, although Linnartz *et al.,* (1966) argue that infiltration is generally unchanged after fire.

While the effects of fire in terms of wetland ecology is well documented, there is little information about the actual burning regime of wetlands (Mallik, 1990; Kotze, 2000, Pers. Comm.). Imeson (1971) argues that since peat requires several years to regenerate, lengthy periods of erosion may ensue after burning, as opposed to the burning of grasslands which recover more rapidly, and thus may be less affected by a single burn (Garland, 1987). Wetlands H2, H4 and H5 were unintentionally burnt in 1999, as a result of a run-away fire break (Gabela, 2000, Pers. Comm.). Vegetation regrowth, however, appeared to largely precede the rainy period, suggesting that soil erosion may not be too substantial. It is proposed that the rapid regrowth may be the result of the ample moisture reserves. Further research is however required before any conclusive evidence can be drawn.

The Kamberg Reserve and surrounding area

The high sediment loads and hence high turbidity of the Mooi River following heavy rainfalls, may be attributed in part to a number of anthropogenic activities in the catchment area above Stillerust. A number of activities which may potentially increase sediment loads are discussed below.

☐ A significant cut bank (former quarry), created by the KwaZulu-Natal Nature Conservation Services Roads Department (Figure 5.8), is located adjacent to the Game Pass Road, Kamberg Nature Reserve (Figure 2.2). It is likely to increase sediment production substantially. While efforts have been made to stabilize the cutback by means of pole check structures and vegetation planting, rehabilitation has been extremely slow and not very successful (Glaum, 1999, Pers. Comm.).

☐ The 'Working for Water' programme has been actively involved in the removal of alien Black Wattle trees (*Acacia mearnsii*) from the valley side slopes in the Game Pass area. While the removal of aliens may have beneficial responses from a hydrological and biological viewpoint; the removal of trees without replanting may substantially increase runoff and hence sediment entrainment. According to Federal Interagency Stream Restoration Working Group (1999), vegetative removal from streambanks may conflict with the hydrologic and geomorphic functions of stream corridors (Federal Interagency Stream Restoration Working Group, 1999). The positive effects of vegetation with respect to water flow retardation and soil erosion reduction, is outlined in Section 5.1.3.

☐ The Mooi River passes through a number of private farms, namely: Riverside, East Meshylynn and South Meshylnn before traversing through the Stillerust wetland area. While sediment from South Meshylynn, is likely to be fairly insignificant, the area is primarily grazing land in good condition, cultivation along the banks of the Mooi River was noted on the other two farms. According to Federal Interagency Stream Restoration Working Group (1999), tillage and soil compaction interferes with the soil's capacity to partition and regulate the flow of water in the landscape, which will inevitably lead to an increase in surface runoff. Increased surface runoff may impact on wetland dynamics and functioning, by influencing the volume and rate of water and sediment entering wetland systems.

☐ The relatively dense settlement and subsistence agriculture activities of the Thendele township, located along the banks of the Mooi River, may also contribute to the sediment load of the Mooi River.

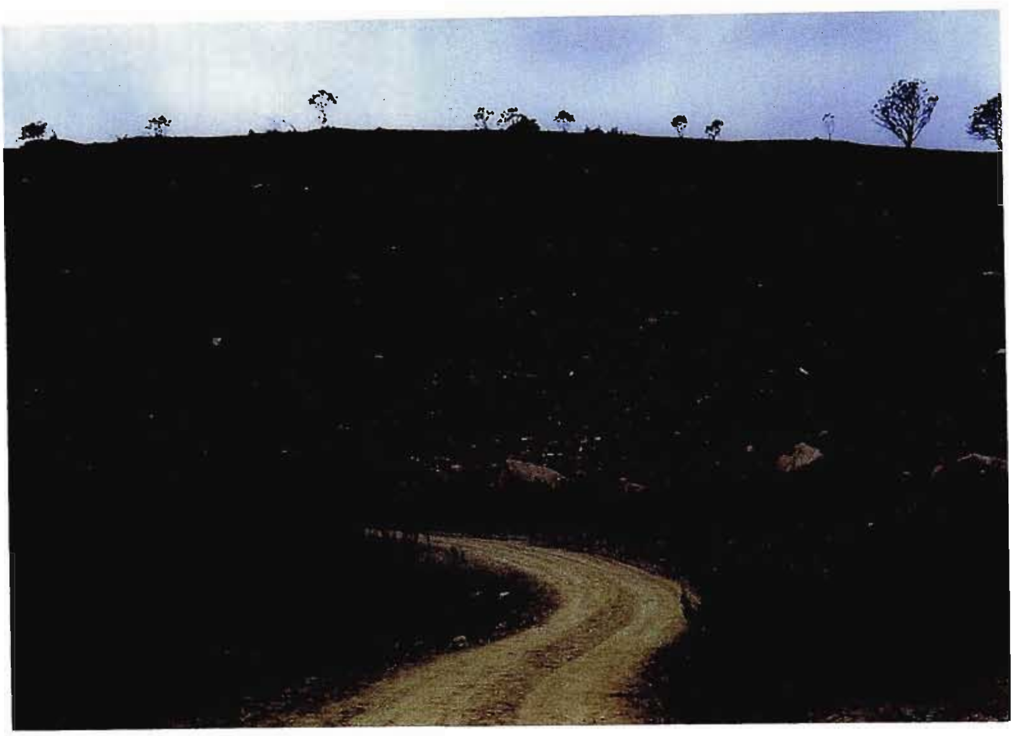

Figure 5.8 Cut bank situated adjacent to the Game Pass road, Kamberg Nature Reserve. Significant volumes of sediment are likely to be eroded during heavy rainfalls.

5.1.6 Implications of sustained sediment input

The preceding discussion emphasizes the fact that wetlands are undoubtedly sensitive to geomorphic events in their catchments. The capacity of wetland systems to function as sediment sinks (i.e. sediment input > sediment output), suggests that the storage capacity of wetlands may be compromised over time, ultimately affecting the wetland's ability to function. As already indicated, Rowntree (1993) argues that the presence and extent of wetlands are both a reflection and determinant of the magnitude of sedimentation and water storage within a drainage basin.

Wetlands may be in-filled completely, to the point where they are converted into dryland. While the conversion of wetlands to dryland can be the result of natural erosion and deposition processes (wetlands being transient features over geological time frames); anthropic acceleration of sediment input as a result of poor soil management practices in upland zones can accelerate the in-filling process substantially (see examples of factors outlined above, Section 5.1.3). Schwabe (1989) argues that if the catchment has been damaged, it is highly probable that it will not be able to regulate floodwater flow which results in the wetlands having to handle quantities of water and sediment above its capacity. According to Jurik *et al.,* (1994), increased sediment loads could have negative impacts on affected wetlands if loadings of sediments exceed sustainable levels. Sustainable loadings of sediments are, however, at present not sufficiently understood. Furness (1983) argues that any change in sediment loading will affect the functioning of the wetland. The increase in sediment input into wetlands as a result of change in catchment use is a widely recognized problem (Heeg and Breen, 1982). An increase in sediment may choke waterways, alter conditions for plant growth, smother plants, alter the physical and textural characteristics of wetland soil, as well as the chemical characteristics (Russell, 1961 *in* Furness, 1983). Whilst being transported to a wetland, inorganic sediments can adsorb nutrients, such as: Ca, Mg, Na, K, N and P. While this may promote productivity by providing a reservoir of nutrients, excessive quantities of sediment input may lead to eutrophication and the negative associations therewith, see *inter alia* the Federal Interagency Stream Restoration Working Group (1999). The cation exchange capacity of clay sediments also promotes the absorption of heavy metals, such as: Zn, Mn and Cu (Keulder, 1974). Heavy metal input into a wetland can have serious implications, as many of these substances are toxic to plants and animals at low concentrations. Under anaerobic conditions, redox potential becomes negative, increasing nutrient availability and the presence of toxic compounds such as hydrogen disulphide (H_2S) (Barko and Smart, 1983 *in* Furness, 1983).

5.1.7 Influence of trout dams and water ways on sediment entrainment and fluvial dynamics

While activities in the upper Mooi River catchment may significantly increase natural suspended sediment loads of the Mooi River, resulting in the Stillerust floodplain being subjected to sediment 'overload', this may be counteracted by the location of trout dams on the Mooi River, located just below the Game Pass area (Figure 2.2). The dams and artificial waterways (Figure 5.9) may aid in removing sediment and counteract the potential for sediment overload in Stillerust.

Figure 5.9 An example of a water way diversion (above the Mooi River), through which water is being channelled into trout dams.

This is a good example of an unintentional "check and balance" in operation within the landscape. While dams, constructed waterways and diversions may be beneficial in that excess sediment is temporarily stored, such structures may themselves alter the natural functioning of wetlands by altering flow periods, flood frequencies and sediment input. Gosselink and Maltby (1990) document that it is frequently the interaction between sediment supply and hydrology that determines the fate and local dynamics of wetlands. In cases where sediments are trapped behind dams, downstream wetlands may begin to experience sediment deficits. The sediment-depleted river may begin to erode downstream, causing long-term changes in the relationship of the river to the channel and floodplain (Gosselink and Maltby, 1990; Cooke and Doornkamp, 1990). The species composition of affected wetlands may be altered in response to these changes (Gosselink and Maltby, 1990; Hughes,1999).

The findings of this study suggest that sediment inputs, while seemingly fairly small, exceed outputs. In other words, the wetland systems investigated did function as sediment traps in the landscape, and may hence support a water purification role in the landscape.

The nature and characteristics of proximal upland areas was found to be paramount in influencing rates and relative quantities of sediment input. While anthropic activities and structures such as dams appears to influence sediment loads, which may negatively impact on wetland functioning, further studies are required to quantify these impacts.

Despite activities in areas above both the Highmoor and Kamberg wetlands potentially increasing sediment loads, at present the wetlands appear to be in a relatively good condition. Further research is required to determine sustainable sediment loadings, since activities promoting enhanced erosion are generally compounded further down in the catchment, as the channel makes its way to its ultimate base level, the ocean. It is proposed that in the light of the possible negative ramifications enhanced sediment input may have in terms of: wetland biota, wetland form and functioning, these factors should be considered in reserve management plans.

5.2 Susceptibility of wetland soils to change

The water content of wetlands, in addition to influencing variables such as soil morphology, soil chemistry and vegetational species composition, influences the 'state' of wetland soil, i.e. whether the soil is solid, plastic and liquid. Soil state is likely to determine the susceptibility of wetland soil to processes of: flowage, cracking, compaction, swelling and shrinking. It is postulated that these processes may greatly alter internal wetland conditions, by influencing both form and functioning of wetland systems. For example, flowage may obstruct water flow paths/channels, alter equilibrium conditions by burying existing wetland vegetation, initiating processes of vegetational succession and so on. Knowledge of a soil's susceptibility to flow, i.e. how prone a particular area may be in terms of slumping, landslides/slips etc., may be a useful management tool. An appreciation of the water content at which a particular wetland soil can be deformed without cracking, may be useful in assessing the susceptibility of a wetland to compaction from activities such as grazing and tillage. Knowledge of the susceptibility of a particular wetland soil to volume changes upon drying, may enable wetland managers to predict the likelihood and the possible extent of volume changes upon natural or human induced drying. Volume changes may alter wetland micro-topography, and hence wetland hydrology, by influencing water flow paths, rates of flow etc.

Atterberg limits, outlined in Section 3.3.3.1, p53, are regarded as an indication of the three soil states, namely solid, plastic and liquid. In addition to Atterberg limits, a number of soil indices such as Plasticity Indices (PI), Soil activity (A_c), clay mineralogy predictions and Soil Swelling Potential (S) were used in attempts towards understanding wetland soil behaviour. The susceptibility of the wetland soils to flowage, cracking, shrinking and swelling forms the focus of the present discussion.

5.2.1 Soil flowage

Liquid limits offer useful information on the susceptibility of soils to flowage and/or mass movement processes. The average liquid limit for the wetland soils investigated in this study was found to be 67.84%. While fairly high, this value is easily obtained in wetlands, which are saturated for at least some time during the hydrological year. The liquid limit values indicate that many sites may be susceptible to flowage under the pressure of a small force, such as the hoof of a grazing ungulate in these zones.

A summary of the liquid limit results for the wetlands investigated is presented in Table 5.2.1. Liquid limit values were found to vary substantially in both lateral and vertical dimensions. Stillerust for example, while displaying the lowest mean liquid limit (53.27%), also displayed the highest standard deviation (SD) of 18.49. Liquid limits were found to decrease with depth, site H2.1.2 being the only exception.

Liquid limit values were poorly correlated to clay content ($p > 0.05$, $r = 0.261$). This lack of correlation is interesting considering the fact that in electrochemical terms, at the liquid limit, clay minerals are far enough apart to reduce electrochemical attraction to almost zero (Carter and Bentley, 1991). The lack of correlation could probably be attributed to variations in clay mineralogy.

Table 5.2.1 Statistics of liquid limit results for wetlands

wetland	n	maximum	minimum	mean	SD
H1	7	80.83	52.85	64.65	9.02
H2	7	82.16	59.42	69.89	9.79
H4	3	86.42	65.23	73.4	11.4
H5	5	90.28	56.9	73.64	14.44
S	10	80.96	26.18	53.27	18.49
T1	1	-	-	73.5	-

(values expressed as % moisture content of dry weight)

According to Carter and Bentley (1991), montmorillonite is characterized by higher liquid limits than illite and kaolinite. The higher liquid limits in the soil surface layers, may also be attributed to higher organic carbon contents. This may very likely have influenced water absorption (samples containing high organic carbon contents are likely to absorb greater quantities of water than samples low in organic carbon). Lower liquid limits at greater depths, however, implies that potential failure zones may tend to be more concentrated at depth than nearer the soil surface. This finding may indicate that soils could be potentially unstable if subject to a trigger force, since in most cases deeper zones were found to be saturated for longer periods during the year than surface horizons, which are subject to drying out by evapotranspiration or water table lowering. Should mass movement processes be initiated, slips are likely to be deep, as opposed to being restricted to shallow surface slips.

Despite the liquid limit values suggesting the wetland soils investigated are highly susceptible to soil movement (flowage/mass movement processes), very little evidence of mass movement was noted within the wetlands themselves. This was attributed to the gentle overall gradient of the wetlands, which counteracts such processes from occurring. Cases of slumping and terracing were however noted on steep, upland valley side slopes (Figures 5.2 and 5.3), and was particularly common in toeslope positions. While most of the sediment input into wetland systems appears to arise from overland flow processes, sediment input via processes of mass movement may, as already discussed, be a fairly significant form of sediment input). Apart from contributing sediment to wetlands, soil flowage may influence wetland form and functioning, as discussed in Section 5.1.

Evidence of slumping was also noted at isolated positions along the banks of the Mooi River. While the river side banks do dry out over the winter period, they remain saturated for the greater part of the year, even when not subject to the direct contact of river water flow. Wet conditions are sustained as a result of capillary rise and water flow from the wetland (water moving from an area of high matric potential to an area of low matric potential). Algae was found growing in numerous locations on the soil face of the channel banks, implying that the channel banks remain wet for substantial periods of time. High pore water pressures over a sustained period of time, together with the influence of gravity and fluvial undercutting, could also make channel banks highly susceptible to slumping/mass movement. In early January, a number of isolated sections of the bank were in advanced stages of failure, with relatively large sections or wedges having "pulled away" from the bank along a vertical plane. A section of the channel that had recently collapsed is illustrated in Figure 5.10. The particularly high water content of river channel banks located within wetland settings, is likely to make these river banks particularly susceptible to failure, influencing the form of both the channel and wetland, as well as fluvial sediment loads.

Figure 5.10 Section of channel bank recently collapsed as a result of high pore pressures, together with probable undercutting by flowing water.

Liquid limits appear to provide a good overview of the susceptibility of wetlands to soil flowage and mass movement processes. Liquid limit determination is a relatively easy and cost efficient analysis, which may be readily applied to wetland management work.

5.2.2 Plasticity of wetland soils

5.2.2.1 Plastic limits

As alluded to in section 3.3.3, as the water content of a soilincreases, water is absorbed between the particles, and the soil, especially one which has a high clay content, becomes plastic. Since plasticity in clays is a function of the electrochemical behaviour of the clay minerals, soils that have little clay do not exhibit plasticity. As their moisture content is reduced, they pass directly from the liquid to the semi-solid state.

The mean plastic limits of the wetlands ranged from 35.12% in Stillerust to 60.56% in wetland H4 (Table 5.2.2). The generally high plastic limit values suggest that a substantial quantity of water is required to prevent cracking and deformation. It is interesting that the plastic limits are not directly related to clay content ($p > 0.05$, $r = 0.185$). Negative correlations were observed at numerous sites, for example: H1.1, H2.12, H5A3.2, H5.5.6 and S6. Again, clay mineralogy information would be useful in accounting for plastic limit variations, but the constraints of the study precluded a detailed analysis of clay mineralogy.

Table 5.2.2 Statistics of plastic limit results for wetlands H1, H2, H4, H5, S and T1

wetland	n	maximum	minimum	mean	SD
H1	7	68.95	10.25	40.99	21.14
H2	7	69.74	44.25	53.65	9.3
H4	3	79.04	50.74	60.56	16.01
H5	5	78.18	38.95	56.47	15.69
S	10	59.64	22.92	35.12	11.49
T1	1	-	-	57.52	-

(values expressed as % moisture content of dry weight)

Although there are a few exceptions, plastic limits were generally higher in surface layers. This may be attributed to the influence of organic carbon in surface layers, which as already discussed, may absorb substantial quantities of water.

In many instances it was very difficult to roll the soil samples into a thread of three millimeters. This may be attributed to the fact that clays are non-smectic, or alternatively, it may be related to the relative proportion of particle size fractions, and the nature and quantity of organic carbon. Samples comprised of amorphous organic matter were very difficult to roll. A very high water content was required to avoid the specimen crumbling. The only sample which could not be rolled into a thread of three millimeters without cracking/crumbling, was site H2.3.4 (0-20 cm). While this site was characterized by a fairly low clay content (14.87%), sites T1 (0-20 cm) and S19.1 (100-200 cm) displayed a lower clay content, yet plastic limit readings were obtainable. The relative particle size and organic carbon proportions for sites H2.3.4, S19.1 and T1 are outlined in Table 5.2.3. This confirms the above postulates that the relative proportions of other particles, namely: silt and coarse, medium and fine sand fractions, as well as organic carbon and clay minerology, may cumulatively influence the water content and the relative ease at which a soil thread is obtained.

Table 5.2.3 Particle size and organic carbon contents

site	% clay	% silt	% coarse sand	% medium sand	% fine sand	% total sand	% O/C
H2.3.4 (0-20 cm)	14.87	25.62	41.37	8.31	9.83	59.51	3.103
S19.1 (100-200 cm)	8.6	19.84	0.1	9.69	61.77	71.56	1.16
T1 (0-20 cm)	11.55	42.5	2.6	9.4	33.95	45.95	7.013

The total sand content of H2.3.4 (0-20 cm) is very high (59.51%); 41.37% of the total sand is comprised of coarse sand, not conducive to being rolled. The relatively low organic carbon content of this site suggests that organic matter would not have influenced the results significantly. S19.1 (100-200 cm) was characterized by a lower clay content and a higher total sand content than H2 and H4, the sand however was largely comprised of fine sand (61.77%). T1 was also dominated by fine sand, but displayed a very high silt content and high organic carbon content. While it may appear surprising that plastic limit values were obtained for these sites, it may be attributed to the fact that sands can possess weak cohesion. This cohesion is a result of meniscus forces in partially saturated sands. In addition, non-plastic silts possess transient cohesion, even though they are non plastic (Carter and Bentley, 1991). Organic matter, apart from physically binding soil particles together, may influence plasticity limits by promoting a 'false plasticity', as a result of the presence of highly charged particles. The nature of the organic matter, i.e. whether it is fibric or amorphous, also appeared to influence the ease of attaining a three millimeter thread.

While a few isolated examples of cracking activity were noted in the field, cracking was not widespread. Wetland H4 displayed the highest plastic limit values, suggesting that this wetland is very susceptible to cracking during winter months, when wetland water contents are reduced. Field evidence confirmed laboratory findings, in that desiccation cracking was more prevalent in this wetland than the others investigated. Despite wetland H4 displaying a larger incidence of cracking relative to the other wetlands, it was not substantial. This may be attributed to the fact that large portions of wetland soil remained wet to moist over the winter period. Alternatively, it may be attributed to the extreme complexity and interaction between clay content, clay mineralogy and the nature of the organic matter, i.e. whether it is composed primarily of amorphous material, or fine root hairs effective in binding soil together. Polygonal cracking of the ground (Figure 5.11), was observed at only three sites during the dry winter months, namely wetland T1 and H4, as well as the Stagstone wetland, located on private farmland.

Figure 5.11 An example of polygonal cracking within the 'Stagstones' wetland. This constituted the most extreme cracking noted.

The sites displaying polygonal cracking are all similar in that they are depressional zones, containing standing water for much of the hydrological year, which inhibited the establishment of hydrophytes in these zones. The apparent restriction of polygonal cracking to zones devoid of vegetation shows that hydrophyte roots are effective in binding the soil together and so prevent cracking. This finding is consistent with that of Whitlow (1994), who reported that there is tendency for cracking where there is sparse vegetation and litter cover. Under these conditions, greater exposure of the ground surface to direct solar radiation occurs, and with that, the drying of the soil. Plants insulate soil against high and low temperatures and so limit the extent of cracking and frost heave. Deep, extensive cracking has been shown by Whitlow (1994) to reduce runoff from early rains in dambos. Cracked solum has been frequently documented as influencing local wetland hydrology, by initially promoting the rapid entry of water to subsurface layers, i.e. acting as temporary sites of groundwater recharge, before the cracks/voids 'swell' close and hence seal off (Stone and Lindley Stone, 1994). The apparent lack of deep, extensive cracking, suggests that the influence of cracks on wetland hydrology is not likely to be very significant in the wetlands investigated.

According to Carter and Bentley (1991), a correlation between plasticity and compressibility frequently exists. A knowledge of the plasticity of wetland soils is important since the soils may be saturated for a substantial period during the year, and frequently remain moist during the dry winter period. Plastic soils are prone to compaction from trampling and trailing activities of livestock/ungulates grazing and drinking in these zones, as well as from farm implements such as tractors (*inter alia* Wilkins and Garwood, 1986; Kotze *et al.*, 1994). According to the Federal Interagency Stream Restoration Working Group (1999), wetland environments are particularly vulnerable to compaction as they are generally wet or moist and have a high clay content.

Wilkins and Garwood (1986) recommend that grazing within a wetland area should be discontinued if the soil becomes flooded or wet to the surface. Wet soils, particularly those with a high clay content, are more susceptible to compaction, poaching (the disruption of soil structure caused by the repeated penetration of hooves into the soil) and erosion. It is argued that such effects will vary depending on soil type and moisture content. The water content of the soil i.e. whether a soil is closer to the liquid or plastic limit, will largely determine the extent of damage. Dry wetland soils were not easily compressed when a force was applied in the field. Similarly, very wet soils appeared to be resistant to compaction when a force was applied to the surface of saturated soils. Wet soil, while easily displaced, appeared to return to conditions prior to disturbance on removal of the force. Moist, plastic soils were found to be very vulnerable to compaction, deforming even under a very slight pressure. This finding suggests that wetlands could be utilized when wetland soil is very dry and/or wet. Similar sentiments are expressed by Kotze (1999), who states that grazing and vehicular traffic may not be too detrimental in very wet soils, since permanent deformation will not occur. Kotze (1999) argues, however, that in plastic soils, soil may be compacted and irreversibly transformed.

5.2.2.1 Plasticity indices

As alluded to previously, a soil with a low plasticity index requires only a small reduction in moisture content to bring about a substantial increase in shear strength. Conversely, a soil with a high plasticity index will not stabilize under load until a large moisture content change has taken place, implying that highly plastic soils are susceptible to compaction.

The plasticity index (PI) values ranged substantially from a low of 3.26 at S19.1 (100 - 200 cm) to a high of 59.42 at H2.3.4 (0-20 cm). The average plasticity index for all wetlands investigated was 18.62. The plasticity index values indicate that while a fairly significant change of water content is required to bring about a 100-fold strength change, it may be attainable at a number of seasonal and temporary sites. This suggests that wetlands may be utilized over dryer periods with minimal negative implications, i.e. the susceptibility to compaction will be substantially reduced.

5.2.2.2 Wetland compaction

Compaction of wetland soils is not an undue concern in the uKhahlamba-Drakensberg Park. The reserves are not subject to anthropogenic influence and have low stocking rates compared to domestic cattle herds on commercial farms. Fairly heavy grazing of cattle and associated soil compaction and path creation was noted in a number of wetlands located on private farms (Figure 5.12 and 5.13). Deformation and compaction of wetland soil as a result of the introduction of farm implements into wet, plastic zones, was observed in a number of farm wetlands. Kotze *et al.*, (1994 a&b) argues that mowing or cutting with machinery when the soil is wet is more likely to result in soil erosion than cutting when the soil is dry. According to McCann (1999, Pers. Comm.) a number of attempts to prepare wetlands for cultivation in the upper Mooi River catchment have been abandoned, owing to the poor trafficability of these plastic wetland soils.

The force exerted by animals and/or farm implements, and the consequent structural damage, i.e. deformation and compaction of wetland soils, is likely to influence natural infiltration and runoff rates. Clay pan formations are likely to enhance or extend the period of wet, waterlogged conditions. Deformation of the wetland surface may also alter water flow paths and hence alter the wetness of different wetland zones.

Figure 5.12 Example of a wetland surface exposed to grazing cattle. Note the relatively low vegetative cover and how the soil has been compacted and churned up. This is likely to influence wetland functioning.

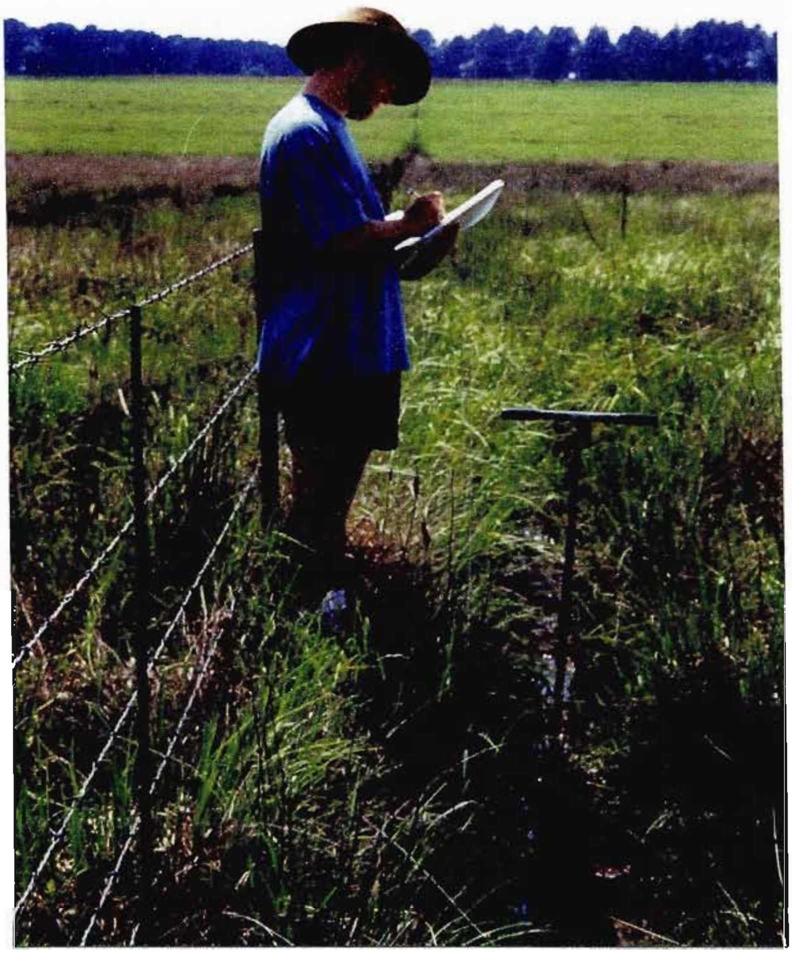

Figure 5.13 The position of the auger indicates a channel created by cattle walking along the fence line. The left side of the fence was significantly drier than the right side; suggesting that the fairly deep and compacted path may alter water movement and hence hydrology.

While the negative impacts of grazing within wetlands has been emphasized in the above discussion, it must be acknowledged that wetlands throughout Africa are extensively utilized by wild game as well as by domestic animals in the dry season (Denny, 1985). Moderate grazing on wetlands during the dry season frequently has numerous beneficial effects i.e. accelerating the nutrient cycling process, or by removing moribund grasses (Rowntree, 1993).

The plastic limit results of the wetlands investigated, while fairly high by upland standards, are easily attained in wetland environments, implying that the majority of sites investigated within the wetlands will remain in a plastic state for much of the hydrological year, and are hence not conducive to grazing. The results of this study indicate the importance of knowing the hydroperiod and the relative wetness of the wetland selected for possible grazing, and the average plastic limits of wetlands, so decisions can be made regarding grazing times and stocking rates.

While plastic limit results may in some cases be influenced by both the skill and experience of the operator, it is argued that plastic limit determination and associated field water content determination, may be a useful analysis in wetland management initiatives. It is an easy, quick and cost efficient indicator of the overall susceptibility of wetland soil, at a particular water content to deformation. It may aid in decision making by determining factors such as: the most desirable timing for wetland utilization, by providing information on when the wetland is less susceptible to compaction from livestock and machinery.

5.2.3 Shrinkage limits

As previously indicated, the shrinkage limit is defined as the moisture content of the soil at which the volume remains constant upon drying (Smith and Atkinson, 1975). Carter and Bentley (1991) outline that clay swelling and consequential ground heave is a common annual phenomenon in areas where prevailing climatic conditions lead to significant seasonal moisture changes in the soil. Shrinkage limits were conducted in the present study in an attempt to:

- ☐ determine the susceptibility of certain wetlands to volume changes with altering water contents; and
- ☐ determine whether wetland hummocks can be attributed to fluctuating water contents and associated volume changes.

The shrinkage limits were all relatively low. Values ranged from a low of 1.35% at site H1.1.2 (70-120 cm), to a high of 11.22% at site H2.1.2 (100-150 cm). The shrinkage limits are generally well below the plastic limits which, according to Carter and Bentley (1991) is a common characteristic of undisturbed organic clays. Descriptive statistics of shrinkage limit results for the wetlands investigated are outlined in Table 5.2.4.

Table 5.2.4 Summary statistics of wetland shrinkage limit results

wetland	n	maximum	minimum	mean	SD
H1	7	8.92	5.47	7.06	1.25
H2	7	11.22	3.11	6.88	3.13
H4	3	8.18	5.81	7.16	1.22
H5	5	8.11	5.2	7.07	1.19
S	10	10.14	1.35	6.07	2.56
T1	1	6.55	6.55	6.55	-

(Values expressed as a percentage)

The relatively low shrinkage limit values, together with high water contents (for at least some time during the hydrological year), suggest that soil shrinkage activity on drying is very likely. Based on Altmeyer's (1955) guide *in* Carter and Bentley (1991), to determine the potential for soil expansion using shrinkage limit results, sites H2.1.2 (50-150 cm) and S8 (0-30 cm) are characterized by a marginal potential for expansion; the remainder of which have a 'critical' potential for expansion (shrinkage limit % < 10). The critical potential of the wetland soils for expansion may provide an explanation for the frequently uneven, hummocked surfaces of these wetlands (Figure 5.4, p 97 and Figure 5.14).

The localized occurrence of hummocks within the wetlands appeared to be largely attributed to water content and alternate wetting and drying cycles, i.e. wetland water flux. The hummocks may be analogized to small scale thufurs. Hummocked surfaces may be analogized to gilgai topography, a term describing the micro-relief sometimes resulting from changes in the volume of swelling clays during prolonged expansion and contraction, due to changes in moisture content, particularly occurring in less humid areas (Goudie, 1994).

Figure 5.14 Typical hummocked micro-topography. Hummocks can attain much larger sizes.

Carter and Bentley (1991) indicate that volume changes will only occur when wetting and drying processes occur. The above discussion explains the apparent absence of hummocks from permanently wet areas, not generally subjected to drying. Soil activity values ranged from 0.2 to 4.0, with a mean activity quotient of 0.78. Sites characterized by high activity values did not always display hummock activity. This may be attributed to a number of other variables such as: water content fluctuations, sediment depth, groundwater chemistry, vegetational characteristics as well as the type of clay minerals present.

While soil obtained from a hummocked site (H4.4.3) was expected to display a low shrinkage limit relative to the other sites, 61% of the samples were in fact lower than this site, suggesting that hummocks may not be the result of swelling and shrinkage processes. Alternative explanations of hummock development are outlined below.

(i) Trampling of grazing activity of ungulates

A number of authors, *inter alia* Begg (1988), have attributed hummock development to trampling of grazing ungulates. The effective lack of grazing in the uKhahlamba-Drakensberg Park and the existence of hummocks disproves this explanation as the sole cause of hummocking activity.

(ii) Peat accumulation

Tallis and Livett (1994) argue that hummocks develop where peat accumulation is most rapid. This hypothesis does not account for the hummock topography of the wetland systems in the Upper-Mooi River catchment. As already discussed, the wetland soils investigated are mineral and peat accumulation is not substantial.

(iii) Erosion in areas not stabilized by vegetation

Water eroding around vegetation tufts, may overtime, produce a hummocked surface, i.e. erosion occurring in the inter tuft area.

(iv) Pipe collapse

The hummock-like topography may arise from pipe collapse at isolated locations (Section 5.3).

According to Chen (1988) *in* Carter and Bentley (1991), a number of researchers have been unable to establish a conclusive correlation between the shrinkage limit and swelling expansion. This finding suggests that a number of factors may work in unison to promote swelling and shrinkage variations.

Sowers (1961) cautions that drying of members of the montmorillonite group have profound and often unpredictable effects on consistency limits, and thereby complicate interpretations. Only one of the sites investigated in wetland H4 displayed a shrinkage limit higher than plastic limit. According to Carter and Bentley (1991), this phenomenon may arise if the specimen is dried slowly from a water content near the liquid limit, or if the sample is dominated by a sandy or silty clay texture. This site is characterized by a "silty clay" texture, soil water content on drying and the length of drying time, may all have influenced the shrinkage limit values obtained.

The shrinkage limit test results should not be viewed as irrefutable, since as pointed out above, a number of factors may influence the results obtained, for example, soil texture, water content, the length of drying time and so on. Despite the fact that the relationship between the shrinkage limit and potential volume assessment is not always absolute, shrinkage limit tests are frequently adopted by geomorphologists and soil engineers in that they are a quick and easy analysis, which may be used in determining the potential for soil expansion/shrinkage.

5.2.4 Physical soil variations and their significance

The behaviour of wet soils in the field was found to be influenced by a multitude of factors. Despite the complexity of wetland soils, it is submitted that Atterberg limits and Plasticity Indices (PI), Soil activity (A_c) determinations, clay mineralogy predictions and soil swelling potential (S), give reasonable estimates of:

☐ the susceptibility of the soil to flow under the pressure of a small force;

☐ the water content at which soil can be deformed without cracking, i.e. soil plasticity indications, assessments of susceptibility to compaction; and

☐ the potential for volume change upon drying, swelling and shrinkage processes.

As indicated previously, data on clay mineralogy analyses would have been beneficial in accounting for and explaining consistency limits and general soil behaviour. Clay mineralogy estimations were frequently contradictory, varying with the indirect clay mineralogy estimate used, as indicated in Table 5.2.5, p121. This is clearly an avenue requiring further research in the future. Despite the many contradictions, all three determinations indicated the dominance of non-smectic clays. Mineralogy estimations using activity and liquid limit values indicate that kaolinite is the dominant clay mineralogy of the wetlands investigated, while plastic limit determinations suggest that illite is the dominant clay mineral.

In spite of the potential problems associated with Atterberg limits, outlined in the preceding discussion, they are relatively easy, cost efficient analyses. They enable very good predictions of a wide range of soil properties, and are frequently used by engineers (Carter and Bentley, 1991). They may hence be valuable in wetland management, in that they provide important information on wetland form and functioning, and may be used to predict the effects of increased/decreased water contents of wetlands as a result of anthropic influence, the impacts of wetland utilization by livestock, impacts of farm implements and machinery.

Table 5.2.5 Shrinkage, Plastic and Liquid limit results and associated indices derived from the Atterberg Limit results

WL	SITE	DEPTH	SL	PL	LL	PI	ACTIVITY	SWELLING POTENTIAL	INFERRED MINERALOGY		
									ACTIVITY	PL	LL
H1	1.1	0 - 30	8.9	68.95	80.8	11.88	0.5	low / medium	K	M	I
		30 - 70	8.6	56.08	69.3	13.24	0.2	low / medium	K	I*	K/I
		70 - 120	6.9	53.47	62.6	9.12	0.2	low	K	I*	K
	1.2	0 - 30	5.5	46.97	66.3	19.29	0.8	medium	I/K	I*	K
		30 - 70	6.8	10.25	57.1	46.85	1.9	high / v. high	M	K*	K
		70 - 120	6.2	31.14	52.9	21.71	0.6	medium / high	K	K	K
	1.3	0 - 20	6.6	20.08	63.6	43.54	2.3	high / v. high	M	K*	K
H2	7	0 - 20	6.2	52.47	64.1	11.64	0.3	low / medium	K	I*	K
	1.2	0 - 20	4.2	58.41	65.4	6.95	0.3	low	K	M*	K
		20 - 50	7.3	44.25	60.7	16.42	0.5	medium	K	I*	K
		50 - 100	11	46.42	75.7	29.29	0.9	medium / high	K/I	I*	I
		100 - 150	11	50.62	81.8	31.48	0.8	high	K/I	I*	I
	3.4	0 - 20	3.1	nr	59.4	-	-	-	-	-	K
	2.4 (r)	0 - 20	5.3	69.74	82.2	12.42	0.5	low / medium	K	M	I
H4	4.3 (H)	0 - 30	7.5	50.74	65.2	14.49	0.4	low / medium	K	I*	K
	4.7	0 - 30	5.8	79.04	86.4	7.38	0.3	low	K	M	I
	B2	0 - 30	8.2	51.89	68.6	16.67	0.3	medium	K	I*	K
H5	5.1	0 - 50	6.9	66.08	87.2	21.16	0.7	medium / high	K/I	M	I
	A 3.2	0 - 20	8.1	78.18	90.3	12.1	0.3	low / medium	K	M	I
		20 - 100	70	52.69	66.1	13.45	0.3	low / medium	K	I*	K
	5.6	0 - 20	8.1	38.95	67.7	28.7	0.7	medium / high	K/I	I	K
		20 - 200	5.2	46.46	56.9	10.44	0.3	low / medium	K	I*	K
S	S1	0 - 30	5.5	59.64	81	21.32	0.6	medium / high	K	M*	I
		30 - 100	6.8	45.24	68.2	22.93	0.8	medium / high	K/I	M*	K
	S 6	0 - 50	6.3	38.75	73.9	35.17	1	high	K	I	I
		50 - 200 +	7.8	30.58	51	20.39	0.5	medium / high	K	K	K
	S8	0 - 30	10	42.3	64.7	22.4	0.5	medium / high	K	I	K
		30 - 100	8.8	31.52	52.1	20.58	0.5	medium / high	K	K	K
		100 - 200 +	5.9	26.42	44	17.56	0.5	medium / high	K	K	K
	S19.1	0 - 40	1.4	30.65	42.8	12.15	0.5	low	K	K	K
		40 - 100	3.5	23.18	28.9	5.7	0.4	low	K	K*	K*
		100 - 200 +	4.7	22.92	26.2	3.26	0.4	low	K	K*	K*
T1	T1.1	0 - 20	6.6	57.52	73.5	15.96	1.4	medium	M	M*	I

(SL - shrinkage limit; PL - plastic limit; LL - liquid limit; PI - plasticity index; nr - no reading; K - Kaolinite, M - Montmorillonite; I - Illite; * - variable (out of predicted ranges outlined *in* Carter and Bentley, 1991)
Swelling potential based on relationship given by Seed *et al.*, (1962): Low (0-1.5%); Medium (1.5-5%); High (5-25%); Very High (> 25%).

5.3 Soil piping in wetlands

Although piping is identified as a significant landscape process from an erosional and hydrological perspective (see *inter alia* Freeze (1972); Jones (1979, 1987); Anderson and Burt (1990); Beckedahl (1996)), the role of soil piping in wetland environments has been largely neglected. A few wetland studies in which pipes have been investigated include that of Mann (1967), Downing (1968), Kirby *et al.*, (1991), Whitlow (1994) and Younger and Stunnell (1995). Consultation with farmers in the study area indicated that this subsurface erosion phenomenon is relatively unknown and little understood. Beckedahl (1996) outlines that the general literature in many respects still regards these erosional phenomena as freak occurrences. Many of the wetlands investigated (both within the protected zone of the uKhahlamba-Drakensberg Park and on private farmlands) were found to display marked piping activity. This refutes the Goudie *et al.*, (1994) statement that pipes are commonly found in arid and semi-arid regions and less commonly elsewhere. Table 5.1 indicates the study sites in which piping was noted.

Despite the fact that soil pipes are likely have a similar influence on wetland functioning irrespective of the actual mechanism of formation, it is argued that knowledge of wetland susceptibility to piping, as well as information on the likely development and maintenance of these features may be useful in wetland management.

Beckedahl (1996) outlines five categories favouring the initiation and development of the piping process, namely:

- ☐ chemical soil properties (and associated dispersion);
- ☐ physical soil properties (including swelling and desiccation cracking);
- ☐ soil-hydrological factors;
- ☐ biotic factors; and
- ☐ geological factors (Bedrock joint systems and scree-slope piping).

Each category will be briefly discussed and the relative importance of each factor, with respect to pipe establishment within the wetlands, reviewed.

5.3.1 Chemical soil properties

The control exerted by soil chemistry with regard to pipe development has been discussed extensively by *inter alia* Bryan and Yair (1982); Jones (1981,1990) and Beckedahl (1996). The primary role of soil chemistry is the weakening of the interparticulate bonds. Dispersion is accompanied by cationic exchange on the surface of the clay micelles. Bonding divalent cations such as Ca^{2+} and Mg^{2+} are replaced by the monovalent ions of Na^{+}, K^{+} or hydrogen bicarbonate in the percolating water, increasing forces of repulsion on the micelles. Of the cations, Na^{+} is the most effective dispersant.

The Na^{+} content of the wetlands investigated was found to be very low, and in a number of instances Na^{+} was below detectable limits (Table 5.3.1). It is generally agreed that dispersion of soil is likely to occur when the exchangeable sodium percentage (ESP) defined as: Na^{+} / Cation Exchange Capacity ($cmol_c kg^{-1}$) is greater than six (Richie, 1963 *in* Beckedahl, 1996), and when the sodium absorption ratio (SAR) defined by Nordström (1988) as:

$Na^+ / \sqrt{((Mg^{2+} + Ca^{2+})/2)}$ ($cmol_c kg^{-1}$) exceeds 15 (Heede, 1971).

Table 5.3.1 Na, ESP, SAR and $(Mg^{2+} + Ca^{2+}) / Na^+$ results for the wetland systems investigated

WL	Na ($cmol_c kg^{-1}$)			ESP			SAR			$(Mg^{2+} + Ca^{2+}) / Na^+$		
	x̄ ± SE	min	max	x̄ ± SE	min	max	x̄ ± SE	min	max	x̄ ± SE	min	max
H1 n = 20	0.21 ± 0.04	0	0.61	0.02 ± 0.00	0	0.05	0.09 ± 0.02	0	0.26	131.62 ± 35.92	18	628
H2 n = 69	0.07 ± 0.01	0	0.56	0.01± 0.00	0	0.09	0.06 ± 0.01	0	0.5	143.72 ± 14.78	8.95	803
H4 n = 28	0.22 ± 0.09	0	2.04	0.03 ± 0.01	0	0.2	0.12 ± 0.05	0	1.04	280.16 ± 83.45	3.8	2184
H5 n = 38	0.07 ± 0.02	0	0.7	0.01 ± 0.00	0	0.03	0.03 ± 0.01	0	0.27	249.59 ± 61.80	19.4	2348
S n = 49	0.06 ± 0.01	0	0.4	0.01 ± 0.00	0	0.05	0.05 ± 0.01	0	0.38	459.17 ± 79.87	9.81	3268
T1 n = 1	0.49	-	-	0.09	-	-	0.44	-	-	5.01	-	-
T2 n = 7	0.29 ± 0.02	0.2	0.39	0.02 ± 0.01	0	0.05	0.28 ± 0.02	0.2	0.39	7.51 ± 0.64	4.72	9.84

The ESP and SAR values of the wetlands investigated are well below 6 and 15 respectively, and in many cases were negligible, suggesting that dispersion is not likely. According to Stocking (1981b), Rooyani (1985) and Nordström (1988), a potentially better erosion index is given by the ratio: $(Mg^{2+} + Ca^{2+}) / Na^+$; the higher the ratio, the greater the erodibility. The $(Mg^{2+} + Ca^{2+}) / Na^+$ erosion index (Table 5.3.1) indicates that certain sites within the wetlands investigated are more conducive to piping than other sites. Values ranged from a low of 3.80 in wetland H4 to a high of 3267.83 in Stillerust. Stillerust also showed the highest mean value of 459.17, yet interestingly enough, showed little piping activity. The apparent absence of piping activity in Stillerust may be attributed to other variables required for pipe initiation being unsuitable, for example, the gradient of this wetland is exceptionally flat. The apparent lack of piping also underscores the observations of researchers (e.g. Beckedahl, 1996), that more work is needed on the predictive capability of cation values, within the context of soil piping.

A number of difficulties in conclusively relating soil chemistry to piping include: the fact that conditions may have changed subsequent to pipe initiation, or alternatively, piping may be related to parameters which need to be measured continuously and with great accuracy in the field, such as critical electrolyte concentrations in throughflow at various points of the pipe system (Imeson, 1986). Despite the difficulties in evaluating the influence of soil chemistry in pipe formation, laboratory studies suggest that chemical soil properties and associated dispersion are not a primary cause for piping activity in the wetlands investigated. Laboratory findings were confirmed in the field. Pipe discharge was generally translucent, indicating that dispersion is negligible. The likely exclusion of chemical soil properties and associated dispersion in explaining pipe establishment within wetlands, suggests that pipe genesis may be better explained by physical factors.

5.3.2 Physical soil properties

Piped soils have been noted by many authors to be characterized by high silt and clay contents (Jones, 1981; Beckedahl, 1996). Fractures and desiccation cracking from a parched surface in strongly seasonal wet-and-dry climates, particularly in areas characterized by the presence of swelling clays, have been known to initiate piping (Beckedahl, 1996). Peat pipes are documented by Gilman and Newson (1980) *in* Younger and Stunell (1995) to be formed by the enlargement of previously existing lines of weakness in the soil. Beckedahl (1996) outlines that surface water flowing into soil cracks may initiate the formation of a cavity, particularly on reaching a highly impermeable subsoil. Once a continuous cavity has been established beneath the surface, enlargement will occur whenever water is available to flow along it and entrain particles, thereby initiating a soil pipe.

Despite indirect clay mineralogy investigations indicating that montmorillonite, a smectic clay with a high swelling potential is not a common characteristic of the wetlands investigated, plastic limits for these soils (Table 5.2.2 and 5.2.5) are nevertheless relatively high, suggesting that the wetlands may be susceptible to cracking. In the wetlands investigated, pipe location was not restricted to sites displaying high silt and clay contents. In addition, relatively little surface evidence of structural discontinuities was noted over the dry winter months. This may, as already indicated, be attributed to cracking activity being minimized by the effective binding of hydrophyte roots. In addition, the surface organic layer may prevent complete drying of the surface. Alternatively, evidence of cracking may have been obscured by the dense, moribund vegetation, or may perhaps have been more prevalent in the cohesive, clay-rich subsoil. Whitlow (1994) established that much of the piping activity in dambos, can be attributed to the physical properties of cohesive, clay-rich subsoils that are prone to vertical cracking.

It was hypothesized that aspect, by its influence on temperature, moisture and vegetation would influence piping. It was further hypothesized that piping would be more prevalent in north facing positions, which are more susceptible to desiccation cracking than the cooler and moist south facing slopes. Piping was, however, found to be dominant at the base of south facing slopes, possibly indicating that soil moisture concentration within the profile may be a more important factor in pipe genesis.

5.3.3 Soil-hydrological factors

A number of authors *inter alia* Jones (1981), Trzcinka *et al.*, (1993), Fernandes *et al.*, (1994) and Beckedahl (1996) have noted that the majority of piped profiles exhibit a markedly layered pattern, frequently termed duplex soils. Many authors maintain that a textural precondition for pipe development appears to be a high silt-clay content in the B or sub-B horizon of the soil profile, overlying a less permeable horizon at greater depth (Beckedahl, 1977, 1996; Crouch *et al.*, 1986). Gilman and Newson (1980) showed that the consequence of an impeding layer within the profile may be the saturation of the soil immediately above, causing lateral saturated flow or matrix throughflow, which may over time, initiate a pipe system.

Preliminary investigations suggest that duplex soil profiles do not offer a unequivocal conclusion for pipe existence in the wetlands. In many places where a duplex situation was found, the surface horizons were very shallow. An example, while rather extreme, was noted at site H5A2.1. The profile is characterized by a clay loam in the first 12 cm, followed by clay

(20-200 cm). Should a pipe become initiated in the very shallow A horizon, it would be particularly vulnerable to roof collapse. Beckedahl (1996) argues that where the pipe roof consists almost exclusively of the A horizon, it may gain its strength from roots and moss. While a number of the pipes displayed a moss lining, the relatively shallow root systems of a number of hydrophyte species are likely to provide only limited support. Many of the sites investigated in wetland H1 showed uniform textural profiles. Sites characterized by layered profiles did not display piping activity. In wetland H4, however, pipe systems were found in the vicinity of a number of sites displaying a duplex character, for example, sites: H4.2, H4.3, H4.4 and H4B3; which suggests that pipe development in these zones may be the result of textural differentiation. A number of sites in wetland H5 (H5.2, H5.5 and H5.6, H5A1.1, H5A1.4 and H5A2.1) showed a layered texture. The layering did not always show an increase in permeability with depth however, frequently the opposite was found. In the Stillerust wetland, the positions sampled did not indicate layering/duplex soils in the classical sense. In many instances the profiles were uniform/massive in texture. Where layering was observed, the top layers were frequently less permeable than basal positions, as is the case in wetland H5. This may offer an explanation for the minimal piping activity in this wetland, where only one pipe was noted. The limited piping, however, can be attributed to a number of other factors, such as the gentle gradient. The relatively large aerial extent of Stillerust, together with multifarious sediment characteristics (outlined in Section 4.2.4) and a relatively limited number of soil samples, negates an authoritative discussion on the relationship between layering/duplex soils and pipe genesis in this wetland.

While the results of this study indicate that the duplex nature of soils may give rise to pipes, in some instances it does not appear to be a dominant mechanism explaining pipe genesis. Similar findings were noted by Smith (1968), who emphasized that textural constraints are not absolute. Heede (1971) and Jones (1975) observed no significant differences in texture between piped and unpiped soil profiles.

5.3.4 Biotic factors and pipe formation

A surprisingly high incidence of soil faunal activity was noted within the wetlands. Numerous vlei rats (*Othomus spp.*) and shrews (*Crocidura spp.*) were sighted, including a limited number of earthworms. These fauna are most likely seasonal visitors to these wetland environments, colonizing wetlands during the drier months of the year and avoiding wet periods. Beckedahl (1996) outlines that rootcasts and animal burrows are likely to channel water into the soil profile. The concentrated flow of water, and associated turbulence along a soil conduit, provides the potential for erosive scour, consequent enlargement and hence pipe genesis. Johnson (1976) and Fernandes *et al.*, (1994) showed that earthworm and ant activity may increase soil permeability and hence infiltration, increasing the incidence of saturated matrix flow and consequent piping. While biotic activity is no longer seen as the primary cause of piping (Jones, 1981), it is proposed that biotic formation may be fairly prevalent in the wetlands investigated. Numerous mole hills, termite mounds and rodent warrens were noted in the wetlands. Wetlands displaying a larger proportion of permanently wet zones appeared to display reduced faunal activity. This suggests that temporary and seasonal wetlands may be more prone to piping as result of biotic initiation.

5.3.5 Geological factors

Beckedahl (1998) cites bedrock joint systems as a potential factor that may be involved in pipe initiation. Preferential flow along joint lines and consequent pipe development may be a feasible process explaining pipe initiation in the wetlands. Further investigations are, however, required to ascertain whether pipe orientation(s) corresponds to the dominant joint direction. An example of what Beckedahl (1998) terms 'scree-slope piping' was noted in a Highmoor wetland system not directly investigated in this study. This form of piping was concluded since the pipe was associated with slope unit 5 (of the nine unit landscape model). Where pipe collapse had occurred, scree deposits were found lining the former base of the pipe (Figure 5.15 and 5.16).

Figure 5.15 Section of a collapsed soil pipe leading into a Highmoor wetland (opposite wetland H2). Note the fairly significant diameter of the pipe.

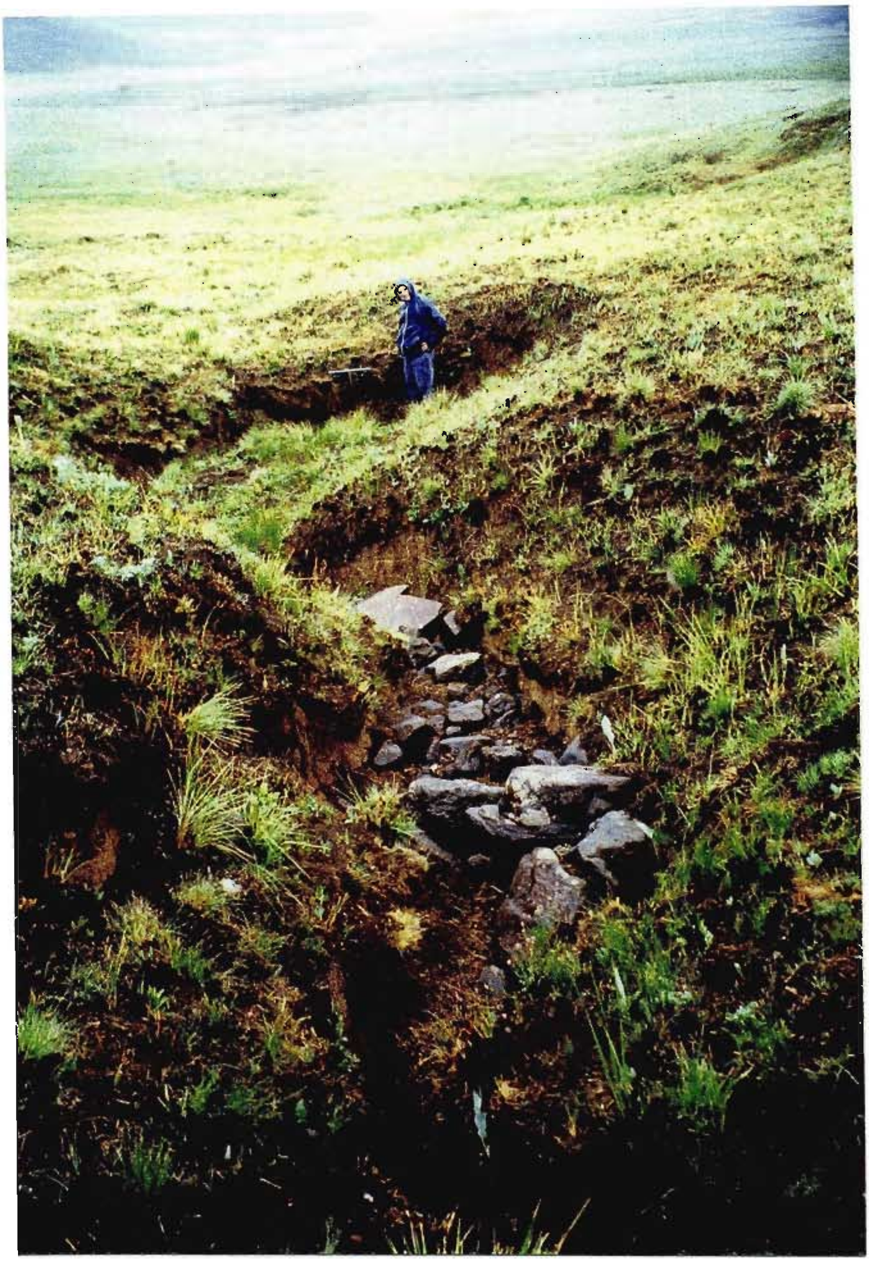

Figure 5.16 Scree slope deposits found lining the former base of the pipe illustrated in Figure 5.17.

5.3.6 Significance of piping in the wetland systems investigated

As in dryland environments, pipes in wetland environments are of importance from both a hydrological and erosional perspective. A brief overview of the hydrological and erosional significance of pipes is outlined below.

Hydrological significance

Pipe flow is a concentrated form of water flow. Beckedahl (1996) outlines that pipes may cause larger volumes of surface water to reach the stream channel network in a shorter time period than would otherwise be the case. Water that would otherwise be stored within a wetland and discharged over a long period of time, or alternatively move slowly as throughflow or diffuse overland flow, is concentrated within pipes, and conveyed at a much faster rate than throughflow or surface runoff. Pipe initiation within wetland environments will not only influence 'reaction times' of the drainage basin, but was found to modify the internal moisture regime of wetlands. Field evidence showed that areas in close proximity to pipe systems were frequently drier than adjacent zones, which may be attributed to water moving from a high water potential to a low water potential, water effectively being conveyed out of the wetland.

A good example of the 'drying' effect of pipes was observed in wetland H1, seepage zone 'd' (Figure 4.1.5). This seepage zone was found to be considerably drier than seepage sites not subjected to piping activity. Indirect evidence of high flow velocities and water pressures of this pipe system was demonstrated in what appeared to be a 'blowout' at position 'A'. The large hole formed by this blowout activity is illustrated in Figure 5.1.7. Water within the hole was turbid and attained a depth of 120 cm. Evidence suggested that the extremely heavy rains experienced a few days prior to the field visit, in combination with the relatively steep gradient of this seepage slope (approximately 18°), may have resulted in the normal flow capacity of the pipe being exceeded, resulting in intense pressure and pipe burst at a point of weakness. The large rock (Figure 5.17) appeared to have made up part of the pipe sidewall. The above evidence indicates that volume and flow rate of the water leading to the wetland must have been fairly substantial to have initiated the "blowout", and have entrained aggregates, attaining an average diameter of 10 cm, a distance of three metres from the hole. This feature may be analogized to what Beckedahl (1996) terms a '*water spout*', which generally arise only at pipe outlets.

Figure 5.17 Evidence of high flow velocities. Note the turbid water in the whole and large boulder which made up the side wall of this pipe system.

The influence of pipes on wetland hydrology (i.e. the rapid conveyance of water and associated 'drying out' effects), appears to be related to the pipe diameter, the piping density, and the position of the pipe in the wetland, i.e. the relation of pipes to dominant flow paths, the gradient and hydraulic head potentials. It is submitted that wetland pipe systems, which in most cases give rise to channel systems as a result of roof collapse, are essentially part of the hydrological system. Similar ideologies are outlined by Mann (1967) and Downing (1968). Downing (1968) in his investigation of subsurface erosion in 'vleis' of KwaZulu-Natal, concluded that subsurface drainage pipes were the headward extension of the drainage channel into the vlei; while Mann (1967) termed pipe systems in dambos 'protostreams'.

Erosional significance

Beckedahl (1996) notes that under suitable environmental conditions, piping may account for an additional 77% of the sediment loss sustained as a consequence of surficial processes. While at the time of investigation pipe discharge was translucent, suggesting minimal sediment entrainment; isolated zones of pipe roof collapse were frequently observed. Pipe roof collapse occurs if the soil horizons forming the roof of the system, do not have a sufficiently high inherent shear strength to support their own weight (Beckedahl, 1998). In wetland environments, soil shear strength may be substantially reduced in wetter periods - high moisture contents resulting in high pore water pressures. A small force such as the hoof of an animal grazing within the wetland, may result in pipe roof collapse. Mann (1967) contends that through pipe roof collapse, sediment is lost from wetlands. It is argued that while the collapse of pipe roofs may initially results in increased erosion, in the long term, pipe roof collapse may create wetland surface irregularities, and thereby retard water runoff by increasing surface irregularities and hence surface friction. This process may account for the 'hummocky' wetland surface at places. Deep doline-like depressions, in the order of one to one and a half metres, were observed in an extensive wetland system located in the vicinity of the "*Highmoor Ruins*" (Figure 2.2). These depressions appeared to have originated from rapid re-vegetation following pipe roof collapse at isolated positions. Pipes and pipe collapse can clearly have a significant influence on wetland geomorphology/micro-topography.

The entire collapse of a pipe roof may offer an explanation for the initiation and development of the numerous first order channels found within the wetlands. Downing (1968) outlined that pipe collapse may lead to the formation of a new gully system, or extension of a pre-existing gully. Whitlow (1994) discusses piping within dambos in Zimbabwe as a possible cause of gullying within wetlands. The gully noted in wetland H1 appeared to follow the same orientation of the pipe. It is proposed that in the absence of anthropogenic interference this gully may very well have developed from pipe roof collapse, leading to gully initiation and headward extension. Piping within wetland systems can perhaps be described as a insidious form of soil erosion; by removing sediment from wetland systems it may very likely prevent problems of 'sediment overload', discussed in Section 5.1.

The lack of conclusive evidence for pipe genesis suggests that a number of factors favouring pipe initiation may co-exist at one site. Cognisance must be made of the fact that factors identified as favouring pipe initiation pertain to dryland or upland environments. Further investigations of pipe genesis in wetland environments are required, since the abundance of water in wetland environments may result in different mechanisms of pipe initiation. The continual throughflow of water along percolines for example, may over time, erode to form a pipe conduit.

The absence of pipes in wetland H2 is surprising, as conditions were not grossly different from the other wetlands investigated. The relatively shallow soil profiles in this wetland together with a high sand content offer probable reasons for their absence. Certain sections of the wetland, however, were characterized by deep soils, and in places was duplex in nature, yet piping activity was absent. While a potential reason points to the negligible gradient in this wetland, wetlands H4 and S are also characterized by a negligible gradient, yet exhibit pipes. This emphasizes the complexity in accounting for pipe genesis. While the present study is unable to account for the precise genesis of individual pipe systems in the wetlands studied, factors promoting piping initiation in wetlands have been outlined and the complexity emphasized.

The high water contents characteristic of wetland environments suggest that pipe systems located within these environments may be inherently unstable. While piping within wetlands is a natural phenomenon (pipes being present in the pristine wetlands of the uKhahlamba-Drakensberg Park), accelerated pipe development and collapse as a result of anthropogenic factors, may substantially alter wetland functioning. Considering the significant role pipes impart on wetland hydrology and geomorphology (erosion and form particularly), it is proposed that where possible, farmers should refrain from utilizing wetlands containing significant piping activity for purposes such as grazing, since as already outlined, pipe roof collapse and consequent channel/gully initiation is likely. In situations where alternative grazing is not possible, it is advisable that farmers/wetland mangers identify the location of pipes and attempt to restrict grazing to less sensitive zones, by erecting temporary fences etc. Cognisance must however be taken, that pipes are dynamic geomorphological features, and may extend in length and vary in orientation over time, continual monitoring is therefore required. While direct draining of wetlands is now prohibited by law, indirect activities leading to reduced water contents may result in cracking and general structural discontinuity, particularly in wetlands characterised by heavy, montmorillonite clay, which may very likely initiate pipe development, promoting concentrated, rapid flow of water out of the system. A positive feedback mechanism is likely to arise, piping promoting further cracking, and hence providing further opportunities for pipe development.

The lifespan of pipe systems is believed to be determined by the balance between erosion by subsurface flow, pipe collapse or clogging with allochthonous debris (Younger and Stunell, 1995). Ephemeral flow and desiccation have been found to hasten pipe collapse (Younger and Stunell, 1995). Pipes may hence be regarded as ephemeral features, pipe creation and collapse may greatly contribute to wetland dynamics. It is submitted that considering the significant erosive and hydrological influences of pipes on wetland functioning, this relatively neglected area of study requires further study, particularly with respect to pipe genesis and maintenance.

5.4 Channelling within wetlands

River channels and river processes are considered to be one of the most important geomorphic systems of the earth's surface, and are recognised as being among the most dynamic components of landscapes (*inter alia* Leopold *et al.*, 1964; Morisawa, 1968; Dardis, Beckedahl and Stone, 1988). The importance of fluvial processes in maintaining floodplain wetlands and in regulating the evolution of this type of wetland system has been discussed in Section 4.2. As already indicated, one of the primary differences between riverine/floodplain systems and source seepage wetlands, is that the existence of the former wetland is largely attributed to the river channels, while source seepage wetlands initiate a river channel. Despite source seepage wetlands only giving rise to a single, well established, yet relatively small first order river channel at its base, the wetland surfaces of these source seepage wetlands were in most instances characterized by a maze of small channel systems, in the order of 30 x 30 cm. The channels were found to be dynamic, influencing wetland hydrology, erosion and micro-topography. These relatively small river/stream channels form the focus of the present discussion. They were investigated with the view to understanding the dynamics of these wetland systems. It was hypothesized that fluvial dynamics may significantly contribute to, and explain wetland dynamics. A brief overview of the micro-channel morphometrics and hydrology (flow period, velocity and discharge dynamics), including the environmental significance of channels located within the Highmoor wetland systems, are presented below.

5.4.1 Channel location and geometry within wetlands

The headward reaches of the Highmoor source seepage wetlands generally did not display channelling activity. The absence of channelling suggests that the capacity for stream initiation and erosion is low in these zones. The primary factor inhibiting stream establishment is most likely the very gentle gradient of these zones. Similar findings are presented by Kotze *et al.*, (2001). The absence of channelling suggests that throughflow processes are operative. Support for this observation is provided by McFarlane *et al.,* (1995), who argued that integrated subsurface water movements can be deduced where no stream channels are recognizable. The absence of sulphur rich soil, frequently documented as a characteristic of wet, anaerobic conditions, is a further indicator suggesting that shallow throughflow is a dominant form of water movement. According to Hughes (2000, Pers. Comm.) the absence of a sulphur smell in wet, anaerobic soils, may be attributed to the continual subsurface throughflow of water, which inhibits sulphur gas emission.

In the upper- to mid-reaches of the wetland arms, small 'first order' channel systems arose. McFarlane *et al.,* (1995) argued that shallow throughflow can be recognized as a "destructive agent", and a precursor to stream development. The initiation of stream channels appears to be attributed to an increase in water volume, (the catchment area increases from the source area), and a slight increase in gradient, steeper gradients promoting higher flow velocities, and hence erosion potential. See Section 5.4.5 for probable hypotheses of channel formation. Channel systems were widespread within the greater body of the wetlands, and did not appear to be prevalent in any particular area, i.e. base of slopes, permanently wet areas etc.

The channels, while predominantly soil based, frequently exhibit an agate/armouring layer, with rock bases in some localities. In most instances channels were relatively small. A representative sample of the spectrum of channel dimensions noted within the wetlands is outlined in Table 5.4.1.

Table 5.4.1 Dominant channel characteristics recorded in wetlands H2 and H5

Channel Location / site	Channel diameter (cm)	Channel depth (cm)	width:depth ratio	Flow velocity (ms^{-1})	Discharge (m^3s^{-1})
WETLAND H2					
H2.2	25	25	1	0.2	1.44
H2.5	45	12	3.75	0.25	1.35
H2.1.4	15	15	1	0.14	0.32
H2.1.4 - H2.1.5A	30	15	2	0.14	0.63
H2.1.5A	30	70	0.43	0.2	4.2
H2.1.6	50 - 60	18	3.06	0.25	2.48
H2.1.7	60 - 200	10	13	0.5	6.5
H2.2.3 (L)	40 - 60	10	5	0.26	1.3
H2.2.3 (R)	20	10	2	0.25	0.5
H2.2.4	40 - 100	3	7	0.25	0.52
H2.3.5	15 - 20	15	1.17	0.25	0.66
H2.3.5	20 - 30	15	1.67	0.3	1.12
AVERAGE	**47.78***	**18.75**	**3.42**	**0.25**	**1.75**
WETLAND H5					
H5.2	30 - 40	20	1.75	0.25	0.02
H5.3	30 - 40	60	0.58	0.25	0.05
H5.5A	20 - 80	20	2.5	0.25	0.02
H5A1.2	30 - 50	40	0.44	0.5	0.08
H5A1.3	15 - 20	30	0.58	0.25	0.01
H5A3.4 - H5.6	80 - 400	5	48	0.25	0.03
H5.8	100	40	2.5	0.67	0.03
H5.9	60	30	2	0.6	0.11
beyond H5.9	80 - 120	40	2.5	0.5	0.2
AVERAGE	**74.69***	**31.67**	**6.76**	**0.39**	**0.06**

* Where channel diameter is represented by a range i.e. 50-60, both values were used to calculate the average channel diameter. Discharge estimate based on mean channel diameter.

The geometry of these micro-wetland channels appears to be conditioned largely by geological, pedological, geomorphological and hydrological factors. Narrow, relatively shallow channels (Figure 5.18) were frequently transformed into wide, shallow, rock based channels, in areas characterized by resistant geology and shallow soils. Wide, shallow channels are a common characteristic above waterfall features (resistant dolerite sills or dykes) in these wetland systems. Channels traversing shallow soils and resistant parent rock, are forced to erode laterally, as opposed to vertically. Figure 5.19 illustrates the much flatter and wider nature of the stream channels, while Figure 5.20 illustrates a typical 'micro-waterfall' feature, commonly found within this type of wetland system.

Micro-valley topography was noted to become more pronounced below the waterfall features. These sections of the wetland did not display classical 'wet land' conditions, the narrow micro-valleys inhibiting the spreading out of water. The water is hence concentrated and generally fast flowing - active erosion and incision occurring until the river reaches its new base level. The gradual decrease in gradient and increase in valley width, was associated with the creation and maintenance of wet conditions once again.

The predominance of relatively narrow and shallow channels, may be attributed to the gentle gradient of the wetlands, which reduce flow velocities and hence down-cutting erosion potential. Alternatively, it may be attributed to preferential flow paths in shallow solum zones.

Channels were, however, not restricted to zones characterized by shallow soils. In areas characterized by deeper soils, channels were frequently substantially deeper than depths recorded in shallow solum zones. The maximum channel depth was recorded at site H5.3 (channel depth: 60 cm; profile depth: 200 cm). A further factor which may account for the generally shallow channel depths, is the variable flow regimes. The channels are predominantly ephemeral or seasonal. Downward cutting and erosion may in many cases be restricted to a few days, weeks or months of the year. They are also subject to deposition following reduced flow competence or sedimentation from overland flow processes when channels are dry.

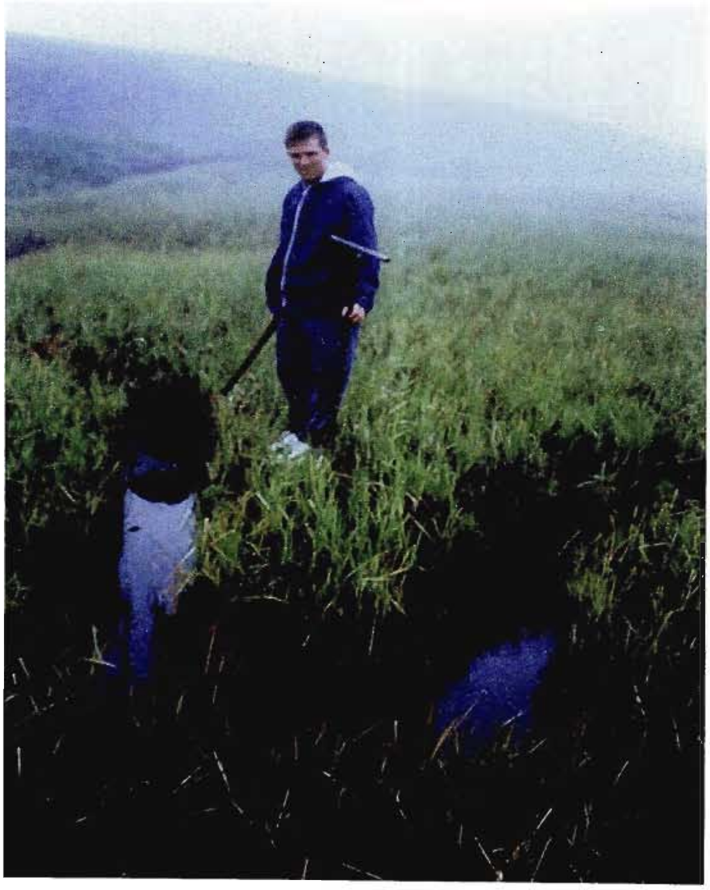

Figure 5.18 Typical channel characteristics found within these source seepage wetlands.

Figure 5.19 The geometry of the channels become wider and shallower when traversing shallow soils overlying resistant bedrock.

Figure 5.20 The geometry of the channels become wider and shallower when traversing shallow soils overlying resistant bedrock.

5.4.2 Channel patterns and channel dynamics

The channel patterning alternated between straight and meandering. In some places the channel approximated an anastomosing or anabranching pattern. The variation in channel pattern appeared to be largely related to gradient. In steeper areas, channels are generally straight, while in flat areas, the channels assume a highly sinuous pattern (Figure 5.21).

Figure 5.21 Highly sinuous channeling patterns frequently develop in flat areas.

The reasons why streams develop meandering courses are not fully understood; meander development is widely discussed in the literature. Well known works include those of *inter alia* Hjülstrom (1949), Leopold and Wolman (1960), Schumm (1977). In the wetlands investigated, the complex, sinuous patterning of the micro-wetland channels appeared to be the result of the transfer of energy. Large zones of relatively resistant bedrock, overlain by a shallow solum layer, results in downward cutting energy being converted into lateral energy.

As previously indicated, channel systems are commonplace in the wetland body of most wetlands, channels generally forming a complex maze, channels, oxbow lakes etc, 'scattered' over the wetland surface. Wetland H1 was the only Highmoor wetland that did not display a maze of channel systems. This can most likely be attributed to the fact that it is characterized by a steeper gradient and deeper soil body than the other Highmoor wetlands. Wetland H1 is instead dominated by a complex pipe mosaic. A small, straight channel does, however, arise in the mid- to upper-reaches of this valley wetland. Wetland channels merged together at scattered locations. Channel confluences were in most cases well defined.

In many instances the geometry of the 'second order' channel was not any different from the 'first order' channels. In addition the 'second order' channel did not display a noticeable increase in discharge. This may be attributed to a close association between the wetland soil matrix and channel systems. Water may simply move through the channel sidewalls (influent flow) and be absorbed by the surrounding wetland soil matrix (See Figure 1.5, p 22, indicating influent seepage). The wetland soil therefore functions as a 'sponge', by absorbing and retaining water.

In wetlands H2 and H5, a single channel exits each arm-like extension. While a maze of channels is once again initiated in the main body, in all the source seepage wetlands investigated (including wetlands not referred to directly in this study), the maze of channels give rise to a single, well-defined river channel. A single channel exits the main wetland body, the emergent stream attaining features characteristic of all low order, high altitude tributaries (see Figure 4.1.9).

5.4.3 Channel flow and discharge characteristics

Period of channel flow

While the channel systems both within and between wetland systems were generally fairly similar in terms of physical and geometrical characteristics, the flow period was found to vary significantly. Channel flow varied from perennial to seasonal and ephemeral flow. While most channel systems conveyed water during the December-February period, only a few dominant channels were found to convey flowing water during the dry winter period. Even in the wet season, a number of dry channels were noted. While this may be attributed to channel abandonment, they may simply be ephemeral channels, containing flowing water only following exceptionally heavy rainfall/flood events. Water flow during periods when rainfall is negligible, suggests that water flow may be derived from:

- ☐ effluent seepage from water stored in the surrounding soil matrix (Figure 1.5, p 22), where the stream flows at the saturation level; and

- ☐ capillary seepage/groundwater seepage, where water from the water table is brought by capillary action to be discharged on the surface (Process outlined in Gregory and Walling, 1973).

Channel velocity and discharge characteristics

The velocity readings ranged substantially in the wetlands investigated, from a low of 0.14 ms^{-1} in wetland H2, to a maximum velocity of 0.67 ms^{-1} in wetland H5. Velocity and discharge readings for particular sites within wetlands H2 and H5 are given in Table 5.4.1. Variations may be attributed to a number of factors, such as: wetland gradient, vegetation growth within the channel, site specific channel characteristics (such as surface roughness), wetted perimeter and time of sampling in relation to rainstorms. The average flow velocity of wetland H5 was higher than H2, namely 0.39 and 0.25 ms^{-1} respectively. The higher flow velocity of wetland H5 can most likely be attributed to the steeper gradient and larger catchment area of wetland H5 relative to wetland H2. The numerous waterfalls located in wetland H5 offer a further explanation. As already outlined, areas below waterfalls are frequently characterized by a steeper gradient than the greater wetland area, exhibiting river channels in an active state of incision, as the channels attempt to attain a new base level.

All channels exiting the wetlands were shallow, rock based channels, with fairly substantial flow velocities. The channel existing wetland H2 (Figure 4.1.9) is a typical example.

The discharge of primary channels exiting the Highmoor wetlands in summer (January), is indicated in Table 5.4.2. While the discharge exiting these 'marshy' wetland zones with little standing water is appreciable, it is not considerable, especially considering the size and abundance of water contained/stored within these wetland systems. This finding suggests that these wetland systems are effective in retaining significant volumes of water, and thereby providing a flood attenuation and water storage function in the landscape. Since these wetlands are the precursors of a number of important rivers, namely the Little Mooi and Mooi River, these wetlands are clearly important in sustaining flow during the dry winter period, i.e. maintaining perennial river flow.

Table 5.4.2 Discharge of channels *exiting* the source seepage wetlands

wetland	discharge (m^3s^{-1})
H1	0.03
H2	0.06
H4	0.04
H5	0.05

Cognisance must be taken of the fact that readings outlined in Tables 5.4.1 and Table 5.4.2 provide only an approximate idea of the volume and nature of water flow within the wetlands during summer (high flow periods). They do not provide a comprehensive picture of wetland fluvial dynamics. Field investigations illustrated that discharge and flow velocities do not only vary fairly significantly between seasons, but also before, after and during rainfall events. Flow meter devices and data loggers would unquestionably be the best method of obtaining a comprehensive idea of channel and hence wetland hydrological functioning and fluctuation, but was beyond the financial and manpower resources available in the present project.

5.4.4 Channel water pH within wetlands

In situ pH readings of standing and flowing water were taken at a number of sample sites within the wetlands investigated (*HI 1290, Amplified Electrode, piccolo2 by Hanna*). pH readings ranged from 4.16 (in slow moving channels and hollows), to a high of 9.01 (in channels where water velocities were high). High pH values of flowing water contrast greatly to the acidic pH conditions of the wetland-soil complex. This may be attributed to a significant proportion of the water entering the wetlands arising from overland flow. Furness (1983) documents that high concentrations of Ca^{2+} and Mg^{2+} have been noted within overland flow in the uKhahlamba - Drakensberg Park in particular. Similar findings were made by Jacot Guillarmod (1968). He found the pH of a number of the peat bogs in the KwaZulu-Natal Drakensberg and Lesotho to have surface water supplies with pH values of between 7.0 - 8.5.

Water flowing within pipe and channel systems of the wetland body is relatively isolated from the acidic soil-water complex of the wetlands. The water may hence be able to retain its high pH status. The relatively low pH values of slow moving, standing water in the wetlands can be attributed to acidification - the alkalinity in the water is consumed by the *in situ* wetland acids.

5.4.5 Channel formation

While the wetland channels assume a similar geometry, all channels are 'u-shaped', varying from narrow, relatively shallow channels, to wide and very shallow channels. Field investigation suggests that the wetland channel systems may have arisen via different mechanisms of formation. Probable mechanisms of formation include:

(i) Erosion of the wetland surface by water runoff

As previously discussed, many geomorphologists, *inter alia* Morgan (1993) and Goudie (1994) have recognised that runoff is rarely in the form of a uniform sheet of water, but generally assumes a mass of braided water courses. Concentrated surface water flow may eventually lead to rill formation, which may then develop into small channel systems over prolonged flow periods.

(ii) Collapse of subsurface pipes

Field evidence suggests that a number of channel systems present in the wetlands were initiated as a result of roof collapse of soil pipes, discussed in Section 5.3.

(iii) Faunal initiation

Wetland zones, as previously discussed, offer a refuge for animals in the dry season, providing both forage and water. Trampling of vegetation and compaction of the soil along animal paths/trails, may in many instances provide preferential flow paths for flowing water, as indicated in Figure 5.13, p 116, and Figure 5.22 below.

Figure 5.22 A cattle path through the *Carex* wetland vegetation leading to a dam. With continual usage and heavy rains, this may develop into a rill/gully, and may hence act as a drain.

The concentrated flow of water along animal trails may, over time, result in channel development. Similar postulates are made by McCarthy, Ellery and Bloem (1988). They found that regular movement of hippopotami (*Hippopotamus amphibius*) along trunk trails in the Okavango Delta, Botswana, keeps trails clear of vegetation, which over time, results in the enlargement and incision of paths. Numerous rodent trails were abundant, particularly in winter. Water concentrating in these micro-channels following summer rains may also result in the enlargement of these trails and first order channel initiation as described above.

(iv) Water throughflow obstructions by tufaceous root systems

The predominantly tufaceous root systems of wetland vegetation may result in the deflection of diffuse, subsurface flow. Water may hence be 'forced' to concentrate between root systems. Continual throughflow between root systems may, over time, lead to denudation of unvegetated zones, while solum stabilized by the binding effect of roots, retains its character. The denudation of inter-vegetational zones may eventually lead to channel initiation, and explain the frequently complex, 'deranged' channel patterning observed in many source seepage wetland.

5.4.6 Environmental significance of wetland channels

Hydrological significance

Channels situated within source seepage wetlands appeared to be an important determinant of the *in situ* water status of wetland systems. The direction of seepage i.e. influent and effluent flow, appeared to vary throughout the hydrological year. In the dry winter months, areas adjacent to channels were frequently wet, indicating that influent seepage processes may be operative. During wetter periods, areas proximal to channel systems were in a number of instances relatively dry, suggesting that channels "abstract" residual soil water. Similar observations were made by Brookes (1988). According to Brookes (1988), the water content of wetlands may be related to the density and depth of the channel network, which provides a pathway for the drainage of water from the wetland system. The micro-channels and wetland soil-water complex appear to achieve an equilibrium condition. In times of excess water, channels convey water out of wetland systems, while during dry periods, water moves out of channels and is absorbed and retained by the soil. More detailed investigations are required to determine whether channel depth, density and location may be correlated to *in situ* water contents and wetland hydrological regimes (permanent, seasonal and temporarily wet zones).

Erosional significance

Despite the complex, meandering nature of channels across the wetlands investigated, the channels themselves generally appeared stable. The stability of these small micro-channel systems may be attributed to: the cohesive nature of the wetland soil, increased shear strength provided by the binding influence of hydrophyte roots, and agates lining the channel base. These act as an armouring layer, and thereby restrict downward cutting/vertical erosion. In a number of instances, hydrophyte establishment within channels was noted. This not only strongly suggests that channels are seasonal, but that the vegetation increases surface roughness, retarding water flow, and thereby reducing the potential for erosion. The channels generally appeared to be in a state of equilibrium - no appreciable erosion or deposition was noted. This suggests that flow competence is relatively constant within these systems, promoting the development of graded channels. The micro-channels found in the Highmoor wetlands, displayed generalized characteristics for straight and meandering channels. A brief overview as given by Schumm (1981) is presented in Table 5.4.3.

Table 5.4.3 Predicted/generalized characteristics for straight and meandering channels

Physical characteristics	Rating
relative stability	high
bed load	low
sediment size	small
sediment load	small
flow velocity	low
stream power	low

(*After:* Schumm, 1981)

It is postulated that the concentration of excess water into stable, relatively resilient channel systems, may substantially reduce wetland erosion, potentially arising from overland flow processes. Similar deductions were made by Jacot Gulliarmod (1963), van Zinderen Bakker *et al.*, (1974) and Schwabe (1989). These authors argue that in certain wetlands, the concentration of water within channels protects the greater wetland surface area from the erosive forces of overland flow.

Biological significance

Channelling within wetlands was found to influence not only water flow paths, but also species richness. Meanders or lateral shifts of river channels are documented by Swanson *et al.*, (1988) as being a dramatic example of geomorphic disturbance, promoting secessional processes. Oxbow lakes, abandoned channels, blind ending channels and pools were scattered across the wetland surfaces, creating a 'maze' effect. These geomorphic features emphasize the dynamic, transient nature of these fluvial channels and hence the wetland itself. The diverse wetland surface therefore creates a wide range of niches for both fauna and flora.

The above discussion indicates that channel systems within wetlands are important from a geomorphological, hydrological and biological perspective. The location of small channel systems within pristine wetland systems appears to reduce wetland erosion and ensure effective conveyance of excess water through the wetland system. In so doing, channels maintain the perennial flow of larger river systems. It is postulated that the dynamic, transient state of wetland channels contributes to the dynamic nature of the wetlands investigated. Alterations in the wetland-channel equilibrium of a wetland, following an increase or decrease in the extent and location of channelling, may negatively influence wetland systems by altering the inherent nature, structure and functioning of wetland systems. A greater channel concentration is likely to influence the efficiency with which the available moisture is collected and carried from wetland systems to water courses. Channels may also result in the lowering of the local water table (as is the case with artificial drainage, outlined in Rowntree (1993)); which may lead to wetland drying, i.e. conversion to dryland. According to Schwabe (1989), in certain wetlands in Lesotho, erosion channels caused by disturbances to the system are responsible for the total drainage of the wetland.

Enhanced channel initiation may arise as a result of: stocking above the carrying capacity, or not enforcing that hikers adhere to designated path. Two undocumented hiking paths were noted within the wetland H2 and H4 respectively. These paths have the potential to develop into rills and possibly channel systems if continuously/extensively utilized (see Sumner, 1995), emphasizing the importance of both education and monitoring/policing in reserves.

The importance of not exceeding the carrying capacity in both protected areas and farmlands is transparent. The finely tuned balance between wetland channel systems and wetland functioning, emphasizes that both intentional and unintentional anthropogenic influences may easily alter the inherent natural functioning of wetland systems. Effects may frequently be unpredictable, varying from negligible to extensive. This depends on factors such as the location of channels within the wetland body and wetland water table depth.

5.5 Soil leaching as an indicator of process

Leaching has been defined as the translocation or migration of soluble salts along with percolating soil water during drainage (Bohn *et al.*, 1985; Ross, 1989; Donkin, 1991). The gradual loss of alkali (Na^+ and K^+) and alkaline earth (Ca^{2+} and Mg^{2+}) cations, leads to their replacement on the exchange complex by protons, H^+ and Al^{3+} ions (Bohn *et al.*, 1985). According to Duchaufour (1977), this leads to a gradual acidification of non-calcareous profiles and a lowering of the base status of the whole profile. Duchaufour (1977) highlights that while re-adsorption of cations in the B-horizon can occur, the movement of generally very mobile soluble salts, favours the process of subtraction from the whole profile, rather than the redistributions between the A and B horizons. In all soils, to a greater or lesser extent, leaching is accompanied by chelluviation, i.e. the translocation of colloidal clay particles (Ross, 1989). Constant downward flow of water can move the more mobile constituents (organic decay products, clay and other colloidal material) out of the A horizon. In some soils leached materials are deposited in a fairly restricted layer within the B horizon. Confined zones of limited permeability in a profile are called indurated horizons or natural pans, frequently observed as a pale grey to black horizon (Farr and Henderson, 1986). As outlined in Section 1.2.2, wetlands subject to intense leaching, i.e. recharge wetlands, are generally characterized by a grey or iron-depleted soil matrix, with ferric iron lining the pores around the roots, as well as argillic (indurated) horizons in basal positions (Stone and Lindley Stone, 1994 and Richardson, 1996).

Jacot Gulliarmod (1963) and Schwabe (1989) argue that most upland wetlands (in the KwaZulu-Natal Drakensberg) are normally subjected to strong leaching. The high rainfall in the KwaZulu-Natal Drakensberg zone suggests that leaching may well be operative in the wetland systems located in this area. High rainfall frequently promotes leaching of the soil and the development of impermeable horizons within the soil profile (McCarthy and Hancox, 2000). A number of authors including Killick (1961); Schulze (1974); Granger (1976); Bainbridge (1987) and Boelhouwers (1988) have attributed the high summer rainfall and the long exposure to weathering, as being instrumental in the genesis of the generally acidic, highly leached soils of the Little 'Berg.

As alluded to in Section 3.3.9, soil pH, leaching indices, clay distribution within profiles and field indicators (matrix chroma, site hydroperiod, oily coverings etc.) were examined in an attempt to determine whether leaching is a dominant process within the wetlands investigated, or alternatively, whether the wetlands are dominated by the reverse process i.e. groundwater discharge. Groundwater discharge wetlands as discussed in Section 1.2.2, are frequently enriched by iron, calcium, carbonate and various salts (Stone and Lindley Stone, 1996 and Richardson, 1996). It is argued that knowledge of whether wetlands are dominated by groundwater recharge (leaching) or discharge processes, is beneficial in that it aids in explaining a number of soil attributes, such as soil acidity, base saturation, variation of clastic sediment within wetland soil profiles. In addition to soil information, a knowledge of dominant water movements in wetlands, provides information on wetland hydroperiod, hydrophyte composition and distribution, and general wetland functioning within the landscape.

5.5.1 pH as an indicator of leaching in wetlands

As previously indicated, leaching gradually removes soluble salts and more readily soluble soil minerals and bases (non-acidic cations such as Ca^{2+}), resulting in the leached surface soil becoming slightly to moderately acid. All the wetlands investigated in this study are acidic. Acidity descriptions of the wetlands (following the 1992 French Référentiel Pédologique nomenclature) are outlined in Table 5.5.1.

Table 5.5.1 Acidity descriptions of wetlands investigated

pH RANGE	ACIDITY CATEGORY	WETLAND(S)
pH between 4.2 & 5.0	acid	H1, H2, H4, H5, S, T1
pH between 3.5 & 4.2	very acid	T2

The low pH of the wetland soils investigated suggests that leaching may be operative within these wetland systems. Cognisance must however be taken of two further variables which promote acid conditions in wetlands namely: (i) sulphuric acid formed by the oxidation of organic sulphur compounds, and (ii) the occurrence of humic acids produced in the water (Greenland and Hayes, 1981). The O/C and pH (KCL) results of this study are contradictory to a number of results presented in the literature. There is frequently a relatively strong negative association between O/C content and pH. Bishel-Machung *et al.*, (1996) for example, quote a fairly strong negative association ($p = 0.02$, $r = -0.534$) between O/C and pH results in wetland environments. The lack of correlation ($p > 0.05$) between pH (KCL) and O/C in this study cannot be attributed to the well established cation retention function of organic matter, discussed by *inter alia* Greenland and Hayes, 1981; Bohn *et al.*, 1985; Baize, 1993 and Bridgham and Richardson, 1993. The alkaline-earth cations were negatively correlated to O/C at the 99% confidence level, suggesting that the exchange sites of O/C are not involved in the retention of these bases. The negative association of bases with organic carbon was not expected, since the CEC of organic matter is frequently higher than that of clay minerals (Baize, 1993). While this lack of association may suggest that leaching is operative, the exchange surfaces of organic carbon being saturated with H^+ ions may be attributed to the fact that CEC is generally found to increase with the degree of humification. According to Baize (1993), the greater the oxidation, the more acid carboxyl groups are present which can retain exchangeable cations. The organic matter found within the wetlands investigated generally displayed a low degree of humification and oxidation. Further possible explanations for the apparent lack of correlation of exchangeable bases and colloidal soil material include the fact that:

- cations released by weathering and organic decay vary greatly in ion charge, size and polarizability, and thus respond differently to the ions and surfaces encountered in the soil (Bohn *et al.*, 1985);

- the cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) are essential macro-nutrient ions (Bohn *et al.*,1985). During the growing season (time of sampling), they may be preferentially absorbed by wetland hydrophytes, reducing the cation concentration associated with colloidal material, and;

- the burning regime of the area may have influenced soil chemical concentrations as well as the nature of colloidal surfaces. According to Mallik (1990), there is potentially a higher level of nutrients available to plants as a result of fire. The influence of fire in wetland environments is not well understood as yet (Kotze, 2000). Further investigations are required before any definite conclusions can be offered in this regard.

Despite weak correlations existing between pH and geology, the PCA plot illustrates that wetland bases are negatively correlated to both dolerite and sandstone geologies. A strong positive correlation between Ca^{2+} and Na^{+} and the dolerite/sandstone complex of wetland H1 was, however, identified. The overall negative correlation between wetland bases (Ca^{2+} and Mg^{2+}) and dolerite is interesting, since dolerite contains significant quantities of these bases (Buol *et al.*, 1980; Donkin, 1991). The acidic, low pH conditions of the Highmoor wetlands situated on a dolerite base, is further substantiation of leaching activity, since soils developed on dolerite are generally characterized by a high base status and associated high pH.

The low pH readings at sites appearing to be dominated by groundwater discharge (groundwater characteristically displaying a high base content), may be explained by the fact that the inherent, strong, acidic wetland conditions may consume the alkalinity provided by deep groundwater.

While sandstone and siliceous environments tend to produce soils of low pH (Buol *et al.*, 1989), pH and sand were positively correlated ($p < 0.01$) for all sand categories (coarse: $r = 0.195$; medium: $r = 0.205$ and fine: $r = 0.240$). This finding is surprising since sandy soils are usually acidic as a result of low electrochemical forces. Sands do not usually retain exchangeable bases as strongly as clay fractions. In addition, infiltration and leaching of bases generally reaches a maximum in sandy soils, characterized by high porosities and permeabilities. This association between high pH and sand, may be attributed to recharge of base rich groundwater at sandy sites. According to Gardiner (1999), sites dominated by sand create preferential groundwater discharge zones, and hence chemical additions. Not too much emphasis should be placed on the above relationships, however, since the correlation coefficients are relatively low.

The relative hydroperiod of a site will also influence the base status. For example, in permanently wet sites, groundwater discharge and recharge is unlikely to operate. Chemical concentrations at a particular site are therefore likely to remain relatively uniform. The negative association between clay and wetland pH (i.e. acidic conditions associated with a high clay content), could be attributed to the predominance of 1:1 as opposed to 2:1 clays, or alternatively, advanced leaching activity. Further investigations are required to assess the influence of clay mineralogy on wetland pH.

Wetland pH findings suggest that the acidic conditions (low pH values) of the wetland soil investigated, may very well be attributed to leaching. Bohn *et al.*, (1985), argues that as weathering proceeds further, even acidic components are leached from the soil, the entire soil profile then approaches neutrality. The very acidic conditions of the wetlands investigated suggest that the wetland systems may not have been subject to advanced weathering/leaching as their acidic components have not as yet been removed.

5.5.2 Soil leaching indices and chelluviation identification

The S-values per unit mass of clay (S-values) and Ca:Mg ratios (Table 5.5.2), suggest that leaching is not a dominant process operative within the seven wetlands investigated. S-values are fairly large and Ca:Mg ratios are relatively low, indicative of only slight leaching activity.

Table 5.5.2 Descriptive statistics of two leaching indices: S-value per unit mass clay and Ca:Mg

WL	S-value per unit mass clay					Ca:Mg				
	$\bar{x}$	SE	SD	min	max	$\bar{x}$	SE	SD	min	max
H1	33.53	4.6	20.57	3.53	93.45	3.3	0.25	1.1	1.65	5.06
H2	36.04	3.67	30.47	4.52	188.38	2.6	0.58	4.86	0.84	41.84
H4	24.65	2.67	14.1	9.37	67.38	2.56	0.15	0.81	1.53	4.87
H5	27.07	4.18	25.75	7.77	166.89	3.22	0.19	1.15	0.5	7.42
S	30.4	2.41	16.84	4.77	79.65	2.66	0.12	0.86	1.16	4.82
T1	73.7	-	-	-	-	5.11	-	-	-	-
T2	10.62	0.68	1.81	7.61	12.87	2.93	0.15	0.4	2.37	3.44

Despite the overall predominance of low Ca:Mg ratios, mean values are higher than the customary Ca:Mg ratios for dolerite and sandstone (1.21 and 0.81 respectively), as outlined by the Geological Survey, Pretoria (1964). Higher ratios suggest that leaching processes may have operated in the past, or may currently be operative within the wetlands. Cognisance must, however, be taken of the fact that Ca:Mg values may be influenced by the very acidic wetland soils. According to Wild (1988) in Donkin (1991), under acid conditions, the ratio of exchangeable Ca^{2+} to exchangeable Mg^{2+} narrows due to the slow release of Mg^{2+} from silicates, acidic conditions resulting in delayed removal or leaching of Mg^{2+} from the wetland soil body. It is important to note, however, that while acidic conditions may delay Mg^{2+} removal, organic acids account in part for the dissolution and movement of iron, aluminum and manganese through the soil profile (Bohn *et al.*, 1985).

The relatively high standard error (SE) and standard deviation (SD) values of S-values and Ca:Mg ratios, particularly in the case of the Highmoor wetlands, confirms field assumptions that zones of recharge and discharge may be found within a particular wetland system. These findings are in accordance with Hardwick and Gunn (1995), who argue that within a particular wetland system, there may be sites of recharge and discharge. The relative proportion of each wetland classed as: dystrophic, mesotrophic and eutrophic, corresponding to: strongly leached (< 5 $cmol_c\ kg^{-1}$ clay), moderately leached (5 to 15 $cmol_c\ kg^{-1}$ clay) and slightly/not leached (> 15 $cmol_c\ kg^{-1}$ clay), as defined by the Soil Classification Working Group (1991), is illustrated in Table 5.5.3. Wetland H1 is characterized by the largest proportion of dystrophic or strongly leached sites/samples. Despite the existence of strongly leached zones, the wetland as a whole displayed a predominance of slightly leached profiles, many sites exhibiting no leaching characteristics.

Table 5.5.3 Relative percentage of each wetland which is dystrophic, mesotrophic and eutrophic

wetland	dystrophic (%)	mesotrophic (%)	eutrophic (%)
H1	10	5	85
H2	3	19	78
H4	0	21	79
H5	0	24	76
S	0	18	82
T1	0	0	100
T2	0	100	0

Cheluviation does not appear to be a significant process in wetland H1. Sites in which a number of samples were taken down the profile (i.e. sites: H1.2, H1.5, H1.7 and H1.8) did not exhibit notable soil induration or clay pan development.

As in wetland H1, leaching processes do not appear to be very significant in wetland H2, with only three percent of the samples displaying strong leaching. A few sites did however display typical signs of leaching. Site H2.3.3 for instance, is a fairly good example of a leached profile (Figure 5.23). The alkali and alkaline earth cations generally show an increase with depth. Clay pan development is also recognizable at this site. Clay increases substantially with depth, from 17% in the first 40 cm, to 35% in the basal horizon. S-values indicate the first 100 cm of this site is indicative of moderate leaching, while the 100-130 cm layer is only slightly leached. The Ca:Mg ratio is also very high (41.84), indicative of a strongly leached site. The 0 - 40 cm layer at this site was a very dark grey (10 yr 3/1), implying that iron (Fe^{3+}) may have been leached from this soil layer. The dark colouration of surface layers may be attributed to the high organic matter in surface horizons, masking visual signs of gleying. Gleyed soil colours were prevalent in lower layers, including dark greenish grey colouration (BG 4/1) and greenish grey colours (5G 6/1 and 5 BG 5/1), indicative of advanced leaching, and the presence of ferrous iron (Baize, 1993).

Wetlands H4 and H5 differ from wetlands H1 and H2, in that no samples are characterized by strong leaching activity. As was the case in wetlands H1 and H2, the majority of samples were only slightly leached, some not displaying any signs of leaching. Only 21 % and 24 % of sites within wetland H4 and H5 respectively, displayed moderate leaching.

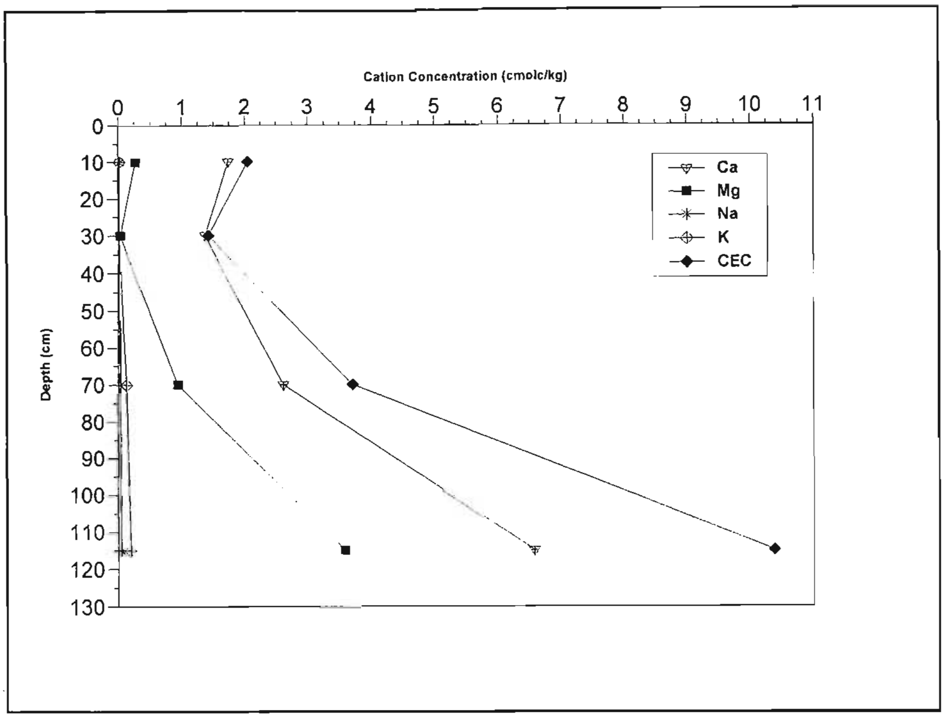

Figure 5.23 Leaching activity found at site H2.3.3. Note the substantial increase of Ca^{2+} and Mg^{2+} with depth. Na^{+} and K^{+} concentrations remain low in subsurface soil horizons, indicating total removal from the profile.

Site H4.2, Figure 5.24, is another good example of a site potentially exhibiting leaching and chelluviation processes. In most instances, the exchangeable bases increased with depth. Clay content increased from 32 % in surface layers displaying moderate leaching, to 54 % in basal horizons, displaying slight to no leaching activity.

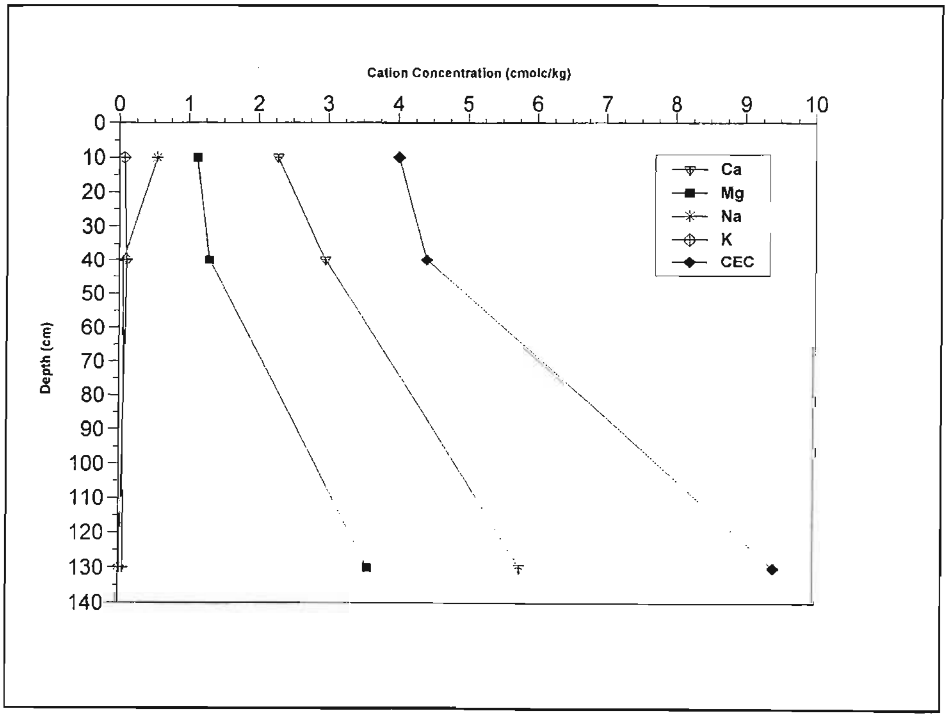

Figure 5.24 Leaching activity found at site H4.2. As in site H2.3.3, note the substantial increase of Ca^{2+} and Mg^{2+} in particular with depth.

This site is not, however, characterized by low chroma colours. The 0 - 20 cm layer, is characterized by a dark, reddish grey colouration (2.5 yr N3/), the 20 - 60 cm layer is a very dark greenish brown to yellow (10 yr 3/2 and 10 yr 7/8), while the basal horizon is characterized by a yellow brown/dark yellowish brown colour (10 yr 5/6; 10 yr 4/4), indicative of a reduced drainage status, see Section 1.2.2. The high Na content in surface horizons, together with soil morphology indicates a high iron content. This suggests that this top sediment layer may have been recently deposited.

The predominance of sites displaying no signs of leaching or very slight leaching activity in the Highmoor wetlands was not unanticipated, since as already mentioned, field evidence suggested that these wetlands or at least zones within the wetlands, are subject to groundwater discharge (zones being permanently wet, and displaying two or more indicators of discharge, see Section 3.2.5). Despite evidence suggesting that leaching may not be a dominant wetland process, the prevalence of gleyed profiles suggests that leaching processes have been, or are operative within the Highmoor wetlands.

As indicated in Table 5.5.3, the majority of sites within Stillerust display no leaching activity to only slight leaching. Site S2 is an example of a typical site displaying no apparent leaching. Exchangeable bases, illustrated in Figure 5.25 and clay content (Table 4.10, Appendix 4) did not increase with depth.

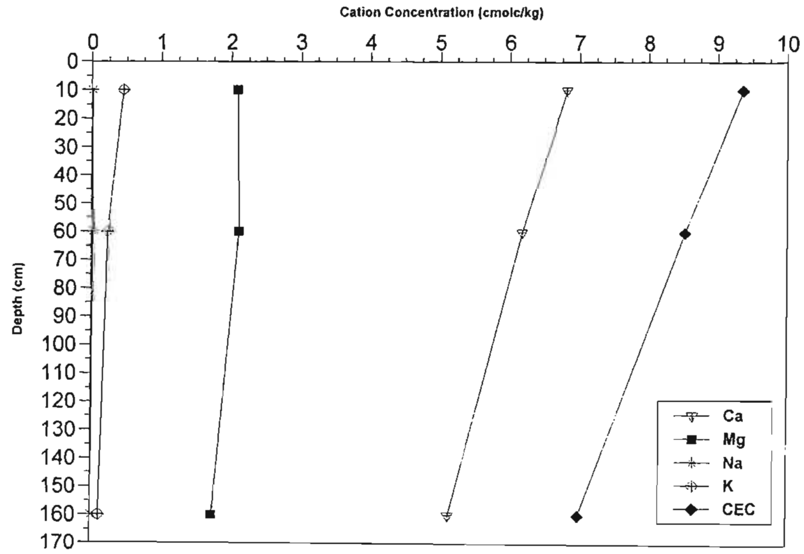

Figure 5.25 Stillerust, site S2. A typical example of a profile showing no apparent leaching. In fact CEC values are higher in surface horizons, which may be related to higher organic carbon contents in surface positions.

The absence of dystrophic sites was not expected. A number of profiles, for example, S3 (0-150 cm) and S15.3 (0-100 cm), were sandy and temporarily to seasonally wet, conditions suggesting that leaching processes should prevail. As in the Highmoor wetlands, many of the profiles were characterized by low chromas and gleying, indicative of leaching activity.

The sample obtained from tarn T1 indicates slight to no leaching. This confirms the postulate made earlier that groundwater discharge is a contributing factor in this wetland. The S-values of wetland T2 are all relatively low, this tarn being characterized solely by moderately leached soils. While basal horizons displayed a higher clay content in relation to surface horizons, it was not substantially different from surface layers, i.e. a well developed clay pan did not exist.

While chelluviation and clay pan development is one of the characteristic features of leached profiles, clay content variations with depth in the wetlands investigated did not always correspond to leaching indices. Sites H2.1.2 and H2.1.8 for example, are both characterized by slight to no leaching. Clay content increased with depth at site H2.1.2, while at site H2.1.8 the opposite was true. This emphasizes the fact that numerous processes simultaneously operative within wetlands may counteract or mask other processes. In situ chemical weathering of bedrock for example, may be dominant at certain sites, resulting is high clay contents in basal horizons. Throughflow processes may counteract elluviation processes, making definitive conclusions of profile characteristics difficult.

Cognisance must be made of the fact that leaching indices have been found to be influenced by the nature of the bedrock (Donkin, 1991). Grey *et al.*, (1987) *in* Donkin (1991), argue that under similar conditions, soils formed on base rich parent materials such as dolerite, give rise to higher S-values than soils derived from base impoverished parent materials such as sandstone. Geology appeared to have an inconsequential affect on S-values in this study. These findings correlate to findings made by Donkin (1991) in his study of soils in the KwaZulu-Natal midlands. Donkin (1991) attributes this to differences being more easily identified in regions of greater aridity. The lack of apparent differences between S-values and parent rock in this study, may be attributed not only to the fact that the wetlands are located in a humid region, but to the extreme complexity of wetland environments. Not only are they characteristically wet, but they are also frequently effective sediment traps. Sediments, particularly clays with a high CEC, may adsorb nutrients, providing a reservoir of nutrients within wetlands, see Section 5.1. In addition, nutrient rich groundwater discharge may counteract the influence of bedrock.

5.5.3 Leaching of wetland soils

Dystrophic, mesotrophic and eutrophic zones within a single wetland system emphasizes the complexity of wetland systems. Some zones are preferential recharge areas, while other sites may be preferential discharge zones, and yet other sites may not be characterized by either recharge (leaching) or discharge - a characteristic of permanently wet zones. These findings suggest that the wetlands investigated may be able to act as both recharge and discharge wetlands, depending on the season or the amount of water contained at a specific time, which is in accordance with findings of Hardwick and Gunn (1995).

Variable leaching activity within wetlands may be attributed to the spatial variation of the following factors: topography and vegetation (Ross, 1989), soil temperature, which determines the effectiveness of rainwater in dissolving minerals (Fanning and Fanning, 1989), soil structure, texture and porosity (Donkin, 1991). The pore-size distribution, pore continuity and structural attributes of soils will also influence water movement, chemical transformation and consequent leaching potential (Donkin, 1991). Unfortunately, the quantification of soil physical characteristics of this nature is often difficult, and was beyond the scope of the present study. The nature of the bedrock, i.e. the location of structural discontinuities such as joints, which may act as conduits for water flow, together with site hydrological factors such as the depth of the aquifer, wetland hydroperiod and water throughflow are all likely to influence water movement and hence the base and clay content of the soil.

Disparities in wetland leaching indicators at a particular site, emphasize the complexity of wetland environments and the potential problems facing wetland scientists and practitioners. It is important to recognise that wetlands are dynamic, variable systems, S-values and Ca:Mg ratios may hence provide only a small window period of wetland leaching status. Ideally samples should be taken throughout the hydrological year, and over a number of years to obtain a better indication of the *in situ* hydrological dynamics of wetlands. Despite possibilities of inaccurate interpretations, it is submitted that by adopting a range of indicators, i.e. a number of different leaching indices in conjunction with field observations, fairly accurate assumptions of leaching can be obtained. The methods used in this study provide a broad overview of leaching intensity. Where accurate, site specific determinations are required, the use of piezometers could be beneficial.

5.6 Wetland processes in summary

The processes investigated in this study, namely: wetlands as accreting systems, the susceptibility of wetland soil to change, soil piping, channelling and leaching, have emphasized that the rates and relative importance of processes in terms of wetland functioning may vary between different types of wetland systems, within wetlands of the same 'type', i.e. across an individual wetland. Processes may also vary temporally, between seasons and over a number of years. The processes investigated are clearly instrumental in directing a number of hydrological, pedological and geomorphological variables, and thereby influence the inherent character of individual wetland systems. This suggests that wetlands characterized by similar processes may develop similar internal conditions over time, and provide similar functions in the landscape.

The present study has highlighted the dynamic nature of wetland systems. Wetland dynamism was largely attributed to the dynamic or transient nature of processes operative within these systems. This study has emphasized the importance of recognizing that processes operate in a four dimensional framework, namely: vertical, lateral, longitudinal and temporal. A schematic illustration of the dominant process dimensions governing wetland dynamics is illustrated in Figure 5.26.

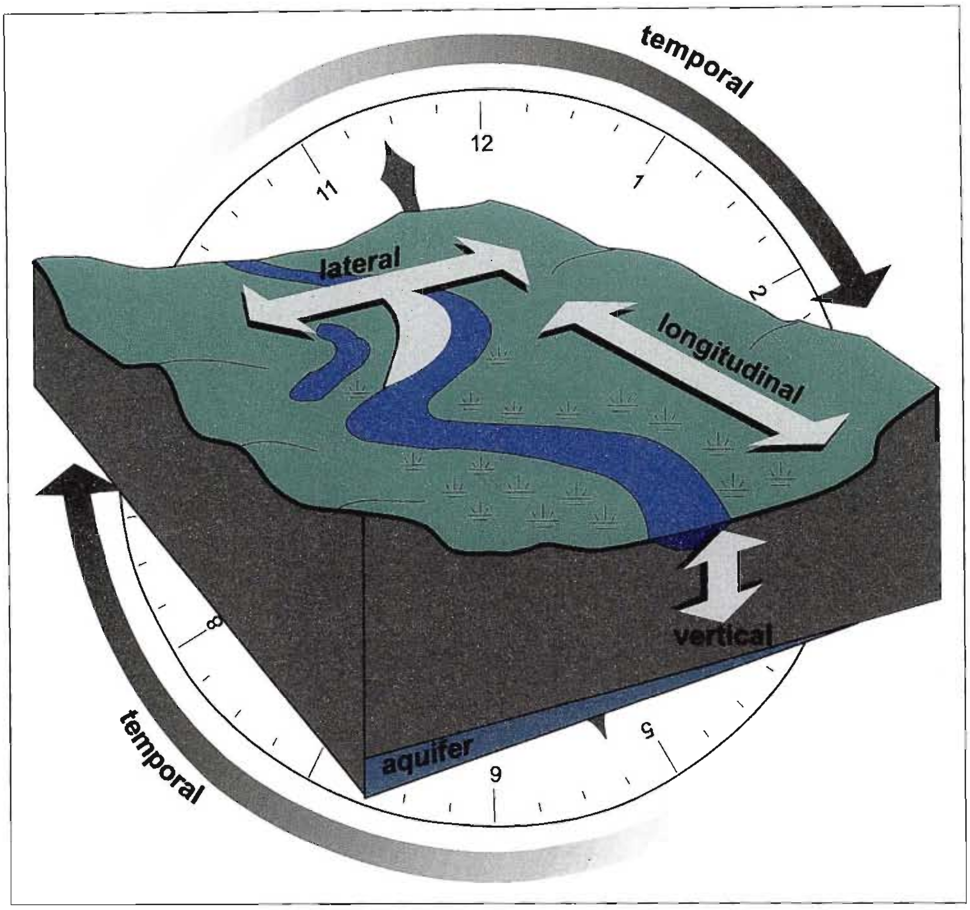

Figure 5.26 Four important dimensions contributing to the nature and dynamics of wetland systems.
(*Adapted from:* Stream Restoration Working Group, 1999).

Untrained observers of wetlands very often concentrate on only the longitudinal and lateral dimensions of wetland environments. The vertical and temporal framework is frequently neglected. It is postulated that the oversight of vertical and temporal dimensions may result in an incomplete understanding of wetland functioning, which may result in inappropriate rehabilitation and management techniques being applied. Further investigation and a greater understanding of wetland process would clearly be valuable in wetland management and conservation.

The variation between the different wetland systems investigated follows in Chapter 6.

Chapter 6

6. Wetland variation

6.1 Determination of wetland variation

Canonical Variate Analysis (CVA) was undertaken to investigate possible differences between the wetlands studied in terms of the environmental parameters investigated. CVA was used to address the problem of separating groups, i.e. to determine whether the wetland types investigated in this study are significantly different to warrant a sub-classification of the "palustrine" system. CVA takes into account that the observations are grouped, i.e. that the measurements of variables were obtained from different wetlands (Manly, 1986). It selects a linear combination of environmental variables that maximizes dispersion of the wetlands along axes, and on the basis of this, it separates the wetlands. CVA was run using the following pedological variables: exchangeable bases (Ca^{2+}, Mg^{2+},Na^{+}, K^{+}), pH (KCL), O/C, clay, silt and total sand. Detail on sand fractions were also included, namely: fine, medium and coarse sand. Altitude, terrain position, shape and approximate area were not included in the CVA since they were found to display minimal influence in prior runs, and proved difficult to include in an analysis of this nature. Geology was excluded since the different wetland geologies is known. Mathematical or linear functions of other variables, such as CEC, which is a function of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} percentages were omitted. The CVA was conducted using the CANOCO program for windows (Version 4).

The results of the CVA analyses (Figure 6.1), which have the constraint that the ordination axes must be linear combinations of the supplied environmental variables, were interpreted according to the rules given in Ter Braak (1987, 1988, 1990). The sites are represented by points in a biplot, the joint plot of sites and environmental variables. Environmental variables are represented by an arrow indicating their direction of maximum variation, the longer the arrow, the more important the environmental variable. Nominal environmental variables (e.g. sand grade) are plotted as points (diamonds) located at the centroid of sample scores belonging to each class. The intersection of an orthogonal line from the site points to the environmental arrow represents the weighted average 'centre' of the site distribution along the particular environmental axis. Centroids for each wetland were plotted as points (circles). Plots were also constructed to show "within" wetland variation (Figure 6.2). Individual sample sites/points are indicated on these plots, different symbols corresponding to different wetlands (see Legend). The relative locations of the wetland types are defined by the centroids (mean position of the respective sample sites). The wetland samples are enclosed by an envelope (10% of the outliers excluded) for easier interpretation. A Monte Carlo Permutation test was run (n=199) to ensure that environmental differences displayed in the CVA are unlikely to have arisen by chance. The Monte Carlo Permutation test randomly mixes site and environmental data and then conducts the ordination (CVA) a specified number of times (in this case 199 times) to determine the probability of obtaining the observed pattern by chance. It counts the number of times out of 199 + 1 times, that the observed statistic (an F-ratio of variance accounted to variance unaccounted), could be obtained by randomly allocating environmental data to sites.

6.2 Distinguishing between wetlands

The first four axes of the Canonical Variate Analysis plot account for 95.2% of the environmental variation. The strength of the latent roots or eigenvalues among wetlands on the first two axes illustrate a very good separation of entities (67.17%). According to Manly (1986), latent roots above 50% indicate a good separation of entities. The results of the Monte Carlo permutation test (n=199 runs), undertaken to assess whether the chosen environmental variables could significantly discriminate between wetland types along the first CVA axis, and for all CVA axes, are given in Table 6.1.

Table 6.1 Monte Carlo permutation test for a CVA of the seven wetlands investigated

	eigenvalue	**F- ratio**[2]	**P value**
Axis one	0.469	16.432	0.015
All canonical axes (Trace[1]**)**	1.404	5.926	0.005

1 - sum of eigenvalues for all canonical axes (i.e. those fitted to environmental variables)
2 - ratio of explained to residual variance

Both the first CVA axis ($p< 0.015$), and the sum of all eigenvalues, i.e. the trace, ($p< 0.005$) were significant (Table 6.1). This indicates that wetland types differed significantly in the assessed environmental characteristics.

Along the first CVA axis, tarns T1, T2 and wetland S are distinct from wetlands H4 and H5 (Figure 6.1). Along the second axis, wetlands S, T1 and T2 are distinct from wetlands H1 and H2, as well as H5 to a limited extent. The CVA indicates that wetlands characterized by high clay contents can be distinguished from wetlands characterized by high sand contents. The plot indicates that wetlands H1, H2, H4 and H5 have a relatively high base status and are characterized by higher pH contents than the other wetland systems investigated. The third axis accounts for 40.5% of the variation. T1 and T2, as well as H1 and H2, are further distinguished on the third axis by higher O/C, lower medium sand and slightly higher Na^+ content.

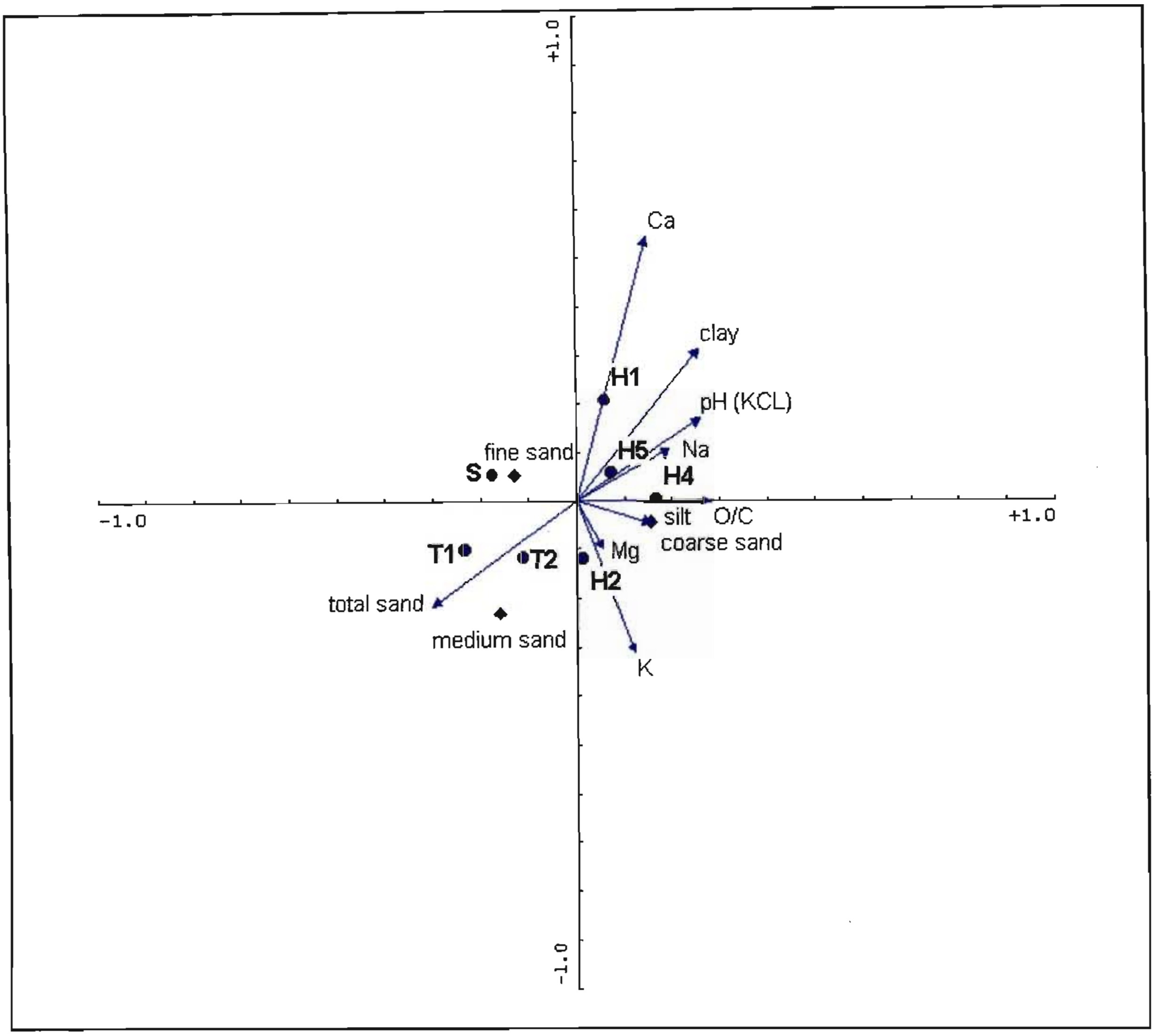

Figure 6.1 Plot of variables along axis one (horizontal) and axis two (vertical) of a Canonical Variate Analysis (CVA) of: Ca, Mg, Na, pH (KCL), clay, silt and sand (fine, medium and coarse). The eigenvalues among wetlands on the first two axes is 67.17%. Centroids for nominal variables (sand grade) are represented by diamonds. Arrows represent the weighted average 'centre' of the site distribution along the particular environmental axis. Centroids for each wetland were plotted as points (circles).

The CVA scatter plot (Figure 6.2), illustrates that Stillerust is a 'tight' group, displaying minimal overlap, and relatively distinct from the other wetlands investigated. While the centroid of this wetland does not lie within the 'envelope' or scatter of other wetland systems, S does overlap with wetlands H1, H2 and H5 to a limited extent. The sample obtained from T1 is clearly distinct from other sites, yet does show a fairly close association to T2. T2 is not only closely associated to T1, but overlaps completely with wetland H2. The scatter or 'envelope' of T2, is however distant from the centroid of wetland H2.

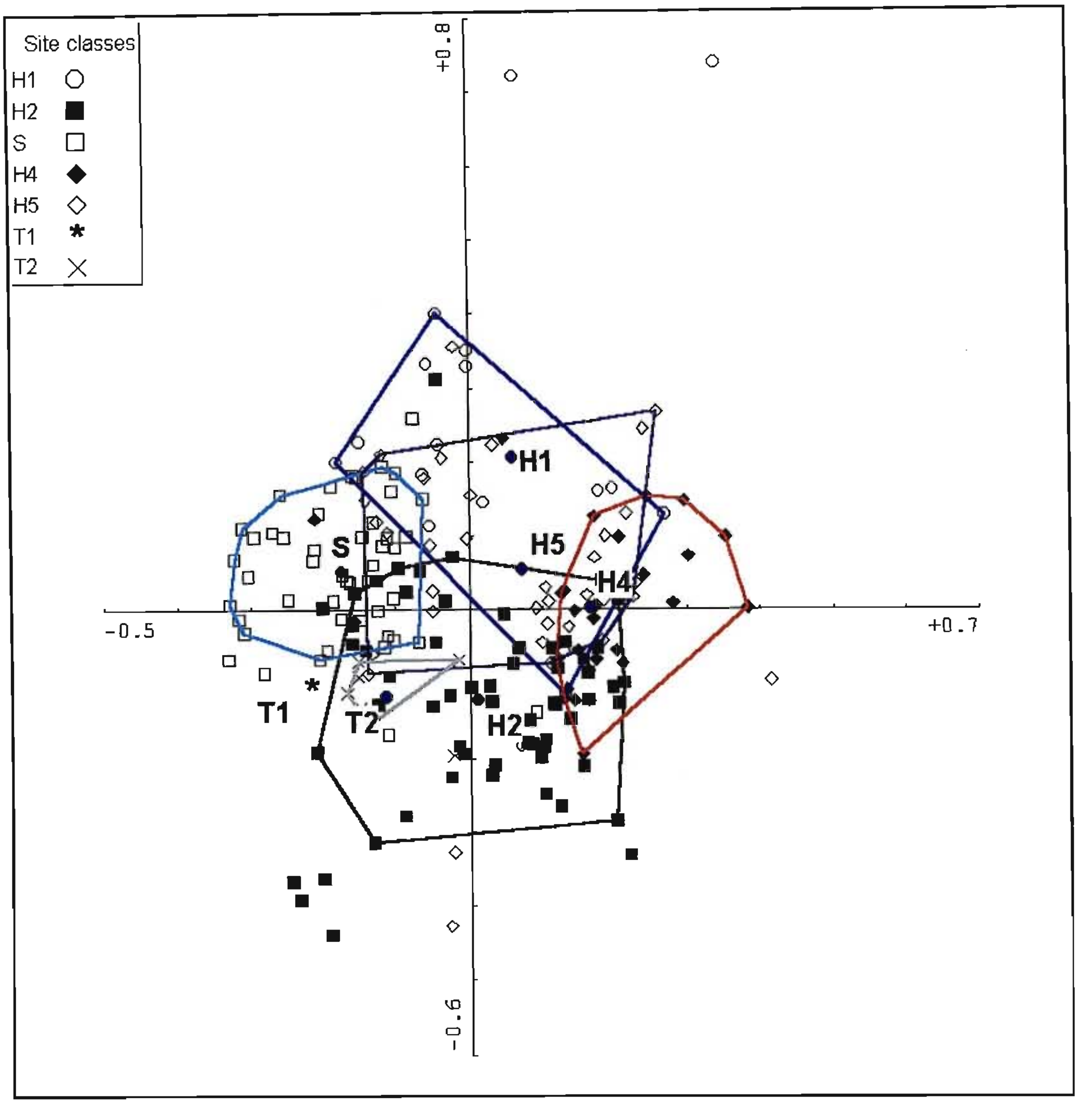

Figure 6.2 CVA plot showing "within" wetland variation. Individual sample sites are indicated on these plots, different symbols corresponding to different wetlands (see Legend). The relative locations of the wetland types are defined by the centroids (mean position of the respective sample sites), indicated by the symbol "●". The wetland samples are enclosed by an envelope (10% of the outliers excluded) for easier interpretation.

Wetland H2 is characterized by a very wide scatter, indicating a significant variation in environmental parameters. Wetland H2 overlaps with all the other wetland systems, with the exception of T1. The apparent absence of overlap of wetland H2 and T1 cannot be confidently deduced, since only one sample was obtained from T1.

While the inherent problems of a single sample site and possible introduction of inaccuracies is acknowledged, wetland T1 was included in this analysis since:

☐ the base of the tarn was predominantly bedrock. Where sediment was present, it attained a maximum depth of 16 cm;

☐ the small areal extent of this tarn suggests that proximal areas are not likely to be a function of different processes, and are hence not likely to differ substantially. Field examination of texture and colour, showed no change across the tarn, suggesting that other pedological variables should remain relatively constant; and

☐ laboratory results were very different from the other wetland systems studied, and on this basis was included.

The CVA plot illustrates that wetlands H1 and H5 are also in themselves a broad group of wetlands. H1 shows elements of commonality with wetlands H2, H4, H5 and S, while wetland H5 overlaps with wetlands H1, H2, H4 and T2. The similarity between the tarns (T1 and T2) was not unexpected, since they are both high altitude depressions, situated on a sandstone base, and are 'isolated' from the fluvial system. The inappreciable overlap or distinctiveness between the tarns and other wetlands investigated is not surprising. The tarns are substantially smaller than the other systems investigated and are relatively 'closed', isolated systems, in that, they are not directly linked to the fluvial system as is the case with the other wetland systems investigated. In addition, the tarns are located at higher altitudes than other wetland systems in this study, and display a very different morphometry.

While the Stillerust wetland does not overlap with the tarns in the scatter plot (Figure 6.2), it does show a relationship with the tarns on the CVA axis one. Similarities between the tarns (T1 and T2) and Stillerust, two intuitively different wetland systems, may have arisen since they share a common geology - both systems are located on a sandstone base. The soil depths of S and T2 are substantially deeper than in the other wetlands investigated, since they both display a mean soil depth of 150 cm. Tarns T1 and T2 showed relatively high latent vector loadings of total and medium sand. High sand contents may, as already discussed, be attributed to *in situ* weathering of the sandstone base. More likely however, is the prospect that the tarns act as 'sediment traps' within the landscape. The high sand content and deep soil profiles of Stillerust however, may be primarily attributed to overbank flooding of the Mooi River. Deposition (vertical accretion) following periodic overbank flooding of the Mooi River appeared to be a more significant process than *in situ* weathering of the sandstone base. The above discussion emphasizes that two very different wetland systems, dominated by different processes, may display similar internal conditions.

The CVA plots illustrates that wetland H2 and H5 overlap with tarn T2. Wetland H2, while not underlain by the same geology, and not located in the same terrain unit as T2, may be compared to T2 in that this wetland is located in a basin setting and thus acts as an effective sediment trap within the landscape. The sandy, wet soils of these two wetland systems, may over time assume similar internal conditions to T2. A very slight overlap between wetlands T2 and H5 is evident. The overlap is surprising, since field investigations did not show any significant similarities. Intuitively one may have expected wetland H4 to be more closely associated with the tarns, considering the existence of a number of isolated pools within this wetland, from which samples were obtained (See Figures 6.3 and 6.4). Further investigations are required to determine whether the 'pools' located within wetland H5 are significantly different from the tarns.

Figure 6.3 A rock based pool/depression located within wetland H4 (site B5a).

Figure 6.4 A sediment based pool/depression located within wetland H4 (site 8a).

As has been suggested several times, the Highmoor wetlands all have some degree of commonality. This association is to be expected considering that they are all:

☐ underlain by a common geology (dolerite);

☐ located within the same bioclimatic zone, in fairly close proximity to each other (Figure 2.1); and are

☐ located in similar landscape positions (position 7 and 8 of the 9-unit slope model) and all give rise to a river channel.

Despite varying landscape positions, hydrological regimes and dominant modes of water input, throughput and output, the similarities or overlap of the different wetland systems investigated was not altogether unexpected. Similarities were expected since the wetlands investigated in this study are located in the same bioclimatic zone, and are in essence, all 'wet land', in that they are periodically saturated with water and sustain distinctive wetland vegetation; the wetlands are hence amenable to similar internal processes, for example anaerobic conditions and O/C accumulation.

6.3 Canonical Variate Analysis

Despite areas of overlap suggesting similarity, the CVA demonstrates that there are some important and significant environmental differences among the palustrine wetlands studied. The CVA results confirmed field assumptions that the palustrine wetlands investigated in this study can be divided into three broad groups, namely:

☐ source seepage wetlands (H1, H2, H4 and H5);

☐ tarns (small mountain lakes) (T1 and T2); and

☐ floodplain / riverine wetland (S).

Since pedology is a good indicator of process and hydrological conditions (*inter alia* Daniels and Hammer, 1992; Baize, 1993), it can be assumed that the wetlands investigated do possess variations in internal processes and hence function. Since significant differences between the range of palustrine wetland systems have now been established, it is argued that a sub-classification of the palustrine system is warranted - a concept discussed further in Section 6.6.

Variables identified in the CVA as strongly contributing to wetland differentiation include: Ca^{2+} concentration, clay content, pH (KCL), O/C content, K^+ concentration and total sand. It is likely that these variables may largely condition internal wetland characteristics, and thereby account for much of the similarity and/or differences between the different wetlands investigated. A one-way analysis of variance (ANOVA) was conducted on each of the above variables to test for significant differences between wetlands. While an ANOVA provides information on whether a significant difference exists among wetland, it does not outline which means differ. The Tukey test, also known as a post hoc or multiple comparison test, was conducted to determine which specific wetland means differ with respect to each variable outlined above. *Statistica* software was used for this analysis. The Tukey test for comparing means is discussed in greater detail in *inter alia* Cohen and Holliday (1996) and Statsoft (2001).

6.4 Pedological variables and wetland variation

ANOVA results indicate that the wetlands investigated in this study (excluding T1, for which only one sample was obtained), display significantly different mean: Ca^{2+} concentrations, clay contents, pH (KCL) values, O/C contents and total sand contents. The K^+ concentrations however, did not differ significantly between the different wetlands studied (Table 6.2).

Table 6.2 Results of ANOVA performed on Palustrine wetland systems (H1, H2, H4, H5, S and T2)

Variable	Sum of Squares	d.f.	Variance	F value	P - level
Ca conc.	42.37	5	5.756	7.361	0.0001 ***
% clay	429.42	5	110.938	3.871	0.00228 **
pH(KCL)	198	5	0.123	6.781	0.0001 ***
% O/C	97.678	5	13.154	7.426	0.0001 ***
K conc.	5.205	5	2.422	2.149	0.0612 NS
% total sand	713.324	5	179.431	3.975	0.0019 **

Mean, Standard Deviation (SD) and Standard Error (SE) values of the above variables are presented in Figure 6.5. Post hoc (Tukey tests) to compare means, yielded inconclusive results. This can be attributed to differences in the sample sizes of wetlands investigated, which range from eight samples in tarn T2 to 69 samples in wetland H2, and variation within wetlands. Possible explanations for the similarities and differences of the above variables are briefly discussed, and the associated implications outlined.

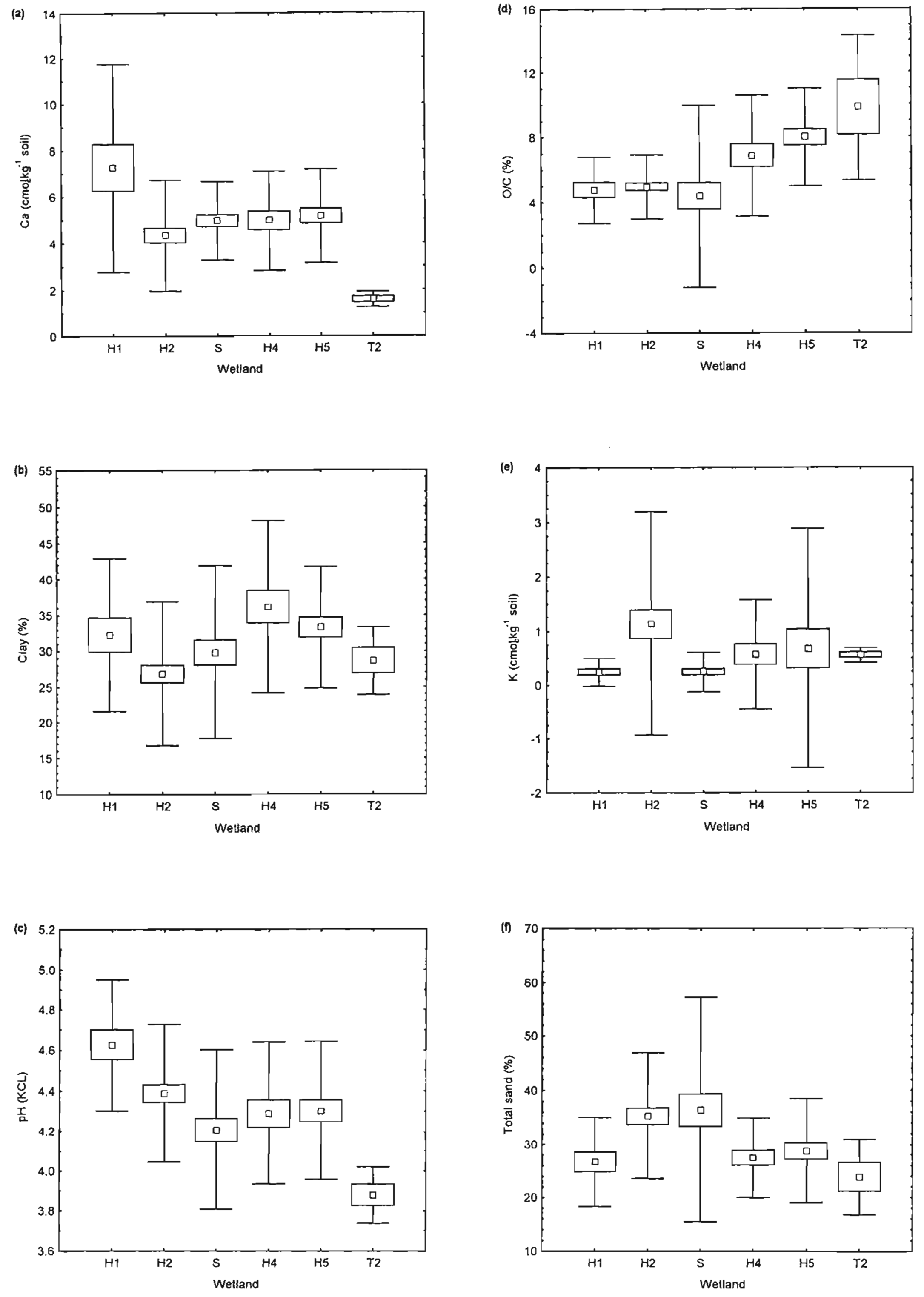

Figure 6.5 Box and whisker plots of (a) Ca, (b) clay, (c) pH (KCL), (d) O/C, (e) Potassium (K) and (f) total sand, for wetlands H1, H2, H4, H5 and T2. Box includes: 2x SE, range includes: 2x SD.

6.4.1 Wetland clay content

The mean clay contents of the wetlands investigated range from 36.12% in wetland H4 to 26.79% in wetland H2 (Figure 6.5 b). The dominance of clay in the Highmoor wetlands can be attributed to the dolerite base of these wetlands (cf.Section 5.1.1). No reasons are immediately apparent to explain the relatively low clay content of H2 (26.79%). The ESP and SAR values (Table 5.3.1) were generally low, and similar to the other wetlands examined, indicating that clay dispersion and consequent erosion is not prevalent in this wetland. Limited weathering in this zone may be a possible explanation. The degree of weathering on the upland side slopes will also influence the quantity of clay minerals produced and available to be transported and deposited.

The low clay contents of Stillerust and tarn T2 may be attributed to the sandstone base of these wetlands. The clay contents were, however, not substantially lower than the dolerite based wetlands. In fact, maximum clay values recorded in Stillerust and H4 are essentially identical (S: 56.69% and H4: 56.01%). While the high clay contents may be attributed to clay deposition, it is recognized that should the sandstone contain a feldspar content ≥25%. Soils formed in residuum from such rocks will tend to be clayey as feldspar weathers to clay (Buol *et al.*, 1980).

Tarn T1 displayed a low clay content of 11.55%. Despite T1 being characterized by a similar landscape location, geomorphology and geology as T2, both being situated on a sandstone base, the low clay content may be attributed to the facies of the Elliot formation in the area, which comprises of predominantly coarse to very coarse grained sandstone (Eriksson, 1983). In addition, the very much higher pH (KCL) of T1 (4.26), may reduce chemical weathering and hence clay formation. While detailed geological tests were beyond the scope of this study, future investigations in this regard should aid in explaining *in situ* characteristics and wetland process.

6.4.2 Percentage total sand within wetlands

Total sand concentrations were identified as an important distinguishing characteristic of the wetlands investigated, represented on axis one of the CVA. T1 was characterized by a much higher sand content than the other wetlands investigated, with a value of 45.95%. It was not, however, included in the ANOVA since only one sample was obtained. As discussed in Section 4.3, the high sand content can be attributed to the Elliot sandstone base of this wetland being at an advanced stage of weathering, as well as the fact that the Elliot formation is comprised predominantly of coarse to very coarse grained sandstone (Eriksson, 1983), which is generally fairly resistant to chemical weathering.

Wetlands S and H2 also showed high mean total sand contents, with mean values of 37.12% and 35.73% respectively (Figure 6.5 f). Stillerust shows a very high standard error. The total sand content displayed a substantial range of 64.91%, with minimum and maximum values of 9.43% and 74.34% respectively. The high variance and standard error of total sand in Stillerust may be attributed to the complex, mosaic nature of floodplain soils, which can be attributed to differential processes operative on the floodplain, discussed in Section 4.2.4. The mean total sand content of wetland H2 (35.73%) is higher than the other Highmoor wetlands,

wetlands H1, H4 and H5 displayed mean total sand percentages of 26.68, 27.51 and 28.81 respectively. The high sand content of wetland H2 may be attributed to the steep sideslope of H2 being composed of Clarens sandstone. Advanced weathering of this geological type and the inevitable entrainment and deposition as a result of overland flow, may offer a possible explanation for the high sand content. Clarens sandstone ridges were further away from wetlands H4 and H5, H1 being an exception.

6.4.3 pH (KCL) variation

As previously discussed, all the wetlands investigated are acidic. pH values range from a maximum of 4.63 in wetland H1, to a minimum of 3.88 in tarn T2 (Figure 6.5 c). While the pH range between wetland H1 and T2 is relatively small (0.75), cognisance must be taken of the fact that pH is measured on a logarithmic scale. The standard deviations of wetland pH are, however, fairly substantial, as illustrated in Figure 6.5 c. While the wetlands showed relatively symmetrical pH distributions, wetlands H1, H4, S and T2 are characterized by slightly negatively skewed distributions, while H2 and H5 were positively skewed. The pH of the Stillerust wetland is the least symmetrical, and is characterized by the greatest standard deviation. Minimum and maximum pH values of 3.40 and 4.84 respectively were obtained. The high standard deviation of pH within the Stillerust wetland may be attributed to this wetland displaying the greatest heterogeneity in terms of wetness and vegetational mosaics. The variation in pH both within and between wetlands, may be primarily attributed to a host of variables. Likely factors are discussed below.

- ☐ The quantity of sulphides and organic compounds present, which is largely a function of a site's hydroperiod. Hydrogen disulphide (H_2S), humic and fulvic acids are naturally produced in large quantities in wet, anaerobic soils (Greenland and Hayes, 1981). Variation in wetland pH may hence be correlated to varying wetness regimes.

- ☐ The effectiveness of the carbonate buffering system at particular localities (see *inter alia* Baize, 1993; Federal Interagency Stream Restoration Working Group, 1999).

- ☐ The nature of the bedrock. As already discussed, soils developed on sandstone tend to produce soils of low pH, especially if formed in a humid climate where acid leaching reaches a maximum (Buol *et al.*, 1980), while soils developed on dolerite are generally characterized by a high base status and hence, potentially higher pH than the soils derived from sandstone.

- ☐ The relative density of standing crops of aquatic plants. Uptake of carbon dioxide by plants during photosynthesis removes carbonic acid from the water, which may increase pH by several units (Federal Interagency Stream Restoration Working Group, 1999).

Cognisance must be taken of the fact that pH readings presented in this study present only a small window period of time; pH values have been noted to drift with varying dilutions, increasing dilution tending to shift the pH towards neutrality (Smith and Atkinson, 1975). Fluctuations of pH with water content is of particular relevance in wetland environments, where water fluxes are commonplace, varying significantly between seasons. pH fluctuations are explained by the dilution of H^+ ions in the soil solution primarily by rain water, and biological activity. The production of organic acids generally reaches the optimum in summer (Baize, 1993). The seasonal variation of pH generally amounts to a few tenths of a pH unit, but may reach a whole pH unit in some instances, particularly in calcareous soils. The uptake of carbon dioxide by plants during photosynthesis removes carbonic acid from the water, which may increase pH by several units. pH levels may hence also fall by several units during the night, when photosynthesis does not occur and plants give off carbon dioxide (Federal Interagency Stream Restoration Working Group, 1999).

The identification of pH as an important wetland variable is not limited to this study, but has been used as a means of differentiating between wetlands and understanding internal wetland functioning by many wetland scientists (Mitsch and Gosselink, 1986). According to Bridgham and Richardson (1993) for example, bogs and fens in northern peatlands (U.S.A), are frequently successfully differentiated in terms of pH. More detailed investigations into this rather alterable parameter are required before attempts can be made to classify wetlands according to pH.

6.4.4 Organic carbon

The organic carbon contents varied fairly substantially between the different wetland systems investigated. The highest mean organic carbon content (9.83%) was found in wetland T2, while Stillerust displayed the lowest mean organic carbon content of 4.34% (Figure 6.5 d). Wetland T2 is not only characterized by the highest mean O/C content, but is also characterized by the highest SE of 1.70, O/C values ranging from a low of 4.23 to a high of 18.94%. The very high organic carbon content of T2 may be attributed to the following factors:

☐ The site supports a dense hydrophyte stand of *Cyperus Fastigiatus*.

☐ Tarns are effectively closed systems and organic matter is hence not easily flushed out of the system.

☐ It is permanently saturated. Decomposition rates are therefore reduced.

☐ The substantially higher altitude of these wetland features compared to the other wetlands investigated (Table 2.1), may result in orographic modification of the regional macro-climate. Precipitation generally increase with altitude while temperatures decrease, high lying areas are frequently characterized by higher incidences of snow (Bayfield, 2001). The microclimate of this area is likely to enhance organic matter accumulation. According to Kotze *et al.*, (1996), for a given water regime, more organic matter will accumulate in a cool climate.

☐ The area is seldom burnt (Campbell, 2000, Pers. Comm.). (The effect of fire on organic matter accumulation is however not clearly understood. Cass *et al.*, (1984) cite several references reporting both increases and decreases of organic matter after a burn. Daubenmire (1968), *in* Cass *et al.*, (1984) however, suggest that in most cases increases appeared to be attributed to the accumulation of charcoal in the soil, rather than true organic matter). The lower O/C content of T1 (7.01%) relative to T2, may be attributed to the standing water depth of T1 being markedly higher than the other wetlands investigated. Standing water in excess of 1.5 m is not conducive to hydrophyte growth (Dely *et al.*, 1995). Vegetation was hence restricted to the perimeter of the tarn, located in small isolated patches.

The relatively low mean O/C content of Stillerust (4.35%) was not expected, as many of the samples were taken from seasonally or permanently wet areas. Possible explanations include the fact that:

- ☐ this wetland is more "open" than the other wetlands investigated, O/C may be flushed out of the system following heavy rains, flooding etc.; and

- ☐ field examinations revealed that the organic matter was generally less fibrous than the other wetlands investigated, at many sites the organic matter was amorphous. This finding suggests that the nature of the organic matter, as well as the degree of organic matter breakdown, may influence O/C results.

Explanations for the O/C contents of the Highmoor wetlands are not obvious. For example, wetland H4 is characterized by a relatively high average organic carbon content of 6.86%, while H2 is substantially lower than H4, with a value of 4.85%. This finding is interesting in that H4 did not appear to be wetter than H2, in fact, 66.76% of the samples collected from wetlands H2 and H4 showed signs of permanent wetness. In addition, the vegetation composition and density of wetland H4 was not any different from other Highmoor wetlands. Probable explanations accounting for the difference in the O/C content of the Highmoor wetlands include:

(i) Relationships between organic carbon and texture

Certain particle size compositions or textures may be more favorable for organic matter accumulation than others. According to Gaunt *et al.*, (1997), decomposition of organic matter in soil may be controlled by its chemical nature, as well as its physical protection, which may be related to soil structure and mineralogical characteristics. For example, the oxidation and decomposition of organic matter generally reaches a maximum in sandy soils as a result of large interparticular voids, promoting the free entry of air. Wetland H4 for example, is characterized by a lower sand and higher clay content than wetland H2, which may explain the higher O/C content of H4 (4.85% as opposed to 6.86%).

Associations between O/C, clay and coarse sand were, however, not significant ($p > 0.05$) in this study. A negative association between O/C and fine sand was however detected $r = -0.207$, $p \leq 0.01$). The lack of association between O/C and coarse sand may be attributed to the hydroperiod of the site. Wetland soils characterized by large proportions of coarse sand appeared to be zones of preferential groundwater recharge, anaerobic conditions are hence likely to restrict decomposition processes. The lack of association between O/C and clay is surprising, as associations between these two variables have been documented in the literature (Gaunt *et al.*, 1997). The positive correlation of O/C with silt ($r= 0.228$, $p < 0.01$) and medium sand ($r= 0.249$, $p < 0.01$), imply that these textures may be most conducive to O/C accumulation. The difficulty in associating preferential organic carbon accumulation to a particular grain size may be attributed to organic carbon accumulation favouring specific particle size compositions or textures. In addition, the hydroperiod of the site may also be more important in terms of organic carbon accumulation than texture.

(ii) Differential burning of the wetlands

Wetlands H2 and H5 were burnt in 1999 prior to sampling, while H4 was burnt in September 2000, once field sampling was complete. The lower O/C content of wetland H2 may very well be attributed to the burn. Wetlands T1 and S however, showed below average organic carbon contents, and were not burnt the year prior to sampling. Different burning times, temperatures etc. make the comparison of organic matter contents at different sites complex. As already discussed, the effect of fire on organic matter accumulation is not clearly understood. Controlled, long term experiments are required if the influence of burning is to be understood.

The relatively high SE readings, particularly in the case of wetlands T2 and S, characterized by deep profiles, may be attributed to the fact that the top- and sub-samples were pooled in this analysis, O/C content generally decreasing with depth *inter alia* Brady (1990), Baize (1993). High standard error readings may also be attributed to the wetlands displaying a diverse array of micro-habitats, generally resulting from topographical and wetness variations, but also differences in soil textural characteristics, which may lead to differential rates of decomposition. While the climate would be constant for the Drakensberg zone, variations in micro-climate, for example the influence of aspect, may explain accumulation in some areas. Differential water flow i.e. 'flushing' processes, may also influence O/C contents.

6.4.5 Wetland calcium (Ca^{2+}) concentrations

Mean Ca^{2+} values ranged quite substantially from 1.59 $cmol_c kg^{-1}$ in tarn T2, to a high of 7.27 $cmol_c kg^{-1}$ in wetland H1. Wetland H1, however, also displayed a higher variation (SD and SE) than the other wetlands investigated. Minimum and maximum values range from 0.49 $cmol_c kg^{-1}$ to a high of 18.56 $cmol_c kg^{-1}$ (Figure 6.5 a). The Ca^{2+} distribution of H1 was slightly negatively skewed (mean Ca^{2+}: 7.27 $cmol_c kg^{-1}$; median Ca^{2+}: 7.36 $cmol_c kg^{-1}$), indicating that most Ca^{2+} concentrations are below the mean Ca^{2+} content of the wetland. Wetlands H2, H4, H5 and S were very similar in Ca^{2+} content, having mean Ca^{2+} values of 4.13, 4.96, 5.16 and 4.96 $cmol_c kg^{-1}$ respectively (Figure 6.5 a).

The relatively high Ca^{2+} concentration of the Highmoor wetlands may be attributed to the dolerite base of these wetlands (cf. Section 5.5), which consists of significant quantities of bases (Buol *et al.*, 1980). The comparable Ca^{2+} concentrations of Stillerust, situated on a sandstone base, relatively deficient in bases (Buol *et al.*, 1980), may be attributed to the sedimentation of minerals containing Ca^{2+} on their exchange sites in this floodplain wetland, by either overbank flooding or overland flow. Alternatively, the sandstone may contain significant quantities of gypsum ($CaSO_4$) and lime ($CaCO_3$) in cementing materials, which following acidification may release Ca^{2+} ions (Tankard *et al.*, 1982).

Tarn T2 is characterized by a very much lower mean Ca content than the other wetlands investigated (Figure 6.5 a), together with a lower standard deviation and standard error. A mean of 1.59 cmolckg^{-1} was obtained, with minimum and maximum values of 1.23 and 2.03 cmolckg^{-1} respectively. This low Ca content does not appear to be related to high leaching. As indicated in Section 5.5, wetland T2 displayed the lowest S-value per unit mass clay, indicating minimal leaching. The lower Ca^{2+} content of T2 relative to the other wetlands investigated may be attributed to several factors:

- ☐ Sandstone as previously discussed, shows a high variability in the composition of cementing materials. The sandstone base of T2 may not contain significant quantities of gypsum, ($CaSO_4$) and lime, ($CaCO_3$) in cementing materials, which may explain the relative deficiency in bases.
- ☐ The relatively 'closed', isolated nature of this system - the entry of water and sediments into this wetland is limited.
- ☐ The nature of the clay minerals i.e. the clay fraction appears to be dominated by 1:1 as opposed to 2:1 clays, characterized by a much lower Ca^{2+} adsorption capacity.
- ☐ The very low pH of this wetland, low base saturation (23.79%) and very high acid saturation (76.21%). Low pH may lead to the precipitation of Ca salt.

The most probable explanations for the low Ca^{2+} concentrations appears to be the exceptionally low pH of this wetland (3.88) and high aluminum (Al^{3+}) concentration. Aluminum toxicity is a serious concern in the area (Campbell, 2000 Pers. Comm.). While other major exchangeable cations are generally leached from soils during soil formation, aluminum is retained in soils ultimately as solid-phase - bautite ($Al(OH)_3$), the aluminum end product of weathering (Bohn *et al.*, 1985). Exchangeable Al^{3+} and its hydrolyzed-polymerized ($(Al(OH)_x(H_20)_{6-x})_n^{+(3-x)n}$) produce the acidity of most soils as they hydrolyze further towards $Al(OH)_3$. Exchangeable Al^{3+} reacts with water and releases H^+ to the soil solution, thereby further increasing the acidity of the soil (Bohn *et al.*, 1985). The exchangeable acidity values were substantially higher in T2 than in the other wetlands investigated, with maximum values of 89.24 cmol$_c$kg^{-1} being recorded. The high readings were verified on numerous occasions (using different 0.01 M solutions of NaOH and different burettes), confirming the results. The high H^+ and Al^{3+} content suggests that these ions dominate the exchange sites, and thereby allow fewer opportunities for Ca^{2+} adsorption/retention.

6.4.6 Potassium concentrations within wetlands

While potassium ions (K^+) appeared to be an influential variable in the CVA plot (indicated by a long arrow), the ANOVA results indicated that K^+ concentration did not vary significantly between the wetlands investigated. The highest mean K^+ content was found in wetland H2 (1.43 cmolckg^{-1}), and the lowest value was noted in wetland H1 (0.24 cmolckg^{-1}). The range is relatively small (1.19 cmolckg^{-1}), so too is the overall SE (0.15) and variance (0.16) (Figure 6.5 e).

The relatively low K^+ content of the wetlands, particularly the Highmoor wetlands located on base rich dolerite, may be attributed to leaching activity. According to Young (1976), K^+ together with Na^+, are very soluble salts, in the order of 30 - 100 times more mobile than exchangeable basic cations. The relatively high K^+ concentration of wetland H2 relative to the other wetlands investigated, may be attributed to reduced leaching activity in this wetland - the S-value per unit mass of clay was high relative to the other wetlands, see Section 5.5.2. While the SD is relatively large (minimum and maximum K^+ values ranging from 0.01 to 19.49), the distribution is positively skewed, most samples displaying an above average K^+ content (median K^+: 0.46, mean K^+: 1.43 cmolckg^{-1}). The high K^+ concentrations could also be attributed to wetland H2 being characterized by abundant micas or potassium feldspars (orthoclase) in the sand and silt fractions, or micaceous phyllite minerals (illites, glauconites) in the < 2µm fraction or in the fine silt fraction (Baize, 1993).

6.5 Environmental analysis of wetlands

Concentrations of Ca^{2+}, clay contents, pH (KCL) readings, O/C contents, K^+ concentrations and total sand contents were identified as maximizing dispersion on the first two CVA axes. An ANOVA performed on the above variables, indicated that significant differences in terms of the above parameters exist between the wetlands investigated, with the exception of K^+ concentrations. While the CVA plot suggests that the wetlands investigated can be grouped into three broad groups or wetland classes, namely: source seepage wetlands, tarns and floodplain / riverine wetlands, the Tukey test results do not conform to these three classes. This does not, however, invalidate the proposed groupings, instead it highlights that the whole is more than the sum of the individual parts. As already indicated, sufficient field evidence (geomorphology and hydrology information) exists to validate sub-classifying the palustrine wetlands investigated into the above groups.

This study has identified that while every wetland is to some extent unique, some wetland systems are more similar than others as a result of analogous geomorphological features (such as landscape position and wetland form), climate, geology, hydrology and pedological characteristics. It is proposed that a more detailed wetland classification, in which cognisance of internal differences, as derived from formative processes, is taken into account, would be beneficial in wetland management and rehabilitation initiatives. As already indicated in Section 1.2.4, an understanding of the processes and internal functioning of wetlands is now recognized as being fundamental to effective rehabilitation, restoration and management of wetlands. Using quantitative information, laboratory and field measurements (including CVA results conducted on a range of pedological variables), together with field information and scientific intuition, the wetlands in the upper Mooi River catchment/uKhahlamba-Drakensberg Park were classified using a hydro-geomorphic approach. A broad overview of the benefits of adopting a hydro-geomorphic approach is discussed in Section 1.1.5.

6.6 Towards a hydro-geomorphic classification of wetlands

As indicated earlier, the present study supports Semeniuk and Semeniuk's (1995) philosophy that there 'are wetlands and wetlands', with the implication that preservation of diversity warrants the conservation of each of the recognised types. The research reported thus far has facilitated the identification of five 'different' palustrine wetland systems in the upper Mooi River catchment/uKhahlamba-Drakensberg Park. The five recognised types include: bench, basin, valley side slope, confined and unconfined wetlands. A summary of the preliminary hydro-geomorphic classification system for this area is illustrated in Figure 6.6.

The longitudinal profile of a typical catchment, from headwater reaches to the ocean, and the hypothetical nine-unit landsurface model (Figures 6.7 and 6.8 respectively), are included to ensure that the position of the wetland within the surrounding landscape is determined easily and objectively. Figure 6.7 indicates the relative position of zones I - IV demarcated in Figure 6.9. As previously discussed, wetlands found in coastal zones differ substantially from inland 'palustrine' wetlands, in that they are affected by *inter alia* tidal fluxes and higher salinity levels. No attempts have been made to categorise wetlands not pertaining to the study area.

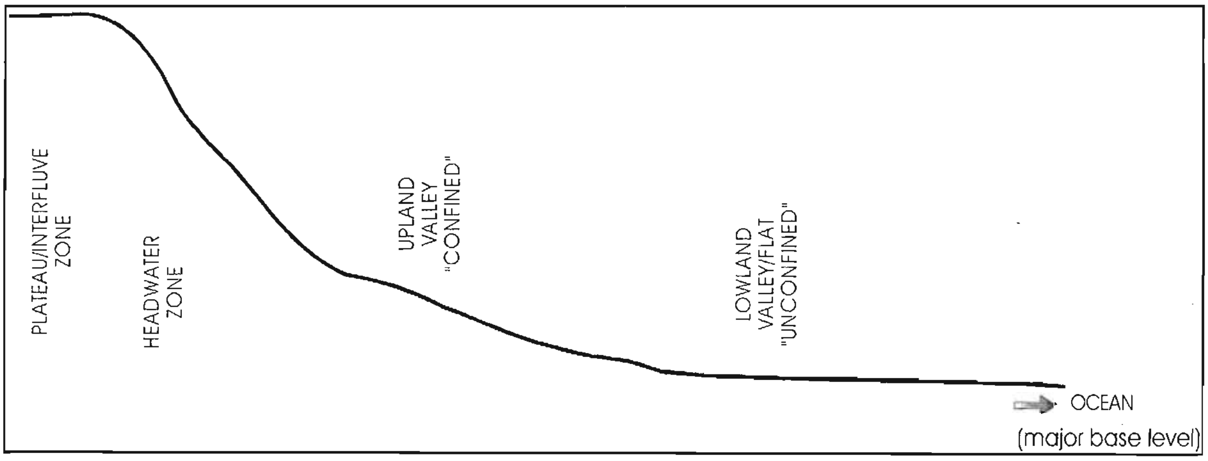

Figure 6.7 Longitudinal profile of a typical catchment, from the headwater reaches to the ocean.

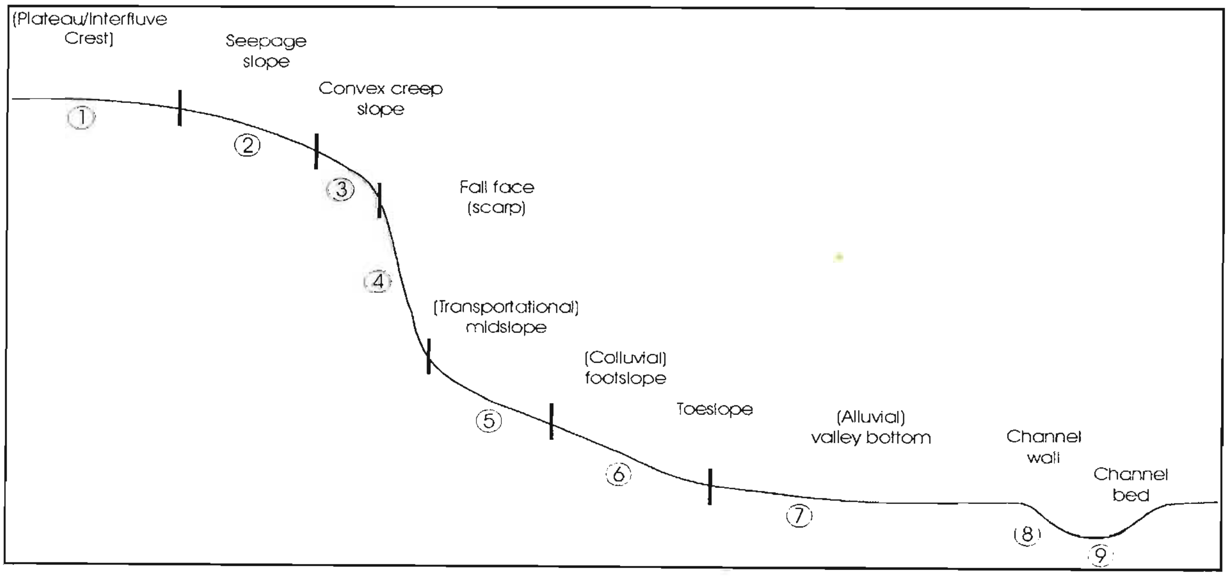

Figure 6.8 The hypothetical nine-unit landsurface model (*After*. Dalrymple *et al.*, 1968).

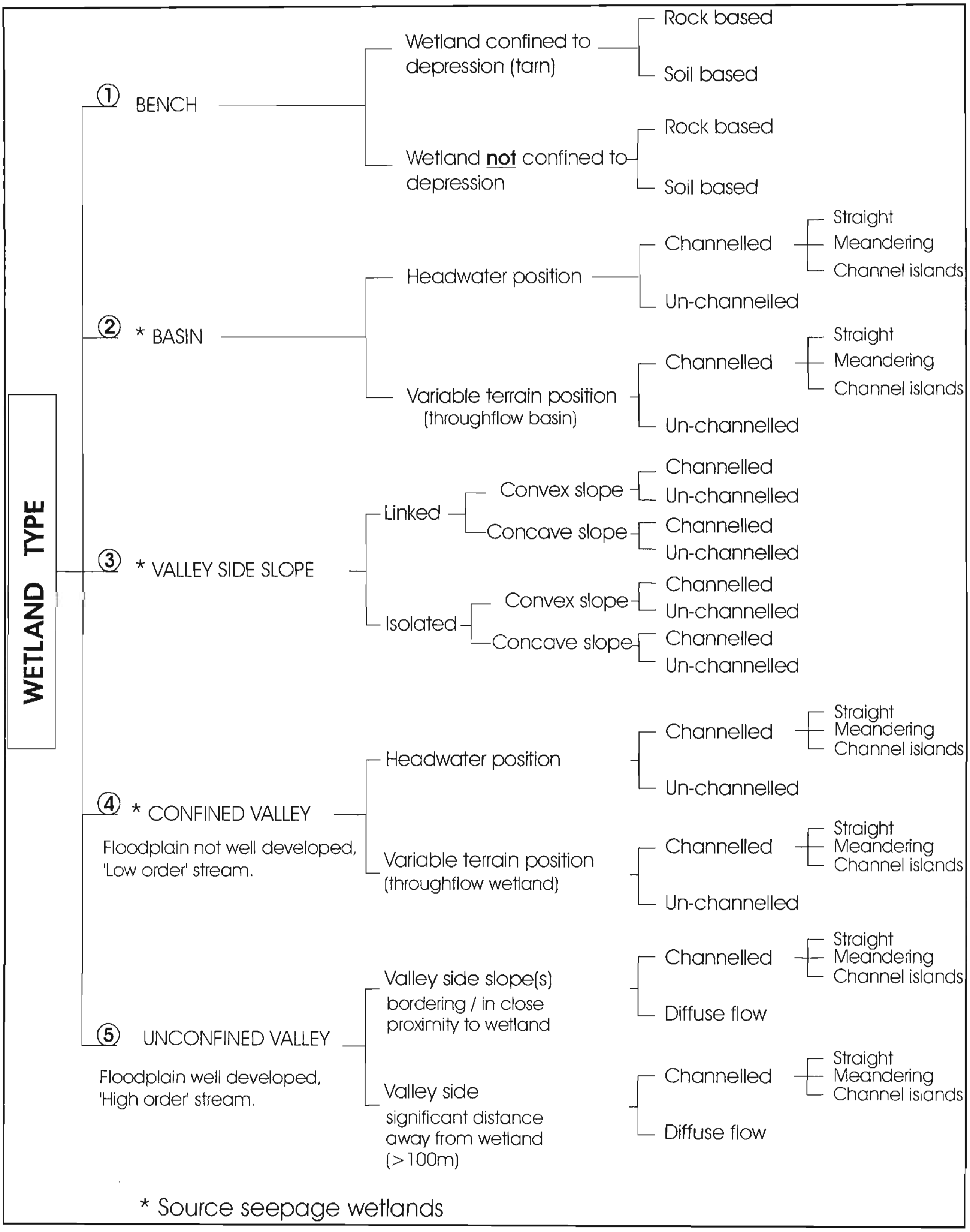

Figure 6.6 Outline of the proposed hydro-geomorphic classification of wetlands in the Upper Mooi River catchment.

Figure 6.9 illustrates the relative positions of the different wetland types identified in the upper Mooi River catchment. As indicated in this diagram, while different wetland types may occur in isolation, they may frequently adjoin different, adjacent, wetland types. An outline of the proposed hydro-geomorphic classification of the wetlands in the upper Mooi River catchment follows. Each wetland type is described using the following descriptors: landscape position, landform characteristics, morphometry, size, hydrology, nature of the substratum and dominant vegetation characteristics. Schematic illustrations (Figures 6.10 - 6.14) are incorporated to provide a broad indication of the relative landscape position and generalized landform characteristics of the five broad wetland types identified, and thereby allow for easier identification and application.

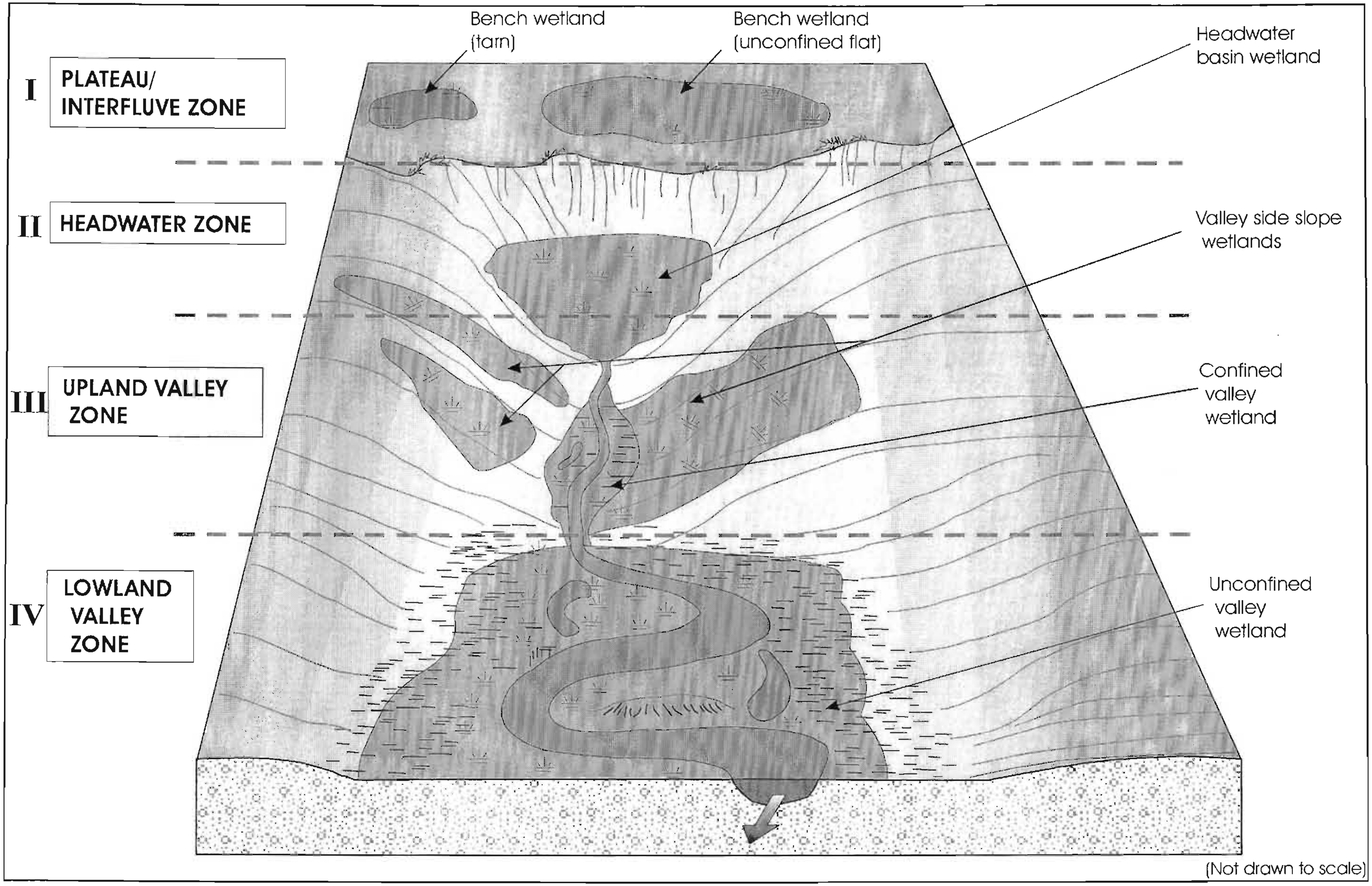

Figure 6.9 Sketch of a typical wetland catchment illustrating relative terrain positions of numerous different wetland types.

TYPE 1: BENCH WETLANDS

LANDSCAPE POSITION

The term 'bench' in this classification refers to an area of high ground, which is generally relatively flat. The bench category has been divided into three broad types, namely:

- **SADDLE WETLANDS** (Saddle referring to relatively flat land situated between two sideslopes)
- **SHELF WETLANDS** (Shelf referring to a break in a slope)
- **INTERFLUVE WETLANDS** (Interfluve referring to an area of high ground which separates two adjacent valleys (see Goudie *et al.*, 1994). An interfluve is hence the highest lying zone in a region).

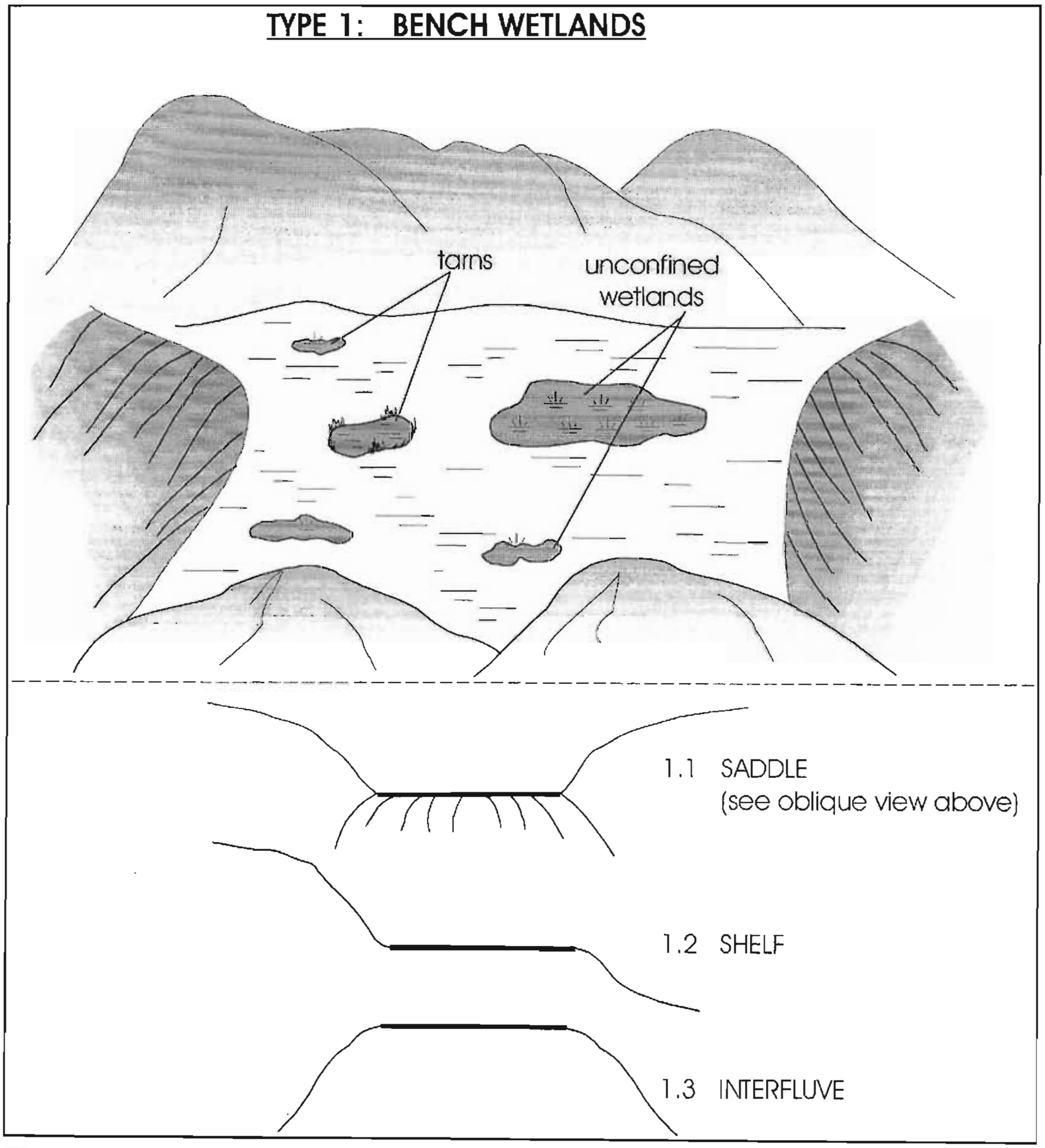

Figure 6.10 Schematic illustrations of relative terrain positions of wetlands typified as bench wetlands.

This subdivision is necessary since the nature and characteristics of proximal areas have been found to influence water inputs, and outputs to a limited extent), and thus wetland hydrology.

▸ LANDFORM CHARACTERISTICS

Benches, while generally relatively flat, may be sloped, with both micro- and macro-topographical variations.

▸ MORPHOMETRY

Two broad types of Bench wetlands can be distinguished according to morphometry, namely:

- wetlands restricted to depressions (commonly referred to as Tarns), and
- wetlands not confined to depressions, but generally restricted to topographic lows or areas underlain by impermeable materials. This wetland type is termed an Unconfined flat wetland.

TARNS

Distinct depressions in the ground, not characterized by a direct opening, i.e. they generally do not display any external/surface drainage. Tarns are frequently endorheic or inward draining. The base of tarns is generally flat or slightly concave. Tarn side walls are generally steep, frequently vertical, varying significantly in height, generally from 15 cm to 2 m. Geometries are generally round, ovoid or kidney shaped.

UNCONFINED FLATS (may be analogised to 'Fens' in the Alpine zones of Lesotho)

Generally located in topographical low areas, but are not found in distinct depressions. The morphometry is variable, being a function of bench micro-topography and bedrock characteristics. Channels, while rarely found, may be present. (A small channel system was noted exiting an unconfined flat wetland on the Siphongweni Plateau/Cobham. A relatively small channel system was also noted exiting an interfluve wetland (29° 21' 45" S, 30° 35' 12" E) in the Highmoor Nature Reserve).

▸ SIZE

TARNS

Very small scale wetlands, encompassed by a frame reference of less than 100 x 100 m, i.e. are smaller than what Semenuik (1987) terms 'microscale' wetlands. They are generally characterized by a diameter of more than five meters, but less than or equal to 35 metres.

UNCONFINED FLATS

The aerial extent is highly variable, dependent on *inter alia*: local topography, gradient, the permeability of the substratum and the availability of water, i.e. the local water balance.

▸ HYDROLOGY

TARNS

Water depth: Depths of between 20 cm and 1.5 m are common, but is shallower than two metres.

Water permanence: Variable - temporary to permanent. The variability may be attributed to a host of factors, such as: climate, geological characteristics (relative permeabilities, structural discontinuities i.e. joints etc.), see discussion in Section 1.2.1.

Water balance

Primary sources of water input

- precipitation
- overland flow
- groundwater discharge

Primary sources of water output

- evaporation
- evapotranspiration
- groundwater recharge
- overflow of tarn sidewalls

UNCONFINED FLATS

Water depth: Usually relatively shallow, standing water generally only found following heavy rains, generally not exceeding 20 cm in depth.

Water permanence: Variable, but generally temporary or seasonal. Water permance may be attributed to: seasonal rainfall, limited catchment area and relative isolation from significant high order channels.

Water balance

Primary sources of water input

- precipitation
- overland flow
- groundwater discharge

Primary sources of water output

- evaporation
- evapotranspiration
- groundwater recharge
- surface runoff
- channel flow (This is contrary to the findings made by Rowntree (1993) in the Eastern Cape. Plateau wetlands were not found to have channelized outflow).

▸ NATURE OF SUBSTRATUM

Both tarns and unconfined flats may have an unconsolidated soil base, or alternatively, may be characterized by a consolidated sheetrock base. Shallow sediment deposits (> 15 cm) may occur in patches, overlying the bedrock. Textural characteristics are variable, generally a function of: the nature and characteristics of the bedrock base, the proximal geological and soil characteristics, as well as the energy of the surrounding landscape. Soil depths in excess of two metres may be encountered. Organic carbon and organic matter contents of tarns are variable, but generally fairly high in surface horizons, in the order of: 7 - 20 %. No organic carbon contents are available for unconfined flats. Organic carbon content is most likely slightly lower than tarns, since these wetlands are generally temporarily or seasonally wet, and relatively open in comparison to tarns.

▸ VEGETATION

Most tarns have some form of vegetation. The margins usually have a narrow zone of subaquatics or marsh plants including: *Juncus* species, *Eleocharis, Schoenoplectus, Eriocaulon* and *Cyperus Fastigiatus.* In many tarns these plants are partly submerged and cover most of the pool. Submerged macrophytes and/or algal mats may also be found, including floating species.

Unconfined flats are generally dominated by short sedges and grasses. Sheet rock wetlands frequently display a unique plant community. Dely *et al.*, 1995 terms the characteristic plant communities that arise in these zones: 'Dwarf sheet rock communities'.

TYPE 2: BASIN WETLANDS

▸ LANDSCAPE POSITION

Generally located in the upper headwater reaches of the catchment (Figure 6.11 and 2.1), but may be found further down in the catchment (Figure 6.11 and 2.2), i.e anywhere where a basin-like topography is found. Generally found in positions 6, 7 and 8 of the 9-unit Slope Model. Catchment size, while fairly small, is greater than interfluve, plateau or valley side wetlands.

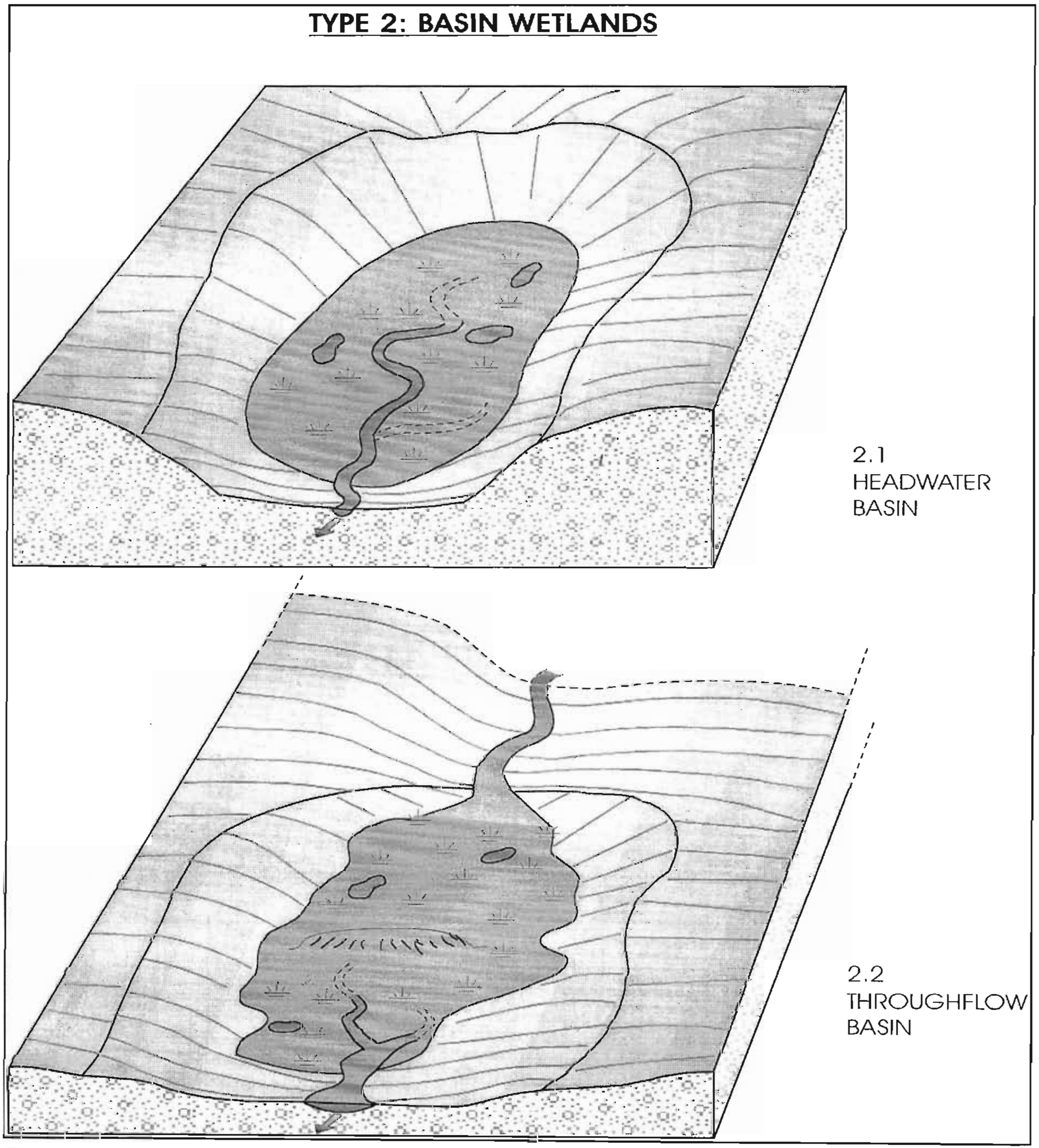

Figure 6.11 Schematic illustration of the relative position and landform characteristics of basin wetlands.

▸ LANDFORM CHARACTERISTICS

This landform setting is intermediate between a flat surface and a typical incised valley setting. This landform is best described as basinal, in that the landform characteristics can be analogized to a basin or saucer.

▸ MORPHOMETRY

The base is generally flat or slightly concave, with side slopes of variable length and steepness. The wetland itself may or may not be channelized. Scattered pools, hummocks and hollows are a common characteristic. Isolated zones of elevated 'upland' areas, may permeate this wetland type.

▸ SIZE

Variable, but generally Mesoscale, encompassed by a frame reference of 500 m x 500 m to 1000 m x 1000 m.

▸ HYDROLOGY

Water depth: Depths rarely exceed 20 cm, except following very heavy rainfall events. Generally below 10 cm.

Water permanence: Variable, frequently predominantly seasonal to permanent.

Water balance

Primary sources of water input

- precipitation
- runoff from the basin side slopes (surface / subsurface flow)
- groundwater discharge
- channel inflow (in the case of a throughflow basin)

Primary sources of water output

- evaporation
- evapotranspiration
- groundwater recharge
- surface runoff, subsurface flow
- channel discharge

▸ NATURE OF SUBSTRATUM

Generally characterized by an unconsolidated sediment layer of varying depth, overlying relatively impermeable bedrock. The solum depth seldom exceeding 60 cm. The textural characteristics are variable. Organic carbon contents, while high, are generally below 10%, soils are hence characteristically mineral. Peaty deposits may be found in isolated zones characterized by permanently wet conditions and standing water.

▸ VEGETATION

Generally characterized by a high species richness. Sedges, *Restionaceae* and hygrophillous grasses are common.

TYPE 3: VALLEY SIDE SLOPE WETLANDS

LANDSCAPE POSITION

This wetland type is found on valley side slopes, it may extend from the seepage slope to the toeslope position, terrain units: 2, 5 and 6 of the 9-unit slope model. Very wet zones generally dominate in unit 6, (the toe-slope position), see Figure 6.12 below.

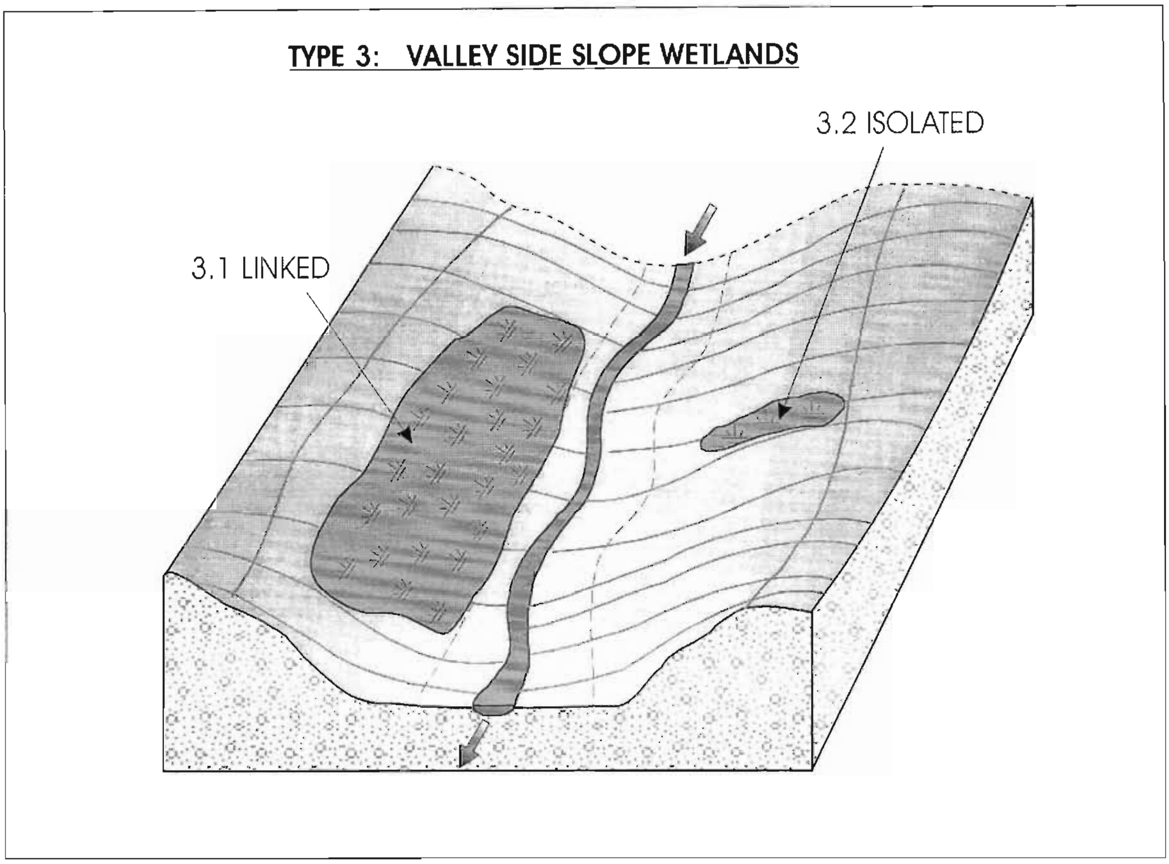

Figure 6.12 Schematic sketch illustrating the position of a typical valley side slope wetland.

LANDFORM CHARACTERISTICS

Slopes may be concave or convex. Gradients are generally relatively steep (> 5 %), but may vary downslope. While the surface is usually smooth, micro-topographical variability may exist.

MORPHOMETRY

Variable shape. This wetland type is generally characterized by a relatively steep gradient. This wetland type may be either isolated from valley bottom wetlands or interlinked.

SIZE

Variable, but generally relatively small in aerial extent. Encompassed by a frame of references less then the micro-scale wetlands (i.e. > 500 m x 500 m). Frequently in the order of 50 m^2.

▸ HYDROLOGY

Water depth: Standing water is rarely found. Water may be temporarily ponded in micro-topographical depressions following heavy rainfall, but soon flows downslope.

Water permanence: Frequently temporary to seasonal. May be permanent if groundwater seepage is dominant and occurs throughout the hydrological year.

Water balance

Primary sources of water input

- precipitation
- overland flow
- subsurface throughflow
- groundwater discharge

Primary sources of water output

- surface runoff, sheetwash
- evaporation
- evapotranspiration
- groundwater recharge
- diffuse subsurface flow
- concentrated pipe flow
- channel discharge (channels may arise in concave positions where water flow is concentrated)

Note: Seepage at the toeslope position is frequently an important source of water input for wetland systems located in the valley bottom position i.e. Confined and Unconfined Valley wetlands.

▸ NATURE OF SUBSTRATUM

Slopes are generally characterized by a thin solum layer, generally in the order of 10 - 20 cm, but may be deeper in concave positions. Exposed bedrock (sheet rock wetlands) may occur in places. Textures are frequently relatively sandy (silt and clay particles being preferentially entrained). Organic carbon contents are generally lower than the other wetland systems investigated, most likely in the of 5 %, as a result of low biomass production on steep slopes and high entrainment/flushing as a result of both surface and subsurface water flow.

▸ VEGETATION

Seasonal to temporary hydrophytic vegetation which appears to "hang" on valley side slopes. *Potamogeton thunbergi, Gunnera perpensa, Mentha aquatica* are common in the uKhahlamba-Drakensberg.

TYPE 4: CONFINED VALLEY WETLANDS

▸ LANDSCAPE POSITION

Found in position 7 and 8 of the 9-unit slope model, valley bottom position. Generally located in Upland valley positions. While generally found close to headwater zones, this wetland type may be found in lower positions in the catchment (Figure 6.13, 4.1 and 4.2).

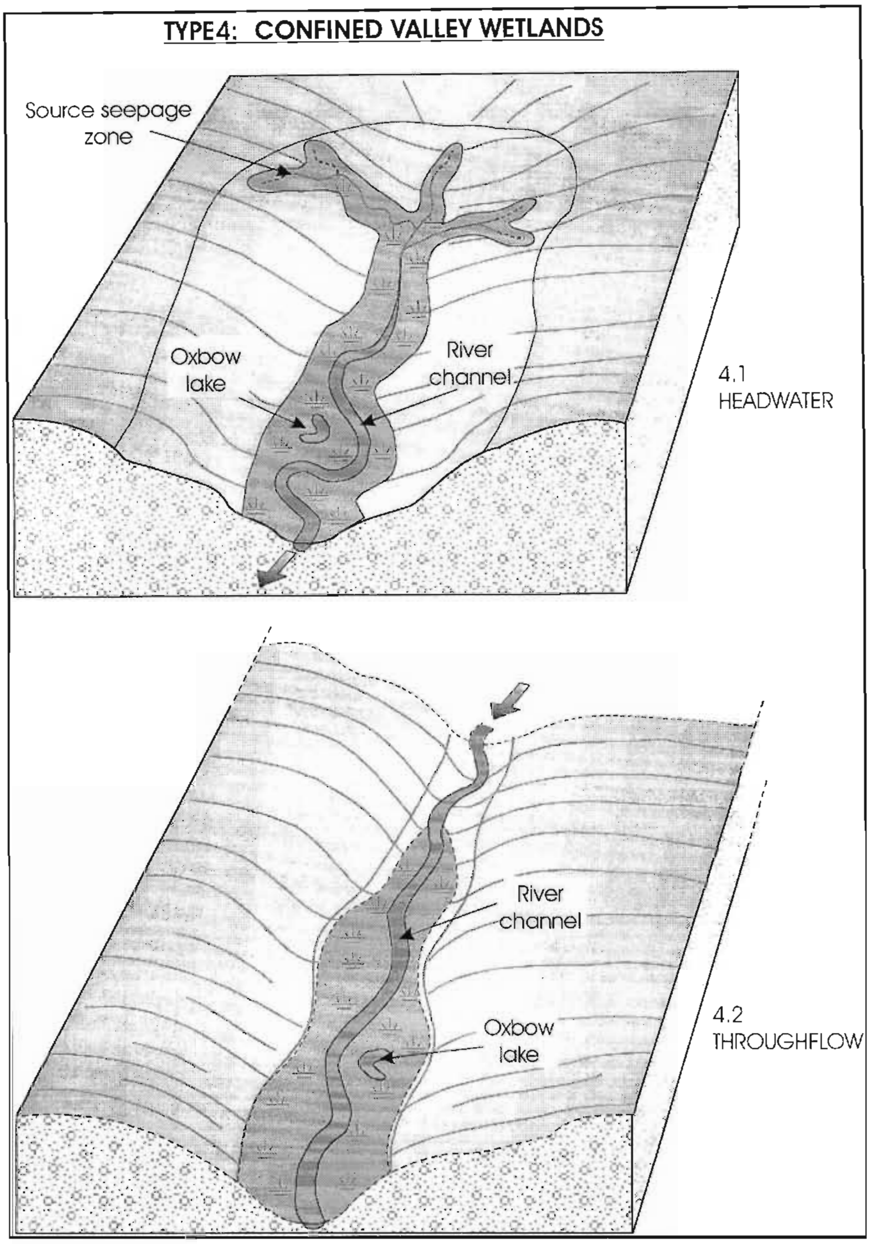

Figure 6.13 Schematic illustration of the relative terrain positions and landform characteristics of confined valley wetlands

▸ LANDFORM CHARACTERISTICS

Relatively narrow, confined valley bottoms. Valley floor is generally flat, but may be slightly concave. The valley floor generally assumes a slight gradient, generally below 3 %, but may vary fairly significantly within this wetland type. Small knickpoints or waterfall features frequently occur within these wetland settings. Areas of high relief (lobes and mounds) may intersect this wetland type.

▸ MORPHOMETRY

Variable, but generally linear and fairly narrow. Confined valley wetlands generally occur between a low order channel and valley sides. A defined channel is not always present, particularly in the upper reaches. Valley side slopes define the wetland's catchment area - lateral extent is limited by the upland valley sides. Confined wetland valleys may assume a digitate pattern when smaller wetland valleys intersect. Upland Valley wetlands are distinguished from lowland valley wetlands by lacking a well developed floodplain.

Channel dimensions and patterning may vary quite substantially, within and between wetlands. Channels are generally straight or meandering, and of a relatively low order. Micro-oxbow lake features are common geomorphic features of wetlands characterized by meandering channels. The wetland surface of this wetland type is frequently characterized by hummock topography, scattered pools and hollows.

▸ SIZE

Variable, generally in between 1000 m x 1000 m and 10 km x 10 km, i.e. meso- to macroscale wetlands.

▸ HYDROLOGY

Water depth: Variable, standing water does not generally exceed 20 cm, usually in the order of: 5 - 10 cm.

Water permanence: Variable, generally seasonal to permanent.

Water balance

Primary sources of water input

- subsurface, toeslope seepage (According to Rowntree (1993), this is the main water supply of wetlands located in this landform setting.)
- surface runoff from valley side slopes
- first order tributaries
- direct precipitation
- overbank flooding of channel
- groundwater discharge

Primary sources of water output

- evaporation
- evapotranspiration
- channel discharge
- aquifer recharge
- surface and subsurface runoff

▸ NATURE OF SUBSTRATUM

Generally an unconsolidated soil layer of variable thickness and textural characteristics. Frequently deeper than basin wetlands, in the order of 100 cm, but may reach depths in excess of two metres in places. Organic carbon contents are usually moderate to high, similar to basin wetlands, i.e. in the order of 6 - 8%, and generally below 10 %. True peat conditions may be found in isolated, wet zones.

- **VEGETATION**

Generally dominated by a dense, relatively short hygrophilous grass and sedge community, seldom exceeding a height of one metre.

TYPE 5: UNCONFINED VALLEY WETLANDS

- **LANDSCAPE POSITION**

Found in position 7 and 8 of the 9-unit slope model, valley bottom position. Generally located in lowland valley bottom positions.

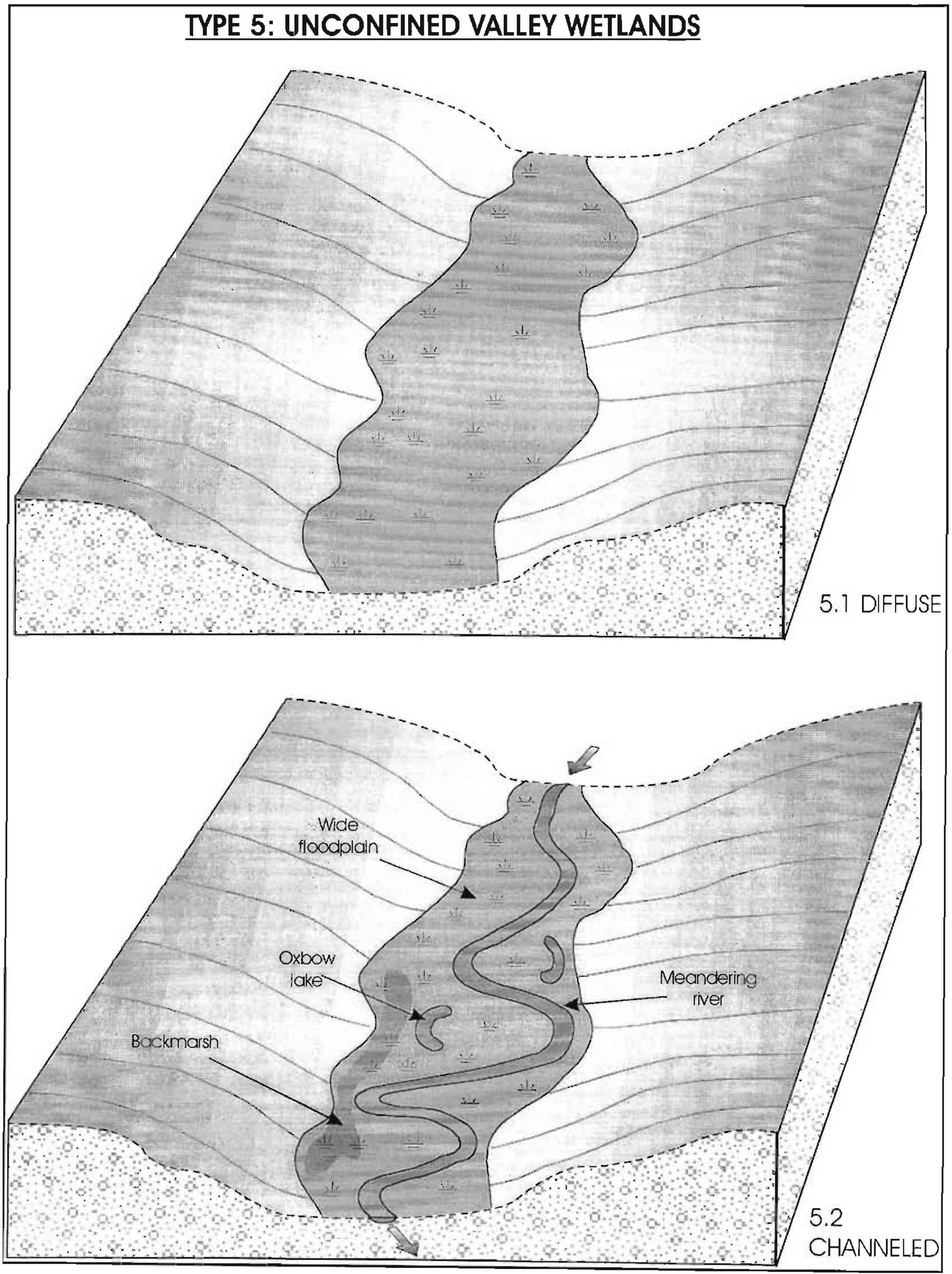

Figure 6.14 Schematic illustration of the relative terrain positions and landform characteristics of unconfined valley wetlands.

▸ LANDFORM CHARACTERISTICS

Generally very flat, characterized by a negligible gradient. May or may not be associated with a significant river channel, distinguished accordingly into: channelled flat and un-channelled flat wetlands. While no examples of un-channelled wetlands were found in the study area, examples of this wetland type include the: Umgeni vlei, Mvoti vlei and Blood River vlei.

Channels may be straight or meandering, but are generally of relatively high stream order. Micro- and macro-geomorphic features commonly found in floodplain locations include: abandoned meanders (oxbow lakes), leveés and depositional mounds.

▸ MORPHOMETRY

Lowland valley wetlands generally have a linear form as a consequence of their proximity to rivers. The lateral extent of this wetland may be limited by valley sides slopes.

▸ SIZE

Variable, dependent on a number of site specific factors, such as the nature of the dominant stream channel, i.e. stream order and patterning, catchment size and relative magnitude and sources of water input. Generally relatively large, meso- to macroscale wetlands, i.e. in between 1000 m x 1000 m and 10 km x 10 km. Unconfined wetlands are generally larger than Confined, Upland valley wetlands.

▸ HYDROLOGY

Water depth: Standing water depth variable. May be in the order of 10 - 30 cm but generally in the order of 10 cm over the greater wetland surface. Depths in the order of two meters may occur in oxbow lakes.

Water permanence: Variable - temporary, seasonal or permanent

Unconfined, channelled valley wetlands, may be sub-classified based on water permanence, into non-storage wetlands and storage wetlands.

- *non-storage wetlands*

  The floodplain is only temporarily or seasonally inundated. It rarely retains water for long periods after floods.

- *storage wetlands*

  These wetlands may be only temporarily to seasonally inundated, yet retain standing water in oxbow lakes and back swamps for long periods between floods. Storage wetlands are generally more interconnected to the fluvial system and exhibit a greater dyanism.

Water balance

Primary sources of water input

- precipitation
- groundwater discharge
- lateral inflows from low order tributaries
- runoff and seepage from valley sideslopes

  In addition to the above, channelled wetlands are subject to influent flow and overbank flooding from the associated river channel.

Primary sources of water output

- evaporation
- evapotranspiration
- groundwater recharge
- overland and subsurface flow

In addition to the above, channelled wetlands are subject to effluent seepage, i.e. reach receives discharge from adjacent floodplain.

▸ NATURE OF SUBSTRATUM

Generally characterized by deep sediment deposits (frequently 100-200 cm +). Textural characteristics are variable and frequently complex. Organic carbon is generally moderate to high in topsoil horizons, generally ranging from 5 - 8 %. Permanently wet zones such as oxbow lakes and pools may display characteristic peat conditions (≥10%). Organic carbon contents will vary according to factors such as flushing cycles, biomass characteristics and hydroperiod.

▸ VEGETATION

Vegetative composition is highly variable, ranging from a narrow grass or sedge dominated grass bank, to permanently flooded reedbeds, characterized predominantly by *Phragmites spp.*, *Typha spp.* and *Cyperus spp.* Woody vegetation such as *Ouhoud*, may also be present, particularly along river margins.

* * * * *

While still subject to further verification in the field, particularly in a range of different catchment settings, it is argued that the proposed classification addresses many of the deficiencies of classifications currently in use (cf. discussions in Section 1.1.4). The proposed classification addresses the following factors.

☐ The geomorphological characteristics of wetland systems themselves, which are often totally ignored.

☐ The geomorphology of the proximal landscape, which is closely connected to the functioning of wetland systems. For example, steep, long slopes are generally associated with rapid overland flow and enhanced erosion. This classification addresses deficiencies of a number of other classifications in which wetlands are essentially viewed as isolated landscape features.

☐ Wetland processes, which are frequently not given due attention.

By addressing factors such as landscape position, landform characteristics and process identification, it is argued that this classification provides an adequate framework for the conceptual understanding of wetlands from a process perspective, a feature which McCarthy and Hancox (2000) argue is a major oversight of previous classifications.

The five broad wetland types identified were named according to landscape position and geomorphological criteria, underpinned by diagnostic characteristics of size, hydrology, substratum characteristics, soil and vegetation. Standard geomorphic terms were used in an attempt to avoid confusion. Colloquial wetland terms such as marsh, vlei, tarn, fen have been avoided for the sake of clarity.

As with the Cowardin *et al.*, (1979) classification system, this classification too is hierarchical, and has been designed to be applied at all levels of data collection, i.e. a wetland can be classified immediately from orthophotos or topographic maps, and can eventually be further categorised and differentiated on important individual characteristics following field investigations, which facilitate a more accurate understanding of dominant wetland processes. This should increase the degree of insight pertaining to the functioning of wetlands within the landscape. It is proposed that this classification, once fully verified, may be useful for wetland managers in that it provides information on wetland process and dynamics; factors which need to be addressed if wetland management and restoration initiatives are to be successful.

Chapter 7

7. General Discussion and Conclusion

The work contained in the foregoing study has emphasized the close connection between wetlands, the surrounding landscape and the hydrological cycle. A brief overview and discussion of the specific findings reported in this study together with the implications of the findings and opportunities for further research follows.

7.1 Dominant factors promoting wetland origin and maintenance

Through field observation and laboratory analysis it has been shown that wetland creation and maintenance in the study area may be attributed primarily to:

(i) Climatic factors (specifically rainfall and temperature)
The Upper Mooi River catchment is situated in a high rainfall region relative to other areas in South Africa. This area not only receives high water inputs, but is also characterized by relatively high water tables. In addition, the cooler temperatures of this high altitude zone is likely to limit both evaporation and evapo-transpiration potentials.

(ii) Landscape position and landform characteristics
The position of the wetland within the landscape was found to be an important factor in wetland establishment and maintenance, by influencing both the type, volume and rate of water inputs. Landform characteristics were also found to explain wetland development and maintenance, by influencing the potential for water accumulation and the rate of water output. Slope wetlands for example, were found to be predominantly temporarily to seasonally saturated, and did not retain standing water. Wetlands located in valley bottom settings or basinal settings were substantially wetter, retaining standing water in summer in particular. Micro-topography (hummocks, inter-hummock zones, pools and abandoned oxbow lakes), were found to promote water maintenance by attenuating throughflow velocities and acting as water storage sites.

(iii) Geological characteristics
Resistant dolerite dykes and sills were found to act as local base levels, promoting the accumulation of water behind these structures. Lithological variations too were shown to influence wetland soil characteristics by influencing textural, chemical and depth variations. While requiring further investigation and verification, jointing activity appeared to be associated with a number of very wet zones, suggesting that ground water discharge may preferentially occur in these zones.

It is argued, that cumulatively, the above factors control the hydrological characteristics of wetlands, which impart an important influence on internal wetland conditions and functioning.

Soil characteristics were not found to be a primary determinant of wetland genesis and location in the Highmoor, Kamberg and Impofana Reserves. 'Wet land' conditions are associated with a wide range of textural characteristics, ranging from clays to sandy loams. Despite soil not appearing to be an important factor in wetland genesis, both field intuition and laboratory investigations suggest that soil influences:

- the susceptibility of the wetland to erosion. Erosion within wetlands appearing to be a function of soil texture, chemistry and organic carbon content;
- the water retention and storage capacity of wetland systems;
- the rate of organic matter decomposition and hence organic carbon content. Organic matter decomposition is a function of porosity and wetness i.e. aeration status;
- the quantity of nutrients and bases that can be retained within a wetland. The retention of nutrients and bases appears to be closely associated to the quantity and the nature of clay and organic matter;
- wetland pH;
- the susceptibility of the wetland to processes such as: flowage, cracking, swelling, piping and channelling; and
- the nature and composition (mosaic patterning) of vegetation.

Soil can hence be regarded as a very important determinant of wetland characteristics and wetland functioning.

7.2 Wetland characteristics, functions and processes

All of the wetlands investigated appeared to act as sediment sinks and thereby support a water purification role in the landscape. While sediment inputs appeared to exceed outputs, the relatively shallow soil depths of the Highmoor wetlands in particular (mean depths ranging from 47.24 ± 7.56 cm to 100 ± 17.92 cm), suggest that a steady state exists. It is postulated that excess sediment may be slowly removed from the wetlands over time, via processes such as pipe and channel erosion. This prevents sediment overload and hence maintains internal wetland functioning. Alternatively, the fact that no former peat deposits were found, suggests that the wetlands are relatively 'young' geological features, and that sediment and organic matter contents may increase with time.

Evidence of cracking, shrinkage and swelling processes were found within the wetlands of the upper Mooi River. The influence of these processes on wetland form and function was found to vary depending on variables such as soil texture and mineralogy, wetland hydroperiod and vegetation characteristics. Atterberg limits were found to vary fairly substantially with depth, as well as between and within wetlands.

Piping genesis was not found to be a function of chemical soil properties (ESP values are well below six, ranging between 0.01 and 0.09). Physical soil properties, soil-hydrological factors, biotic factors and jointing within bedrock, were identified as possible mechanisms of pipe formation. Piping was found to be important in wetland environments from both a hydrological and erosional perspective.

The relatively small channel systems found within the Highmoor wetland systems appeared to arise via different mechanisms of formation, namely erosion via concentrated overland flow processes, collapse of subsurface pipes and faunal initiation. The wetland channels were found to be important from:

☐ a hydrological perspective, by influencing the soil-water characteristics of wetlands;

☐ an erosional perspective, protecting the greater wetland surface from erosive forces of overland flow; and

☐ a biological perspective. Lateral shifts of the river channel and abandoned oxbow lakes are forms of geomorphic disturbance, providing secessional processes and promoting patch dynamics.

In general, the wetlands investigated appeared to act as both recharge and discharge wetlands. The occurrence of dystrophic, mesotrophic and eutrophic zones within individual wetlands emphasizes the complexity of wetland environments. These findings suggests that some zones act as preferential recharge areas, while others act as preferential discharge areas. Geology did not appear to be a primary determinant of the base content of the wetland soils investigated. Instead, the base status of wetlands was found to be a function of leaching and groundwater discharge activities, and the relative 'openess' of the wetland to receive nutrients and bases from proximal areas.

The acid to very acid character of the wetland systems investigated could not be attributed to any one particular factor, but appeared to be influenced by leaching processes, sulphuric acid formed by the oxidation of organic sulphur compounds and the occurrence of humic acids produced in water. The low pH levels within the wetlands not only have important ramifications for the biota concerned, but may also have important consequences for toxic materials. As argued by the Federal Interagency Stream Restoration Working Group (1999), high acidity tends to convert insoluble metal sulfides to soluble forms and can increase the concentration of toxic metals. This finding indicates that the wetland systems investigated would not be efficient storages of toxic heavy metals, nutrients and bases, despite this role frequently being attributed to wetlands.

7.3 Wetland identification and classification

Wetland identification

The present study found that the wetland identification and delineation procedure currently used by a large number of wetland managers and extension workers (discussed in Section 1.1) is not sufficiently comprehensive to encompass all wetlands. It is argued that this could lead to certain wetland types potentially being overlooked. Four shortcomings include: terrain unit description, soil depth and colour descriptors, the presence or absence of sulphidic odour and its relation to soil wetness and organic carbon content. Each of these factors are briefly discussed below.

(i) Terrain unit description

As previously discussed, a number of current practitioners argue that wetland habitats must first qualify as a valley bottom unit. The valley bottom unit is documented as typically occurring in depression areas, or as a depression on a crest, scarp, midslope or footslope. The above criteria exclude slope wetlands and wetlands not restricted to a depression. The findings of this study are in accordance with findings of *inter alia* Semenuik and Semenuik (1995), who have shown that wetlands may occur in a range of terrain settings, including slopes, and are not always restricted to a depression.

(ii) Soil depth and colour descriptors

Begg's (1990) four class system for determining the degree of wetness of soils, should be used only as a guideline. The 0 - 10 cm and 20 - 40 cm depths were found to be fairly restrictive. Frequently a difference in colour was only noted in the 0 - 30 cm, 30 - 60 cm interface. In addition, colour was found to vary with soil wetness. Wet and dry munsell values showed that soils are generally substantially darker when wet. As previously discussed, this suggests that soil colour may vary *in situ*, depending on the moisture conditions of the site at the time of sampling. This finding has important implications, since wetlands are currently being delineated based largely on soil morphology/colour attributes.

(iii) Presence or absence of sulphidic odour and its relation to soil wetness

Soil characterized by a sulphidic odour is commonly used as an indicator of permanent wetness. The present study indicated that the presence or absence of a sulphidic odour is not an accurate descriptor of wetland hydroperiod or wetness, since it is restricted to wet zones characterized by stagnant water. The characteristic sulphidic odour was absent from permanently wet through flow zones.

(iv) Organic carbon content

Organic carbon ranges for permanently, seasonally, temporarily and non-wetland zones, as outlined by Begg (1990), were found to be problematic in the study area. Frequently non-wetland areas and known temporarily wet areas contained high organic carbon, in the order of 10%, which is classified as 'organic' by the Soil Classification Working Group (1991).

Wetland Classification

The present study has shown, by using Canonical Variate Analysis (CVA), that while commonalities exist between the palustrine wetland systems investigated in this study, significant differences exist to substantiate a subclassification of the wetland systems into different palustrine wetland types. Calcium and potassium concentrations, clay content, pH (KCL), organic carbon and total sand contents were identified as maximizing the dispersion on the first two CVA axes. These variables may hence cumulatively explain wetland differentiation. The CVA determinations indicate that the tarns demonstrate unique characteristics, differentiating this wetland type from both the source seepage wetlands and the floodplain system. Stillerust, a floodplain wetland, was found to be significantly distinguished from the source seepage wetlands.

The present study supports Orme's (1990) argument that the distinction between palustrine and other interior wetlands is frequently arbitrary. Field investigations highlighted the genetic association between rivers and floodplains, a relationship recognised by a number of fluvial geomorphologists, for example Nanson and Croke (1991). The findings of this study are in accordance with Gobal and Sah (1995), who argue that while floodplain wetlands may appear to be palustrine systems in different years or in different seasons, their functions and values are directly influenced by their riverine interactions, and should hence be considered a subsystem of the fluvial system. It is argued that the intergradational nature of wetlands, both spatially and temporarily, makes the placement of interior wetlands into palustrine, lacustrine and riverine categories problematic.

The wetland groups identified in the CVA were found to occupy distinct landscape positions. As previously discussed, landscape positions and landform characteristics were identified as being an important factor in promoting wetlands origin and maintenance, by influencing the nature and quantity of water input, throughput and output. Hydrology, as repeatedly indicated in this manuscript, imparts an important influence on wetland processes, vegetation and soil characteristics, and thereby determines internal wetland conditions.

While it is not the intention of the present study to contribute to the multitude of wetland terminologies and classifications, a geomorphic classification of the wetlands in the upper-Mooi River catchment was developed, since a need for scientific rigour in wetland classification was identified. Five broad wetland types were classified according to landscape position and geomorphological criteria, namely: bench, basin, slope, confined and unconfined valley wetlands. While this hierarchical hydro-geomorphic classification system requires fine-tuning and verification, it provides the framework for the conceptual understanding of wetlands from a process perspective, an area which McCarthy and Hancox (2000) argue is an oversight of many classifications. The potential exists to expand it to other geographical areas and incorporate additional wetland types.

7.4 Implications for wetland management and restoration

The concepts of the present work conforms with recently emerging philosophies, that wetland form and functioning is conditioned by activities and geomorphic processes operative in the surrounding catchment. Both off-site and on-site management is clearly required if wetlands are to retain their natural conditions and functioning. In cases where off-site impacts such as overgrazing, cultivation of steep slopes or forestry operations is beyond the control of an individual landowner, negative impacts arising from these landuses may be reduced by ensuring that a sufficient 'buffer strip' of dense upland vegetation exists between the problem source and the wetland. The ultimate option for on-site conservation of wetlands would be to formulate management plans which would exclude activities that negatively impact on wetland functioning. The economic climate in South Africa at present, however, suggests that wetland utilization will not be easily halted. The concept of sustainable utilization of wetlands is the major theme underpinning the initiatives of the International Wetlands Programme of the World Conservation Union (*IUCN*) (Gosselink and Maltby, 1990). This philosophy is supported by the South African Wetland Action Group (SAWAG). In fact the organisation's mission statement: 'Promoting the sustainable use of palustrine wetlands in South Africa', directly reflects this. Efforts clearly need to be directed towards attaining scientifically based knowledge of wetlands, that can be integrated into wetland management principles, to ensure that land-use activities in and around wetlands do not impair the resource, optimising the natural benefits that can be derived from these important ecosystems.

While the primary objectives of the present research was not to formulate wetland management plans or directly investigate suitable methods of rehabilitation, a number of the findings of this study suggest potential activities or actions which can be implemented to ensure wetlands retain their natural characteristics and function. A brief discussion of grazing, burning and gully rehabilitation follows.

(i) Grazing

As previously discussed, heavy grazing within wetlands characterised by plastic soils may result in structural damage to the soil through trampling and trailing, and hereby negatively impact on the natural hydrological functioning of the wetland system. The results of this study indicate the importance of knowing: the hydroperiod and the relative wetness of the wetland selected for possible grazing, and the average plastic limits of wetlands, so informed decisions can be made regarding grazing times and stocking rates.

In addition to the above, knowledge of whether soil pipes are present within a wetland is also important. As discussed in Section 5.3.6, where possible, farmers should refrain from utilizing wetlands containing pipes for purposes such as grazing. Cattle trampling is likely to promote pipe roof collapse and consequent channel/gully initiation is then likely. In situations where alternative grazing is not possible, it is advisable that farmers/wetland mangers identify the location of pipes and attempt to restrict grazing to less sensitive zones, by erecting temporary fences etc. Cognisance needs to be taken of the fact that pipes are dynamic systems, continual monitoring of pipe extent and location is hence required.

(ii) Burning

Wetlands located on both privately owned farmland and in the uKhahlamba-Drakensberg Park, were found to be subject to intense burning activity. Considering the conflicting information of fire on wetland organic carbon contents, nutrient contents, physical soil characteristics, and *in situ* water contents, it is proposed that conservative burning regimes need to be practised within wetlands. Cool burns towards the end of winter and early spring appeared on subjective evidence to be the best time for wetland burning, wetland vegetation appearing soon after the fire as a result of the generally high soil water content of wetlands. Burning at this time will ensure that the wetland surface is protected by vegetation cover prior to the heavy summer rainfalls. Frequent burning of wetland side slopes is also not advisable, since this is likely to enhance erosion and hence sediment input into the wetland. Herbicide had been applied on the valley side slopes and within wetland H5 in an attempt to manage fire breaks (Pers. Obs; Gabela, 2000, Pers. Comm.). It is argued that alternative methods of fire management are clearly required, since herbicides are likely to contaminate wetland soil and water, negatively impacting on wetland biota and wetland function.

(iii) Gully rehabilitation

As previously mentioned, the reasoning of whether efforts should be made to restore wetlands undergoing natural adjustments and changes, particularly with respect to gully initiation, is of concern to a number of wetland extension officers (Walters, 2001, Pers. Comm.). While the location of gullies within wetland systems may often be attributed to general land mismanagement, the location of a substantial gully system (width: 2 - 2.5 m; depth: 4 m; length: 20 m) within a pristine palustrine wetland in the uKhahlamba-Drakensberg Park (wetland H1), highlights that gully initiation within a wetland need not have an anthropogenic stimulus. It may in fact be a natural stage in the secessional sequence of a particular wetland system. As outlined above, if a gully is believed to be 'natural', questions may arise as to whether it should be left to take its course, or whether efforts should be made to curb its development. It is argued that no unequivocal answers to this apparent predicament is forthcoming. Each situation requires an independent assessment so as to determine:

☐ the existing functions and values of the wetland;

☐ the rate of gully extension and incision; and

☐ what the foreseeable implications of continued erosion are in terms of wetland functioning, i.e. to what extent is the gully likely to influence wetland hydrology and hence wetland function.

While the transient and relatively ephemeral nature of wetlands in terms of geological time has been emphasized throughout this document, it is argued that intervention in an effort to prevent wetland loss, even in the case where loss is occurring as a result of natural processes is justifiable, considering that very few wetlands in good functioning condition remain in South Africa. It is, however, important that restoration structures work with and not against natural wetland processes, to avoid the loss of time, money and effort.

The dynamic and ever-changing conditions of wetlands was noted in this work and has been repeatedly highlighted. It is hence argued that in cases were active wetland restoration or rehabilitation is required, involving the intervention and installation of rehabilitation structures, it is essential that rehabilitation methods are sufficiently flexible and dynamic to accommodate the dyanism of wetland environments. The philosophy of the present study supports the sentiments of Oates' (1994), that as far as practicable, any works or activities should be simple and made as non-interventionist as possible.

This study has shown that while wetlands of a 'similar type' display many uniform features, every wetland demonstrates unique characteristics. The present study also found that wetland systems are greater than the sum of their individual parts, namely: climatic, geologic, pedologic, hydrologic and biologic components. They therefore require a holistic approach in trying to ascertain the various interactive components of wetlands, which constantly seek to achieve their own dynamic equilibrium. It is argued that this necessitates that each wetland system is treated according to its unique requirements, i.e. that the 'recipe book' philosophy on restoration, discussed in Federal Interagency Stream Restoration Working Group (1999), is forgotten. Criteria, standards, and specifications should hence be designed or modified for individual projects, taking cognisance of the specific physical attributes, such as soil properties, climatic conditions and landscape location.

Wetland restoration design is currently in an experimental stage in South Africa. Many wetland restoration activities undertaken in South Africa to date have not been as 'sensitive' as they should be. For example, the philosophy of 'plugging' drains and gullies with gabions, in an attempt to counteract wetland drainage and promote waterlogged conditions, may result in undesired effects such as the alteration of natural hydroperiods. Parts of the wetland that may have been temporarily or seasonally wet, may be converted to permanently 'wet land', which may result in a decrease in species richness and altered wetland functioning. In addition to altered hydroperiods, McCarthy and Hancox (2000) indicate that prolonged flooding may cause the accumulation of toxic salts in the ground water, which again may negatively affect biota. Should the soil be dispersive (i.e. sodic), erosion may occur around gabions, exacerbating wetland degradation.

There are no 'quick-fix' solutions to wetland rehabilitation. The complexity of wetland systems, as emphasized in this study indicates that rehabilitation requires expert knowledge and continual monitoring to ensure the desired result is achieved. A wetland rehabilitation manual is currently being devised by leading practitioners in the field, under the auspices of the Mondi Wetlands Project and the Department of Water Affairs and Tourism. It is important that South Africa keeps up to date with the newly emerging philosophies and techniques in terms of wetland restoration and conservation that are currently unfolding in first world countries, the United States in particular. It is submitted that South Africa can and should learn from the restoration oversights and failures of other countries, and thereby avoid making similar mistakes.

7.5 The need for further research

The multi-disciplinary nature of wetlands make them difficult systems to evaluate and understand from any one single discipline. The need for multi-disciplinary wetland research projects cannot be overemphasized. While recommendations for further research have been suggested periodically throughout this manuscript, a number of broad and important areas follows.

☐ Investigations are required to determine to what extent the preliminary hydro-geomorphic classification system developed in this study can be applied to other headwater catchment areas in South Africa. In addition, a number of the descriptors such as the size, sediment characteristics and vegetation types of different wetland types require fine-tuning.

- ☐ The need for long term assessments of wetland soil and hydrology has been repeatedly highlighted in the present study. Investigations over the hydrological year and over a number of years would be beneficial in providing a fully comprehensive view of wetland functioning and dyanism, as well as providing information on the direction and rates of changes and responses. It would be valuable to quantitatively determine sediment input and output rates of wetland systems, as well as determining the storage capacity of wetland systems. Further research is required to ascertain whether soil chromas and values can be adjusted according to the *in situ* water content. This would ensure that hydroperiod assessments based on soil morphology are consistent irrespective of the *in situ* water contents at the time of field investigation.

- ☐ A more detailed account of wetland micro-topography and micro-process would be informative in comparing relative degrees of wetness. Detailed grid sampling procedures, together with interpolations and surfacing using a Geographic Information System (GIS) package, would provide valuable information in terms of determining the internal homogeneity or heterogeneity of wetlands and provide further information of wetland process. Hydro-geomorphic modelling is another area requiring attention.

- ☐ As previously discussed, this study found organic carbon ranges for permanently, seasonally, temporarily and non-wetland areas to be problematic in the study area. Considering that organic matter decomposition is governed primarily by temperature, water abundance, soil texture and the nature/type of vegetation, it is proposed that the creation of an organic carbon content distributional map (similar to Acock's veld-type map and Köppens climate map) would be beneficial in South Africa. A map of this nature would allow wetland organic carbon contents to be compared to proximal non-wetland organic carbon figures, so as to comparatively ascertain whether wetland organic carbon contents are high or low relative to local upland conditions. In addition, the influence of fire on wetland organic carbon contents, nutrient contents and physical soil characteristics, requires attention.

- ☐ Further work is required to determine to what extent the wetlands in the uKhahlamba Drakensberg park can be used as reference wetlands or reference standards for similar palustrine wetland 'types' lower down in the catchment, which have been anthropogenically modified to a much greater extent.

7.6 Concluding remarks

Notwithstanding the above recommendations for further research, the present work contributes towards addressing the paucity of geomorphological wetland research in South Africa. The aims and objectives of the present study have been achieved. The foregoing study indicates that while a degree of similarity or homogeneity exists between the different palustrine wetlands investigated, significant heterogeneity or differences exist to warrant a subclassification of the palustrine system. The present work established that the wetland systems in the upper Mooi River owe their origin and maintenance primarily to climatic, landscape and geological characteristics. Landform position and micro- and macro-landform characteristics were found to be important with respect to internal wetland characteristics and wetland functioning by influencing the rate and quantity of water, sediment and nutrient input, throughput and output in these systems. The study has shown that geomorphic processes contribute significantly to internal wetland characteristics, function and dynamics.

Many of the findings of this research are in accordance with arguments made by Bedford (1996). It is argued that by adopting a hydro-geomorphic approach to wetland classification, the functional equivalency of wetlands can be determined. This study has provided preliminary reference or benchmark data, which, with further testing and evaluation, could prove to be useful in the management of wetlands of the same type lower down in the catchment. Many of the findings of this study, especially with respect to predicting what 'drives' and maintains wetland systems, may facilitate wetland managers and extension officers to predict the probable effects of off-site and/or on-site impacts, induced by either natural and or human influence. For example, it may enable scientists, planners and wetland managers to predict the influence of activities such as channel diversions, borehole pumping and river impoundments on wetland maintenance and functioning.

In conclusion, the hydro-geomorphic approach adopted in this study was found to be beneficial in terms of understanding wetland functioning, dynamics and processes. It is argued that a geomorphological understanding of wetland systems is advantageous in that it allows for a predicative understanding of wetland structure and functioning in response to environmental changes. It is proposed that a number of the findings of the present study can be integrated into wetland management and rehabilitation initiatives of palustrine wetland systems in South Africa, and thereby augment the conservation and wise use of these very valuable assets, deserving conservation and further study.

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Appendix I

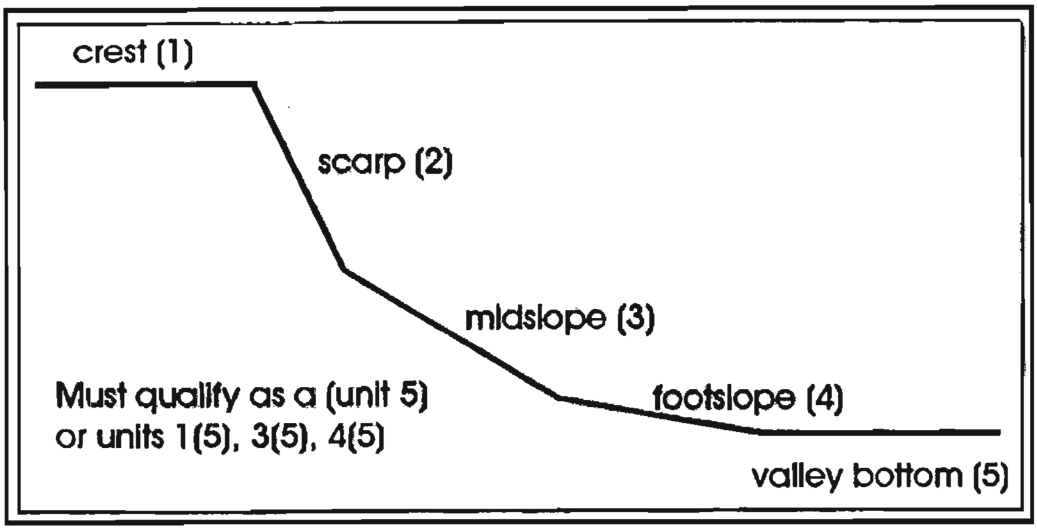


Fig. 1.1 Terrain unit (*as per* Land Type Survey Staff, 1986 and Forest Soils Database 1993).

SOIL FORM

Soil types typically belonging to permanent, seasonal and temporary wetland habitats, as outlined by the Soil Classification Working Group (1991), are outlined below:

☐ **permanent habitat:**

Champagne, Katspruit, Willowbrook or Rensburg soils.

☐ **seasonal and temporary habitats (will have one or more of the following forms):**

Inhoek, Longlands, Wasbank, Lambed, Estkort, Klapmuts, Tukulu, Cartref, Fernwood, Westleigh, Dresden, Avalon, Pinedene, Glencoe, Bainsvlei, Bloemdal, Witfontein, Sterkspruit, Sepane, Valsrivier, Dundee.

Table 1.1 Clay type and associated activity

CLAY TYPE	PREDICTED ACTIVITY
kaolinite	0.3 - 0.5 ; 1
illite	~ 0.9
montmorillonite	> 1.5

(Carter and Bentley, 1991)

Carter and Bentley (1991) maintain that these values hold true not only for the activity of the pure clay minerals but also for coarser-grained soils whose clay faction is composed of these minerals.

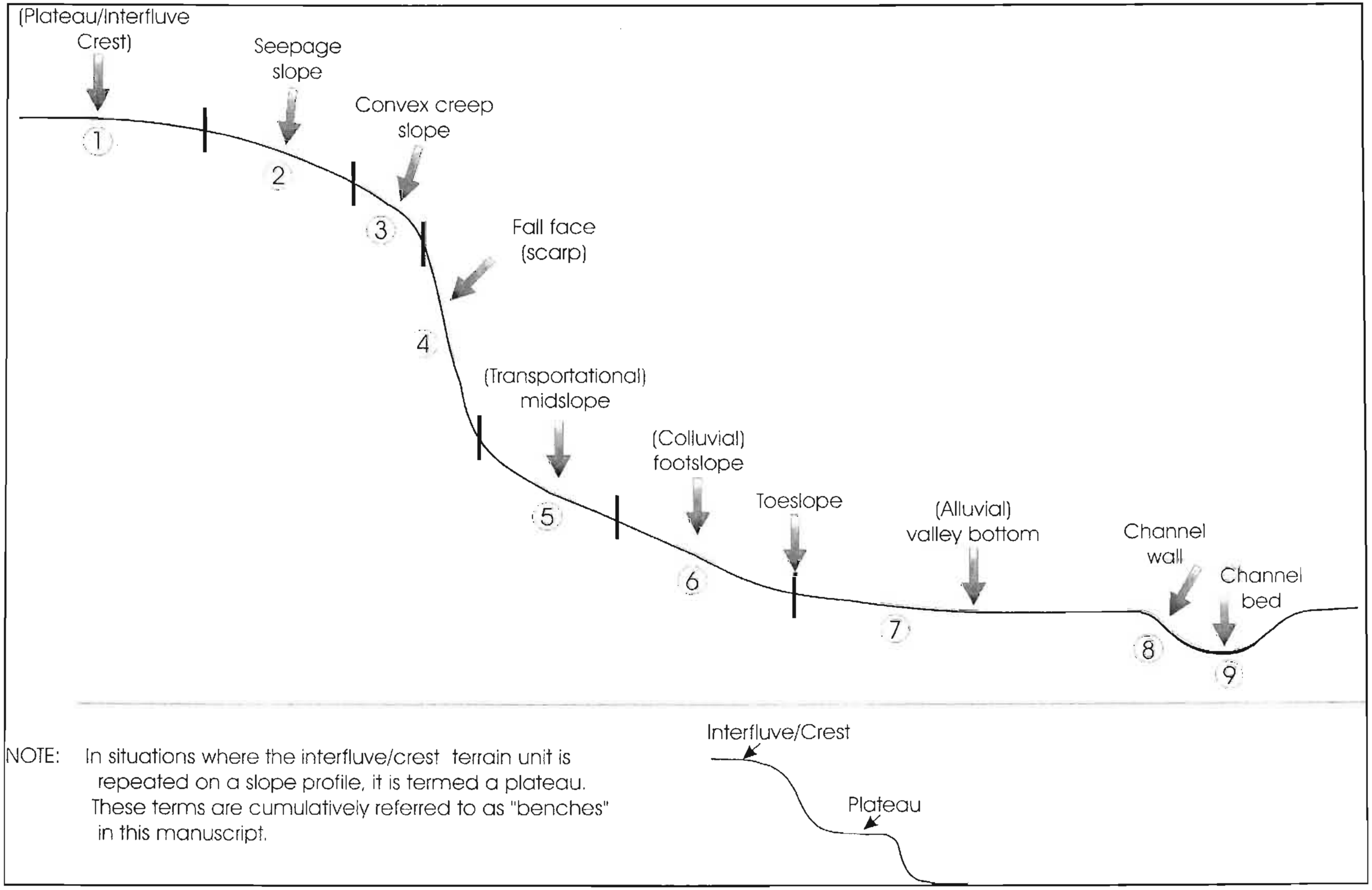
Appendix 2

Indicators (i) and (ii) used to determine discharge sites:

Fig. 2.1 An oily covering on the surface of standing water.

Fig. 2.2 Iron orchre deposits.

Appendix 3



NOTE: In situations where the interfluve/crest terrain unit is repeated on a slope profile, it is termed a plateau. These terms are cumulatively referred to as "benches" in this manuscript.

Figure 3.1 The Hypothetical nine-unit landsurface model (Modified after: Dalyrymple *et al* ., 1968).

Appendix 4

(Field and laboratory data sheets for: H1, H2, H4, H5, S, T1 and T2 respectively)

List of terms and abbreviations

FIELD DATA SHEET

o/m	►	organic matter
F	►	partly decomposed litter, original plant structures visible
H	►	well decomposed litter - original plant structures cannot be seen, frequently mixed with plant matter
O	►	peaty horizon(s) - accumulated under wet conditions
Of	►	fibrous peat
om	►	semi-fibrous peat
Oh	►	amorphous peat
Op	►	mixed (fibrous, semi-fibrous and amorphous peat)
n/s	►	not significant (referring to organic horizons)
n/c	►	not classical (organic matter present, but form of peat not easily identifiable)
clr.	►	colour
moist.	►	moisture
sat.	►	saturated
perm.	►	permanent
seas.	►	seasonal
temp.	►	temporary
nw	►	non wetland

LABORATORY DATA SHEET

EXH.Acidity	►	exchangeable acidity
Teff	►	Effective Exchange Capacity
EAR	►	Exchangeable acidity ratio

Table 4.1 Wetland H1, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	munsell mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
H1.1	**0 - 30**	no	(n/s)	-	2.5 yr 3/2	dusky red	10 yr 3/4	dusky red	few	moist	temp.
	30 - 70	no	(n/s)	-	2.5 yr 2.5/3	dark reddish brown	-	-	-	moist - sat.	nw
	70 - 120	no	(n/s)	few small stones	5 yr 3/4	dark reddish brown	-	-	-	moist - sat.	nw
H1.2	**0 - 30**	yes	F, H, O (n/c)	-	10 yr 2/1	black	-	-	-	sat.	perm.
	30 - 70	no	-	-	10 yr 2/1	black	-	-	-	sat.	perm.
	70 - 120	no	-	-	10 yr 2/1	black	-	-	-	sat.	perm.
H1.3	**0 - 20**	no	(n/s)	few small stones	10 yr 2/1	black	-	-	-	sat.	perm.
H1.4	**0 - 20**	no	(n/s)	-	10 yr 2/1	black	-	-	-	moist - sat.	perm.
H1.5	**0-50**	yes	o/m (n/c)	few stones	10 yr 3/3	dark brown	7.5 yr 6/8	reddish yellow	common	sat.	temp.
	50 - 200	no	(not significant)	-	5 GY 4/1	dark greenish grey	-	-	-	sat.	perm.
H1.6A	**0 - 20**	yes	F, H, Om	few stones	10 yr 3/3	dark brown	-	-	-	moist	temp.
H1.6	**0 - 40**	yes	F, H, Om	-	7.5 yr 2.5/1	black	7.5 yr 5/8	strong brown	common	moist	temp.
	40 - 80	yes	F	-	7.5 yr 2.5/1	black	7.5 yr 6/8	reddish yellow	common	moist - sat.	temp.
H1.7	**0 - 50**	yes	F, H, Om	-	10 yr 2/1 ; 10 yr 5/8	black ; yellowish brown	-		-	sat.	perm.
	50 - 100	yes	F	-	10 yr 2/1	black	10 yr 5/8 (streaks)	yellowish brown	common - many	sat.	seas.
H1.8	**0 - 50**	yes	F, H, Oh	-	10 yr 2/1	black	-	-	-	sat.	perm.
	50 - 100	yes	F, H, Oh	-	10 yr 2/1	black	-	-	-	sat.	perm.
H1.9	**0 - 80**	yes	F, O (n/c)	-	7.5 yr 3/2	dark brown	5 yr 5/8	yellowish red	few	moist	temp.
H1.10	**0 - 40**	yes	F, H, Of	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
	40 - 140	yes	Om - Oh	-	10 yr 3/1 ; 5 GY 4/1	black ; dark greenish grey	-	-	-	sat.	perm.
H1.11	**0 - 200**	yes	F, H, Op	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.

Table 4.2 Wetland H1, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (water)	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H1.1	0 - 30	1.51	0.59	0.02	0.25	2.37	0.01	5.68	4.60	0.25	2.62	90.44	9.56	22.89	45.16	9.09	6.43	16.43	31.95	7.45
	30 - 70	0.49	0.29	0.01	1.14	1.93	0.00	5.56	4.65	0.27	2.20	87.68	12.32	54.72	32.83	1.79	1.34	9.32	12.45	5.27
	70 - 120	1.23	0.41	0.00	0.12	1.76	0.00	5.56	4.60	0.01	1.77	99.44	0.56	41.50	46.28	1.58	1.43	9.21	12.22	4.73
H1.2	0 - 30	7.53	3.33	0.06	0.20	11.12	0.01	5.96	5.09	0.01	11.13	99.94	0.06	25.16	37.90	13.80	5.10	18.04	36.94	5.66
	30 - 70	7.00	3.00	0.03	0.08	10.11	0.00	5.88	4.96	0.32	10.43	96.95	3.05	24.99	44.53	13.30	2.47	14.71	30.48	4.65
	70 - 120	5.94	2.67	0.05	0.06	8.73	0.01	5.99	4.93	0.00	8.73	99.97	0.03	38.02	31.48	9.46	2.45	18.59	30.50	2.98
H1.3	0 - 20	2.69	0.92	0.04	0.07	3.72	0.01	5.41	4.93	0.14	3.86	96.44	3.56	19.03	45.98	19.37	10.11	5.51	34.99	5.30
H1.4	0 - 20	8.44	4.22	0.03	0.13	12.82	0.00	5.77	4.65	0.04	12.86	99.71	0.29	48.03	26.23	12.25	3.28	10.22	25.75	4.64
H1.5	0-50	17.11	3.46	0.61	0.70	21.88	0.03	5.84	4.68	0.07	21.94	99.70	0.30	32.42	39.28	5.50	4.75	18.05	28.30	6.19
	50 - 200	6.86	1.83	0.20	0.20	9.09	0.02	5.51	4.02	2.72	11.82	76.95	23.05	29.02	41.28	7.10	4.55	18.05	29.70	2.02
H1.6	0 - 40	8.25	2.61	0.30	0.14	11.30	0.03	5.62	4.43	0.19	11.49	98.33	1.67	47.14	38.46	2.25	1.20	10.95	14.40	3.12
	40 - 80	7.69	1.82	0.33	0.11	9.95	0.03	5.48	3.99	1.91	11.86	83.88	16.12	50.42	36.18	2.25	1.35	9.80	13.40	1.91
H1.6A	0 - 20	4.23	2.57	0.03	0.31	7.14	0.00	5.46	4.55	0.06	7.19	99.24	0.76	18.54	38.26	11.72	6.04	25.45	43.21	4.97
H1.7	0 - 50	9.23	1.87	0.37	0.33	11.81	0.03	5.18	4.47	0.12	11.93	98.99	1.01	28.54	49.16	2.10	1.90	18.30	22.30	10.08
	50 - 100	8.41	1.85	0.30	0.16	10.72	0.03	5.33	4.62	0.04	10.77	99.58	0.42	29.34	46.56	5.55	2.15	16.40	24.10	4.61
H1.8	0 - 50	7.44	2.03	0.25	0.17	9.90	0.03	5.69	4.75	0.04	9.93	99.63	0.37	26.74	42.86	10.80	5.75	13.85	30.40	4.53
	50 - 100	7.28	2.18	0.23	0.13	9.82	0.02	5.77	4.77	0.03	9.85	99.70	0.30	28.14	39.16	12.20	6.20	14.30	32.70	2.98
H1.9	0 - 80	18.56	3.67	0.31	0.33	22.86	0.01	6.09	5.23	0.02	22.88	99.92	0.08	24.47	50.78	6.05	3.95	14.75	24.75	3.63
H1.10	0 - 140	6.94	1.67	0.31	0.07	8.99	0.03	5.29	4.17	0.21	9.20	97.69	2.31	28.49	43.51	6.15	2.85	19.00	28.00	2.72
H1.11	0 - 200	8.63	2.43	0.61	0.14	11.81	0.05	5.32	4.44	0.11	11.93	99.04	0.96	27.66	45.19	2.90	4.00	20.25	27.15	7.88

Table 4.3 Wetland H2, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	munsell mottling clr	mottling colour	mottling abundance	moist. status	hydroperiod
H 2.1 a	0 - 20	no	-	-	10 yr 3/2	very dark greyish brown	10 yr 5/8	yellowish brown	v. few	moist	temp.
	20 - 50	no	-	-	10 yr 5/8 + 10 yr 3/4	yellowish brown ; dark yellowish brown	10 yr 5/8	yellowish brown	v. few	sat.	nw
	50 - 100	no	-	-	10 yr 5/8 + (10 yr 3/2)	yellowish brown ; very dark greyish brown	small areas 10 yr 3/2,	very dark greyish brown	common	sat.	nw
H 2.1 b	0 - 20	yes	F, Oh	-	10 yr 3/3	dark brown	-	-	-	moist - sat.	nw
	20 - 50	no		-	10 yr 4/6	dark yellowish brown	-	-	-	moist - sat.	nw
H 2.2	0 - 20	no (n/s)	-	-	10 yr 2/1	black	10 yr 5/8 (v. slight/ neglible)	yellowish brown	few	moist - sat.	temp.
	20 - 30	no (n/s)	burnt	-	10 yr 2/1	black	-		-	sat.	perm.
H. 2.3	0 - 5	yes	F, H	-	10 yr 3/2	very dark greyish brown	10 yr 5/8	yellowish brown	v. few	moist	temp.
H.2.4	0 - 30	yes	F, Of, Oh	-	10 yr 2/1	black	-	-	-	sat.	perm.
H.2.5	0 - 20	yes	O, Of	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
H.2.6	0 - 20	yes	F (grass)	-	2.5 yr N, 2.5 / 1	reddish black	-	-		moist	perm.
	20 - 50	no (n/s)	-	-	5 yr 3/2	dark reddish brown				moist - sat.	temp.
	50 - 90	no (n/s)	-	-	5 yr 3/2 + 5 yr 4/3	dark reddish brown ; reddish brown	-		-	sat.	temp.
H.2.7	0-20	yes	F	-	5 yr 2.5/2	dark reddish brown	-	-	-	moist (heavy rain)	temp.
H.2.8	0 - 10	yes	F (v. little)	-	2.5 yr N 2.5/1	reddish black	-	-	-	moist	perm.
	10 - 40	no (n/s)	-	-	5 yr 3/2	dark reddish brown	-		-	moist	temp.
	40 - 100	no (n/s)	-	-	5 yr 4/6	yellowish red	-		-	moist	nw
H.2.9a	0 - 10	yes	F	-	7.5 yr 3/2	dark brown	-	-	-	moist - sat.	temp.
	10 - 30	no	-	-	7.5 yr 3/2	dark brown	-	-	-	moist -sat.	temp.
	30 - 50	no	-	gritty (regolith)	7.5 yr 5/6	strong brown	-	-	-	sat.	nw
H.2.9b	0 - 5	no	(n/s)	-	10 yr 3/4	dark yellowish brown	-	-	-	sat.	nw

Table 4.3 cont. Wetland H2, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	munsell mottling clr	mottling colour	mottling abundance	moist. status	hydroperiod
H.2.10	0- 20	no	(n/s)	high agates	7.5 yr 3/1	very dark grey	-	-	-	moist	perm.
	20-50	no	(n/s)	agates	7.5 yr 3/1	very dark grey	10 yr 5/8	yellowish brown	few -	sat.	seas.
	50 - 60	no	(n/s)	very gritty	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
	60 - 70	no	(n/s)	very gritty	10 yr 3/2 + 10 yr 4/6	very dark greyish brown ; dark yellowish brown	-	-	-	sat.	temp. / nw
	70 - 150	no	(n/s)	very gritty	10 yr 3/6	dark yellowish brown	-	-	-	sat.	nw
H. 2.11	0 - 20	yes	F	-	7.5 yr 3/2	dark brown	-	-	-	moist	temp.
	20 - 50	no	-	-	10 yr 3/2 + 10 yr 5/6	very dark greyish brown ; yellowish brown	-	-	-	moist	temp. - nw
	50 - 100	no	-	-	10 yr 3/2	very dark greyish brown	10 yr 3/1; 10 yr 2/1	very dark grey; black	few	moist	temp.
	100 - 200	no	-	few granules	7.5 yr 4/6	strong brown	-	-	-	moist -sat.	nw
H.2.1.1	0 - 20	yes (n/s)	F (v. little)	-	10 yr 3/1	very dark grey	-	-	-	moist	perm.
H.2.1.2	0 - 20	yes	O, Of	-	7.5 yr 2.5/1	black	-	-	-	sat.	perm.
	20 - 50	yes	O- Om	-	5 GY 6/1	greenish grey	-	-	-	sat.	perm.
	50 - 100	yes	O- Om	-	5 GY 5/2	greyish green	5 yr 5/8	yellowish red	many	sat.	seas.
	100 - 150	no (n/s)	-	-	5 GY 4/1	dark greenish grey	7.5 yr 5/8	strong brown	common	sat.	seas.
H 2.1.3	0 - 20	yes	O- Of	-	10 yr 2/1	black	-	-	-	sat.	perm.
	20 - 40	yes	O- Oh	-	10 yr 2/1	black	10 yr 5/8 (streaking)	yellowish brown	-	sat.	perm.
H 2.1.4	0 - 20	no (n/s)	-	fairly gritty	10 yr 2/1 + little... 5 GY 6/1	black ; greenish grey	-	-	-	sat.	perm.
H 2.1.4 A	0 - 20	no	-	fairly gritty	10 yr 2/1 + 5 GY 6/1	black ; greenish grey	-	-	-	sat.	perm.
	20 - 40	no	-	fairly gritty	10 yr 3/1 + 5 GY 4/1	very dark grey	-	—	-	sat.	perm.
H 2.1.5 A	0 - 20	yes	F, H, O	gritty	10 yr 3/2	very dark greyish brown	-	-	-	sat.	perm.
H 2.1.6 A	0 - 20	yes	F, H, O	gritty	10 yr 2/2	very dark brown	-	-	-	sat.	perm.
H 2.1.7 A	0 - 20	yes	F	fairly gritty	10 yr 3/1	very dark grey	-	-	-	moist	perm.
	20 - 50	no	(n/s)	very gritty	10 yr 3/1	very dark grey	-	-	-	moist	perm.

Table 4.3 cont. Wetland H2, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	mottling colour	munsell mottling clr	mottling abundance	moist. status	hydroperiod
H 2.1.5	0 - 20	yes	O- Om, Oh	-	10 yr 2.5/1	black - very dark brown	-	-	-	sat.	perm.
H 2.1.6	0 - 20	yes	F, O- Om (n/c)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
	20 - 40	yes	F, O- Om (n/c)	slightly gritty	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 2.1.7	0 - 20	yes	O- Of, Om	gritty	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 2.1.8	0 - 20	yes	F, O	-	5 yr 2.5/1	black	5 yr 5/8	yellowish red	few	moist	perm.
	20 - 40	no	-	-	5 yr 2.5/1	black	-	-	-	moist	
H2.2.1	0 - 20	yes	F, O	agates	10 yr 2/1	black	-	-	-	sat.	perm.
H2.2.2	0 - 20	yes	F, O- Om	agates	10 yr 2/1	black	-	-	-	moist -sat.	perm.
	20 - 40	yes	O- Oh	high agates	5 GY 5/1 + 2.5 yr 5/8	greenish grey ; red	-	-	-	moist -sat.	nw
	40 - 100	no	-	less agates	5 GY 4/1 + 7.5 YR 5/8	dark greenish grey; strong brown	-	-	-	sat.	nw
H2.2.3	0 - 20	yes	F, O	-	5 G 4/2 + 10 yr 3/1	greyish green; very dark grey	-	--	-	sat.	perm.
H2.2.4 (r)	0 - 20	yes	F, O- Om	agates	5 yr 3/1 + 5 yr 3/3	very dark grey ; dark reddish brown	-	-	-	moist	perm.
H2.2.4 (l)	0 - 5										
H2.2.4 (c)	0 - 20	yes	F	agates	10 yr 2/1	black	-	-	-	moist -sat.	perm.
	20 - 50	no	-	high agates	10 yr 2/1	black	-	-	-	sat.	perm.
H 2.4.1	0 - 20	yes	F	-	10 yr 2/1	black	-	-	-	moist -sat.	perm.
H 2.3.1	0 - 20	no	(n/c)	-	7.5 yr 3/1	very dark grey	-		-	moist -sat.	perm.
H 2.3.2	0 - 20	yes	F, O- (n/c)	-	10 yr 3/1	very dark grey	5 yr 5/8 (2mm)	yellowish red	common	moist	seas.

Table 4.3 cont. Wetland H2, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	mottling colour	munsell mottling clr	mottling abundance	moist. status	hydroperiod
H 2.3.3	0 - 20	yes	F, O- Of	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
	20 - 40	no	-	-	10 yr 3/1+ 10 yr 6/6 + 5 G 6/1	very dark grey ; brownish yellow ; bluish grey	-	-	-	sat.	perm.
	40 - 100	no	-	gritty	5 BG 4/1 + 5 BG 5/1 + 2.5 y 5/3	dark greenish grey; greenish grey; reddish brown	-	-	-	sat.	perm.
	100 - 130										
H 2.3.4	0 - 20	yes	F, H, O-Om	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 2.3.5	0 - 20	yes	F	-	N 2.5 /1	black	-	-	-	moist -sat.	perm.
H 2.3.6	0 - 20	yes	F, O	-	5 yr 5/8	yellowish red	5 yr 5/8	yellowish red	common - many	moist -sat.	nw

Table 4.4 Wetland H2, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H 2.1 a	0 - 20	1.50	0.85	0.02	1.74	4.11	0.01	4.34	0.36	4.47	91.96	8.04	29.15	31.92	10.60	7.49	20.83	38.93	4.51
	20 - 50	0.98	0.44	0.01	0.82	2.25	0.00	4.32	1.31	3.56	63.16	36.84	38.98	27.03	16.04	5.29	12.66	33.99	3.48
	50 - 100	1.42	0.79	0.04	0.61	2.86	0.01	4.22	2.68	5.53	51.64	48.36	29.72	24.59	11.15	6.37	28.18	45.69	1.44
H 2.1 b	0 - 20	1.68	0.67	0.03	3.63	6.01	0.01	4.20	1.55	7.56	79.56	20.44	16.62	37.81	26.58	9.74	9.26	45.57	6.50
	20 - 50	3.38	2.90	0.01	19.49	25.78	0.00	4.14	0.38	26.16	98.55	1.45	35.47	35.98	5.82	8.31	14.42	28.55	3.54
H 2.2	0 - 20	5.24	2.49	0.05	1.16	8.94	0.01	4.79	0.01	8.95	99.87	0.13	11.27	47.90	18.22	5.84	16.77	40.83	6.06
	20 - 30	4.69	2.08	0.10	3.04	9.91	0.01	4.75	0.02	9.93	99.80	0.20	26.79	52.14	1.86	1.06	18.16	21.08	5.62
H. 2.3	0 - 5	4.26	2.09	0.08	0.03	6.46	0.01	5.56	0.00	6.46	99.98	0.02	9.99	25.11	8.92	10.56	45.43	64.90	3.28
H.2.4	0 - 30	7.24	3.52	0.17	0.66	11.59	0.01	5.13	0.00	11.59	99.98	0.02	15.56	46.75	12.28	3.60	21.81	37.69	7.90
H.2.5	0 - 20	3.42	2.38	0.09	0.80	6.69	0.01	4.45	0.08	6.76	98.86	1.14	22.94	43.62	4.17	3.91	25.36	33.44	6.22
H.2.6	0 - 20	1.77	1.74	0.00	0.63	4.14	0.00	4.30	0.85	4.99	83.01	16.99	31.66	46.52	2.93	2.56	16.33	21.82	6.97
	20 - 50	1.65	0.81	0.02	0.31	2.79	0.01	4.30	1.30	4.09	68.24	31.76	37.67	36.64	5.26	4.69	15.74	25.69	5.14
	50 - 90	1.71	0.69	0.01	1.89	4.30	0.00	4.29	1.29	5.59	76.97	23.03	39.76	33.92	5.84	5.03	15.45	26.32	4.83
H.2.7	0-20	2.86	1.13	0.02	0.29	4.30	0.00	4.30	0.40	4.71	91.42	8.58	42.45	29.15	8.58	5.12	14.71	28.41	5.84
H.2.8	0 - 10	2.67	1.24	0.08	1.12	5.12	0.02	4.24	1.69	6.81	75.13	24.87	39.03	32.97	5.77	5.18	17.06	28.01	7.69
	10 - 40	0.62	0.27	0.03	1.33	2.26	0.01	4.27	1.72	3.97	56.79	43.21	45.87	30.69	4.94	3.67	14.83	23.44	6.50
	40 - 100	0.80	0.26	0.03	1.67	2.77	0.01	4.33	1.41	4.17	66.32	33.68	43.15	31.83	4.52	4.03	16.47	25.02	3.94
H.2.9a	0 - 10	2.68	1.21	0.02	7.42	11.33	0.00	4.00	0.72	12.05	94.03	5.97	34.50	37.93	9.92	5.24	12.41	27.57	5.43
	10 - 30	2.17	0.86	0.01	0.05	3.09	0.00	3.86	1.01	4.10	75.48	24.52	31.65	38.97	14.37	4.44	10.57	29.38	3.98
	30 - 50	4.09	2.28	0.05	0.03	6.45	0.01	4.21	0.13	6.58	98.06	1.94	14.47	44.93	19.85	7.98	12.77	40.60	2.14
H.2.9b	0 - 5	2.09	0.80	0.02	0.02	2.94	0.01	3.98	0.38	3.32	88.54	11.46	19.05	28.47	40.89	4.23	7.36	52.48	2.43
H.2.10	0- 20	4.05	2.16	0.05	1.01	7.27	0.01	4.47	0.05	7.32	99.32	0.68	18.27	42.84	19.92	8.52	10.45	38.89	4.81
	20-50	5.23	2.76	0.07	0.95	9.01	0.01	4.56	0.05	9.05	99.48	0.52	15.42	48.96	19.35	6.97	9.30	35.62	4.00
	50 - 60	4.16	2.48	0.04	0.17	6.85	0.01	4.56	0.03	6.88	99.53	0.47	21.27	41.20	20.40	7.10	10.03	37.53	3.84
	60 - 70	3.54	3.46	0.03	0.20	7.23	0.00	4.08	1.55	8.78	82.37	17.63	32.70	35.02	5.97	7.19	19.12	32.28	2.33
	70 - 150	9.85	5.93	0.15	6.68	22.60	0.01	3.91	0.34	22.94	98.54	1.46	17.69	40.56	6.84	9.03	25.88	41.75	0.98

Table 4.4 cont. Wetland H2, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H. 2.11	0 - 20	9.21	5.23	0.05	0.52	15.01	0.00	4.78	0.02	15.04	99.85	0.15	24.41	50.44	9.07	5.31	10.77	25.15	5.94
	20 - 50	5.94	3.98	0.07	0.68	10.67	0.01	4.05	0.52	11.18	95.38	4.62	51.66	35.25	1.88	1.44	9.77	13.09	5.46
	50 - 100	6.36	3.98	0.12	0.13	10.60	0.01	3.78	2.04	12.63	83.89	16.11	38.35	46.03	2.13	2.01	11.48	15.62	3.93
	100 - 200	6.21	6.11	0.05	0.25	12.62	0.00	4.03	1.27	13.89	90.87	9.13	26.23	40.81	5.91	6.72	20.33	32.96	1.89
H.2.1.1	0 - 20	3.04	2.47	0.01	0.69	6.21	0.00	4.24	0.40	6.61	93.91	6.09	25.83	47.70	6.18	7.70	12.59	26.47	5.52
H.2.1.2	0 - 20	5.27	2.48	0.06	3.04	10.85	0.01	4.45	0.08	10.93	99.23	0.77	27.05	26.70	8.43	9.60	28.22	46.25	6.08
	20 - 50	5.53	3.55	0.09	0.43	9.60	0.01	4.47	0.07	9.67	99.26	0.74	31.04	24.56	12.22	7.35	24.83	44.39	4.58
	50 - 100	10.39	3.54	0.25	0.04	14.22	0.02	4.69	0.02	14.24	99.87	0.13	33.23	41.04	2.17	3.72	19.85	25.74	3.50
	100 - 150	9.21	8.16	0.20	0.01	17.58	0.01	4.61	0.02	17.60	99.87	0.13	37.48	44.26	1.98	1.08	15.20	18.26	0.81
H 2.1.3	0 - 20	3.41	1.88	0.05	0.12	5.46	0.01	4.32	0.14	5.60	97.50	2.50	14.17	43.16	11.20	8.11	23.36	42.67	6.03
	20 - 40	3.67	1.74	0.04	0.01	5.46	0.01	4.10	0.29	5.75	95.04	4.96	22.00	32.55	14.42	7.70	23.34	45.45	5.29
H 2.1.4	0 - 20	2.71	2.23	0.07	0.25	5.26	0.01	3.78	0.98	6.24	84.36	15.64	29.94	32.87	9.73	9.65	17.82	37.20	4.22
H 2.1.4 A	0 - 20	6.21	4.05	0.10	0.46	10.82	0.01	4.47	0.05	10.87	99.55	0.45	31.28	28.12	20.76	6.85	12.99	40.60	5.22
	20 - 40	0.89	0.32	0.01	0.21	1.43	0.01	4.29	1.60	3.03	47.34	52.66	31.72	29.42	18.83	5.65	14.38	38.86	3.02
H 2.1.5 A	0 - 20	4.37	2.21	0.09	0.28	6.96	0.01	4.63	0.04	7.00	99.41	0.59	25.21	33.41	13.80	7.94	19.64	41.38	5.27
H 2.1.6 A	0 - 20	2.45	2.51	0.05	0.91	5.91	0.01	4.61	0.07	5.98	98.85	1.15	25.67	39.43	16.27	7.90	10.73	34.90	5.62
H 2.1.7 A	0 - 20	6.96	4.21	0.03	0.36	11.56	0.00	4.66	0.06	11.62	99.46	0.54	32.83	41.83	13.99	2.32	9.03	25.34	6.14
	20 - 50	7.02	4.44	0.04	0.28	11.79	0.00	4.38	0.81	12.60	93.59	6.41	34.27	36.44	18.41	1.94	8.95	29.30	4.78
H 2.1.5	0 - 20	3.97	1.82	0.09	0.87	6.75	0.01	4.11	0.24	6.99	96.62	3.38	33.00	41.86	9.20	3.97	11.97	25.14	7.49
H 2.1.6	0 - 20	6.63	3.31	0.05	1.56	11.55	0.00	4.79	0.02	11.57	99.81	0.19	37.03	33.37	6.25	4.44	18.91	29.60	6.39
	20 - 40	4.78	2.18	0.09	0.71	7.76	0.01	4.62	0.02	7.78	99.69	0.31	36.43	35.58	8.35	3.08	16.56	27.99	5.12
H 2.1.7	0 - 20	4.40	2.11	0.06	5.09	11.65	0.01	4.82	0.01	11.66	99.93	0.07	22.03	27.41	25.14	10.73	14.69	50.56	4.46
H 2.1.8	0 - 20	1.11	0.43	0.03	7.03	8.60	0.00	4.66	0.03	8.62	99.70	0.30	22.45	43.88	11.86	6.21	15.60	33.67	7.96
	20 - 40	1.12	0.50	0.05	0.28	1.95	0.02	4.45	0.64	2.59	75.40	24.60	8.92	23.25	38.92	14.60	14.31	67.82	7.84

Table 4.4 cont. Wetland H2, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H2.2.1	**0 - 20**	6.40	3.46	0.08	0.20	10.14	0.01	4.76	0.02	10.16	99.83	0.17	27.06	30.72	23.74	5.23	13.25	42.22	5.92
H2.2.2	**0 - 20**	3.30	2.40	0.04	0.19	5.93	0.01	4.64	0.02	5.96	99.60	0.40	23.41	32.00	13.62	7.59	23.39	44.60	6.39
	20 - 40	6.20	7.42	0.11	0.01	13.74	0.01	4.06	0.32	14.06	97.72	2.28	37.20	32.37	7.66	2.02	20.75	30.43	2.46
	40 - 100	10.39	4.36	0.10	11.13	25.97	0.00	4.36	0.07	26.04	99.74	0.26	26.61	42.72	2.12	1.09	27.46	30.67	1.42
H2.2.3	**0 - 20**	3.51	1.94	0.05	0.47	5.97	0.01	3.96	0.41	6.38	93.56	6.44	32.89	37.00	6.43	3.92	19.76	30.11	7.04
H2.2.4 (r)	**0 - 20**	3.24	2.07	0.11	0.50	5.93	0.02	4.17	0.17	6.10	97.15	2.85	25.01	41.61	8.98	4.69	19.71	33.38	6.68
H2.2.4 (l)	**0 - 5**	2.11	1.01	0.27	1.25	4.64	0.06	4.13	0.15	4.79	96.87	3.13	2.46	36.73	11.88	15.82	33.11	60.81	7.96
H2.2.4 (c)	**0 - 20**	3.91	2.11	0.03	0.19	6.24	0.01	4.44	0.15	6.39	97.71	2.29	24.06	43.74	8.06	5.03	19.11	32.20	5.84
H2.2.4 (c)	**20 - 50**	3.79	2.01	0.04	0.12	5.96	0.01	4.45	0.12	6.08	98.07	1.93	26.33	41.24	7.64	4.38	20.41	32.43	5.16
H 2.4.1	**0 - 20**	3.00	2.12	0.07	0.23	5.43	0.01	4.41	0.22	5.65	96.13	3.87	29.70	46.50	5.09	2.97	15.75	23.81	7.86
H 2.3.1	**0 - 20**	4.76	3.28	0.06	0.40	8.51	0.01	5.06	0.00	8.51	99.97	0.03	8.02	37.72	14.20	7.07	32.99	54.26	6.01
H 2.3.2	**0 - 20**	4.59	1.52	0.10	0.29	6.51	0.02	4.60	0.07	6.59	98.88	1.12	16.87	56.01	3.06	1.30	22.76	27.12	5.12
H 2.3.3	**0 - 20**	1.74	0.27	0.02	0.02	2.05	0.01	3.99	1.07	3.11	65.77	34.23	19.83	38.34	26.74	4.92	10.17	41.83	4.78
	20 - 40	1.38	0.03	0.01	0.01	1.43	0.01	4.08	0.76	2.19	65.18	34.82	15.24	42.54	27.94	4.58	9.71	42.23	3.00
	40 - 100	2.61	0.94	0.03	0.12	3.70	0.01	3.95	1.00	4.70	78.82	21.18	34.83	30.59	22.77	4.20	7.61	34.58	1.23
	100 - 130	6.57	3.58	0.04	0.19	10.38	0.00	4.04	0.59	10.97	94.65	5.35	35.22	44.79	9.68	2.52	7.79	19.99	0.84
H 2.3.4	**0 - 20**	3.71	1.28	0.56	0.50	6.06	0.09	4.50	0.06	6.12	99.00	1.00	14.87	25.62	41.37	8.31	9.83	59.51	3.10 ?
H 2.3.5	**0 - 20**	6.39	1.97	0.04	1.80	10.20	0.00	4.61	0.04	10.24	99.57	0.43	16.06	32.27	14.93	9.38	27.36	51.67	9.06
H 2.3.6	**0 - 20**	7.91	2.81	0.03	0.32	11.08	0.00	5.03	0.01	11.09	99.90	0.10	25.68	41.20	11.67	4.42	17.03	33.12	5.86

Table 4.5 Wetland H4, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stonniness	munsell clr. (wet)	munsell clr. description	munsell mottling clr.	mottling colour	mottling abundance	moist. status	hydroperiod
H 4.1	0- 20	yes	O, Of, Om, Oh, Op	2 - 5 mm agates	7.5 yr 5/8	strong brown	10 yr 2/1	black	few - common	sat.	nw
H 4.2	0 - 20	yes	F, O, Of	agates.	2.5 yr (N3/1) + 7.5 yr 5/6	dark reddish grey	7.5 yr 5/6	strong brown	common	sat.	nw
	20 - 60	yes	O, Of	v. few agates	10 yr 3/2 + 10yr 7/8	very dark greyish brown; yellow	na	-	-	sat.	temp. + nw
	60 - 200 +	no	-	-	10 yr 5/6 + 10 yr 4/4	yellowish brown + dark yellowish brown	na	-	-	sat.	nw
H 4.3	0 - 10	yes	O, (Of), Om, Oh, Op	-	2.5 yr 3/6	dark red	na	-	-	sat.	nw
	10 - 20	yes	F, H (n/c)	few agates	7.5 yr 2.5 / 1 + 10 yr 5/8	black ; yellowish brown	na	-	-	sat.	perm. - nw
	20 - 50	yes	O, Of	high agates	10 yr 3/1	very dark grey	na	-	-	sat.	perm.
H 4.3 (H)	0 - 30	yes	F	few agates	7.5 yr 2.5 /1	black	10 yr 4/6	dark yellowish brown	many	sat.	seas.
H 4.4	0 - 20	yes	F (o- n/s)	high aggates	10 yr 3/1	very dark grey	10 yr 5/8	yellowish brown	common	sat.	seas.
	20 - 60	no	-	high aggates	10 yr 4/1	dark grey	10 yr 6/8 (streaking)	brownish yellow	abundant	sat.	seas.
	60 - 200 +	no	-	high aggates	10 yr 4/2	dark greyish brown	-	-	-	sat.	temp.
H 4.5	0 - 20+	yes	F (H/O - n/s)	high aggates	10 yr 2/2	very dark brown	10 yr 5/8	yellowish brown	common	moist	seas.
	20 - 80	no	-	-	10 yr 3/2 + 10 yr 5/6	very dark greyish brown	10 yr 5/8	yellowish brown (streaking)	common	sat.	temp.
	80 - 110	yes	F, O, Of	-	10 yr 5/6 + 5 GY 6.1	yellowish brown ; greenish grey	-	-	-	sat.	perm. + nw
H 4.6	0 - 30	yes	F (H/O - n/s)	-	10 yr 3/1	very dark grey	10 yr 5/6	yellowish brown	few	moist - sat.	perm.
H 4.7	0 - 30	yes	O - Of, Om, Oh, Op	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 4.8 a	0- 20	no	-	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 4.8 b	0 - 40	yes	F, (O- Op..n/c)	-	10 yr 2/1	black	10 yr 6/6	brownish yellow	few	sat.	perm.
H 4. A1	0 - 40	yes	F, O - Of, Om, Oh, Op (n/c)	high agates	10 yr 3/1	very dark grey	-	-	-	sat. (> depth)	perm.

Table 4.5 cont. Wetland H4, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stonniness	munsell clr. (wet)	munsell clr. description	munsell mottling colour	mottling colour	mottling abundance	moist. Status	hydroperiod
H 4. A2	0 - 30	yes	O - Of	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 4. B1	0 - 20	yes	O - Of	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 4. B3	0 - 30	yes	O - Of, Oh	-	10 yr 2/1	black	-	-	-	sat.	perm.
	30 - 60	no	-	few agates	10 yr 3/1 + 10 yr 5/8 (streaks)	very dark grey ; yellowish brown	- (streaking)	-	common	sat.	seas.
	60 - 80	no	-	more agates	10 yr 3/1 + 10 yr 5/8 (streaks)	very dark grey ; yellowish brown	- (streaking)	-	common	sat.	seas.
H 4. B4	0 - 15	yes	F, O - Oh (n/c)	-	10 yr 2/1	black	10 yr 5/8	yellowish brown	few	moist - sat.	perm.
H 4. B5	0 - 30	yes	F, H, O- Om (n/c)	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 4. B6 a	0 - 5	no	-	-	10 yr 2/1	black	too wet to tell	too wet to tell	-	sat.	perm.
H 4. B6 b	0 - 15	yes	O - Om	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 4. C1	0 - 30	yes	O - Om	-	10 yr 2/1	black	-	-	-	sat.	perm.

Table 4.6 Wetland H4, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (H_2O)	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H 4.1	0- 20	2.31	1.32	0.03	1.92	5.58	0.01	5.41	4.51	0.07	5.64	98.80	1.20	41.27	33.09	12.82	3.59	9.23	25.64	3.84
H 4.2	0 - 20	2.28	1.12	0.54	0.07	4.01	0.13	5.20	3.96	0.71	4.72	84.87	15.13	32.04	40.59	12.78	4.93	9.66	27.37	6.26
	20 - 60	2.96	1.30	0.05	0.10	4.41	0.01	5.15	3.99	0.57	4.99	88.53	11.47	43.43	29.85	15.29	3.18	8.26	26.73	3.20
	60 - 200 +	5.75	3.57	0.06	0.01	9.40	0.01	5.29	3.68	2.19	11.58	81.12	18.88	54.77	33.81	5.78	1.00	4.64	11.42	1.38
H 4.3	0 - 10	o/m	o/m	o/m	o/m	o/m	o/m	5.07	o/m	o/m	o/m	o/m	o/m	o/m	o/m	o/m	o/m	o/m	o/m	o/m
	10 - 20	1.94	0.59	0.01	4.50	7.04	0.00	4.77	3.73	1.82	8.87	79.46	20.54	35.58	35.50	10.74	5.26	12.92	28.92	7.59
	20 - 50	2.75	1.27	0.01	0.26	4.29	0.00	5.01	3.79	1.05	5.34	80.30	19.70	45.77	30.10	8.53	3.89	11.72	24.14	5.52
H 4.3 (H)	0 - 30	2.90	1.17	0.05	0.37	4.48	0.01	5.23	3.98	0.85	5.33	84.08	15.92	35.89	38.06	9.52	4.16	12.37	26.05	7.78
H 4.4	0 - 20	3.10	1.45	0.00	2.11	6.66	0.00	5.08	4.18	0.82	7.48	89.09	10.91	33.26	37.29	15.93	3.98	9.54	29.45	4.24
	20 - 60	4.91	2.93	0.03	0.53	8.39	0.00	5.61	4.09	1.42	9.81	85.54	14.46	38.85	34.27	11.87	4.79	10.22	26.88	1.83
	60 - 200 +	7.60	4.98	0.04	0.02	12.64	0.00	5.89	4.12	1.53	14.17	89.18	10.82	40.37	32.64	4.21	5.29	17.49	26.99	0.50
H 4.5	0 - 20	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
	20 - 80	4.91	2.73	0.99	0.07	8.69	0.11	5.41	4.54	0.22	8.91	97.57	2.43	46.17	31.44	9.82	4.65	7.92	22.39	4.00
	80 - 110	4.90	2.85	2.04	0.04	9.83	0.21	5.56	4.33	0.22	10.05	97.80	2.20	56.01	30.52	4.03	2.55	6.90	13.48	4.29
H 4.6	0 - 30	4.32	1.80	0.90	0.19	7.22	0.12	5.50	4.31	0.55	7.77	92.94	7.06	30.25	44.78	9.67	3.64	11.66	24.97	6.88
H 4.7	0 - 30	4.85	2.11	0.05	0.10	7.12	0.01	5.10	4.11	1.00	8.12	87.73	12.27	23.87	42.57	17.72	5.10	10.74	33.56	11.90
H 4.8 a	0- 20	4.20	1.50	0.00	0.05	5.75	0.00	5.63	4.39	0.09	5.84	98.40	1.60	43.95	23.38	23.36	4.85	4.46	32.67	3.71
H 4.8 b	0 - 40	4.60	1.76	0.01	0.19	6.56	0.00	5.42	4.44	0.46	7.02	93.43	6.57	29.10	42.40	10.20	6.03	12.28	28.51	7.51
H 4. A1	0 - 40	7.01	2.53	0.07	0.09	9.71	0.01	5.59	4.93	0.43	10.14	95.77	4.23	15.68	37.72	16.25	8.78	21.57	46.60	5.77
H 4. A2	0 - 30	10.00	3.64	0.07	0.48	14.18	0.00	5.49	4.58	0.06	14.24	99.58	0.42	36.49	41.16	5.29	3.13	13.93	22.35	12.29
H 4. B1	0 - 20	9.54	3.54	0.04	0.45	13.56	0.00	5.41	4.86	0.24	13.80	98.29	1.71	20.13	37.11	20.32	8.13	14.31	42.76	13.07

Table 4.6 cont. Wetland H4, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (H_2O)	pH_KCL	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H 4. B2	0 - 30	6.32	2.49	0.02	0.13	8.96	0.00	5.18	4.29	0.49	9.44	94.86	5.14	50.19	31.70	7.01	2.86	8.24	18.11	9.17
H 4. B3	0 - 30	6.54	1.97	0.04	2.54	11.09	0.00	5.58	4.47	0.20	11.29	98.24	1.76	38.54	33.92	12.98	3.78	10.79	27.55	11.26
	30 - 60	5.53	2.01	0.07	0.09	7.69	0.01	4.94	4.28	0.35	8.04	95.65	4.35	48.35	25.93	12.68	3.11	9.93	25.72	7.12
	60 - 80	6.23	3.08	0.07	0.05	9.42	0.01	5.49	4.14	0.90	10.31	91.32	8.68	50.74	25.69	11.84	2.24	9.49	23.57	3.56
H 4. B4	0 - 15	4.35	1.51	0.02	0.61	6.50	0.00	5.68	4.40	0.45	6.95	93.58	6.42	24.06	44.88	17.23	4.26	9.57	31.06	10.49
H 4. B5	0 - 30	8.25	3.32	0.68	0.30	12.54	0.05	5.74	4.78	0.10	12.64	99.20	0.80	38.56	38.90	9.14	2.76	10.64	22.54	10.24
H 4. B6 a	0 - 5	3.89	0.80	0.01	0.15	4.84	0.00	5.81	4.69	0.17	5.00	96.68	3.32	11.00	59.78	13.36	4.22	11.64	29.22	12.05
H 4. B6 b	0 - 15	2.81	0.80	0.05	0.38	4.05	0.01	5.47	4.78	0.54	4.59	88.17	11.83	14.86	45.67	19.65	7.25	12.57	39.47	12.24
H 4. C1	0 - 30	4.22	0.92	0.09	0.10	5.34	0.02	4.98	3.71	1.99	7.33	72.87	27.13	32.12	35.56	7.22	4.54	20.56	32.32	4.35

[Sample H4.3 0 - 10 comprised entirely of organic matter (o/m); Sample H4.5 0 - 20 comprised entirely of agates (★)]

Table 4.7 Wetland H5, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr (wet)	munsell clr. description	munsell mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
H 5.1	**0 - 50**	yes	F, H, O (Op)	-	5 yr 2.5 /1	black	5 yr 5/8	yellowish red	common - many	moist - sat.	seas.
H 5.2	**0 - 20**	yes	F, O (Op)- (n/c)	-	10 yr 2/1	black	-	-	-	moist - sat.	perm.
	20 - 50	yes	F, O, Op (n/c)	-	10 yr 3/1	black	-	-	-	sat.	perm.
H 5.3	**0 - 50**	yes	F, O- Op	-	5 yr 3/2	dark reddish brown	-	-	many	sat.	seas.
	50 -60	★	★	★	★	★	★	★	★	★	★
	50 - 200	yes	F, O- Op	↑ agates	5 GY 5/1 + 10 yr 3/1	greenish grey ; very dark grey	-	-	-	sat.	perm.
H 5.4	**0 - 20**	yes	F, O- Op (n/c)	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 5.5	**0 - 20**	yes	F, H, O (Op)	-	10 yr 2/1	black	-	-	-	sat.	perm.
	20 - 150	yes	F, H, O (n/c)	-	10 yr 2/1 + 5 GY 5.1	black ; greenish grey	-	-	-	sat.	perm.
H 5.5 A	**0 - 20**	yes	F, H, O - (n/c)	-	10 yr 2/1	black	-	-	-	sat.	perm.
	20 - 80	yes	F, H	-	10 yr 2/1	black	-	-	-	sat.	perm.
H 5.5 B	**0 - 20**	yes	F, H, O- (n/c)	-	10 yr 2/1	black	-	-	-	moist - sat.	perm.
	20 - 100	yes	H	-	10 yr 2/1 + 5 GY 5/1	black ; greenish grey	-	-	-	sat.	perm.
H 5 A 1.1	**0 - 20**	yes	F, H, O- (n/c)	n/s	10 yr 2/1	black	-	-	-	moist - sat.	perm.
	20 - 80	no	(n/s)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
	80 - 150	no	-	-	10 yr 2/1 + 5 GY 4/1	black ; dark greenish grey	-	-	-	sat.	perm.
H 5 A 1.2	**0 - 60**	no	F, H	-	10 yr 3/1 + 5 GY 4/1	very dark grey	-	-	-	moist - sat.	perm.
H 5 A 1.3	**0 - 20**	yes	F, H, O - (n/s)	-	10 yr 3/1	very dark grey	10 yr 3/6	dark yellowish	v. few	sat.	perm.
	20 - 60	yes	F, H	regolith	10 yr 2/1 + 10 yr 5/8 (R)	black; yellowish brown	small nodules	brown	-	sat.	seas. + nw

Table 4.7 cont. Wetland H5, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr (wet)	munsell clr (wet)	munsell mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
H 5 A 1.4	0 - 20	yes	F, H, O - (n/s)..burn?	-	10 yr 3/2 + 5 GY 5/1	very dark greyish brown ; greenish grey	10 yr 5/8	yellowish brown	few	moist - sat.	seas.
	20 - 60	no	-	-	10 yr 3/1 + 5 GY 6/1	very dark grey ; greenish grey					perm. + nw
	60 - 150	no	-	-	10 yr 5/6 + 5 G 5/2 + 5 G 4/2	yellowish brown ; greyish green	10 yr 3/1	very dark	-	moist - sat.	perm. + nw
H 5 A 1.5	0 - 40	yes	F, H	-	10 yr 3/1 + 10 yr 5/8 + 5 GY 5/1	very dark grey ; yellowish brown; greenish grey	-	-	-	sat.	seas.
	40 - 80	no (n/s)	-	-	10 yr 3/1 + 5 GY 5/1	very dark grey ; greenish grey	-	-	-	sat.	perm.
H 5 A 2.1	0 - 20	yes	F, H	-	7.5 yr 3/2	dark brown	10 yr 7/8	yellow	common	sat.	temp.
	20 - 100	no	-	-	(10 yr 3/1 + 3/4)+(5 GY 6/1 + 5/1)	very dark grey ; dark yellowish brown; greenish grey	-	-	-	sat.	seas.
	100-200	no	-	-	5B 5/1 + 10 yr 3/1	bluish grey ; very dark grey	-	-	-	sat.	perm.
H 5 A 3.1	0 - 20	yes	F, H	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 5 A 3.2	0 - 20	yes	F, H	-	10 yr 2/1	black	-	-	-	sat.	perm.
	20 - 100	no	(n/s)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 5 A 3.3	0 - 40	yes	F, H	-	10 yr 3/1	very dark grey	10 yr 5/8 (streaks)	yellowish brown	-	sat.	perm.
H 5 A 3.4	0 - 20	yes	F, H, O- (n/c)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
H 5.6	0 - 20	yes	F, H, O- burnt	-	10 yr 3/1	very dark grey	10 yr 5/8	yellowish brown	few - common	sat.	seas.
	20 - 200	no	-	-	10 yr 3/1	very dark grey	(n/c)	-	-	sat.	perm.
H 5.7	0 - 30	yes	F, H, O- (n/s)	-	10 yr 5/3, 5/8 ; 5 GY 5/1 (little)	reddish brown; greenish grey	10 yr 5/8	yellowish brown	few	sat.	seas.
	30 - 90	yes	F, H, O- (n/s)	-	10 yr 5/3	brown	-	-	-	sat.	nw

Table 4.7 cont. Wetland H5, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr (wet)	munsell clr (wet)	munsell mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
H 5.8	**0 - 10**	no	-	high agates	N3/	very dark grey	-	-	-	sat.	perm.
H 5.8 A	**0 - 30**	yes	F, H	-	10 yr 3/1	very dark grey	-	-	-	moist	perm.
H 5.8 B	**0 - 100**	yes	F, H, O- (n/s)	-	10 yr 3/1	very dark grey	-	-	-	moist	perm.
H 5.9	**0 - 30**	yes	F, H	-	10 yr 2/2	very dark brown	-	-	-	moist	temp.

Table 4.8 Wetland H5, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H 5.1	0 - 50	3.85	1.60	0.05	0.19	5.70	0.01	4.22	0.83	6.52	87.30	12.70	31.70	46.06	2.78	2.84	16.62	22.24	13.53
H 5.2	0 - 20	5.04	1.60	0.08	0.19	6.91	0.01	4.19	0.43	7.34	94.15	5.85	32.14	48.47	2.73	3.10	13.56	19.39	11.21
	20 - 50	4.22	1.10	0.05	0.00	5.37	0.01	4.03	0.50	5.88	91.43	8.57	32.30	46.52	4.60	3.03	13.55	21.18	8.50
H 5.3	0 - 50	4.14	1.20	0.06	0.13	5.53	0.01	4.57	0.17	5.70	97.06	2.94	29.15	48.94	5.71	3.80	12.40	21.91	9.85
	50 - 200	5.40	2.18	0.08	0.01	7.67	0.01	4.07	1.04	8.71	88.05	11.95	29.49	38.14	8.56	5.28	18.53	32.37	5.41
H 5.4	0 - 20	2.95	0.79	0.01	11.73	15.48	0.00	3.76	2.68	18.16	85.26	14.74	31.33	48.43	4.61	2.35	13.28	20.24	7.05
H 5.5	0 - 20	5.96	1.89	0.07	0.34	8.27	0.01	4.53	0.15	8.42	98.23	1.77	34.47	45.91	3.34	2.63	13.65	19.62	11.50
	20 - 150	6.49	2.56	0.07	0.08	9.19	0.01	4.28	0.27	9.47	97.12	2.88	35.86	34.24	7.11	5.27	17.52	29.90	5.51
H 5.5 A	0 - 20	2.61	0.52	0.03	0.18	3.35	0.01	4.30	0.84	4.19	79.99	20.01	34.26	31.80	11.68	5.85	16.41	33.94	10.63
	20 - 80	2.02	0.27	0.02	0.21	2.52	0.01	4.32	1.72	4.24	59.34	40.66	22.61	39.44	13.76	5.51	18.68	37.95	9.27
H 5.5 B	0 - 20	3.01	0.59	0.04	0.25	3.90	0.01	4.56	0.13	4.03	96.69	3.31	32.67	40.51	9.48	5.15	12.19	26.82	8.60
	20 - 100	8.01	2.03	0.04	0.09	10.18	0.00	4.69	0.08	10.26	99.20	0.80	33.59	36.90	11.36	4.97	13.18	29.51	7.15
H 5 A 1.1	0 - 20	6.48	2.02	0.05	0.37	8.91	0.01	4.23	0.33	9.24	96.40	3.60	45.09	38.55	1.95	1.53	12.88	16.36	12.17
	20 - 80	7.27	2.17	0.05	0.09	9.59	0.01	4.25	0.17	9.76	98.29	1.71	19.72	49.02	8.23	4.52	18.51	31.26	10.92
	80 - 150	10.04	3.46	0.10	0.01	13.61	0.01	4.55	0.07	13.68	99.46	0.54	42.83	27.95	7.26	4.05	17.91	29.22	5.31
H 5 A 1.2	0 - 60	4.82	1.32	0.03	0.16	6.33	0.00	4.40	0.35	6.68	94.73	5.27	27.27	39.77	8.46	4.52	19.98	32.96	7.54
H 5 A 1.3	0 - 20	5.74	1.63	0.11	0.17	7.64	0.01	4.43	0.07	7.72	99.03	0.97	33.71	31.50	6.90	4.87	23.02	34.79	10.24
	20 - 60	5.80	1.40	0.01	0.02	7.23	0.00	4.15	0.26	7.49	96.55	3.45	30.55	28.83	9.31	5.68	25.64	40.63	8.31
H 5 A 1.4	0 - 20	3.91	1.16	0.04	0.09	5.20	0.01	4.12	0.21	5.40	96.15	3.85	43.42	33.16	6.50	3.86	13.06	23.42	5.80
	20 - 60	3.38	0.94	0.01	0.05	4.38	0.00	3.79	0.73	5.11	85.73	14.27	37.63	35.80	8.46	3.28	14.83	26.57	4.93

Table 4.8 cont. Wetland H5, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
H 5 A 1.5	0 - 40	6.19	3.08	0.05	0.11	9.43	0.01	4.42	0.07	9.50	99.31	0.69	32.05	32.15	19.78	4.92	11.10	35.80	8.73
	40 - 80	9.39	4.20	0.70	7.63	21.91	0.03	5.07	0.02	21.93	99.90	0.10	38.92	35.71	7.90	2.83	14.65	25.38	4.15
H 5 A 2.1	0 - 20	2.89	0.96	0.05	0.03	3.94	0.01	3.89	0.39	4.34	90.89	9.11	32.12	42.40	12.03	3.08	10.37	25.48	5.80
	20 - 100	2.48	0.95	0.04	0.01	3.47	0.01	3.63	1.38	4.85	71.52	28.48	44.64	32.96	8.37	2.75	11.28	22.40	3.86
	100 - 200	4.17	2.70	0.07	0.09	7.03	0.01	3.52	3.07	10.11	69.59	30.41	53.65	30.08	5.18	1.47	9.62	16.27	1.93
H 5 A 3.1	0 - 20	5.07	1.83	0.12	0.63	7.64	0.02	4.95	0.04	7.68	99.48	0.52	4.58	39.20	10.75	10.26	35.21	56.22	14.01
H 5 A 3.2	0 - 20	4.40	1.66	0.02	0.18	6.26	0.00	4.41	0.23	6.49	96.40	3.60	38.04	42.13	4.44	3.19	12.20	19.83	12.56
	20 - 100	4.11	1.47	0.02	0.03	5.63	0.00	4.13	1.19	6.83	82.55	17.45	40.76	41.33	6.48	2.22	9.21	17.91	9.76
H 5 A 3.3	0 - 40	3.98	1.32	0.01	0.04	5.36	0.00	4.29	0.17	5.53	96.88	3.12	27.67	36.37	17.78	5.41	12.77	35.96	4.35
H 5 A 3.4	0 - 20	5.63	2.30	0.05	0.27	8.25	0.01	4.54	0.10	8.34	98.86	1.14	33.49	28.76	11.65	6.14	19.96	37.75	10.43
H 5.6	0 - 20	4.72	2.73	0.03	0.07	7.55	0.00	4.10	0.50	8.04	93.83	6.17	43.06	44.74	1.30	0.92	9.98	12.20	7.83
	20 - 200	5.47	1.27	0.04	0.05	6.83	0.01	3.88	1.35	8.18	83.44	16.56	38.38	35.54	5.11	3.67	17.30	26.08	6.99
H 5.7	0 - 30	7.10	2.56	0.02	0.45	10.13	0.00	4.55	0.26	10.39	97.48	2.52	37.79	36.02	5.13	2.52	18.55	26.20	6.96
	30 - 90	6.10	2.07	0.05	0.17	8.39	0.01	4.14	0.77	9.16	91.61	8.39	33.30	32.31	7.52	4.35	22.52	34.39	5.89
H 5.8	0 - 10	1.69	3.37	0.11	0.27	5.43	0.02	4.45	0.13	5.56	97.73	2.27	19.46	23.59	19.15	9.83	27.97	56.95	1.74
H 5.8 A	0 - 30	9.11	2.06	0.03	0.19	11.38	0.00	4.68	0.10	11.48	99.16	0.84	29.53	41.30	10.74	4.47	13.97	29.18	9.56
H 5.8 B	0 - 100	4.86	1.27	0.00	0.68	6.81	0.00	4.60	0.29	7.09	95.96	4.04	26.59	46.07	7.05	4.17	16.12	27.34	8.17
H 5.9	0 - 30	7.44	2.62	0.09	0.14	10.29	0.01	4.78	0.04	10.32	99.64	0.36	31.70	29.19	8.93	7.78	22.40	39.10	7.44

Table 4.9 Wetland S, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	munsell mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
S1	**0 - 30**	yes	F, H, O (Of, Om, Oh, Op)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
	30 - 100	yes	F, H, O (Of, Om, Oh, Op)	-	2.5 y 3/1	very dark grey	-	-	-	sat.	perm
S1.2	**0 - 150**	yes	O, Of, Op	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
S2	**0 - 20**	yes	F, H	-	7.5 yr 3/1	very dark grey	-	-	-	moist	perm
	20 - 80	yes	F, H	-	7.5 yr 3/2	dark brown	-	-	-	moist - sat.	temp.
	80 - 200 +	yes	F, H		7.5 yr 3/2 + 5 y 2.5/ 1 &2	dark brown	-	-	-	sat.	temp.
S3	**0 - 30**	yes	F, H	-	7.5 yr 3/2	dark brown	-	-	-	moist	temp.
	30-80	yes	F, H (v. little)	-	10 yr 3/2	very dark greyish brown	-	-	-	moist - sat.	temp.
	80-150	no	-	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
S4	**0 - 30**	yes	F, H, O- Op	-	10 yr 3/1	very dark grey	2.5 yr 3/6	dark red	many	sat.	seas.
	30 - 180	yes	F, H, O- Om, Oh, Op	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
S5	**0 - 200 +**	yes	F, H, O (Om - Oh)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
S6	**0 - 50**	yes	F, H, O- Om	-	10 yr 3/1	very dark grey	2.5 yr 4/4	reddish brown	common	sat.	seas.
	50 - 200+	yes	F, H, O- Op	-	10 yr 3/1	very dark grey	10 yr 6/8 (blotches / streaks)	brownish yellow	common	sat.	seas.
S7	**0 - 200 +**	yes	F, H, O- Op	-	10 yr 3/1	very dark grey	10 yr 5/6	yellowish brown	few	sat.	perm
S8	**0 - 30**	yes	F, H, O- Op	-	10 yr 3/2	very dark greyish brown	10 yr 5/8	yellowish brown	many	moist - sat.	seas.
	30 - 100	yes	F, H, O- Op (v. little)	-	10 yr 4/2	dark greyish brown	10 yr 5/8 (blotches)	yellowish brown	common	sat.	temp.
	100 - 200 +	yes	F, H, O- Op (n/s)	-	10 yr 4/3	brown	-	-	-	sat.	nw

Table 4.9 cont. Wetland S, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	munsell mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
S9	0 - 200 +	yes	F, H, O- Op	-	10 yr 3/1 + 10 yr 5/2	very dark grey ; greyish brown	-	-	-	sat.	perm / temp.
S10	0 - 30	yes	F, H, O- Op (n/s)	-	10 yr 2/1	black	-	-	-	sat.	perm
S11	0 - 40	yes	F, H, O- (n/s)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
	40 - 80	yes	F, H, O- (n/s)	-	10 yr 3/1	very dark grey	10 yr 5/8	yellowish brown	many	sat.	seas.
S12	0 - 40	yes	F, H, O- Op (n/)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
	40 - 100 +	yes	F, H, O- v. little	-	10 yr 5/1 + 10 yr 5/8	grey ; yellowish brown	-	-	-	sat.	perm / nw
S13	0 - 60	yes	F, H	-	7.5 yr 3/3	dark brown	-	-	-	moist	nw
S14	0 - 40	yes	F, H	-	7.5 yr 3/2	dark brown	-	-	-	dry - moist	temp.
S15.1	0 - 40	yes	F, H	-	7.5 yr 3/2	dark brown	-	-	-	sat.	temp.
	40 - 60	yes	F, H	-	5 yr 3/2	dark reddish brown	10 yr 5/8	yellowish brown	few	moist	temp.
	60 - 200 +	no	(n/s)	-	10 yr 5/3	brown	10 yr 5/8	yellowish brown	common	moist	perm
S15.2	0 - 50	yes	F, H, O- Om, Oh, Op	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
S15.3	0 - 100	yes	F, H	-	10 yr 4/3	brown	-	-	-	moist - sat.	nw
	100 - 150	no	(n/s)	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
S17	0 - 40	yes	F, H, O-Op (v. high)	-	10 yr 2/1	black	-	-	-	sat.	perm
	40 - 200 +	yes	F, H, O-Op (not as high 0 - 40)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
S18	0 - 40	yes	F, H	-	7.5 yr 3/2	dark brown	7.5 yr 5/6 (large)	strong brown	common	moist	seas.
	40 - 100 +	no	-	-	7.5 yr 3/2	dark brown	-	-	-	moist - sat.	temp.

Table 4.9 cont. Wetland S, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr. (wet)	munsell clr. description	mottling clr.	mottling clr.	mottling abundance	moist. status	hydroperiod
S19.1	**0 - 40**	yes	F, H	-	7.5 yr 3/2	dark brown	-	-	-	moist	temp.
	40 - 100	no	(n/s)	-	7.5 yr 3/3 ; 7.5 yr 3/4	dark brown	-	-	-	sat.	nw
	100 - 200 +	no	(n/s)	-	10 yr 3/2	very dark greyish brown	-	-	-	moist - sat.	temp.
S19.2	**0 - 40**	yes	F, H, O (n/c)	-	7.5 yr 3/2	dark brown	7.5 yr 5/8 + 7.5 yr 2.5/1	strong brown ; black	few	moist	temp.
	40 - 100	no	n/s	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
	100 - 200 +	no	n/s	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
S19.3	**0 - 40**	no	n/s	-	7.5 yr 3/2	dark brown	-	-	-	moist - sat.	temp.
	40 - 100	no	n/s	-	5 yr 3/2	dark reddish brown	-		-	sat.	temp.
	100 - 200 +	no	n/s	-	5 yr 3/2 + 10 yr 5/8 *	dark reddish brown ; yellowish brown	(blotches)	-	-	sat.	temp. - nw
S20	**0 - 40**	yes	F, H, O (n/c)	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp.
	40 - 100	no	n/s	-	10 yr 3/2	very dark greyish brown	5 yr 5/8	yellowish red	many	sat.	seas.
S21	**0 - 100**	yes	Of	-	10 yr 3/1	very dark grey		-	-	sat.	perm
	100 - 150	n/s	-	-	10 yr 4/2 ; 10 yr 4/1	dark greyish brown ; dark grey	-	-	-	sat.	perm
S22	**0 - 200 +**	yes	F, H, O (Om - Oh)	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm
S23	**0 - 100 +**	no (n/s)	-	-	5 yr 3/2	dark reddish brown	-	-	-	moist	temp.

Table 4.10 Wetland S, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
S1	**0 - 30**	3.39	0.94	0.09	0.16	4.58	0.02	3.89	4.85	9.42	48.57	51.43	32.93	53.22	2.64	0.83	10.38	13.85	6.47
	30 - 100	5.95	1.23	0.07	0.24	7.50	0.01	3.91	4.10	11.59	64.66	35.34	28.96	46.81	1.71	0.46	22.06	24.23	5.51
S1.2	**0 - 150**	4.05	1.37	0.06	0.12	5.59	0.01	4.07	1.93	7.53	74.31	25.69	27.59	50.22	1.06	3.50	17.63	22.19	4.48
S2	**0 - 20**	6.82	2.09	0.01	0.45	9.36	0.00	4.48	0.27	9.63	97.23	2.77	26.66	30.01	1.81	3.59	37.93	43.33	4.93
	20 - 80	6.18	2.11	0.02	0.23	8.53	0.00	4.49	0.28	8.81	96.81	3.19	23.31	31.71	0.64	3.47	40.87	44.98	2.51
	80 - 200 +	5.13	1.74	0.01	0.12	7.00	0.00	4.57	0.12	7.12	98.33	1.67	20.02	20.47	0.39	8.58	50.54	59.51	2.42
S3	**0 - 30**	6.52	1.93	0.01	0.16	8.62	0.00	4.70	0.07	8.69	99.24	0.76	16.00	21.19	1.26	13.57	47.99	62.82	1.84
	30-80	4.49	1.50	0.01	0.08	6.08	0.00	4.67	0.09	6.16	98.60	1.40	14.25	12.80	0.38	16.64	55.93	72.95	0.87
	80-150	4.52	1.60	0.01	0.03	6.16	0.00	4.72	0.15	6.31	97.68	2.32	19.02	8.30	0.58	14.80	57.30	72.68	1.06
S4	**0 - 30**	4.55	1.91	0.19	0.48	7.12	0.03	3.84	5.37	12.49	57.03	42.97	17.57	11.76	0.83	14.02	55.82	70.67	5.60
	30 - 180	4.04	1.68	0.08	0.05	5.85	0.01	3.81	3.46	9.31	62.79	37.21	32.43	53.02	2.78	0.41	11.36	14.55	8.31
S6	**0 - 50**	7.11	3.40	0.06	0.14	10.70	0.01	4.29	0.40	11.10	96.39	3.61	35.63	43.34	0.93	0.84	19.26	21.03	3.03
	50 - 200 +	5.16	2.40	0.02	0.17	7.75	0.00	4.41	0.26	8.01	96.74	3.26	37.22	36.95	0.39	1.86	23.58	25.83	1.55
S7	**0 - 200 +**	3.25	1.10	0.02	0.03	4.41	0.00	3.60	3.84	8.25	53.43	46.57	36.38	40.17	0.61	0.29	22.55	23.45	2.99
S8	**0 - 30**	6.54	4.60	0.03	0.10	11.27	0.00	4.18	1.35	12.62	89.27	10.73	43.94	42.18	1.61	1.20	11.07	13.88	4.64
	30 - 100	5.95	4.38	0.01	0.19	10.53	0.00	4.30	0.42	10.95	96.15	3.85	42.74	39.63	1.89	1.92	13.82	17.63	1.93
	100 - 200 +	6.40	5.51	0.02	0.17	12.10	0.00	4.84	0.08	12.17	99.37	0.63	32.46	45.62	1.42	1.67	18.83	21.92	0.87
S9	**0 - 200 +**	1.98	0.91	0.00	0.06	2.95	0.00	3.61	7.02	9.97	29.55	70.45	42.86	38.61	1.08	0.87	16.58	18.53	4.83
S10	**0 - 30**	1.93	0.58	0.05	0.01	2.57	0.02	3.74	5.70	8.27	31.04	68.96	53.80	36.77	1.30	0.41	7.72	9.43	6.67
	30 - 140	2.85	1.27	0.03	0.02	4.18	0.01	3.40	7.30	11.48	36.38	63.62	51.02	34.16	0.93	1.35	12.55	14.83	4.15

Table 4.10 cont. Wetland S, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH_ (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
S11	0 - 40	2.62	1.32	0.08	0.24	4.26	0.02	3.99	3.46	7.72	55.14	44.86	46.40	25.66	3.31	5.07	19.56	27.94	5.31
	40 - 80	1.35	0.59	0.01	0.01	1.96	0.01	3.79	5.61	7.58	25.93	74.07	27.41	30.09	4.57	7.60	30.34	42.51	1.35
S12	0 - 40	3.35	2.09	0.06	0.06	5.56	0.01	3.46	8.16	13.72	40.52	59.48	46.01	35.91	2.42	2.77	12.89	18.08	2.32
	40 - 100 +	6.34	4.97	0.08	0.15	11.54	0.01	3.52	7.25	18.78	61.42	38.58	56.69	27.75	2.24	1.70	11.62	15.56	2.32
S15.1	0 - 40	7.59	2.78	0.02	0.86	11.25	0.00	4.75	0.04	11.29	99.63	0.37	27.21	33.73	1.02	2.51	35.53	39.06	4.73
	40 - 60	6.84	3.50	0.04	0.35	10.72	0.00	4.37	0.37	11.09	96.65	3.35	30.32	31.34	0.89	2.28	35.17	38.34	3.48
	60 - 200 +	5.30	3.46	0.02	0.18	8.97	0.00	4.44	0.21	9.18	97.70	2.30	27.08	30.10	0.32	2.34	40.16	42.82	2.69
S15.2	0 - 50	3.71	1.14	0.03	0.13	5.02	0.01	3.88	2.98	7.99	62.77	37.23	30.41	56.52	1.42	0.67	10.98	13.07	6.96
S15.3	0 - 100	4.98	1.57	0.06	0.24	6.85	0.01	4.70	0.08	6.93	98.90	1.10	12.07	15.15	5.36	21.50	45.93	72.78	1.93
S16	0 - 150	3.83	0.86	0.03	0.54	5.26	0.01	4.17	1.18	6.44	81.66	18.34	20.03	22.99	3.64	34.48	18.85	56.97	39.90
S17	0 - 40	3.95	1.66	0.09	0.54	6.24	0.01	4.07	2.13	8.36	74.58	25.42	27.04	47.92	1.26	0.86	22.92	25.04	4.66
	40 - 200 +	3.98	2.49	0.03	0.37	6.88	0.00	4.14	0.22	7.09	96.92	3.08	30.84	37.40	0.66	2.71	28.39	31.76	3.15
S18	0 - 40	6.07	2.46	0.00	0.18	8.71	0.00	4.19	0.19	8.90	97.81	2.19	27.04	32.28	0.23	2.07	38.38	40.68	2.90
	40 - 100 +	5.53	2.63	0.02	0.14	8.32	0.00	4.31	0.24	8.56	97.22	2.78	17.91	14.30	0.16	8.43	59.20	67.79	2.18
S19.1	0 - 40	7.00	2.31	0.01	0.37	9.69	0.00	4.63	0.04	9.73	99.63	0.37	23.07	25.81	0.71	4.41	46.00	51.12	3.48
	40 - 100	6.11	2.05	0.05	2.45	10.65	0.00	4.64	0.03	10.68	99.71	0.29	13.37	19.84	0.46	8.32	58.01	66.79	2.90
	100 - 200 +	4.81	1.88	0.01	0.09	6.79	0.00	4.76	0.01	6.80	99.85	0.15	8.60	19.84	0.10	9.69	61.77	71.56	1.16
S19.2	0 - 40	8.33	2.59	0.01	0.52	11.45	0.00	4.65	0.05	11.49	99.59	0.41	31.31	39.63	0.27	0.95	27.84	29.06	4.54
	40 - 100	7.72	2.47	0.01	0.25	10.44	0.00	4.54	0.08	10.53	99.20	0.80	25.89	47.05	0.29	0.48	26.29	27.06	3.96
	100 - 200 +	5.18	1.68	0.03	0.01	6.89	0.00	4.32	0.22	7.11	96.92	3.08	13.87	28.74	0.56	9.33	47.50	57.39	2.42

Table 4.10 cont. Wetland S, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH_ (KCL)	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
S19.3	**0 - 40**	5.41	1.35	0.01	0.31	7.09	0.00	4.40	0.14	7.23	98.05	1.95	15.60	27.57	0.61	8.23	47.99	56.83	3.19
	40 - 100	4.59	1.12	0.01	0.04	5.75	0.00	4.58	0.04	5.80	99.25	0.75	14.60	16.48	1.59	20.09	47.24	68.92	1.45
	100 - 200 +	3.51	0.83	0.01	0.01	4.36	0.00	4.40	0.13	4.49	97.02	2.98	12.48	13.18	6.54	25.65	42.15	74.34	1.06
S20	**0 - 40**	5.31	2.74	0.04	0.13	8.22	0.01	4.19	0.58	8.81	93.37	6.63	33.88	50.41	0.50	2.74	12.47	15.71	5.60
	40 - 100	6.04	3.77	0.04	0.11	9.96	0.00	4.23	0.40	10.36	96.18	3.82	35.17	48.14	0.32	0.13	16.24	16.69	4.15
S21	**0 - 100**	2.45	1.11	0.36	0.15	4.07	0.09	3.88	3.54	7.61	53.53	46.47	46.56	38.24	0.55	0.65	14.00	15.20	3.73
	100 - 150	3.54	2.02	0.37	0.19	6.12	0.06	3.75	5.13	11.25	54.43	45.57	54.46	29.59	0.25	0.55	15.15	15.95	3.02
S22	**0 - 200 +**	3.49	1.19	0.40	0.18	5.26	0.08	3.65	4.87	10.13	51.90	48.10	31.19	43.96	2.00	2.60	20.25	24.85	8.85
S23	**0 - 100 +**	7.53	2.16	0.26	0.28	10.24	0.03	4.67	1.26	11.50	89.02	10.98	21.98	51.52	0.20	0.60	25.70	26.50	4.63

Table 4.11 Wetland T1, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr (wet)	munsell clr (wet)	munsell mottling clr.	mottling clr.	mottling abundance	moisture status	hydroperiod
T1	0-20	-	-	- (CaCO$_3$ nodules)	10 yr 3/1	very dark grey	2.5 yr 4/8	red	common - many	sat.	seas.

Table 4.12 Wetland T1, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH_KCL	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F. SAND	% TOT SAND	% O/C
T1	0 - 20	2.03	0.40	0.49	0.48	3.40	0.14	4.26	1.74	5.13	66.17	33.83	11.55	42.50	2.60	9.40	33.95	45.95	7.013

Table 4.13 Wetland T2, field data sheet

SITE NO.	DEPTH	litter layers present	organic horizons	stoniness	munsell clr (wet)	munsell clr (wet)	munsell mottling clr.	mottling clr.	mottling abundance	moisture status	hydroperiod
T2 O	0 - 100	n/s	-	-	10 yr 3/1	very dark grey	-	-	-	moist	perm.
T2 1.1	0 - 20	no	-	-	10 yr 5/6	yellowish brown	-	-	-	sat.	nw
	20 - 40	yes	Om	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
	40 - 200	yes	Om	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
T2 1.2	0 - 100	yes	Of	-	10 yr 3/1	very dark grey	-	-	-	sat.	perm.
	100 - 200	yes (n/s)	F	-	10 yr 3/2	very dark greyish brown	-	-	-	sat.	temp
T2 1.3	0 - 100	yes	F, H, O (Om-Oh)	-	10 yr 2/1	black	-	-	-	sat.	perm.
	100 - 200	n/s	-	-	10 yr 2/1	black	-	-	-	sat.	perm.

Table 4.14 Wetland T2, Laboratory results

SITE NO.	DEPTH	Ca	Mg	Na	K	CEC	ESP	pH_KCL	EXCH. ACIDITY	S-VALUE	BASE SATN %	ACID SATN %	% CLAY	% SILT	% C. SAND	% M. SAND	% F SAND	% TOT SAND	% O/C
T21.0	0 - 100	1.24	0.46	0.36	0.54	2.60	0.14	4.11	51.66	54.26	4.79	95.21	22.61	43.49	2.80	6.80	24.30	33.90	9.27
T2 1.1	0 - 20	1.31	0.44	0.23	0.70	2.68	0.09	3.92	6.04	8.71	30.71	69.29	26.62	57.48	1.10	2.30	12.50	15.90	7.25
	20 - 40	1.47	0.54	0.25	0.76	3.01	0.08	3.89	5.61	8.62	34.92	65.08	23.40	59.25	1.40	3.05	12.90	17.35	9.27
	40 - 200	1.32	0.56	0.28	0.48	2.63	0.11	3.82	89.24	91.87	2.87	97.13	34.59	47.36	3.30	4.30	10.45	18.05	10.08
T2 1.2	0 - 100	1.97	0.57	0.28	0.60	3.42	0.08	3.98	2.65	6.07	56.35	43.65	32.89	42.66	1.55	5.45	17.45	24.45	18.94
T2 1.3	0 - 100	2.03	0.59	0.39	0.49	3.50	0.11	3.74	7.12	10.62	32.96	67.04	28.29	45.26	3.25	4.85	18.35	26.45	9.75
	100 - 200	1.82	0.63	0.25	0.34	3.04	0.08	3.70	73.52	76.56	3.97	96.03	31.96	36.49	4.70	8.95	17.90	31.55	4.23