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Geomorphic attributes of palustrine wetlands in the upper Boesmans river catchment, KwaZulu-Natal.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

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ABSTRACT

Title of dissertation : Geomorphic attributes of palustrine wetlands in the upper Boesmans river catchment, KwaZulu-Natal.

by

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Degree : Magister Artim

Wetlands within South Africa are an important source of water and nutrients necessary for biological productivity and often the survival of the local people. In a country where the rural communities depend on wetlands for their day to day provision of water, food and materials it has become necessary to understand the functions within wetland systems, so that proper conservation measures can be applied in order to protect and ensure the sustainable use of wetlands. Due to the fact that South Africa has a semi arid climate, thereby affecting the availability of water it is sensible that studies are under-taken in which, more is explored about the water resources, the protection as well as the sustainable use of the wetlands within the region. Despite the fact that the total area which wetlands cover in South Africa is relatively small, the functions which they provide is of fundamental magnitude not only to wildlife but also as an essential part of the human life support system.

Wetlands have the ability to regulate regional flow regimes and are often situated in areas of impeded drainage, which may contribute to the regulation of water. It is thus plausible that if headwater/palustrine wetlands are destroyed, many of the streams and rivers which under normal circumstance are perennial, would not only become non-perennial but the consequence of a drought would be far more severe, as well as increasing the risk in flood damage further down the river.

In Giants Castle Game Reserve, situated in the KwaZulu-Natal Drakensberg, several palustrine wetlands where studied to identify the geomorphic attributes which contribute to the origin and maintenance of these wetlands. An added motive for the study was the fact that, according to Ramsar, one of the reasons for conserving the Drakensberg wetlands is to ensure the maintenance and production of water quality to KwaZulu-Natal. Seven wetlands within the Boesmans river upper catchment were identified and studied.

Soil investigations were undertaken in an effort to determine the driving forces behind the origin and maintenance, as well as to improve the understanding relating to the functioning of the wetlands. The geomorphic attributes which were identified as being important to the genesis and maintenance of wetlands were found to be the following: low relief, soil piping within wetlands, sediment trapping ability of wetlands, the surface roughness of wetlands, channeling within wetlands, organic matter accumulation as well as geological barriers within wetland system. The adaptability of Longmore's (2001) Hydro-Geomorphic classification to different catchment areas was also tested and was found suitable for these wetlands, although the influence of piping on wetlands evidently requires further investigation and incorporation into classifications.

<u>Keywords</u>: Palustrine wetlands
Geomorphic attributes
Giants Castle Game Reserve
KwaZulu-Natal Drakensberg
Water storage
Sediment traps
Wetland classification
Water purification
Wetland vegetation
Low flow

Chapter 1: Introduction

Wetlands systems have the ability to regulate regional flow regimes and are often situated in areas of impeded drainage, which may contribute to the regulation of water. This ability is best explained by Mitsch and Gosselink (2000, p.584) in that wetlands intercept storm water and store the flood waters, "thereby changing the sharp runoff peaks to slower discharge over longer periods of time"**.** It is thus plausible that if headwater/palustrine wetlands are destroyed, many of the streams and rivers which under normal circumstance are perennial, would not only become non-perennial but the consequence of a drought would be far more severe (Breen and Begg, 1987), as well as increasing the risk of flood damage (Mitsch and Gosselink, 2000). Wetlands within the KwaZulu-Natal Drakensberg are important despite that they form only a small percentage of land area; no wetlands is small enough to be regarded as insignificant. It is important for the conservation and management of wetlands that as much information is collected with the use of wetland inventories (Finlayson and van der Valk, 1995). According to Ramsar one of the reasons for conserving the Drakensberg wetlands is to ensure the maintenance and production of quality water (Ramsar information sheet, 2006).

Due to the fact that South Africa has a semi arid climate, thereby affecting the water resources (availability of water), it is sensible that studies are undertaken in which more is explored about the available water resources within the region. Since wetlands are known for their water holding abilities, the conception or genesis and maintenance of such systems are of vital importance (Longmore, 2001). Despite the fact that the total area which wetlands cover in South Africa is relatively small, the functions which they provide are of fundamental magnitude not only to wildlife but also as a essential part of the human life support system (Zaloumis, 1987). Wetlands within South Africa are an important source of water and nutrients necessary for biological productivity and often also the survival of the local people (Thompson, 1996; Schuyt, 2005). It is only through the understanding of functions within wetland systems, that proper conservation measures can be applied in order to protect and ensure the sustainable use of wetlands.

Wetland related studies are not a new field and have been under investigation for a number of years (Cowardin, 1979; Brinson, 1993; Lyon, 1993; Finlayson and van der Valk, 1995; Kotze, 1996a; Acreman, 2000; Mitsch and Gosselink, 2000). It is however only in the last few years that there has been an upsurge within the field of wetland geomorphology. To better understand the functions and values of wetlands it is important to have a firm understanding of the different wetland definitions which are available to the researcher.

1. Literature Review

With the wide variety of definitions available it is necessary to narrow down the definitions to those that are directly applicable to the study. A number of relevant definitions are listed below, and briefly explained.

1.1. Definitions

There are a vast number of wetland definitions in the international literature, which emphasises the fact that there is a wide range of conditions that may constitute wetlands (Longmore, 2001). Despite variations in definitions the consensus is that wetlands are water dominated areas that have impeded drainage where soils are saturated with water for at least part of the growing season, as well as the characteristic assemblages of flora and fauna (Finlayson and van der Valk, 1995; Gaigher, 1985).

Since South Africa is a contracting member to the Ramsar Convention, and that the Convention plays a very important role in the protection of wetlands, it is only fitting to use the Ramsar Conventions definition of wetlands. The Ramsar Convention on wetlands (Ramsar, 1971, Article 1.1 in Ramsar, 2006) defines wetlands as: “areas of marsh, fen, peatland or water natural or artificial, permanent or temporary, with water that is static or flowing, brackish or salt, including areas of marine water the depth of which does not exceed six meters" and "may also include adjacent riparian and coastal zones" Article 2.1, provides that wetlands: "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetland"

Under the above definition all wetlands inland as well as coastal, have been grouped. The Ramsar definition is broad and suited to its purpose as an international definition. Another uncomplicated way to describe a wetland is the definition given by Kotze (1996a) in WETLANDS-USE: wetlands are areas which are transitional between terrestrial and aquatic systems. Areas in which the soil is flooded or saturated at or close the surface for part of the growing season or long enough for anaerobic conditions to develop. Thus wetlands can be defined using hydrology, hydrophytic vegetation and hydric soil. Wetlands may be permanently, seasonally or temporarily saturated. Herewith a short definition of each of the wetlands indicators is given to provide clarity. (The three indicators will be explained in greater detail later in the chapter.)

- Hydrology: the occurrence and movement of water on land (Anon., 1987)
- Hydrophytic Vegetation: can be defined as macrophytic plants which grow in water, soil or on a substrate which is at least periodically deficient in oxygen due to excessive water content. (Federal Interagency Committee of Wetland Delineation, 1989)
- Hydric soil: can be defined as soils that are ponded, saturated or flooded long enough during the growing season so the anaerobic condition can form in the upper reaches of the soil profile (Kotze, 1996a).

It is necessary to narrow down the definitions to inland wetlands and again to Palustrine wetlands which will be under discussion in this document. Cowardin et al. (1979) devised a classification system (for the USA) in which five wetland systems are identified, namely; Marine, Estuarine, Riverine, Lacustrine, and Palustrine. Cowardins' classification is based on a hierarchy which progresses from Systems, Subsystems, Classes, Subclasses, Dominance Types and Special Modifiers which define the wetland precisely. Within this classification the Palustrine Systems is the only system which does not have a Subsystem.

Inland wetland systems are, Riverine, Lacustrine and Palustrine, and defined according to Cowardin et al. (1979, p. 7.) as follows:

- Riverine: "includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in the excess of 0.5ppt." The Riverine system can be further divided into Subsystems, Classes, Subclasses, Dominance Types and Special Modifiers.
- Lacustrine: "includes wetland and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses, or lichens with greater than 30% aerial coverage; and (3) total area exceeds 8 ha. Similar wetland and deepwater habitats totalling less than 8 ha are also included in this system if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2m at low tide. Lacustrine water may be tidal or nontidal, but ocean-derived salinity is always less than 0.5ppt." The Lacustrine system can be further divided into Subsystems, Classes, Subclasses, Dominance Types and Special Modifiers.
- Palustrine: "all non-tidal wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and all such wetlands that occur in the tidal areas where salinity stemming form ocean-derived salts is below 0.5ppt. It also includes wetlands lacking such vegetation but with all of the four following characteristics: (1) area less then 8 ha; (2) lack of active wave-formed or bedrock shoreline features; (3) water depth in the deepest part of the basin less then 2m at low water; and (4) salinity stemming from ocean-derived salts less then 0.5ppt". The Palustrine system can be further divided into, Classes, Subclasses, Dominance Types and Special Modifiers.

Dini and Cowan's (2000) classification is based on Cowardin et al. (1979) and differences between the three inland wetland definitions are:

- Riverine: Emergent habitats have been removed from the Riverine system.
- Lacustrine: Emergent habitats have been removed from the lacustrine system.
- Palustrine: Dini divided the Palustrine system into six Subsystems, on the basis of host landform on which the wetlands are situated. This was done due to the fact that the majority of South Africa's wetlands have a palustrine nature and that valuable information would be lost by not distinguishing the System into more finely resolved Subsystems.

Although there are many different definitions for palustrine wetlands this study utilises the above definitions since they are at present the most widely used and accepted definitions, used and accepted by the Mondi Wetlands Project and the National Wetland Indaba (previously know as the South African Wetland Action Group).

1.2 Wetland geomorphology

1.2.1 Geomorphic Processes

Wetlands are intricately linked to other elements of the landscape as well as their landscape forming processes. Process can be defined in geomorphological terms as the action produced when a force induces a change, be it chemical or physical, in the materials or forms at or near the earth surface (Ritter, 1986). It is suggested by Ritter (1986) that landscape forms will maintain their character as long as there is no change in the fundamental controls of that landscape. Each ecosystem has a different set of equilibrium limits and when these limits are exceeded, the ecosystem is temporarily in disequilibrium and a major response may occur. The system is thus forced to find a new equilibrium (e.g. sedimentation/gully erosion in a wetland due to a large flood the system will try to erode back to the previous base level) deposition and erosion. Therefore, it may be stated that landscapes are in constant adjustment to the new forces or resistance controls in an attempt to establish the new equilibrium (Ritter, 1986; Federal Interagency Stream Restoration Working Group, 1998). Wetlands are sustained by the flow of materials and energy through the system and the transformation which may occur during this flow of materials. Interactions of energy and material produce weathering, erosion, transport and deposition of material, which are the four fundamental processes in landscape development (Ritter, 1986; Smith and Pizalotto, 2000). A short explanation of each of the geomorphic processes follows.

1.2.1.1 Weathering

Due to the fact that many rock formations form under pressure and temperatures that are very different from surface condition, they are unstable and subject to alteration once exposed. The degree and intensity of the weathering is a function of climate, topography and time. Most weathering takes place in the shallow subsurface and results from interaction between rock and groundwater (Smith and Pizalotto, 2000). Weathering of rock may occur in one of three ways; mechanical, biological or chemical (Smith and Pizalotto, 2000). It is not within the scope of the document to go into detail about weathering process, more detailed information regarding the above may be found in Ritter (1986).

1.2.1.2 Erosion

The current hypothesis on erosion is that erosion is initiated when the force of water flowing over an area is greater that the critical soil shear stress, allowing scouring or tunnelling to take place (Dietrich et al., 1993). Added to the above, areas with a mean annual rainfall in the range 600-800 mm are particularly vulnerable because of the impact of highly variable rainfall on surface area (Beavis, 2000). Rainsplash, as well as runoff energy are active erosive agents and they may produce five more or less distinct sub-processes namely: splash erosion, sheetwash, rainflow, rill erosion and piping or tunnel erosion (Bryan, 2000). Each one can act in isolation, but all are active on hillslopes, either sequentially or simultaneously.

Also of paramount importance in soil erosion is water movement into, through and over the soil, which encompasses infiltration, percolation and retention. These factors are mainly controlled by the volume, size, distribution and continuity of pore space, and thus the geometric arrangement of textural particles and aggregates (Bryan, 2000). Properties which determine erodibility such as soil shear strength and aggregation, are strongly affected by climatic factors, rainfall distribution and frost action, and show systematic seasonal variation (Smith and Pizalotto, 2000; Bryan, 2000). The properties may also change significantly over short time scales with subtle variation in soil water conditions, organic composition, microbiological activity, age hardening and the structural effect of applied stresses to the soils. It must be noted that these properties change between and during storms and this can dramatically affect the incidence as well as the intensity of rill and interrill erosion and therefore both the short and long-term hillslope erosional responses (Bryan, 2000).

A new theory relating to erosion has come to the forefront it is the relationship which the underlying geology has on erosion. As stated by Beavis (2000) it is a complex relationship and is described as the structure (of the underlying geology) determining the location of erosion within the landscape, with lithology and texture, through controlling mineralogy and particle size, determining the severity of erosion. For an in-depth discussion relating to erosion processes see, Bryan (2000), Beavis (2000), and Dardis and Moon (1988).

1.2.1.3 Transport

Sediment may be transported by wind, water, or by force of gravity. For the vast majority of sediment, water is the principal transport medium (Smith and Pizalotto, 2000). Sediment which is transported by water can be subdivided into dissolved, suspended, and bed load. Dissolved load includes all ions of weathered material; suspended load is fine material in the main body of flow which is kept suspended by the upward momentum in turbulent eddies; bed load is coarse material that moves by rolling or sliding along the bed of a stream (Smith and Pizalotto, 2000).

1.2.1.4 Deposition

As with erosion and transport, deposition is largely controlled by water velocity. Therefore, any surface area in a watershed where overland and channel flow is slowed down is a potential site for deposition. Thus is can be said that deposition is enhanced by low slopes, dense vegetation, and broad, rough shallow water areas (wetlands) (Smith and Pizalotto, 2000). Sediment storage in an area may be temporary or long term, temporary storage components of a landscape are controlled by intensity, duration, frequency, as well as timing of rainstorms, and rapid snow melt. Long-term storage is determined by the subsidence history of an area, subsidence may be caused by neotectonism, sediment compaction or ground water pumping (Smith and Pizalotto, 2000). Within wetlands there are three forms of deposition namely: clastic sedimentation, organic matter accumulation and chemical sedimentation.

- Clastic sediment deposition takes place in wetlands in areas where there is a reduction in the capacity of a stream to carry its load (Kotze, 2001). Deposition usually occurs in the upper reaches of the wetland. Depositional features which can be identified with clastic depositions are; valley fills, alluvial fans, floodplains and deltas (Kotze, 2001).
- Organic matter accumulation: organic sedimentation transpires as peat formations or organic matter accumulation in wetland soils. This type of sedimentation usually occurs in the middle reaches of large wetland systems where there is little clastic sedimentation, but where there is prolonged flooding. The process leads to infilling of basins, decreasing the gradient of the stream in an upstream direction, and increasing its gradient in the downstream area (Kotze, 2001).
- Chemical sedimentation: Chemical sedimentation occurs in the following way, chemicals in solution are introduced into wetlands through streams, as part of the overall sediment load. Due to the fact that transpiration is the dominant means of water loss within a wetland, the chemical sediments are deposited. Therefore, the surface water and its solute load are drawn down into the root zone. Not all solutes are taken up by the plants thus they

saturate chemically and precipitate out of solution, accumulating in the soil. Thereby increasing the volume of the soil, leading mainly to the vertical expansion and therefore lowering of the gradient in the upstream wetland area (Kotze, 2001). The processes described above are predominant in the lower reaches of a wetland system (Kotze, 2001).

Kotze (2001, p.37) best explains the relationship of the three forms of sedimentation within a wetland. ‘These three forms of sedimentation are interrelated in a feedback system such that overall gradient is likely to be maintained within a wetlands system for prolonged periods. Thus excessive clastic sedimentation to the apex of a wetland will steepen the gradient in a downstream direction, leading to increased flooding of distal reaches of a wetlands, giving rise to increased peat formation and chemical sedimentation in the middle and distal reaches respectively, thus maintaining gradient overall.’ However, if the gradient downstream becomes too low, the organic deposits may subside and chemical sedimentation may take place in more proximal reaches, so that the overall gradient of the wetlands is maintained in the long-term (Kotze et al., 2001).

It is through the constant erosion and deposition that new landscapes are created or lost (Kotze, 2001). Thus with a better understanding of geomorphic processes which operate within a landscape the geomorphic settings of wetlands can be discussed.

An overview of the types of processes which may occur within a wetlands system is outlined in Table 1.1 as adapted from Longmore (2001). Several processes may have a greater effect on internal and structural conditions in one wetland in contrast to another. The summary of processes within Table 1.1. is broad but may not be a comprehensive overview of all the processes which may occur within a wetland system.

Subsequently, such parameters as watershed size, position of the wetland in the watershed, the shape and form of the watershed, and local climate influence the capacity of wetlands to provide specific functions (Smith and Pizalotto, 2000) which are governed by the geomorphic setting of the wetland.

HYDROLOGICAL PROCESSES	Ctgry	BRIEF DEFINITIONS
infiltration	1	Water enters the surface horizon of the soil. Controlled by, intensity of precipitation, soil surface porosity and cracks.
groundwater discharge	1	The lateral movement of groundwater to the ground surface.
sedimentation	1	Deposition of sediment by water or wind into an area.
enrichment	1	General term for the addition of material to a soil body.
littering	1	The accumulation of undecomposed plant and animal material on the soil surface.
accretion	1	Vertical accumulation of sediments or organic matter.
interflow	1,2	Lateral movement of water beneath the surface, has a greater lag time then throughflow.
overland flow	1,2	Nonchannelized sheet flow that usually occurs during and immediately following a rainfall event.
evaporation	2	The return of water vapour to the atmosphere by evaporation from land, water and transpiration of vegetation.
groundwater recharge	2	Water flowing from the soil to the water table.
surficial soil erosion	2	Removal of material from the surface layer of a soil.
leaching	2	General term for the washing out of soluble materials from the solum.
elluviation	2	Movement of material out of a portion of the soil profile.
capillarity	3	Rise of moisture to the soil surface. This process takes place sporadically in all but waterlogged soils.
illuviation	3	Movement of material into a portion of the soil profile (as in the argillic or spodic horizon).
dealkalization	3	Leaching of sodium ions and salts from natric horizons.
lessivage	3	Mechanical migration of small mineral particles from the A to B horizons of a soil, producing in B horizons relative enrichment in clay (argillic horizons).
pedoturbation	3	Biologic, physical churning and cycling of soil materials, thereby homogenizing the solum in varying degrees
melanization	3	Darkening of light-coloured mineral initial unconsolidated materials by admixture of organic matter (as in dark A1 or mollic of umbric horizons).
near surface flow	1,2,3	Flow that is not visible - just below the surface. Occurs in the rhizophere where hydraulic permeability is high
slumping	1,3	Movement of a mass of earth downslope under the influence of gravity.
channel incision	4	Downward cutting of channel floor by flowing water.
swelling, shrinkage & cracking	4	Processes arising from moisture content changes and the changes in soil properties; expansion, contraction and deformation.
redox depletion	4	Bodies of low chroma where the natural colour of the parent sand, silt, or clay results when soluble forms of iron, manganese or clay are leached out of the soil.
decomposition	4	The breakdown of dead organic matter into simpler substances.
humification	4	The transformation of raw organic material into humus.
paludization	4	Accumulation of more than 30cm deposits of organic mater.
ripening	4	Chemical, biological and physical changes in organic matter after air penetrates previously waterlogged soils.
mineralization	4	Release of oxide solids through the decomposition of organic matter.
gleization	4	A process in saturated or nearly saturated soils which involves the reduction of iron, its segregation into mottles and concretions, or its removal by leaching from the gleyed horizon.
subsurface erosion	2,4	Removal of material from the subsurface soil layers.
soil piping	2,4	Removal of material from the subsurface layer of a soil, resulting in the formation of a subsurface channel.

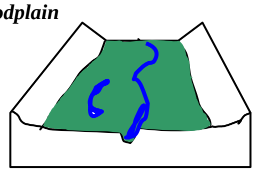
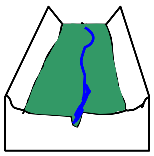
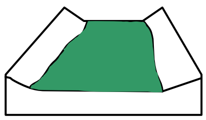
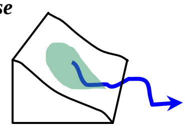
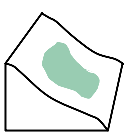
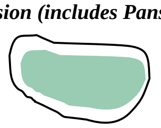
Table 1.1: An overview of characteristic processes operative within wetland systems, adapted from Longmore 2001. (The processes have been ranked into various categories, which is abbreviated as 'Ctgry' in the table. The categories are as follows: 1. Additions to the wetland soil body; 2. Losses from the wetland soil body; 3. Translocation within the wetland soil body; 4. Chemical or physical transformation of material within the wetland soil body.)

1.2.2 Geomorphic Setting

The geomorphic setting of a wetland plays a role not only in the formation of the wetlands but also on the persistence of the wetland in the setting. Semeniuk and Semeniuk (1995) identified five landforms that may determine the occurrence of wetlands: basins, channels, flats, slopes and highlands or hills. Semeniuk and Semeniuk (1995) state that landforms are the 'containers', or 'host' to wetlands. The landform determines the size and shape of wetlands, as well as the depth (pertaining to basins).Within the South African context, Kotze et al. (2005) has identified six geomorphic types: floodplain, valley bottom with a channel, valley bottom without a channel, hillslope seepage feeding a watercourse, hillslope seepage not feeding a watercourse, and depressions (Table 1.2). Ellery et al (2005) adapted their geomorphic types from Kotze (1999) and Brinson, 1993. The landform settings are as follows: hillslope seepage not feeding a stream, hillslope seepage feeding a stream, valley bottom without a stream, valley bottom with a stream, floodplain, pan/depression and fringe wetlands.

The influence which geomorphic setting has on wetlands is discussed below. Wetlands which are situated in the upper portions of large watersheds generally have less area draining into them but are subject to intense runoff events associated with storms (Smith and Pizalotto, 2000). Under such conditions there is a tendency for wetlands to have variable water levels as well as irregular hydroperiods. The size of the watershed also influences the sediment yield of that watershed (Smith and Pizalotto, 2000). Thus it is important to have numerous functioning wetlands in the upper and middle reaches of large watersheds so as to act as sediment traps.

Morphology of the watershed firmly influences the hydrology and biology of the landscape. Therefore the basin relief plays an important role as a hydrologic parameter. As stated by Smith and Pizalotto (2000) with the increase in relief, steeper hillslopes and higher stream gradients, the ratio of runoff to infiltration increases and time of concentration of runoff decrease, in thus increasing flood peaks.

Hydrogeomorphic types	Description	Source of water maintaining the wetland[1]	
		Surface	Sub-surface
Floodplain 	Valley bottom areas with a well defined stream channel, gently sloped and characterized by floodplain features such as oxbow depressions and natural levees and the alluvial (by water) transport and deposition of sediment, usually leading to a net accumulation of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.	***	*
Valley bottom with a channel 	Valley bottom areas with a well defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterized by the net accumulation of alluvial deposits or may have steeper slopes and be characterized by the net loss of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.	***	*/ ***
Valley bottom without a channel 	Valley bottom areas with no clearly defined stream channel, usually gently sloped and characterized by alluvial sediment deposition, generally leading to a net accumulation of sediment. Water inputs mainly from channel entering the wetland and also from adjacent slopes.	***	*/ ***
Hillslope seepage feeding a watercourse 	Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs are mainly from sub-surface flow and outflow is usually via a well defined stream channel connecting the area directly to a watercourse.	*	***
Hillslope seepage not feeding a watercourse 	Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from sub-surface flow and outflow either very limited or through diffuse sub-surface and/or surface flow but with no direct surface water connection to a watercourse.	*	***
Depression (includes Pans) 	A basin shaped area with a closed elevation contour that allows for the accumulation of surface water (i.e. it is inward draining). It may also receive sub-surface water. An outlet is usually absent.	*/ ***	*/ ***

[1] Precipitation is an important water source and evapotranspiration an important output in all of the above settings

Water source:

Water source:	*	Contribution usually small
	***	Contribution usually large
	*/ ***	Contribution may be small or important depending on the local circumstances

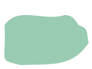
 Wetland

Table 1.2: Wetland hydrogeomorphic types which typically support inland wetlands in South Africa (Kotze et al., 2005).

The geomorphology of wetlands strongly influences the following wetland aspects: the local patterns of water movement (surface and sub-surface) and the degree to which wetlands are open to lateral water exchanges namely; sediments, nutrient and pollutants (Bedford and Preston, 1988; Kotze, 1999). As previously stated wetlands have a set of indicators which can be used to identify possible wetlands, namely hydrology, hydrophytic vegetation, as well as hydric soils. Each of which will be explained in greater detail in the following sections.

1.3 Wetland Hydrology

The hydrological processes which occur within wetlands are the same as those which occur on the surrounding areas and are referred to as hydrologic cycles (Carter, 1997). The hydrologic cycle describes the continuous transfer of water from the atmosphere in the form of precipitation to surface water and to ground water, then to storage and runoff, and eventually back to the atmosphere through transpiration and evaporation (Stream Corridor Restoration, 1998) and thus starting the cycle again. Once precipitation reaches the earth it may follow one of three 'pathways' namely; it may return to the atmosphere; penetrate the soil surface; or become run-off into streams, dams, wetlands or other water bodies (Stream Corridor Restoration, 1998). There are four major components within the hydrological cycle; precipitation, surface-water flow, ground-water flow, and evapo-transpiration (ET). It must be noted that the significance of each of the above components varies from wetland to wetland.

Each wetland also has its own a water budget, which is the total inflow and outflow of water from a wetland. It is within the water budget that four components interact to create a hydrological signature for each individual wetland. The calculation of the water budget, within a wetland is impaired by the fact that climate varies from year to year as does the water balance. However, the water budget of a wetland can provide a basic understanding of the hydrological processes and water chemistry of a particular wetland (Carter, 1997; Kotze, 2001). For a wetland to occur in a specific area it is imperative that the sum of the input components are higher then the sum of the output components for a certain amount of time during the growing season (spring to summer) (Kotze, 2001).

1.3.1. Hydrological effect

The effect that hydrology has on wetlands has long been debated yet most researchers share the viewpoint that wetland hydrology plays a very important part in the species richness of wetland vegetation (Mitsch and Gosselink 2000). There are three basic principles or attributes that can be attributed to hydrology, namely:

- Hydrology can limit or enhance species richness and composition,
- Primary productivity can be enhanced by flowing conditions whereas stagnant conditions can repress productivity,
- Organic accumulation, export and nutrient cycling (Mitsch and Gosselink 2000).

These are briefly explained below:

1.3.1.1 Species Composition and Richness

The hydrology within wetlands can lead to a unique composition of vegetation which can either limit or enhance the species richness of wetlands. Hydrology can act as a stimulus or a limit to species diversity, depending on the hydroperiod as well as physical energies of the hydrological cycle. At the very least hydrology "selects" water-tolerant vegetation thus excluding flood-intolerant vegetation from the wetland area (Mitsch and Gosselink, 2000). It is the waterlogging of the soils and the ensuing changes in the oxygen content as well as other chemical alterations which limit the number and type of rooted plants that can survive in such an environment. Stagnant water may have the ability to decrease the species richness of an area whereas flowing water increases the species richness within a wetland area (Mitsch and Gosselink, 2000).

1.3.1.2 Primary Productivity

Flow conditions and a pulsing hydroperiod enhance the primary productivity whereas stagnant conditions often depress primary conditions. The hydrology of a wetland is the main source by which nutrients are transported to and from wetlands. It is believed that the productivity of a wetland increases if the wetland receives its main source of water from overland flow as a-posed to purely precipitation. The reason for this may be the added nutrients and sediments, which overland flow collects as it passes over the area. Water movement within a wetland is important, due to the fact that constantly stagnant condition or drained conditions may affect the productivity within a wetland (Mitsch and Gosselink 2000).

1.3.1.3 Organic Accumulation, Export and Nutrient cycling

Wetland hydrology also controls the accumulation of organic matter through its influence on the primary productivity, decomposition as well as the export of particulate organic matter (Mitsch and Gosselink, 2000). For decomposition of organic matter to take place a collection of activities from organisms within the soil food web is necessary. Added to this are two other influences namely; ambient temperature and the activity of macrodetritivores. The decay of organic matter is crucial to the nutrient cycling and mineralization within ecosystems (Neher, et al., 2001). Nutrient cycling is rapid when the wetland has a pulsing hydroperiod, however, when productivity and decomposition is slow the nutrient cycling is also slow. Due to the anaerobic conditions within a wetland decomposition is slow and organic accumulation high but during floods the organic matter may be exported and deposited in rivers (Mitsch and Gosselink, 2000; Kotze, 1996a)

1.4. Hydrophytic Vegetation

Few plants can deal with the anaerobic soil conditions associated with long periods of saturation as well as the dry periods (in seasonally, temporarily or on the edges of the wetlands) as is present in a wetland system (Department of Water Affairs and Forestry, 2003). Hydrophytic vegetation have adapted to the wet conditions within wetlands. Hydrophytes are plants whose active photosynthetic parts are permanently or, for several weeks or months of each year, partly or wholly submerged in water, or plants which float on the surface water (Cook, 2004; Cowan, 1998; Federal Interagency Committee for Wetland Delineation, 1989). Hydrophytes have through morphological, physiological and reproductive adaptation, the ability to grow, compete, and reproduce, in anaerobic soil conditions. Adaptations which the hydrophytes have undergone are namely: the presence of air pockets in the roots and stems, adventitious roots, shallow rooting systems, hypertrophied lenticels (large internal pores), as well as seed dispersal by water (Department of Water Affairs and Forestry [DWAF], 2003). According to Rogers (1995) and Cook (2004) there is insufficient in-depth research relating to wetland plants. Few intensive studies have been undertaken on wetland vegetation types, and if a certain wetland vegetation type has been well researched, there is seldom more then one example of such a study.

1.5. Hydric soil

When any given soil is subject to flooding or saturation for more then two weeks per year, it may often demonstrate waterlogged or hydric soil characteristics. These hydric conditions will greatly influence the soil chemistry and the conditions available for plant life (Lyon, 1993). Due to the wetness of the soils during the growing season, hydric soils tend to develop certain morphological properties, which can be readily identified in field. The prolonged anaerobic condition which the soil is subjected to lowers the soil redox potential and causes a chemical reduction of some soil components, effecting mainly iron oxides and manganese oxides. The reduction affects the solubility, movement and aggregation of the oxides that in turn is reflected in the soil colour (Federal Interagency Committee for Wetland Delineation, 1989). Hydric soils can be grouped into two major types on the basis of material composition. First organic soils: the anaerobic condition promote the accumulation of organic matter. For soils to be classed as organic, certain criteria has to be met; a minimum proportion of organic carbon (OC) in the soil material of 10%, 200mm of organic material within the upper 800mm of the soil or organic material of any thickness extending from solid surface to rock or gravel (Kotze et al., 1996; Federal Interagency Committee for Wetland Delineation, 1989; Mitsch and Gosselink, 2000). Second, mineral soils that have less OC then organic soils (less than 10% organic carbon). Gleying is the most widely recognised processes which reflects the intense reduction of mineral soils as a result of prolonged saturation. Mottles are created by the repeated re-precipitation of reduced iron in localised areas which results in the formation of yellow, red or black mottles (Kotze, 1996a; Federal Interagency Committee for Wetland Delineation, 1989; Mitsch and Gosselink, 2000).

Values have been assigned to wetlands in an effort to protect and conserve the remaining wetlands. Wetland value ranges from water retention and storage to habitat support. Wetland functions are what the wetland does without including the benefit which the function will have on human kind, as discussed below.

1.6. Values, functions and benefits of wetlands

1.6.1 Value of wetlands and interaction within the environment

To ensure the proper understanding of wetland functions and values a short explanation is necessary. Wetland functions are the indirect services which wetlands provide society (water retention/storage, sediment and pollutant removal, habitat support). Wetland values are the direct services provided by wetlands to society and may be either given a monetary or a relative value such as flood attenuation, water quality, and recreational services (King et al., 2000; Kotze and Breen, 1994; Smith, 1995). In an effort to conserve wetlands, scientists have adopted the traditional economic principle of the less there is of a certain commodity (wetlands) the more valuable that commodity (wetlands) becomes (Mitsch and Gosselink, 2000). Wetlands function within the surrounding landscape with or without interference from humans. Humans have placed value on to these functions as they have proved to be useful. Values are assigned to wetlands from a human perspective and there after often protected legally (Mitsch and Gosselink, 2000). The three mostly frequently cited functional values are; hydrological, erosion control, and the ecological values (Kotze, 1994), each of which will be discussed in greater detail.

1.6.2. Hydrological Values and Functions

1.6.2.1Water Quality

In a country such as South Africa where a large percentage of the population is depended on the natural environment for survival, wetlands play an exceptionally important part in provision of clean sediment free water to the rural committees. Wetlands have the ability to filter or trap suspended sediments, pollutants, heavy metals, disease-causing bacteria and viruses, organic and inorganic nutrients which may enter the site. Through this filtering/trapping the water quality is not only improved but the wetlands plants are repeatedly fertilized, therefore many wetlands are dependent on the input of waterborne sediments (Gaigher, 1985; Day, 2003). It can therefore be stated that water leaving the wetland is purer than the water entering into the wetland (Kotze et al., 2001). The attributes which are credited for the purification of wetland water according to Mitsch and Gosselink (2000) and Kotze (2001) are as follows:

- There is a very high rate of productivity within wetlands and this promotes high rates of mineral uptake by plants which subsequently leads to the burial of chemicals in sediments when plants die.
- As water enters into a wetland there is a reduction of water velocity, which in turn causes sediment and chemical sobbed sediment to descend out of the water column.
- Certain chemicals can be removed with the help of variety of anaerobic and aerobic processes in close proximity, promoting denitrification, chemical precipitation as well as other chemical reactions.
- With the accumulation of organic matter in wetlands chemicals (elements such as heavy metals) may become permanently buried with the wetland.
- Due to the diversity of decomposers and decomposition processes in wetlands, sediments pollutants can be removed.
- In respect of the shallow water, wetlands have a large contact surface with sediments, thus leading to significant sediment-water exchange.

Thus the significance of wetlands in the respect of water purification cannot be disputed.

1.6.2.2 Flood control potential

Wetlands can act as a natural storage area which in case of high outpours in the upper reaches of the catchment, reduces the downstream flood peaks (Ammann and Stone, 1991). It is thus possible for freshwater wetlands to act as natural flood regulators in which water is stored, and after the flood event the water is slowly released downstream (Breen and Begg, 1987). The way in which this flood retention takes place is as follows; water enters the wetland in the form of rainfall, surface runoff, steam flow as well as ground water, the water is then slowed down by the shrubs, trees, reeds, rushes, and the gentle topography of the wetlands. The size of the wetland also plays a role in the reduction of waters velocity (Kotze and Breen, 1994), thereby reducing the amount of water within the river system at the time of the actual flood (Ammann and Stone, 1991; Kotze, 2001; Carter, 1997). Protecting the area from flood damage, the wetlands will over time slowly release the water back into the environment thereby attributing to the low flow. This low flow can be defined as the ability of wetlands to retain storm water as well as sediments, and then release the water back into the river after flooding has taken place (Mitsch and Gosselink, 2000). Therefore, with the loss of wetlands the probability of floods is increased downstream. It has been argued in Mitsch and Gosselink (2000) that to maintain the pulse control function which wetlands have, it is preferable to have a greater number of wetlands in the upper reaches of a watershed as apposed to fewer larger wetlands in the lower reaches.

1.6.2.3 Groundwater Recharge and Discharge

Wetlands play a very important part in the recharge or discharge of groundwater. It is a well know that the relationship between wetlands and groundwater discharge and re-charge is complicated (Acreman, 2000; Kotze and Breen, 1994). In areas where the water table is high the underlying aquifer may supply the wetland with water in the process known as groundwater discharge. However, when the groundwater level drops and the hydraulic gradient reverses the wetland may supply the aquifer with water, this process is known as groundwater recharge (Acreman, 2000). Wetlands help keep the soil water in balance which again contributes to low flow characteristics (Kotze 2001; Mitsch and Gosselink, 2000,)

1.6.3. Erosion Control:

As sediment laden water enters a wetland the velocity or the water is slowed by plants and thus much of the sediment load settles. According to Ammann and Stone (1991) as much as 80 – 90% of sediment in water may be removed as the water passes through the wetland. The ability of wetlands to act as sediment traps can be attributed partly to the vegetation, as the water passes through the vegetation its velocities decreases due to friction and thus causes sedimentation (Carter, 1997). Wetlands are mostly regarded as deposition areas rather than sediment sources, the effectiveness of wetland vegetation to absorb erosive forces depends largely on the vegetative composition and root structure, sediment type, the frequency and intensity of the water flow (Carter, 1997; Kotze, 2001).

1.6.4. Ecological Value

1.6.4.1 Wetland conservation

Wetlands have in the past often been considered as soggy wastelands, a breading place for mosquitoes and diseases. Within the past few decades this view on wetlands has changed. Wetlands are now perceived as being one of the most productive and biologically richest ecosystems on earth. These ecosystems are associated with a variety of specially adapted water plants, as well as feeding, sheltering, and nesting of great concentration of all forms of animal and bird life. South Africa alone has 120 bird species which are dependent on wetlands for their survival (Gaigher, 1985), reason enough for wetland conservation to become a priority.

1.6.4.2 Biodiversity of Wetlands

As stated by Gaigher (1985) wetlands are a rich source of biodiversity providing food, nesting and shelter for a large number of birds, micro-organisms, larger and small mammals, fish, invertebrates, amphibians and reptiles. Several of the above mentioned biota are dependent upon wetlands for at least part of their life cycle, thus with the increased loss of the habitat the survival of certain species becomes less likely into the future. Indirect human activities play a considerable role in threatening wetland systems, the threats can range from changes in water quality, invasions of alien species, to the physical alteration of watersheds which supply the wetland with surface and groundwater (Whigham, 1999). Added to this is the direct impact humans have on wetlands through, for example, poor farming techniques, bad burning practises, planting of forest in wetlands, draining and damming of wetland areas. All these activities play a large role in the destruction of wetland habitat which may lead to the extinction of a number of rare and endangered species (Zaloumis, 1987; Kotze and Breen 1994, 1996b).

1.6.4.3 Wetland Loss

Zaloumis (1987) maintains that as little as ten per cent of the original wetlands exist in their destabilised river system and degraded catchments. Begg and Breen (1987) estimate that fifty-eight percent of the original wetland area was lost in the Mfolozi catchment, and that only two percent of the catchment is occupied by wetlands at present. On a national scale it is estimated that fifty percent of wetlands in some catchments have been destroyed (Dickens et al., 2003). This is not a South African based problem alone, in the United States, Whigham (1999) states that more then fifty percent of the nation’s original wetlands have been lost and that they continue to lose most types of wetlands. In Europe wetland loss is calculated to be as much as sixty-seven percent in France between 1900-1993 and sixty-six percent in Italy between 1938-1984 (Acreman, 2000). Wetland loss is occurring at alarming rates despite the fact that all the above countries have the necessary legislation to protect the areas, thus questioning the effectiveness at governmental department implementation of legislation.

1.6.4.4 Reference Sites

Reference wetlands are used as benchmarks against which other wetlands can be compared for a number of purposes such as assessment, training, mitigation, and restoration. The decisive factor for the identification of reference wetlands is that they should include representatives of natural or quasi-natural wetlands that have occurred in the region or presently occur there. The array of reference wetlands should be such that they represent similar 'types', such as; specimens in vegetation, localities for geologic formation, and series of soils. Added to the natural reference sites, degraded or disturbed wetlands should be included, thus providing insight between the functions, structure, and nature of disturbance (Brinson, 1993).

1.6.4.5 Aesthetic Value

Due to the ecological diversity and species richness, wetlands are not only an inviting place to relax and bird watch but also an area where extensive research and information can be gathered. It has been noted by several authors (Kotze, 1996b; Mitsch and Gosselink, 2000; Haskins, 1998) that wetlands form part of a number of rare or endanged bird species habitat or breeding areas.

1.7. Wetland classifications

Classification is a tool which is used to group similar objects together and separate objects which are dissimilar (Ollis and Ewarth-Smith, 2005). Classification systems which group wetlands into types have been developed by institutions and individuals, both internationally (Cowardin et al., 1979; Brinson, 1993), continental (Roggeri, 1995) as well as nationally (Dini and Cowan, 2000; Ewart-Smith et al., 2006)**.**

1.7.1. Brief wetland classifications

Internationally wetland classifications have been well researched, resulting in a substantial amount of literature available. The classifications range from ecological to hydrological and geomorphological. A brief look at a number of classifications which has been developed internationality as well as locally appears below. It must be noted that this is not intended as a complete collection of classifications available.

Author	Brief Classification
Cowardin et al.(1979)	CLASSIFICATION OF WETLANDS AND DEEPWATER HABITATS OF THE UNTIED STATES. In this classification wetlands are defined according to three variables namely, 1. Plants (hydrophytes), 2. Soils (hydric soil), and 3. Frequency of flooding, Deepwater habitats are also included in to the classification. The classification hierarchy is divided as follows; Systems, Subsystems, and Classes. Systems are the highest level in the classification hierarchy in which five wetlands are defined, and then within each system there may be a subsystem, which in turn has classes. Classes are based on the substrate material as well as the flooding regime, or on vegetation.
M.M. Brinson (1993)	A HYDROGEOMORPHIC CLASSIFICATION FOR WETLANDS. The emphasis of Brinson’s (1993) classification lies on the hydrologic and geomorphic controls, which take place in wetlands. The approach which is used moves the emphasis which usually lie on biotic features to the abiotic features which are found in wetlands. The classification relies almost solely on the geomorphic, physical, as well as chemical properties of wetlands. The three main components are as follows: 1. Geomorphic setting, (topographic location) 2. Water source and its transport, (precipitation, surface, groundwater)

	3. Hydrodynamics (direction and strength of flow)
C.A. Semeniuk (1995)	WETLANDS OF THE DARLING SYSTEM- A GEOMORPHIC APPROACH TO HABITAT CLASSIFIACTION. Semeniuks classification is based on the suggestion that "the landforms determines the wetland size, shape and depth". The classification can be divided into two components namely; land form and hydroperiod. 1. Landform component one would find, cross-sectional shape, size, plan shape, stratigraphy, and origin. 2. Hydrology component; water permanence, water salinity, consistency of water salinity, and water maintenance.
H. Roggeri (1995)	A classification based on geomophological units and ecological units for Africa. Roggeris' (1995) classification distinguishes 3 first characterizations which are: (1) Alluvial lowlands (fringing floodplains, inner deltas as well as coastal deltas), (2) Small valleys (which include headwater lowland and small overflow valleys), (3) Lakeshore wetlands (on the shores of a deep lake or shallows), (4) Depressions (in a river of lake system or isolated depressions). Added to this Roggeri specifies three ecological units of wetlands, namely; (1) Periodically flooded ecosystems, (2) Swamps and marshes, (3) Permanent shallow lakes and water bodies.

	As noted by Schuyt (2005) these ecological units may often interlink in a complex way, added to this several ecological units may make up one geomorphological unit.
Warner et al. (1997)	THE CANADIAN WETLAND CLASSIFICATION SYSTEM. (Second Edition) The system contains three hierarchical levels: (1) Class, (2) Form, (3) Type. There are five classes which are recognised on the basis of the overall genetic origin of the wetland. Forms are differentiated by surface morphology, water type, surface pattern, and the morphology of the underlying mineral soil. Types are then classified according to the vegetation physiognomy.
Dini and Cowan (2000)	CLASSIFCATION SYSTEM FOR THE SOUTH AFRICAN WETLAND INVENTORY. This classification system is based on Cowardins (1979) *Classification of wetlands and deepwater habitats of the United States*, with changes being incorporated to better suit the needs of South Africa's particular wetlands. The classification consists out of Systems, (wetlands influenced by similar hydrologic, geomorphologic, chemical or biological factors), Subsystems, (which reflect the hydrologic conditions within the systems) and Classes (a description on the appearance of the wetland based on the vegetation structure and composition, or the substrate where vegetation is absent).
Kotze et al. (2001)	A hydrogeomorphic classification of South Africa's wetlands.

	Kotze (1999) proposed a landform classification system based on Brinson's (1993) classification. The classification consists of landform settings (hillslope, headwater, riparian high gradient, riparian low gradient, depression and fringe) and hydrologic components (inputs, throughputs and outputs).
Kotze et al. (2005)	A hydrogeomorphic classification of South Africa's wetlands. Kotze et al. (2005) developed tools (WET-Health & WET-EcoServices) which are based on the hydrogeomorphic approach to wetland classification. For use in the tools the following hydrogeomorphic types have be defined on the basis of geomorphic setting, water source and how the water moves through a wetland. (1) Floodplain, (2) Valley bottom with a channel, (3) Valley bottom without a channel, (4) Hillslope seepage feeding a watercourse, (5) Hillslope seepage not feeding a watercourse, and (6) Depressions. Kotze et al.'s (2005) work has been taken further to develop a wetland classification system for the South African National Wetland Inventory by Ewart-Smith et al. (2006) (Ollis and Ewart-Smith, 2005).
Ewart-Smith (2006)	National Wetland Inventory: Wetland Classification System for South Africa. The system is hierarchical, and organised according to landform and hydrological characteristics as the primary determinants of ecological character and the functions that a wetland performs. The hierarchy of the classification is as follows: Systems, Subsystems, Functional Units, Structural

Units and Habitat Units. Discriminators are used to distinguish one wetland from another and are applied consistently at each level of the hierarchy. There are three types of discriminators namel: *Primary discriminators* distinguish Functional Units, *Secondary discriminators* distinguish Structural Units, and *Tertiary discriminators* distinguish Habitat Units (Ewart-Smith et al., 2006).

1.8. Aims and objectives

The importance of wetland hydro-geomorphology has been acknowledged although little detailed work has been undertaken on the subject, particularly in the KwaZulu-Natal Drakensberg headwaters. It was thus deemed necessary to do a detailed geomorphologic study, as the research will help with the basic understanding as to the functioning and maintenance of wetlands in an upper catchment area.

The main aim is to deal with the current lack of information on palustrine wetlands, and thereby increasing the understanding of the systems, particularly in mountain environments. The secondary aim of the study is to identify the essential geomorphological factors for the maintenance and functioning of the wetlands. A hydro-geomorphological classification, developed by Longmore (2001), is tested for a section of the Drakensberg to verify the adaptability of the classification to a different catchment. Longmores (2001) classification is the only classification which focuses on the hydro-geomorphology of palustrine wetlands in the upper reaches of a catchment, added to this it also the only classification currently available to field and academic staff which specifically deals with palustrine wetlands.

The objectives of the study are thus to:

- Identify the general attributes of selected wetlands within the study area.
- Investigate the geomorphology and soils of the wetlands in detail.
- To test the adaptability of Longmores (2001) hydro-geomorphologic classification to

different catchment areas.

And finally to:

- Highlight issues pertaining to wetland classification within ecological management programmes.

Chapter 2: Environmental Setting

2.1. Location of study site

Wetlands in the upper Bushman river catchment were investigated (Table 2.1). These wetlands occur within the KwaZulu-Natal Drakensberg (Giant's Castle Game Reserve) which form part of the eastern escarpment of Southern Africa (Figures 2.1, 2.2, 2.3). The Drakensberg Park, or *uKhahlamba*, is crescent-shaped, stretches from latitude 20°05' to 29°55'south and longitude 29°45' to 29°44' east (Bainbridge, 1991), in totality extends from the Stromberg Mountains of the Southern Cape up to the eastern part of the Northern Province, and is situated between 100km and 150km from the Indian Ocean (Tyson, et al., 1976). Located in the eastern KwaZulu-Natal, along the border between South Africa and the Kingdom of Lesotho (Bainbridge, 1991; Kabii, 1997) the Park has an area of 242 813 ha, with the Giant's Castle Game Reserve measuring 34 638 ha. Study sites are in close proximity to the Mamndeni river a tributary to the upper Boesmans (or Bushmans) river catchment area. Geographic location (GPS readings) of the respective wetlands are listed in Table 2.1.

Name of wetland	Longitude	Latitude	Site name
Giant's Castle 01&02	29°12.716' S	29°32.611' E	J1 & J2
Giant's Castle 03	29°12.664' S	29°32.55' E	J3
Giant's Castle 04	29°12.599' S	29°31.518' E	J4
Giant's Castle 05	29°12.259' S	29°31.582' E	J5
Giant's Castle 06 a,b,c	29°12.570' S	29°31.105' E	J6 a,b,c
Giant's Castle 7	29°12.527' S	29°30.332' E	J7

Table 2.1. Location of the wetland study sites. (Site names will be used the identify the wetlands in this manuscript.

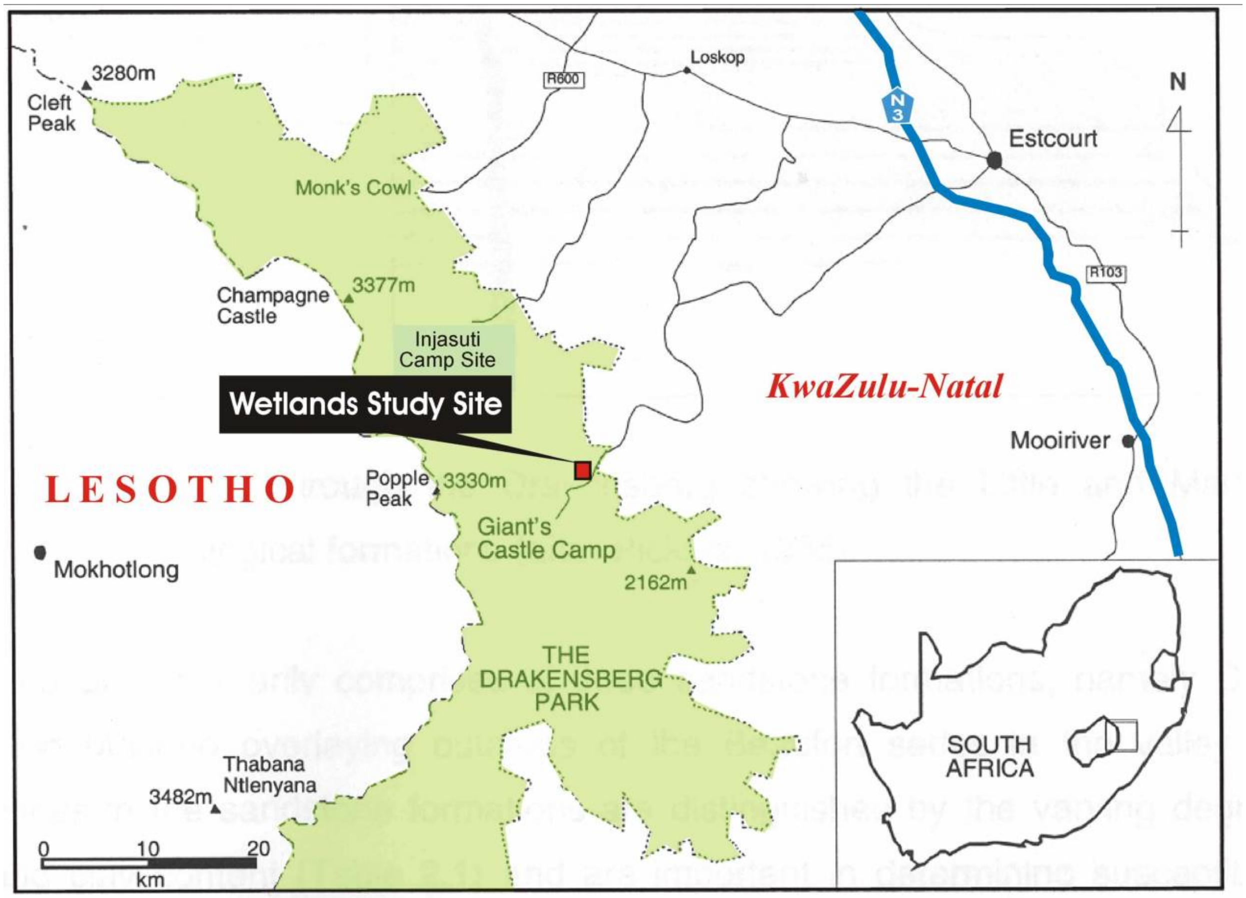


Figure 2.1. Location of wetland study site in the uKhahlamba Drakensberg Park.

2.2. Topography

Giant's Castle Game Reserve can be divided into three topographic zones namely the Little Berg, Escarpment and the Lesotho Plateau (Figure 2.2). Peaks on the escarpment exceed a height of 3400m above sea level and the valley floors of the Little Berg continue down to 1500m above sea level (Sumner, 1997; Watson, 1988). Two main tributaries drain to the Tugela river, the Boesmans river and the Injasuti river, which drain to the northeast (Sumner, 1997; Bainbridge, 1991).

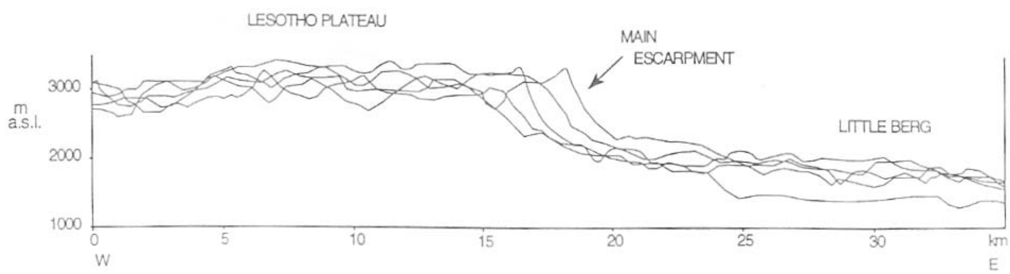


Figure 2.2. Superimposed transects at Giant's Castle Game Reserve (modified after Boelhouwers, 1992, from Sumner, 1997).

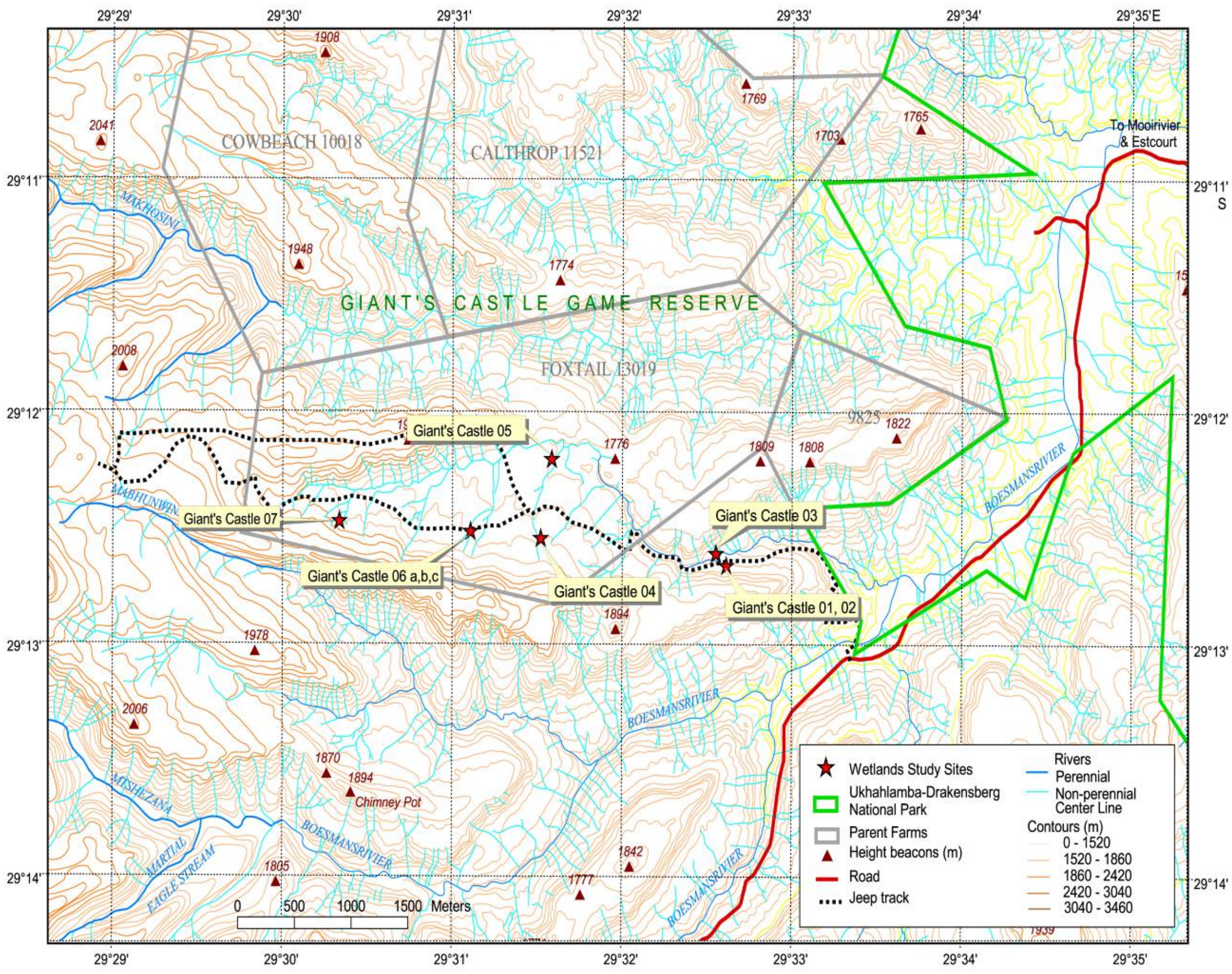


Figure 2.3. Location of wetland study sites in the Boesmans river catchment

2.3. Geology

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 formations (Table 2.2). The KwaZulu-Natal Drakensberg is characterised by a concordant sequence of sedimentary strata overlain by basalts which all belong to the Karoo Supergroup (S.A.C.S, 1980). At places, the horizontal sedimentary rocks are intruded by lattices of dolerite sills and dykes (Sumner, 1995).

2.3.1 Drakensberg Group Basalts

Thick layers of Drakensberg basalt consisting of numerous individual lava flows, which covered the horizontal and sub-horizontal sedimentary units, was forced into cracks, fissures and other discontinuities in the basalts as well as the underlying sediment, creating a lattice of dolerite sills and dykes (Garland, 1987).

2.3.2. Clarens Formation

Sandstones of the Clarens Formation (previously referred to as the Cave Sandstone), form the massive, buff coloured, often sheer cliffs, normally located at an altitude of just below 2000m (Garland, 1987). The contact of the Clarens formation and the overlying Drakensberg volcanics is generally sharp. Nonetheless, small and erratic-shaped extrusions of basalt below the contact suggest that minor volcanism took place prior to the ending of sedimentation (Eriksson, 1983). In the KwaZulu-Natal Drakensberg the Clarens formation reaches 145m think.

2.3.3. Elliot formation

The Elliot formation (previously referred to as the Red Beds), is characterized by red siltstones and mudstones, containing occasional subordinate lenses of fine to coarse sandstone

(Eriksson, 1983). These subordinate lenses exhibit mainly planar and trough cross-stratification (Eriksson, 1983).

2.3.4. Molteno Formation

The Molteno formation is characterized by light-coloured, sandstone with interbedded shale and mudstone. The Molteno formation can be found at an altitude of 1600m above sea level and with an average thickness of 50m (Eriksson, 1983). A summary of the lithologies of the upper stratigraphic sequences of the Karoo Supergroup is shown in Table 2.2. All the wetlands studied fell within the Clarens (sandstone) formation (1700-2000m) in the Little Berg.

GROUP	FORMATION	LITHOLOGY	THICKNESS	ALTITUDE
Drakensberg	-	basalt	1350m	>1880m
No group name	Clarens	Sandstone	120m	1720-1880m
	Elliot	Red siltstone and mudstone / sandstone lenses	50-80m	1630-1720m
	Molteno	Sandstones / mudstones / shales	7-20m	1600m

Table 2.2 Characteristics of the dominant stratigraphic sequences of the Karoo Supergroup found in the study area (modified after Boelhouwers, 1992, in Sumner, 1995)

2.4. Geomorphology

The geomorphology of the Drakensberg Zone has been a long standing debated since the late nineteenth century (Longmore 2001, Sumner, 1995). Numerous interpretations of the geomorphological evolution of the Main Escarpment have emerged over time (Longmore 2001). Well known interpretation and assessments include those of: Sues (1904); Penck (1908); King (1963, 1972); Birkenhauer (1985). Due to the apparent conflicting interpretations, re-evaluation of the geomorphological history of the subcontinent was undertaken by Partridge and Maud (1987). The re-evaluation by Partridge and Maud (1987) of the mountainous regions above the Great Escarpment found it to be unrelated to particular phase of erosion, this is in contrast to King's reference to a Gondwana surface, however generally discrete phases of erosion were identified. The oldest surface identified by Partridge and Maud (1987), the African surface, coincides with King's (1967) description of the African surface. Two Post-African ages were identified, and are referred to the as the Post-African I and Post-African II surface. The relationship between the surfaces and stages is conceived as being indicative of landform development by progressive backwearing and downwearing, where the existing surfaces continue to develop at the expense of the high-lying areas (Partridge and Maud, 1987, Longmore 2001, Sumner 1995). However Van Der Beek et al. (2002) propose an alternative model for the landscape development. In which the escarpment was initiated at the coast but was later rapidly destroyed by rivers flowing from an interior drainage divide. It is proposed that the divide existed at a local high on the Karoo basalt plateau just seaward of the present day Drakensberg Escarpment (Van der Beek et al. 2002). While controversy still reins the topic, for the purpose of this study it is sufficient to recognize that the active incision of rivers plays an important role regarding the erosion of the Escarpment both presently and historically.

2.5. Soils

There has still been no comprehensive soil survey done for the Natal Drakensberg (Sumner 1995), although a few small-scale soil survey were conducted in the Cathedral Peak area (Schultze, 1974; Granger, 1976). Van der Eyk et al. (1969) mapped the Tugela Basin at a scale of 1:100 000, however little attention was given to the soils of the Little Berg and Escarpment zones as most of the area was classified under mapping unit N, outlined as being Mountainous land, mostly steep, but including inaccessible land of the high plateaux, with no further information provided (Garland, 1987; Longmore 2001; Sumner, 1995). The combined effects of high summer rainfall, low dry season temperature and the long exposure to weathering have been instrumental in the genesis of the structureless, ferrallitic, leached, acid soils in the Little Berg (Schulze, 1974, Granger, 1979; Bainbridge, 1987; Boelhouwers, 1988). The Drakensberg soils are in general shallow, with skeletal soils on the mountain slopes and deeper soils in the valley floors (Killick, 1978; Irwin and Irwin, 1992; Grab, 1997). The shallow soils of the high Drakensberg slopes are in the order of 0.15m in depth, are referred to as “lithosols”, while the valley floors and heads are represented by “mollisols”, mollisols are usually found to be deeper and darker than the soil found on the slopes mentioned above (Grab, 1997; Longmore, 2001).

Five soil forms have been identified in the Giant’s Castle Game Reserve, Hutton, Griffin, Clovelly, Katspruit and Mispah form (Van der Eyk et al., 1969; Garland, 1987; Boelhouwers, 1988). Table 2.3 lists the dominant soil forms which are found in the Giant’s Castle Game Reserve and the surrounding area.

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

Table 2.3. Soil forms found in Giant’s Castle Game Reserve (modified after Van der Eyk et al., 1969; Garland, 1987; Boelhouwers, 1988, in Sumner, 1995.

2.6. Vegetation

The distribution of plant species in the Drakensberg is determined primarily by altitude, aspect and soil (Irwin and Irwin, 1992). According to Granger (1976) topographic position is believed to have considerable influence on plant distribution and colonization. Added to this Granger (1976) states that the topographically induced variation in radiant energy will lead to corresponding variations in soil moisture status, and thus cause alteration in the plant environment. The long history of controlled burning is believed to also have influence the vegetation of the Drakensberg, favouring the maintenance of herbaceous vegetation over woody vegetation (Garland, 1987; Bainbridge, 1991; Bijker, et al., 2001).

The Altitudinal zones of vegetation according to Killick, 1963, are defined as follows; the Montane belt (1280–1829m.a.s.l) the Subalpine belt (1829–2865m.a.s.l) and the Alpine belt (2865–3353m.a.s.l). While the composition of flora varies slightly in different areas with the Drakensberg, for general purposes it is regarded as ecologically fairly homogeneous form north to south (Irwin and Irwin, 1992).

2.6.1 Montane belt (1280–1829m.a.s.l)

The Montane belt consists of the relatively short, bunched grasses of the *Themeda-Trachypogon* sub-climax community. Two dominant species are *Themeda triandra* and *Trachypogon spicatus.* Small communities of *Protea Savanna* are found in favourable locations. Small areas of forest or woodlands, which consist of *Leucosidea sericea* and *Buddleja salvifolia* occur in kloofs, on streambanks and rocky soil (Garland, 1987). In the temporarily to seasonally wet areas in valleybottom and terrace setting with deep mineral soils *Miscanthus capensis* meadow typically occurs (Bainbridge, 1991).

2.6.2. Subalpine belt (1829–2865m.a.s.l)

The subalpine belt most extensive plant association is *Themeda-Festuca* grassland, in which *Themeda triandra* is common, particularly on the north-facing slopes, and *Testuca costata* is common on south facing slopes. Subalpine fynbos, consisting of a variety of small leaved shrubs, exist only where there is some measure of protection from fire (Garland, 1987). In the subalpine and alpine areas which are temporarily to seasonally wet areas in valley floors and terrace setting with deep mineral soils *Merxmuellera* spp meadow typically occurs (Bainbridge, 1991). The wetlands areas with very shallow soils which are maintained by groundwater discharge over sheetrock terraces, are characterized by *Rhodohypoxis* spp. and *Crassula* spp. (Bainbridge, 1991).

2.6.3. Alpine belt (2865–3353m.a.s.l)

The dominant association is *Danthonia-Festuca-Pentaschistis*. The vegetation within the alpine best is characterisitic of a harsh climate of wet summers and freezing soils in winter (Boelhouwers, 1988; Sumner, 1995). The predominant species in Sedge/grass meadow areas is usually *Scirpus ficinioides* and *Kniphofia caulescens* is usually the dominant and most conspicuous species on the wetter seepage slopes (Bainbridge, 1991).

2.6.4. Wetland vegetation

Despite the fact that the topography of the Drakensberg does not, in general favour the development of large wetlands, a wide range of wetland vegetation types and wetland dependent species are represented in the Park (Bainbridge, 1991). Dely et al. (1995) described 11 wetland vegetation types which characterise the wetlands of the Park. These are outlined in Table 2.3 with the dominant and other characteristic species.

Sedge/grass meadow area, are characterized by species such as *Festuca caprina,* which usually occur in temporarily to seasonally wet areas surrounding marshes and on elevated hummocks with the marshes, as well as on slopes (Bainbridge, 1991; Dely, 1995). Marshes, which are generally permanently waterlogged on very gentle slopes or in depressions, are characterized by various vegetation types dominated by Cuperaceae and, to a lesser extent, Juncaceae. *Carex* marsh, which is dominated by *Carex acutiformis*, occurs predominantly in ‘backmarsh’ areas. Mixed sedge marsh is characterized by a number of sedges (e.g. *Carex cognata* and *Pycreus cooperi*) and rushes (e.g. *Juncus oxycarpus*). *Isolepis* marsh is dominated by *Isolepis fluitans*, and *Eleocharis* marsh, again by *Eleocharis dregeana*, often occur in association with a mixed sedge marsh. Standing open water areas (tarns) have aquatic species such as *Crassula natans* and *Ilysanthes bousii* (Bainbridge, 1991, Dely et al., 1995).

VEGETATION TYPES	**DOMINANT SPECIES**	**OTHER CHARACTERISTIC SPECIES**
Leucosidea scrub	*Leucosidea sericea*	*Miscanthus capensis*
Mixed scrub	*Cliffortia linearifolia*	*Erica evansii, Myrsine africana*
Miscanthus capensis meadow	*Miscanthus capensis*	*Acalypha* spp., *Senecio* spp., *Helichrysum* spp., *Gunnera perpensa*
Merxmuellera spp. meadow	*Merxmuellera macowanii, M. drakensbergensis*	*Afrotysonia glochidiata, Geranium pulchrum, Ranunculus baurii,*
Sheetrock dwarf wetland	*Rhodohypoxis* spp., *Crassula* spp., *Tulbaghia* spp., *Aristida junciformis*	*Styppeiochloa gynoglossa, Bulbostylis humilis*
Sedge/grass meadow	*Festuca caprina, Andropogon appendiculatus, Eragrostis planiculmis, Rhynchospora brownii, Schoenoxiphiun* spp., *Scleria* spp.	*Fuirena pubescens, Bulbostylis schoenoides, Dierama pauciflorum, Xyris capensis, Aristida junciformis, Melasma scabrum, Geranium* spp., *Urginea macrocentra.*
Kniphofia caulescens marsh	*Kniphofia caulescens*	*Scirpus ficinioides, Eriocaulon dregei.*
Mixed sedge march	*Carex cognata, Juncus oxycarpus, Juncus exsertus, Eriocaulon dregei, Pycreus cooperi*	*Juncus dregeanus, Denekia capensis, Cyrtanthus breviflorus*
Carex acutiformis marsh	*Carex acutiformis*	*Guueral perpensa*
Isolepis marsh	*Isolepis fluitans*	*Isolpis constata*
Eleocharis dregeana marsh	*Eloecharis dergeana*	*Isolepis fluitans*
Open water	*Crassula natans, Limosella maior*	*Ilysanthes bolusii*

Table 2.4. The 11 vegetation types characterising wetlands in the UKhahlamba Drakensberg Park (Dely et al., 1995).

The occurrence of the 11 vegetation types is summarized in relation to the typical water regime, altitudinal zone and topographic setting in which they are found, Table 2.5 (after Dely et al., 1995, Bainbridge, 1991).

2.7. Climate

2.7.1. Temperature

When dealing with the temperature information it is pertinent to note that there is a scarcity of data recording stations within the Drakensberg region. The Drakensberg climate varies from hot, wet summers to cool, very dry winters. The hottest month of the year is January when the temperature ranges 23˚ at 800m, to 21˚ above 2 400m. The coldest month in the Drakensberg is July with temperatures ranging from 15˚ at 800m to 12˚ above 2 400m (Tyson et al., 1976; Garland, 1987). At 1900m in Giant’s Castle Game Reserve soil temperatures are unlikely to fall below 0˚C although air and rock surface temperatures may do so in winter (Sumner and Nel, 2006).

2.7.2. Precipitation

The KwaZulu-Natal Drakensberg lies in the summer rainfall area of South Africa, and is one to the wettest areas within the country (Killick, 1961; Schulze, 1979). The Drakensberg derives its rain mainly from oceanic air-streams entering from east coast highs (Tyson et al., 1976). Killick (1961) noted that due to the characteristics of the rainstorms (which are short, intense downpours, with a high eroding capacity), wetlands in the Drakensberg area play an important role in intercepting rain and the sediment laden runoff. The total rainfall of the Little Berg varies between 1100mm to 2000mm at the escarpment (Sumner, 1997, Bainbridge, 1996). Topography has been identified as exerting a powerful influence on Drakensberg rainfall (Longmore 2001).

WETLANDS VEGETATION TYPES	WATER REGIME	ALTITUDINAL ZONES		
		Montane	Subalpine	Alpine
Leucosidea scrub*	Non, Se	V, C		
Mixed scrub*	Se, Non	V, C	V, C	V, C
Miscanthus capensis meadow / grassland*	Se, Non	Fd, V, S, C	C, Fd, S, V	D, C, S, V
Merxmuellera spp. meadow/ grassland*	Se	S, D, V	S, D, V	S, D, V
Sedge/grass meadow	Se	Fs, D	Fs, D	Fs, D
Sheetroch dwarf wetland	Se, Perm			S
Kniphofia caulescens marsh	Perm, Se	V, D, C, S	V, D, C, S	V, D, C, S
Mixed sedge marsh	Perm	V, D, C, Fd	V, D, C, Fd	
*Carex acutiformis*marsh	Perm	V, D, C, Fd	V, D, C, Fd	V, D, C, Fd
Isolepis marsh	Perm, Se	D, V	D, V	
Eleocharis drefeana marsh	Perm, Se	D, V, Fd	D, V	D, V
Open water				

Table 2.5. Drakensberg wetland vegetation types, summarized according to water regimes, altitudinal zones and topographic setting (Dely et al, 1995; Bainbridge, 1991).

Legend

TOPOGRAPHIC SETTING
D = Ridgetop depressions and flats
Fd = Footslopes with deep soils
Fs = Footslopes with shallow soils
S = Midslopes and valleyhead slopes
C = Valleybottom channel and banks
V = Valleybottom ‘backmarsh’ and flat areas

WATER REGIMES
Se = Temporarily to seasonally waterlogged
Perm = Semi-permanently to permanently waterlogged
Non = Also occurs in non-wetland areas

Note: Those topographic settings which are most characteristic of particular vegetation types are underlined.
* These vegetation types may also be found outside of the wetland.

As demonstrated by Schulze (1979) in a cross-section from Bergville (South Africa) to Mothelsassanne (Lesotho), where Bergville (800m.a.s.l.) receives approximately 750mm p.a., the annual total increases to a maximum of 1650mm at 2400m.a.s.l., which is just below the top of the Escarpment at 3000m.a.s.l, although Nel and Sumner (2005) indicate that this may be an overestimate. As stated by Nel and Sumner (2005), the rainfall data are derived by projections from lower altitude stations, and previously no rainfall records existed for the top of the escarpment. Nel and Sumner (2005) show rainfall at the top of Sani Pass (2 850m.a.s.l.) in the southern Drakensberg to be 742mm in 2002 while the rainfall on Sentinel Peak (3 165m.a.s.l.) northern Drakensberg was 765mm during 2003, was marginally lower then the rainfall data collected at adjacent lower altitude stations in the Drakensberg for the same period.

The summer months November to March account for 70% of the precipitation while winter May to August only 10% of the annual rainfall, leading to a summer moisture surplus and a winter moisture deficit. The precipitation manifests themselves in the form of thunderstorms, snow (approximately eight falls per year) and mist (Sumner, 1997, Bainbridge, 1991). Monthly rainfall totals can be seen in Figure 2.6. Thus wetlands in the upper areas of the Drakensberg render an important role in the supply of low flow during the winter months.

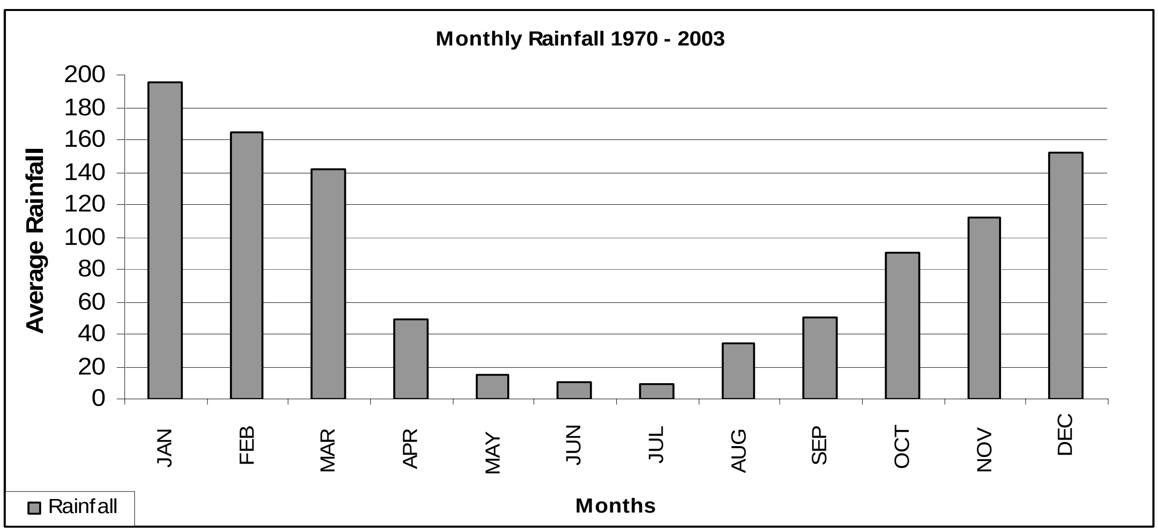


Figure 2.6 Monthly rainfall totals for 1970-2003 for Giant's Castle Game Reserve Main Camp.

2.8. A short history of the Giant's Castle Game Reserve.

Giant's Castle Game Reserve was established in 1903. During the first half of the 1900's cattle were farmed in the reserve by Natal Parks Board staff, this practise was however phased out in the late 1960's and early 1970's. Up to the late 1960's horses were used as a mode of transport, and at any one time numbered between 80 to 100 animals, but due to the increased reliance on motor vehicles the numbers were reduced. Wattle wood lots which were located near the Main Camp were removed after 1972. The Reserve has adopted a biannual burning programme since its establishment in 1903. In the early 1950's the Parks Board built a number of Jeep tracks to provide access to the remote areas within the Reserve, most of the Jeeps tracks were closed off by the late 1970's (Sumner, 1997). (Permission was granted from the Parks Board for the researchers to use one such a Jeep track to gain assess to the study sites.) On 21 January 1997, the UKhahlamba Drakensberg Park was designated as a Ramsar site, as a wetland of international importance (Dini, 2002).

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

Chapter 3: Methodology

3.1. Approach

The study comprised of both field and laboratory work. Inductive, deductive, qualitative and quantitative approaches were synthesized in an effort to meet the aims and objectives of the study. Prior to any field visits, seven wetlands were identified and delineated with the use of topographic maps (1:50 000 & 1: 500), aerial photos, ortho photos, GIS (Geographical Information Systems), geological maps as well as soil maps in an accessible portion of the upper Bushman's river catchment. The following features were noted:

- the geographical position of the wetlands;
- topographical position of the wetland;
- the slope angles at which the wetlands occur;
- the elevation above sea level;
- the type of bedrock (geological maps) on which the wetlands are situated;
- and the wetland size.

thereby gaining an understanding of the location and diversity of wetlands within the study area. Site visits were undertaken to the wetlands which were representative of the dominant physical characteristics of the area as identified by the desk-top study. Preliminary investigation indicated that the water source and hydrodynamics were not easily identified by field/map interpretation. The determination of how and where soil water moves in field has been noted by Daniels et al. (1971) as being labour and time consuming, as well as difficult to measure. Thus wetland soils were investigated as soils reflect the historical hydrological condition of the area, therefore assisting the researcher in tracing the active, rapidly developing processes that maintain wetland functioning and dynamics (Richardson, 1996).

Variables considered being important in driving wetland genesis, maintenance and functioning investigated in the study, are outlined in Table 3.1, added is a brief summary of the methods used. A detailed account of all methods and procedures used in the study is given in the following sections.

Variables	Sub-Variables	Method used
Climate	• temperature • rainfall amounts	Weather Station data analysis, literature.
Geology	• rock type	Geological maps
Geomorphology	• topographic position • landform assessment • aspect, inclination, length of wetland	Field/map assessment: 9-point slope model Semenuik and Semenuik 5 basic landforms types Measuring rod & abney level Field and topographic map measurement
Soil	• fines particle analysis • soil moisture • pH • ash content • organic matter content • bulk density • colour • mottling abundance	Lab Serve Nelspruit Three class system: dry, moist, saturated Laboratory pH meter Dry ashing method Field & laboratory/ashing method Laboratory Munsell soil chart Field assessment
Hydrology	• inputs • outputs • throughflow • hydroperiod • depth of standing water	Direct & indirect assessment • Soil data info • Field indicators Wetness classes (perm, temp, sea) Ranging rod
Vegetation	• effective cover density • dominant vegetation identification	Field estimation Sample collection-consultation with Botany Dept.

Table 3.1. Variables and sub-variables investigated and an brief overview of the methods used.

3.2 Field procedure

3.2.1. Geomorphic description

Each wetland was described in relation to the 9-unit landscape model (Dalrymple *et al.*, 1968), terrain unit and terrain position.

Terrain units – Plateau/interfluve crest, seepage slope, convex creep slope, fall face (scarp), transportational midslope, colluvial footslope, toeslope, alluvial valley bottom, channel wall, channel bed.

Terrain position - Plateau/interfluve zone, headwater zone, upland valley zone, lowland valley zone.

A descriptive geomorphological map was sketched for each wetland indicating soil sampling sites.

3.2.2. Wetland Delineation

The method used to delineate the wetlands was described by Mondi Wetlands and the Department of Water and Forestry Affairs, and is as follows: A good vantage point was found from which the following information was gathered;

- overall layout of the wetland and surrounding areas
- the board hydrology of the area
- geomorphological map drawn of each wetland

Soil samples were taken, using an auger along a transect to depth of 500mm from a known dryland through the wetland. The character of dryland soil profile was noted and vegetation change while moving into the wetland. Each soil sample was inspected for signs of :

- Soil wetness/moisture
- mottle colour and abundance (orange/reddish-brown or dark reddish-brown/black accumulation in hydric soils throughout an otherwise gray soil),
- gleys colour (a soil process resulting from prolonged soil saturation, which is manifested by the presence of neutral grey, bluish or greenish colours in the soil matrix)

This technique can be used to find the wetland edge as well as the different wetness zones within the wetland (DWAF, 2003).

3.2.3. Micro-topography, organic matter

The micro-topography was established by field surveys and the use of cross section and longitudinal profiles. Cross sections as well as longitudinal profiles were measured at various intervals through all the wetlands studied. The longitudinal profiles were done through the centre of all wetlands, abney levels were taken where a visible change in topography was noted or at a maximum of 50 meters intervals.

Organic matter was established infield. The assessment of organic matter within each wetland was preformed in a basic manner which comprised assessing the quantity (low, medium and high) of organic matter on the surface of each wetland as well as the level of decomposition (amount of fibrous remains in the soil). Samples were taken as noted below.

3.2.4. Sampling procedure and samples sites

The wetlands were initially surveyed to ensure an understanding of the area of interest prior to choosing a sampling strategy and specific sample sites. 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 thus the researcher may rapidly establish the local stratigraphic and geomorphic relations (Daniels and Hammer, 1992). This method was adopted and sample sites are indicated on maps in Chapter 4.

Soil samples were taken from each wetland studied. Due the physical diversity of the wetlands, sample intervals ranged from 5 meters to 100 meters. A clay auger was used for sampling; samples were taken at an average interval of 20cm from the soil profile, until bedrock was hit or to the full extension of the auger (1.5m –2m).

Each sample collected was immediately sealed in ‘zip lock’ plastic bags and placed into plastic screw top containers after which the samples were placed in a ‘cooler box' to prevent excessive loss of moisture as well as to protect the sample from extreme temperature fluctuations. Despite the fact that this method is not fully supported by some authors (e.g. Cutis and Trudgill, 1974), it is the most practical and relatively inexpensive form of storage for isolated field sites. Soil sample were taken to the laboratory where the soil moisture experiment was completed. Time between sample extraction and analysis for soil moisture was less then 32 hours.

3.3 Laboratory procedure

3.3.1. Particle Size Distribution

Lab Serve (Nelspruit) undertook the particle size analysis. The method used by Lab Serve is given as follows:

Twenty grams of soil was dispersed by adding 10cm³ Calgon dispersing solution to the pretreated oven dried soil. The suspension is transferred to a 250cm³ centrifuge bottle, fill with 150cm³ de-ionised water, closed with a stopper and shaken overnight on a horizontal reciprocation shaker. Thereafter the sand fraction is removed by washing the dispersed sample on a 0,053 mm sieve, passing the silt and clay through the sieve *via* a funnel into a 1000cm³ cylinder untill the percolate is clear (following USDA 1972; Gee and Bader 1986).

The pipette method was used to determine the fine particle size distribution. A cylinder was filled with the silt and clay suspension to 36cm above base, and covered with a watch glass (at room temperature 20°C). After equilibration, the suspension was thoroughly stirred with a hand stirrer for 30 sec. in a vertical direction. After the appropriate time interval (Table 3.2) for determining the 0,05mm fraction (coarse silt + fine silt + clay), a 25cm³ pipette extraction it taken from the relevant cylinder depth and discharge into a tared evaporation dish, rinsed and added to the suspension in dish. Water is evaporated at 105°C to constant mass, cooled in desicator and the mass determined (following USDA 1972; Gee and Bader 1986).

Particle size distribution is derived by the following formulae:

$$\text{Percent fine silt} = \frac{(A\text{-}B) \times 1\,000 \times 100}{D \times 25}$$

$$\text{Percent clay} = \frac{(B\text{-}C) \times 1\,000 \times 100}{D \times 25}$$

Where: A = mass (g) of pipetted fine silt plus clay

B = mass (g) of pipetted clay

C = mass correction of dispersing agent (0.01g)

D = mass (g) of pretreated oven dry total sample

After which the textural class was determined by means of a textural triangle.

Temperature	0,05 mm (coarse silt)		0,02 mm (fine slit)		0,002 mm (clay)	
°C	30cm Depth		10cm Depth		10cm depth	
	Minutes	Seconds	Minutes	Seconds	Minutes	Seconds
15	1	31	5	17	8	48
16	1	29	5	9	8	34
17	1	27	5	1	8	21
18	1	25	4	53	8	9
19	1	22	4	46	7	57
20	1	20	4	39	7	45
21	1	18	4	32	7	34
22	1	16	4	26	7	23
23	1	15	4	20	7	13
24	1	13	4	14	7	3
25	1	11	4	8	6	53

Table 3.2. Sedimentation times of fine silt and clay as a function of temperature (calculated for the Calgon concentration used in the method and a particle density of 2,65g cm^3) as given by Lab Serve.

All other laboratory procedures and assessments were undertaken by the author at the University of Pretoria.

3.3.2. Soil moisture

The method used to determine soil moisture content was based on the criteria given by (Briggs, 1977; Goudie, 1990) and is as follows:

20 grams of soil was weighed (W^1) and the sample then place in a suitable petri dish and placed into the oven set at 105°C for 16 hours. Thereafter the sample was removed and place into a dissector to cool. The dry sample was then weighed (W^2).

Soil moisture content is given by the following formula:

$$\text{Mw (\% wet weight)} = \left(\frac{W_1 - W_2}{W_1}\right) \times 100$$

or

$$\text{Md (\% dry weight)} = \left(\frac{W_1 - W_2}{W_2}\right) \times 100$$

The moisture content of soil can be expressed as a percentage of wet weight, as well as dry weight. In the case of wet weight the range of moisture content is from 0 to 100%, however is must be noted the relationship between volume of water and percentage moisture content is not constant. Attention should be drawn to the fact that due to the inconstancies mentioned above, a soil with a moisture content of 20% is not necessarily twice as wet as a soil with a moisture content of 10%.

Using dry weight eliminates the above problem, however the result may provide values over 100%. As in the case of peat soils it is well know that values of up till 200% may be found, which may be difficult to identify with (Briggs, 1977; Goudie 1990). It was thus decided to use both methods and compare the two sets of data.

3.3.3. Soil pH

A slurry of 10g fresh soil and 25ml distilled water was mixed into a beaker, left overnight. The pH is measured with an electrode. The pH meter (Piccolo Plus by Hanna instruments) was calibrated using the suitable buffer solution before any readings are to be taken (see Goudie, 1990). The electrode was dipped into the slurry, stirring gently until the instrument showed a stable reading. After each measurement the electrode was rinsed with distilled water.

3.3.4. Ash content and organic matter

The procedure which was used for the determination of the ash content and organic matter is one recommended by Carter et al.(1993).

A sample of 2 grams oven dried soil is placed in a porcelain crucible and placed into the muffle furnace. The furnace temperature is then gradually brought to 375°C and maintained for 1 hour. After which the furnace temperature is raised to 600°C and the sample is ashed for 6 hours. The crucibles are allowed to cool and then place into the oven at 105°C for three hours to remove any moisture which might have accumulated in the cooling off period. The samples are then weighed to and 0.1-mg accuracy and recorded.

The calculation for ash content is:

Ash, g/100g = [(a-c)/(b-c)] * 100

Where a = the final weight (g) of the crucible and ash;
b = weight (g) of crucible and sample;
c = weight (g) of empty crucible.

The above procedure was used to determine the amount of organic matter within the soil sample using the following formula:

% Organic matter = 100 - % mineral content (ash)

3.3.5. Bulk density

The bulk density of soil can be defined as the mass of a unit volume of dried soil. The relationship can be expressed as:

$$Db = \frac{W}{V}$$

Where: Db = is bulk density,
W = dry weight of soil sample,
V = volume of sample.

Samples (indicated on site maps) were collected by hammering a fixed volume core into the soil, using a block of wood as buffer. The samples were placed in ‘zip lock’ plastic bags and into a ‘cooler box’. The volume of sample (V) was calculated by measuring the depth of the core (h) and the radius of the core (r); volume = $h\pi r^2$. The soil samples were oven dried at 105°C for 24 hours. After which the samples were cooled in a dissector, weighed and recorded (see Briggs, 1977; Brady and Weil, 1999).

3.3.6. Hydroperiod assessment and Soil/mottle colour

The hydroperiod of each wetland was assessed with the use of a technique described by Longmore (2001), a study based on Beggs’s (1990) provisional four class system for the assessment of wetland soil moisture (Table 3.3). The hydroperiod of wetlands was indirectly determined using soil morphology criteria, namely; soil/mottling colour, mottling abundance, and soil moisture. In the assessment of the hydroperiod the entire soil profile was examined, as the depth suggested by Begg (1990) and Soil Survey Staff (1975) was found to be too crude for the assessment level which was needed in the study. Thus assessing the hydroperiod only to a depth of 40cm (Begg, 1990) or 50cm (Soil Survey Staff, 1975) was believed to be inadequate for detail needed in the study. As stated by Longmore (2001) the specified depths of 0-10cm and 30-40cm were noted as being too precise as the soil morphology change was only noted between at a coarser level of 20 – 40cms. Therefore, samples were taken at twenty centimetre intervals and the degree of wetness assessed.

Soil and mottle colour was determined with a Munsell colour chart. Not only was soil colour determined but the soil texture as well as the organic matter (peat) for each wetland. This was done to verify the infield assessment as well as check the accuracy of procedures followed in field.

	Degree of wetness			
	Non-Wetland	Temporary	Seasonal	Permanent / Semi Permanent
Matrix Chroma	>3	1 - 3	0 -2	0-1
Mottel 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

Table 3.3. The provisional four class system based on soil morphology for determining the degree of wetness of wetland soils. (Modified after: Begg, 1990 & Longmore, 2001)

3.3.7. Vegetation

Dominant vegetation samples were taken at each of the wetland sites, in an attempt to determine the dominant vegetation types growing on high altitude palustrine wetlands. The vegetation samples were taken at each of the soil sample pits. The vegetation samples were then air dried for 24 hours and identified with the assistance of the Department of Botany at the University of Pretoria.

The results from the laboratory and infield tests of the seven palustrine wetlands investigated are discussed in the following chapter.

Chapter 4: Results

4. The geomorphology, genesis and maintenance of the wetlands

Wetland functioning, maintenance and evolution is governed by factors such as climate, geomorphology, soil characteristics, hydrology and the geology of the area. Due to the fact that all the wetlands studied are situated in the same portion of Giant's Castle Game Reserve, it is postulated that the wetlands will to a certain degree experience the same weather and general climatic conditions. For a wetland to form the area needs surplus water supply (precipitation or surface run off), relatively low temperatures to inhibit organic decomposition and low evaporation rates, and the KwaZulu-Natal Drakensberg can provide the above mentioned requirements. This may be the reason for the large number of wetlands within the KwaZulu-Natal Drakensberg. Added to the above, other factors which are perceived to promote the genesis and maintenance of wetlands are the geomorphology (including topography and micro-topography) of the wetland and surrounding zones, the soil characteristics and hydrology which differ from site to site. Physical characteristics and attributes of the wetlands and the adjacent upland areas were investigated individually, as well as their possible effect on the origin and maintenance on the wetlands assessed. While all the wetlands occupy the upper headward reaches of the Boesmans River the nature of the immediate physical terrain differs from wetland to wetland.

The wetlands were numbered from J1 to J7 and the results for each follow below. On each wetland field map the sample points, cross sections and longitudinal profiles are indicated. Within each wetland a number of soil samples were taken and labelled according to the sequence which removed, e.g. J1:1, J1:2, added to this samples were taken every 20cm into the soil profile, and thus the labelling was J1:1a (from surface to 20cm depth), J1:1b (from 20 - 40cm) until bedrock was struck or the auger was fully extended and no further samples could be taken. Average profile values are provided in this chapter, except where marked contrasts are evident, and all soil analyses values are provided in Appendix A.

4.1. Wetland J1

4.1.1 Relief

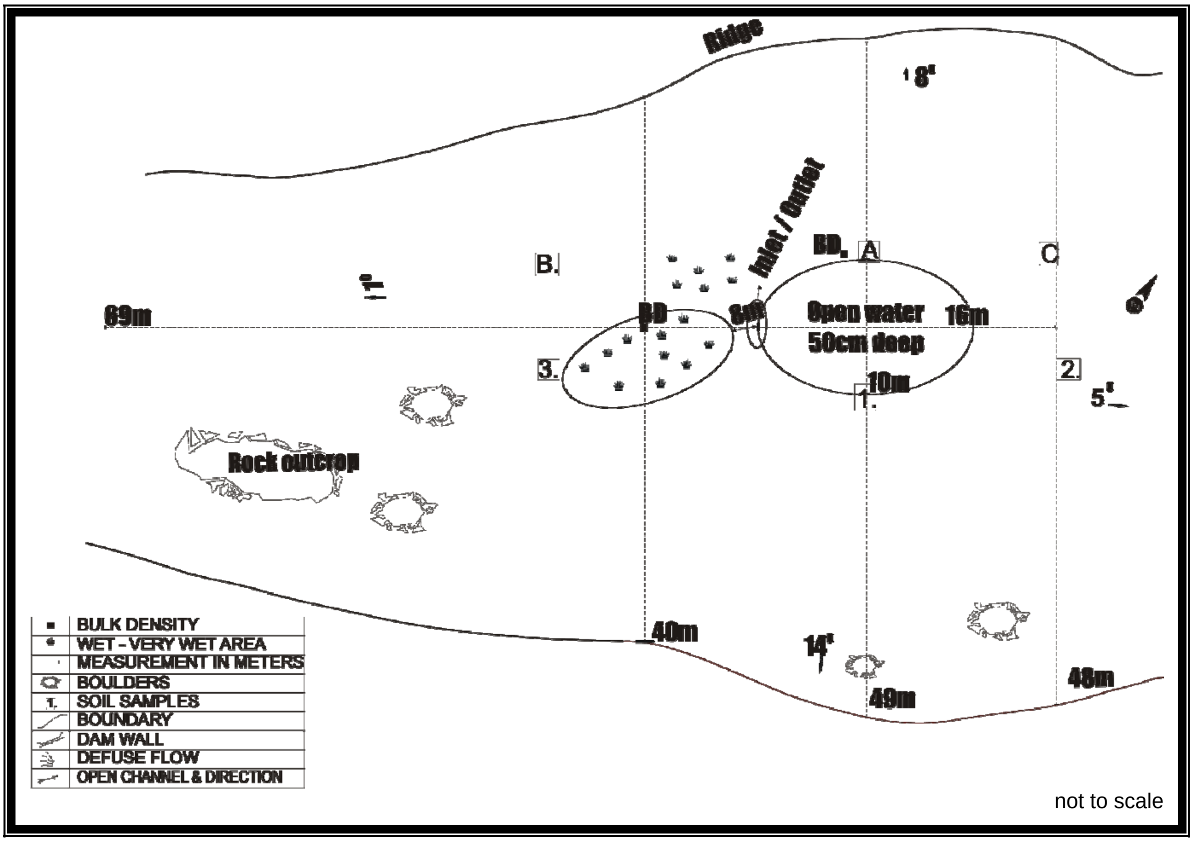
Wetland J1 (Figure 4.1) is situated within position one (plateau) of the nine-unit land surface model (Dalyrymple et al., 1968). J1 can be classified as a pan or depression, as the wetland is basin shaped with a closed elevation contour that is not connected via an outlet to the drainage network (see Ellery et al., 2005). The terrain position is plateau/interfluve zone. The pan itself has a gradient of 0° situated in a depression with an upslope gradient of 10° and a down slope gradient of 2°. Standing water depth 50cm at the time of sampling.

4.1.2. Particle size distribution

Samples were taken inside as well as outside the wetland (Figure 4.1). Sample J1:1 (in the pan) the clay content (53%) was the highest and had the lowest sand (12%) content and silt content of 33% (Figure 4.2).

Within sample J1:2 (20 meters to the NE or right of sample J1:1 in Figure 4.1) the fine particle distribution seems to be more of less equal, sand (32%), silt (40%) and clay (27%). Within sample J1:3 (20 meters to the left of sample J1:1 in Figure 4.1) the sand content is the highest (55%) with the clay fraction (21%) being the lowest and a silt fraction of 24%. In sample J1A, which is to the edge of the pan/depressional wetland, the clay fraction is again the highest at 60%, with silt at 35% and sand being the lowest at 3%. At sample site J1B (15 meters to the left of sample J1A:A) the silt fraction is highest at 38% and the clay fraction is 36% with sand being the lowest of the fine particles at 25%.

In sample J1C (20 meters to the right of sample JA:A) the sand fraction is highest at 45% with clay (28%) and silt (25%) both being low. It should be noted that the clay fraction of the soil increases with depth, where as the sand fraction decreases.



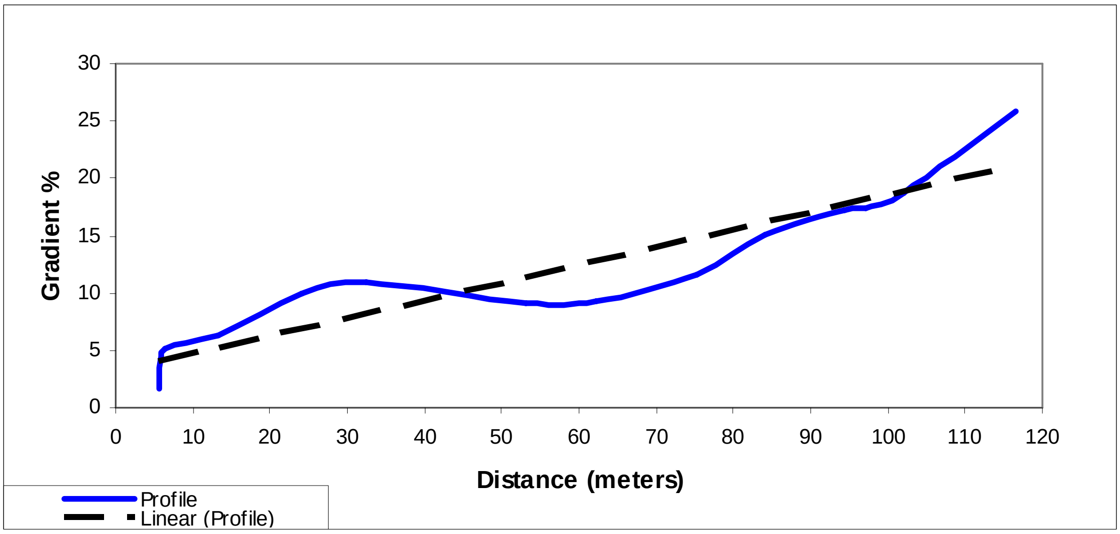


Figure 4.1. Field map and longitudinal profile of wetland J1.

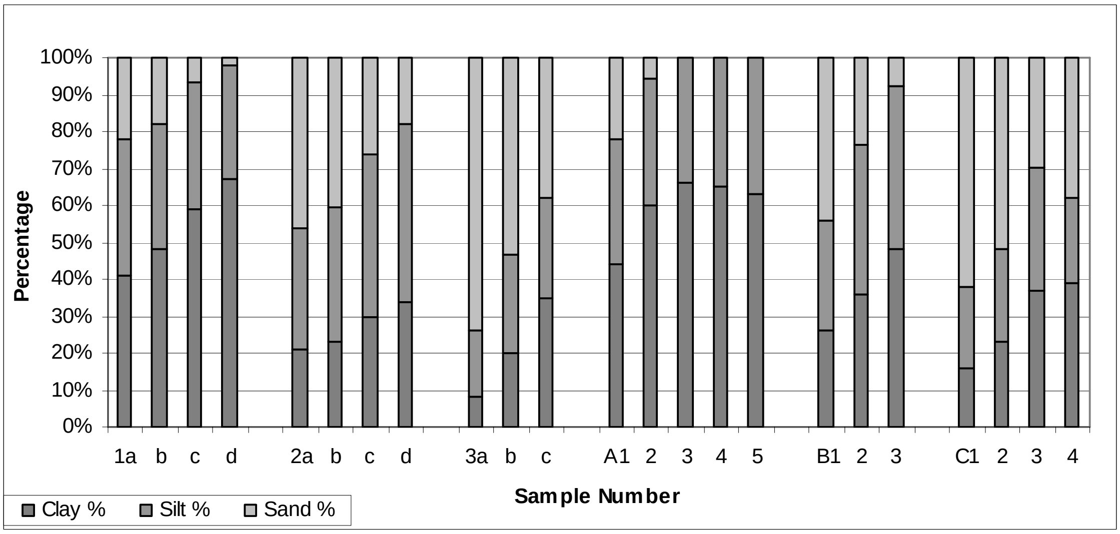


Figure 4.2. Fine particle size analysis for wetland J1.

4.1.3. Soil moisture

In order to compare the soil moisture of each sample site the dry weight will be used as the wet weight relationship between volume of water and percentage moisture content is not constant. Of the six samples (J1:1, J1:2, J1:3, J1:A, J1:B, J1:C) taken sample J1:3 had the highest average moisture content (65%) for sample line J1:1,2,3 and J1:B (46%) the highest for sample line J1:A,B,C (Figure 4.3). This could be due to the fact that both samples were taken out of an area which was highly saturated. Sample J1:3 was significantly wetter then sample J1:2 (31.7%), which was also the lowest moisture content. The soil moisture decreased with depth, indicating that there may be an impermeable clay layer at about 60-80cm, which does not allow the water to penetrate the soil profile. The average soil moisture for wetland J1 was 79%.

4.1.4. Soil pH

Acidity descriptions of the wetlands (Lake, 2000) are in Table 4.1 and values in Figure 4.4.

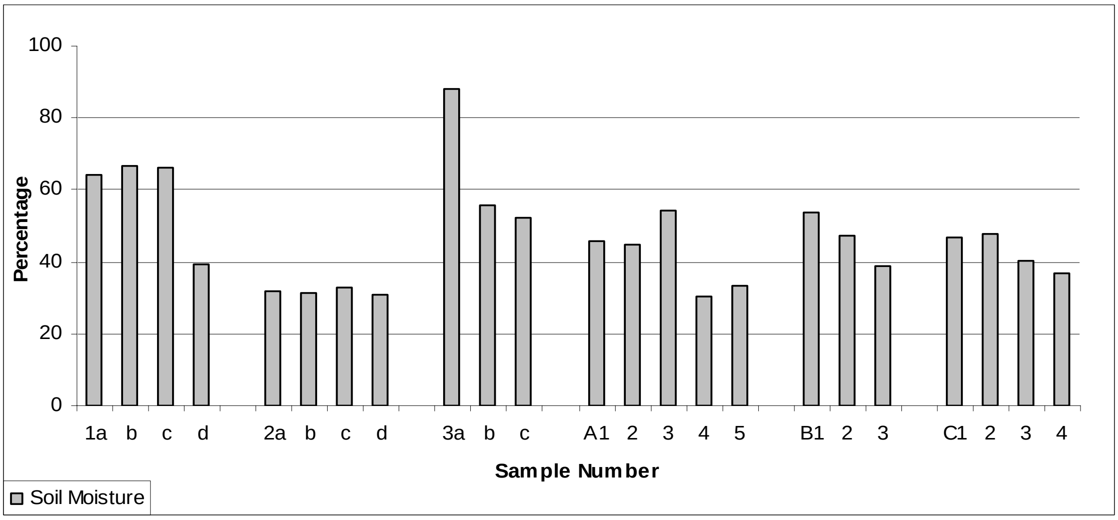


Figure 4.3. Soil Moisture (dry weight) for wetland J1.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE(s)
pH between 4.0 & 4.5	Strongly Acid	
pH between 4.5 & 5.0	Medium Acid	J1:1,2,3
pH between 5.0 & 5.5	Slightly Acid	
pH between 5.5 & 6.0	Very Slightly Acid	

Table 4.1 pH levels within the soils of Wetland J1.

The acidity in the soil ranged 4.81 in J1:1 to 4.93 in J1:3.. All the samples taken from J1 can be classified as medium acid. At a low pH, elements such as phosphorus (P), magnesium (Mg) and calcium (Ca) become less available to the plants. Whereas elements such as aluminium (Al), iron (Fe) and manganese (Mn) may become more available and may also reach levels which are toxic to plants (Lake, 2000). There appears to be no sequence/pattern/correlation in the sample pits related to the depth of the sample and the pH value.

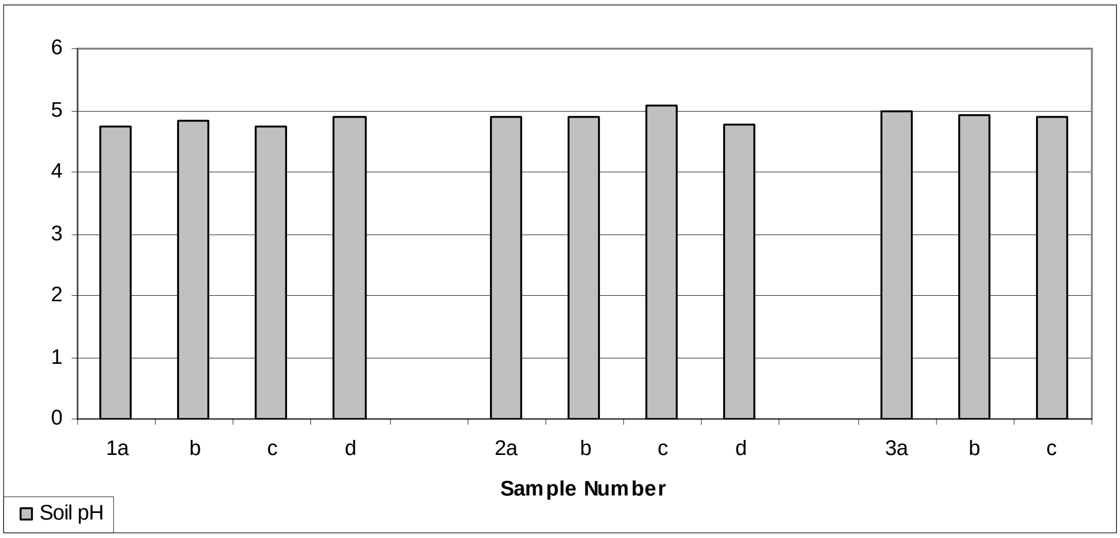


Figure 4.4. Soil pH for wetland J1.

4.1.5. Organic matter and ash content

The average organic matter content for wetland J1 is 8.1%. For Sample J1:1 the recorded average is 8.1% but in the top 20cm the organic matter was 10.3% decreasing to 4.4% at a depth of 80cm. In sample J1:2 (which was taken 20m to the right of J1:1 in the dry land) the average is 7.5% with the highest record percentage of 9.8% in the top 20cm, again decreasing in depth to 4.8% at 80cm. Sample J1:3 (20m to the SW or left of J1:1 in Figure 4.1 in a very wet area) average organic content is 15.2%, decreasing with depth to 7% at 60cm. Samples J1:A-C were taken perpendicular to samples J1:1-3. This was done to establish if there was any key variation in the wetland area. In sample J1:A (taken in the pan) the organic matter content is 8.5% decreasing to 2% at 1m. Sample J1:B (which was 20m to the left of J1:A, in a very wet area), the organic content was 14% decreasing to 7% at 45cm. Sample J1:C (15m to the left of J1:A) the organic content was 10.5% decreasing to 5% at a depth of 90cm.

The highest recorded percentage of was found in sample J1:3 at 15.2% within the top 20cm, the lowest percentage was found at a depth of 1m (2%) at sample pit J1:A. Ash content proportions are given in Figure 4.5.

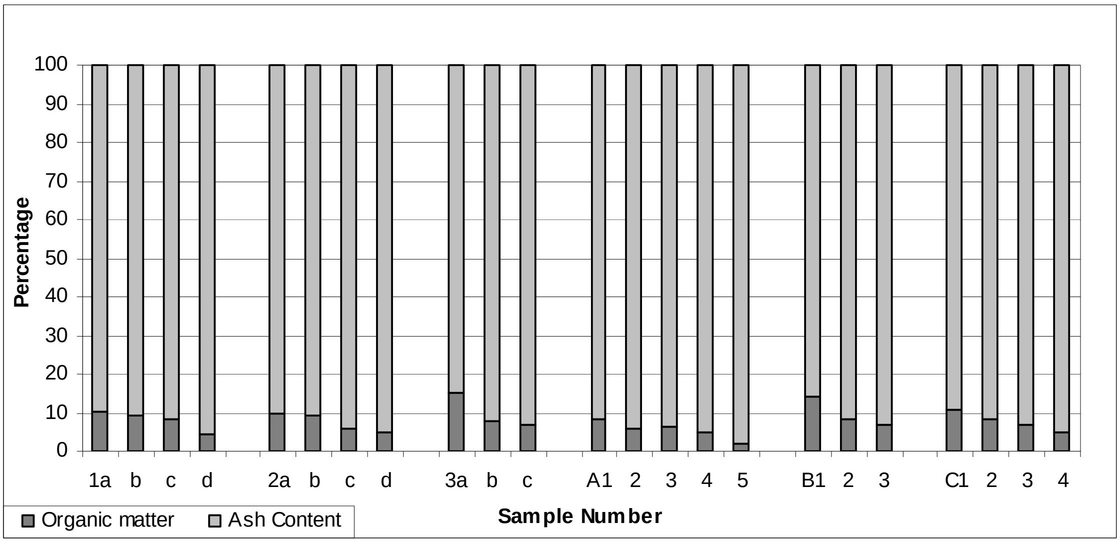


Figure 4.5. Organic matter and ash content proportions within wetland J1.

4.1.6. Bulk density

As can be expected the bulk density samples taken were very low (the sample was taken adjacent to J1:A) the bulk density of the soil was 0.23g/cm³. A second bulk density sample was taken (between sample J1 and J3) in the dry area and had a reading of 0.33g/cm³. Both these samples give very low values and deducting from this the soils have a high organic content and could be classified as Histosols.

4.1.7. Soil and mottle colour

The soil and mottle colour was determined using the Munsell chart. Each soil sample was checked against the colour chart (in a wet state i.e. not air dried), added to this the mottle abundance as well as the mottle colour was recorded. The stoniness of the each soil sample was determined by rubbing the sample between fingers as well as close investigations. In all the samples taken from J1 only two samples could be classified as granular (J1:2a and J1:2b), two samples were classified as blocky (J1:2c and J1:2d), and two more samples were classified as a little gritty (J1:A4 and J1:A5). The soil colour according to the Munsell chart ranged from yellowish brown (10yr5/4) to dark bluish grey (5 pb 4/1) to greenish black (10 y 2.5/1) to black (2.5 y 2.5/1). The mottle colour for J1 ranged from reddish yellow (7.5 yr 6/8) to strong brown (7.5 yr

5/6). The average mottle abundance for J1 was 20%. For an individual look at each sample colour see Appendix B.

4.1.8. Vegetation

A general vegetation identification was done in and surrounding the wetland and the dominant vegetation is outlined in Table 4.2.

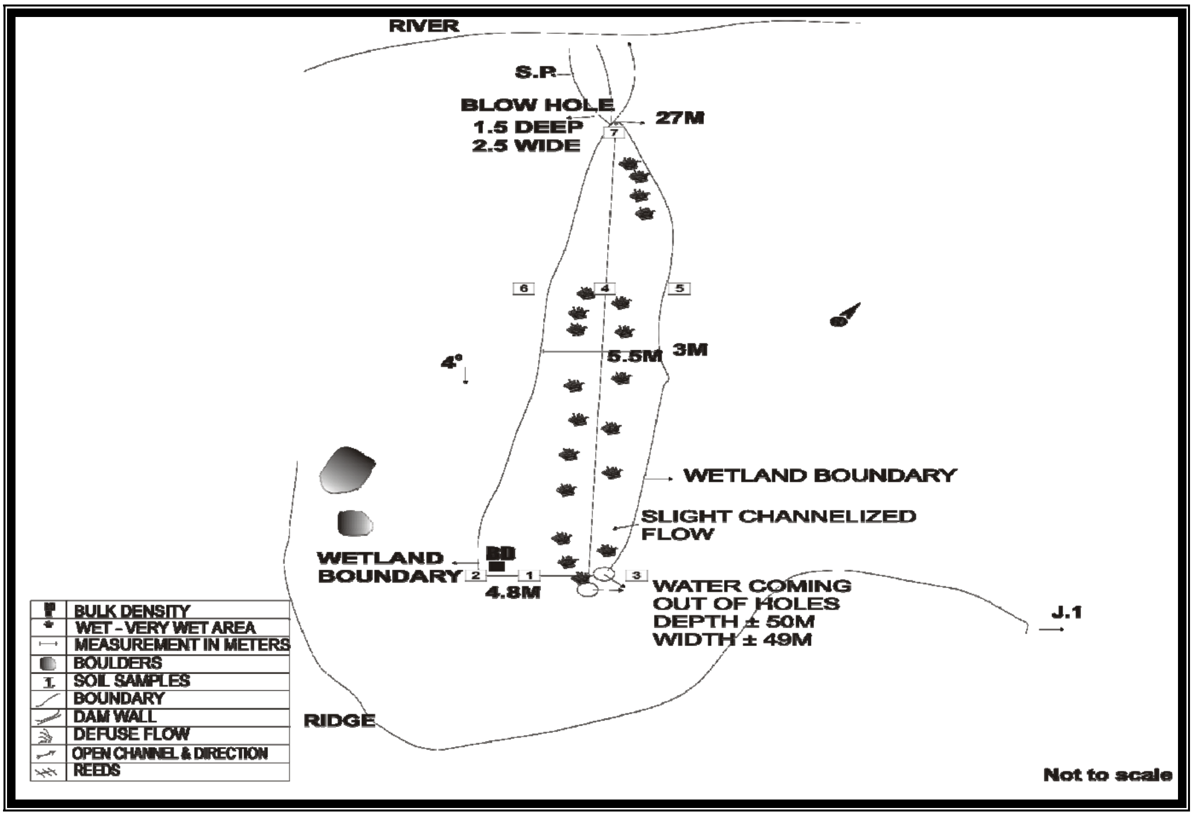
Grasses	Forbs	Sedges
Styppeiochloa gynoglssa (*Poaceae*)	Mentha aquatica (*Lamiaceae*)	Eleocharis dregeana (*Cyperaceae*)
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	
	cf Hibiscus (*Malvaceae*)	
	Senecio decurrens (*Asteraceae*)	
One sample of a Vascular plant or Tracheophyte was found: cf Hypoxis rigidula (*Hypoxidaceae*).		

Table 4.2. Dominant grasses, forbs and sedges found in J1 (with the family name in italic).

4.2. Wetland J2

4.2.1 Relief

Wetland J2 is only 70m to the south east of wetland J1 but despite this it is situated within unit five of the nine-unit land surface model (Dalyrymple et al., 1968). Wetland J2 landform setting is hillslope seepage feeding a stream. A convex slope characterized by the colluvial movement of materials. Outflow is typically by channel into a drainage network (see Ellery et al. 2005). It is noted that outflow from wetland J2 is not directly into a stream or river, but it flows into a number of small soil pipes (the inlet is not visible, the outlets into the river are visible) which drain the wetland. The length of the soil pipes range from 1.5m to 2.5m and with a diameter in region of 50cm. Wetland J2 has no clearly defined channels, and is well vegetated. The water source for J2 is two springs (±50cm deep and ±60cm wide) which overflow on to the wetland area, and it can be expected that subsurface flow is also contributing to the wetland conditions. The average gradient for wetland J2 is 4° (Figure 4.6).



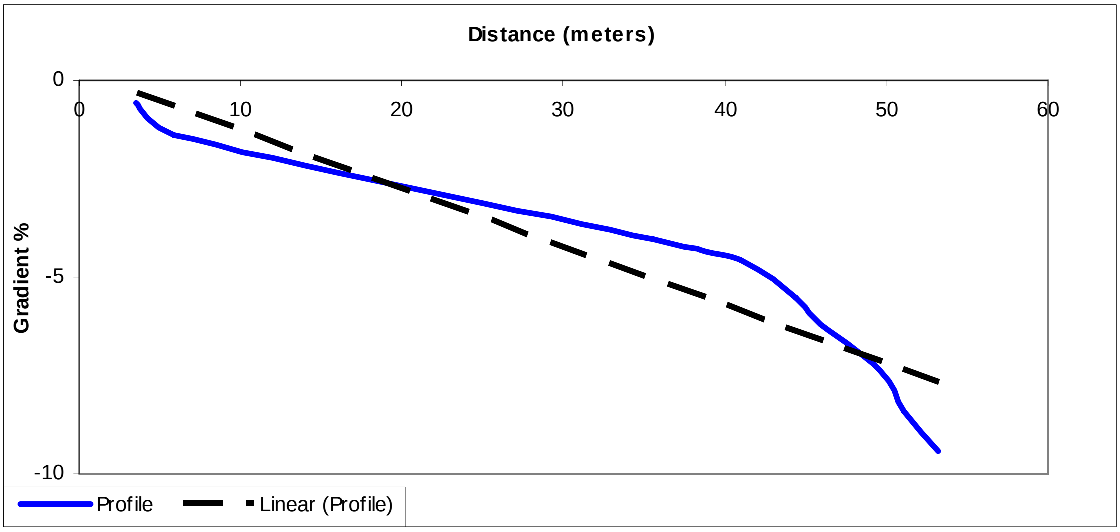


Figure 4.6. Field map and longitudinal profile of wetland J2

4.2.2. Particle size distribution

Sample J2:1 was taken at the source and lateral centre of the wetland (Figure 4.6). Within sample J2:1 the sand fraction is the highest (51%) and the silt fraction is second at 33% with clay being the lowest at 16% (Figure 4.7). In sample J2:2 (which is 1.5 meters to the south west or left of sample J2:1 as it appears in Figure 4.6) once again the sand fraction is highest at 49%, the slit fraction is 29%, and the clay fraction being lowest at 22%. In sample J2:3 (which is 1.5 meters to the right of sample J2:1 in Figure 4.6) the sand fraction again the highest at 42%, with silt being second with a percentage of 36% and clay being the lowest at 22%. In sample J2:4 (which is 10 meters from J2:1 in the centre of the wetland) the sand fraction is highest at 42% with the silt fraction being 32% and clay the lowest at 25%. At sample J2:5 (which is 2 meters to the right of sample J2:4) the silt fraction (37%) is marginally higher than the sand fraction (36.5%) with the clay fraction being the lowest at 26%. At sample J2: 6 (which is 2 meters to the left of sample J2:4) the sand fraction is the highest at 46% and clay the lowest at 21%, the slit fraction within the sample is 33%. Sample J2:7 (which is 17 meters from J2:4, in the centre of the wetland and at the end of the wetland where is enters in to a soil pipe which again enters a low order stream) here the fine particle distribution is as follows, sand (33%), silt (39%) and clay (27%).

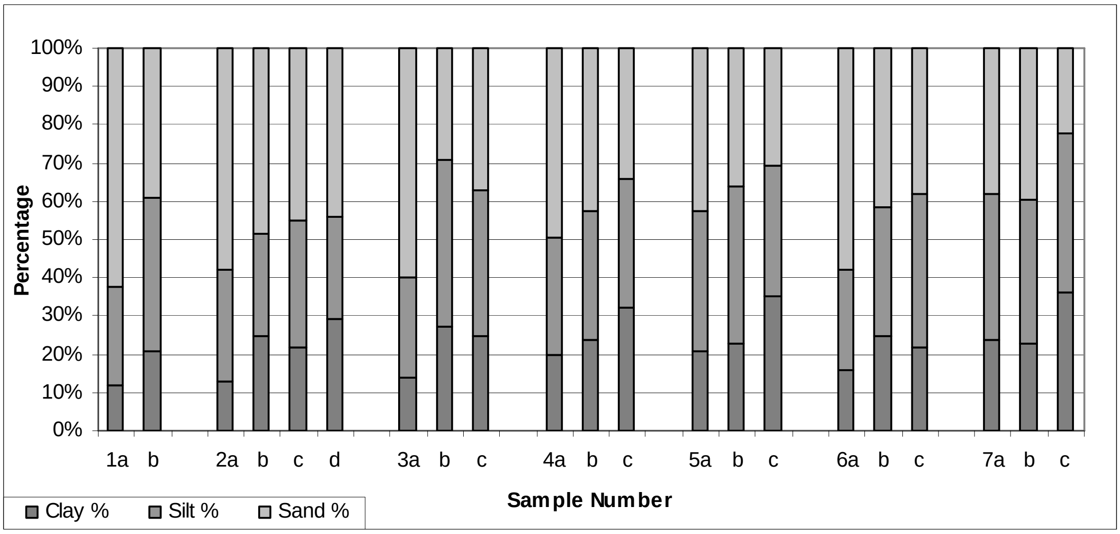


Figure 4.7. Fine particle size analysis for wetland J2

4.2.3. Soil moisture

In order to compare the soil moisture of each sample pit the dry weight will be used as the wet weight relationship between volume of water and percentage moisture content is not constant. The highest average soil moisture was recorded at sample J2:1 (58.7%), the lowest average soil moisture came from sample J2:2 at 28.8% (Figure 4.8). The soil moisture content declines with depth. As can be expected the samples which were taken down the centre of the wetland have more moisture then the samples from the outer edges of the wetland. The average soil moisture for wetland J2 was 41%.

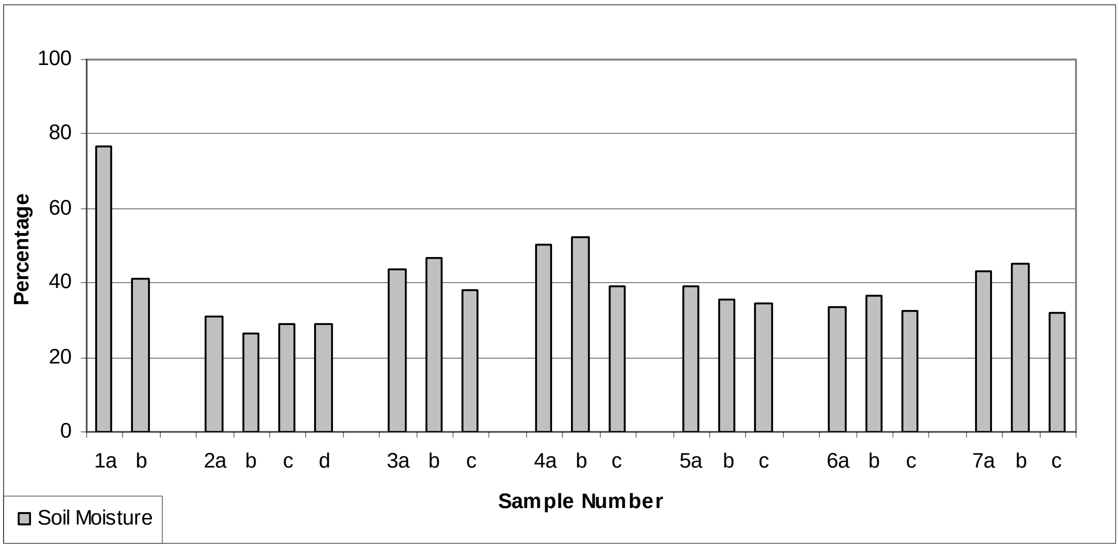


Figure 4.8. Soil moisture (dry weight) for wetland J2.

4.2.4. Soil pH

Samples were taken on a longitudinal transect down the wetland from source to outlet (Figure 4.6). Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.3 and values shown in Figure 4.9. The acidity in the soil ranged 5.4 (slightly acid) in J2:1 to 5.8 (very slightly acid) in J2:7. In samples J2:4 and J2:7 the pH of the soil increases with depth, the opposite is true for J2:1. In wetland J2 it is noted that the acidity of the wetland decrease from source to the outlet of the wetland into a small stream. The average pH for J2 is 5.64. Although J2:4 and J2:7 both show marginal increases in pH with soil depth, there appears to be no general correlation in the sample pits related to the depth of the sample and the pH value.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE(s)
pH between 4.0 & 4.5	Strongly Acid	
pH between 4.5 & 5.0	Medium Acid	
pH between 5.0 & 5.5	Slightly Acid	J2:1,4,7
pH between 5.5 & 6.0	Very Slightly Acid	

Table 4.3 pH levels within the soils of wetland J2.

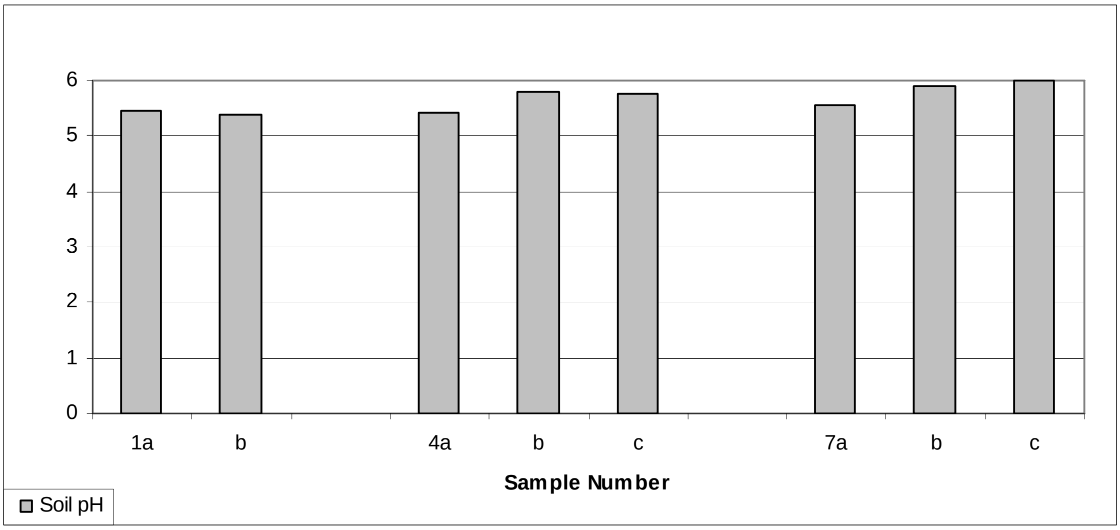


Figure 4.9. Soil pH for wetland J2.

4.2.5. Organic matter and ash content

The average organic matter for wetland J2 is 6.3%. In sample J2:1 the average organic matter is 7%. The organic matter in J2:1 decreases from 9% in the top 20cm to 5% in the lower 40cm. In sample J2:2 the average organics is 5.5%. The organic matter decreases from 8.5% in the top 20cm to 3.5% in the bottom 80cm. J2:3 average is 10%, with the highest organic matter recorded in the top 20cm (15%) and the lowest in the bottom 80cm (7%). Sample J2:4 organic matter average is 5.1%, with the highest recorded organic content again at 20cm (5.5%) and the lowest at 60cm (5%). J2:5 has an average organic content of 4.7%, with 5% being measured at 20cm and the 4.5% measured at 60cm. In sample J2:6 the average is 5.5%, having the most organics (6.6%)

at 20cm and the least at 80cm (4.5%). J2:7 average is 6.2%, with the top 20cm having 7.4% and the bottom 60cm 5%. Ash content proportions are given in Figure 4.10.

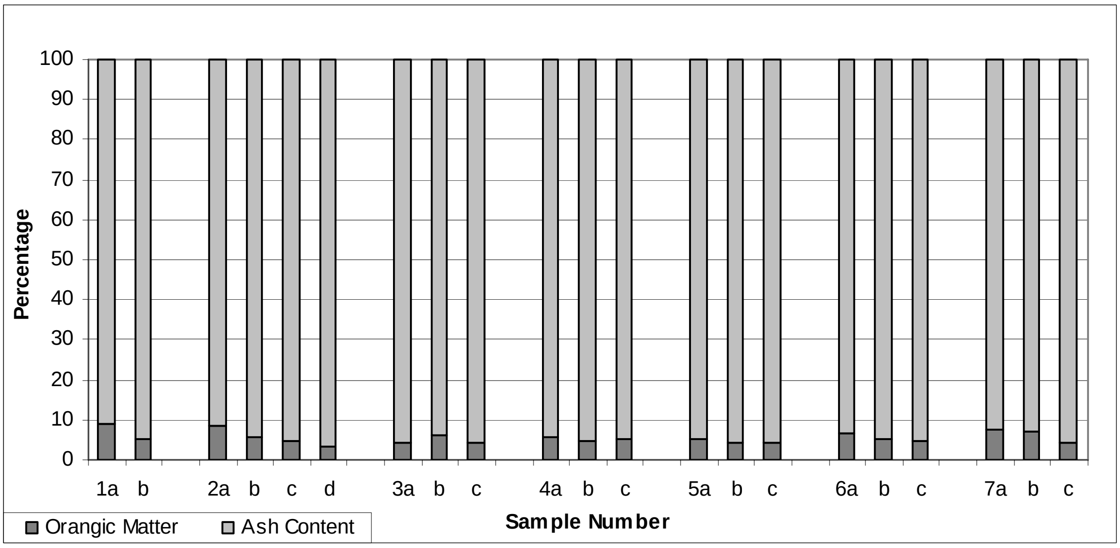


Figure 4.10. Organic matter and ash content proportions within wetland J2.

4.2.6. Bulk density

The bulk density samples were low in value, (the sample was taken adjacent to J2.2) the density of the soil was 0.96g/cm³. Although this is low it is higher then the bulk density of J1 which has an average of 0.28g/cm³. Wetland J2 may thus have a loamy A horizon and clayed oxisal Ap horizons according to Brady (1999).

4.2.7. Soil and mottle colour

The soil and mottle colour was determined using the Munsell chart. Each soil sample was checked against the colour chart (in a wet state i.e. not air dried), added to this the mottle abundance as well as the mottle colour was recorded. The stoniness of the each soil sample was determined as per J1. In all the samples taken from J2 two samples could be classified as sandy (J2:1a and J2:3a), one sample was classified as having few small stones (J2:2a), one sample was classified as having small stones (J2:2b), four samples were classified as having aggregates in the soil (J2:6a, J2:6b, J2:6c, and J2:7a). The soil colour according to the Munsell chart ranged from dark yellowish brown (10 yr 4/4) to bluish black (2.5 5/5 pb) to reddish black (2.5 yr 2.5/1) to black (5 yr 2.5/1). The mottle colour for J2 ranged from yellowish red (5 yr 4/6) to strong brown (7.5 yr 5/6). The average mottle abundance for J2 was 6%. For an individual look at each sample colour see Appendix B.

4.2.8. Vegetation

General vegetation characteristics were noted in and around the wetland are outlined in Table 4.4

Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	Schoenaplectus sp (*Cyperaceae*) Eleocharis dregeana (*Cyperaceae*)

Table 4.4 Dominant grasses, forbs and sedges found in J2 (with the family name in italic).

4.3. Wetland J3

4.3.1. Relief

Wetland J3 is located in zone 5 (transportational midslope) in the hypothetical nine-unite land surface model (Dalyrymple et al., 1968). The landform setting for J3 is hillslope seepage feeding a stream (see Ellery et al., 2005). Wetland J3 is well vegetated with no channels. The average gradient for wetland is 9°. The chief movement of water is in the form of diffuse flow and has one small area of open standing water (Figure 4.11). The wetland drains into a low order stream.

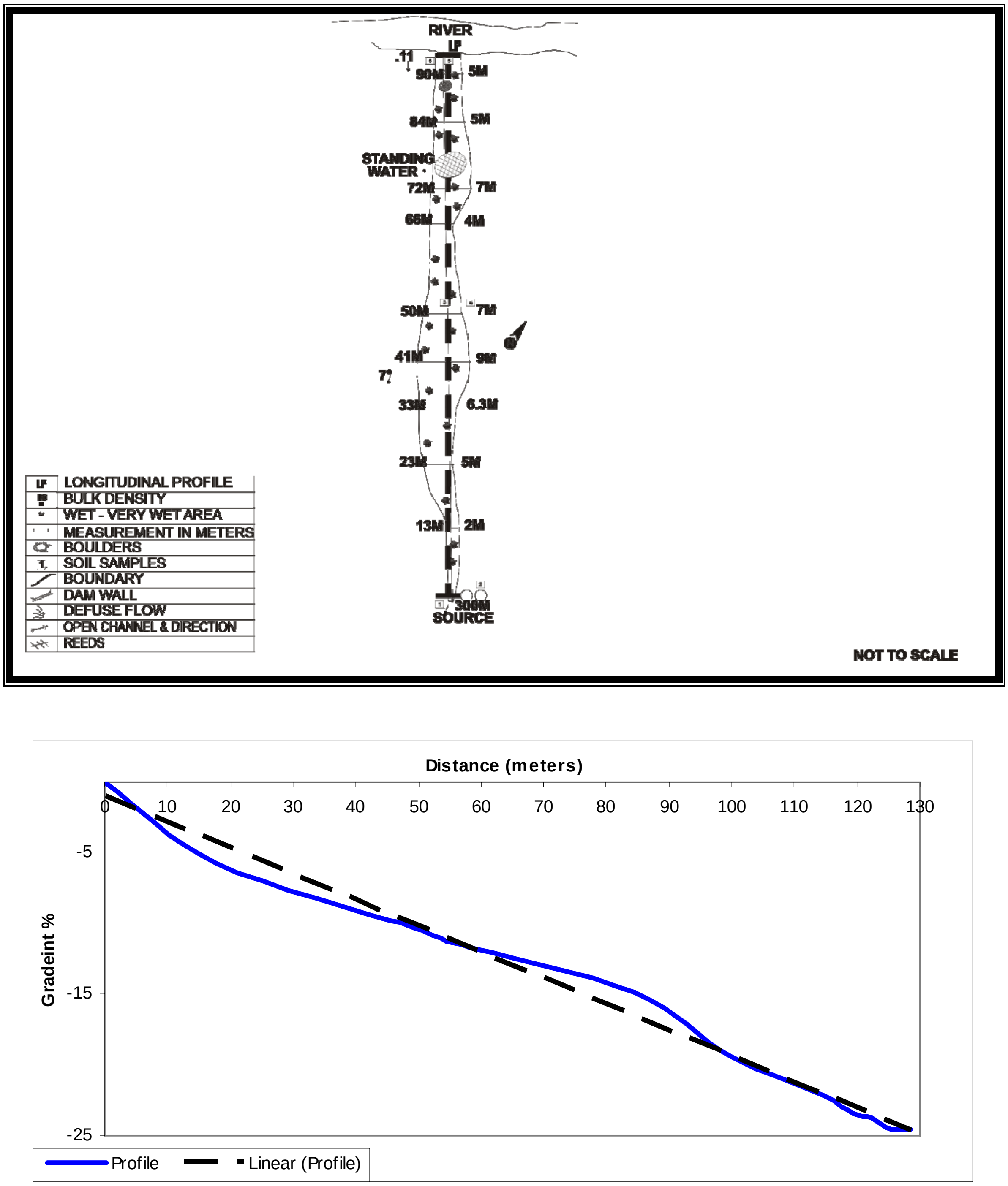


Figure 4.11. Field map and longitudinal profile of wetland J3

4.3.2. Fine particle analysis

Sample J3:1 was taken at the source and centre of the wetland. In sample J3:1 the sand fraction is the highest at 54%, silt fraction is second at 28% with clay being the lowest at 16% (Figure 4.12). In sample J3:2 (which is 10 meters to the right of sample J3:1 on Figure 4.11) the sand fraction very high at 63% with silt being 26%, and the clay fraction low at 12%. In sample J3:3 (is 50 meters from sample J3:1 and in the centre of the wetland) as in the previous samples the sand fraction is highest (53%), with the silt being second (28%) and the clay fraction is the lowest (19%). Sample J3:4 (is 10 meters to the left of sample J3:3) in this sample the sand fraction is highest at 68%, silt second at 24%, and clay is very low at 9%. In sample J3:5 (which is 46 meters from J3:4 in the centre of the wetland at the exit into a low order stream) here as before the sand fraction is highest at 60%, silt at 26% and the clay fraction is lowest at 15%. Sample J3:6 (is 15 meters to the right of sample J3:5) once again sand is highest at 70%, silt 22% and clay low at 12%.

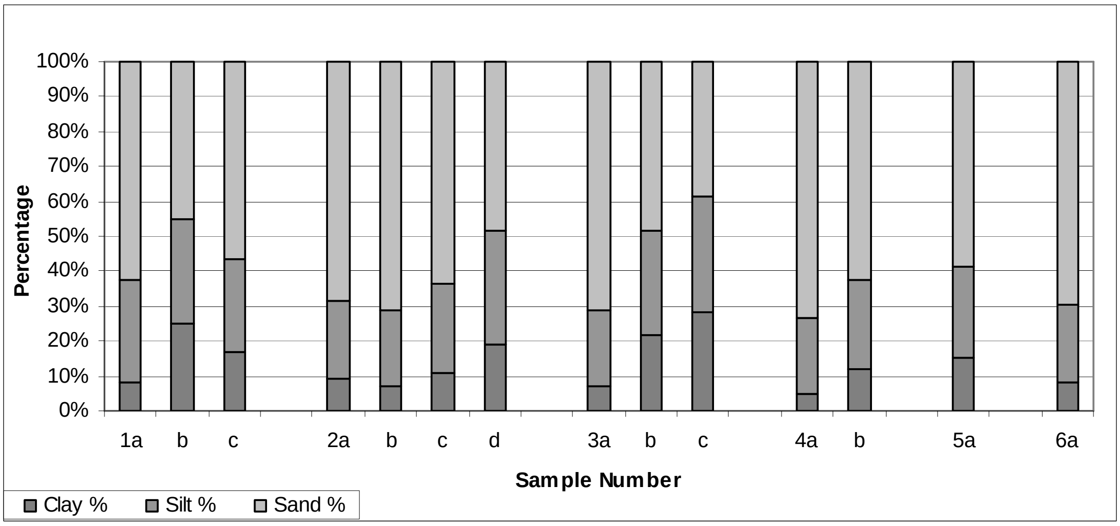


Figure 4.12. Fine particle size analysis for wetland J3

4.3.3. Soil moisture

The highest average soil moisture for wetland J3 was recorded at sample J3:1 (145.7%), the lowest average soil moisture came from sample J3:6 at 46.6% (Figure 4.13). The soil moisture content declines with depth. As can be expected the samples which were taken down the centre of the wetland have more moisture then the samples from the outer edges of the wetland. The average soil moisture for wetland J3 was 81%. As previously mentioned in the case of peat soils it is well know that values of up till 200% may be found, (Briggs, 1977; Goudie 1990), thus the results from J3 indicate a high organic content.

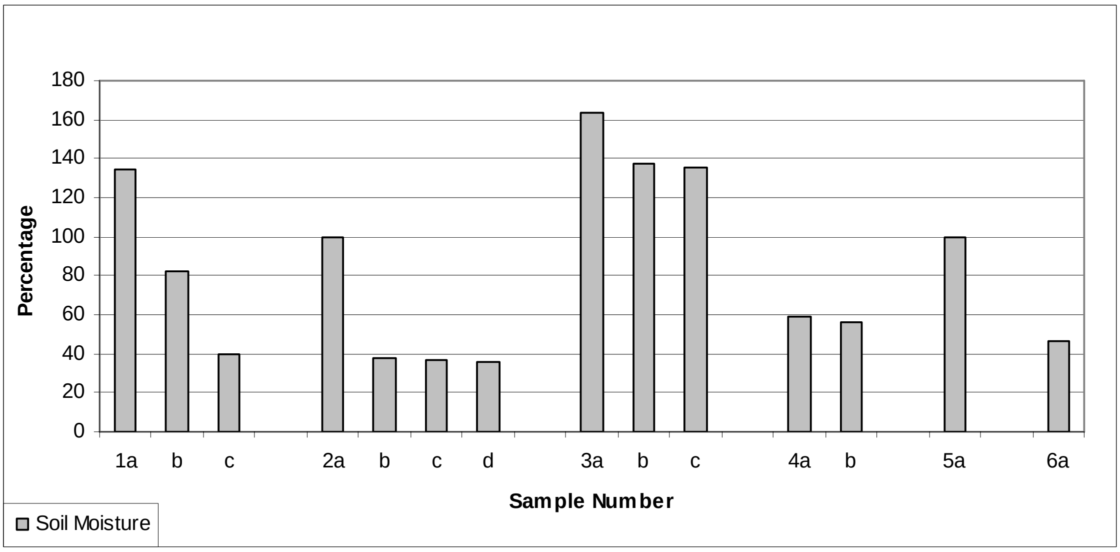


Figure 4.13. Soil moisture (dry weight) for wetland J3.

4.3.4. Soil pH

No pH analysis was undertaken for wetland J3 since the site had been recently burnt at the time of sampling which could affect pH readings.

4.3.5. Organic matter and ash content

The average organic matter for wetland J3 is 11.8%. In sample J3:1 the average organic matter is 9.7%. The organic matter in J3:1 decreases from 13.5% in the top 20cm to 3.5% in the lower 1m. In sample J3:2 the average organics is 6.9%. The organic matter decreases from 7.5% in the top 20cm to 5.5% in the bottom 80cm. Sample J3:3 has an average of 17%, with the highest organic matter recorded in the top 20cm (18.5%) and the lowest in the bottom 1m (14%). Sample J3:4 organic matter average is 11.5%, with the highest recorded organic content again at 20cm (13.5%) and the lowest at 30cm (9.5%). J3:5 has an average organic content of 14%, no soil sample could be retrieved from lower down as the soil was too wet to extract. In sample J5:6 the average is 12%, once again the soil was too wet to retrieve a soil sample further down the profile. Ash content proportions are given in Figure 4.14.

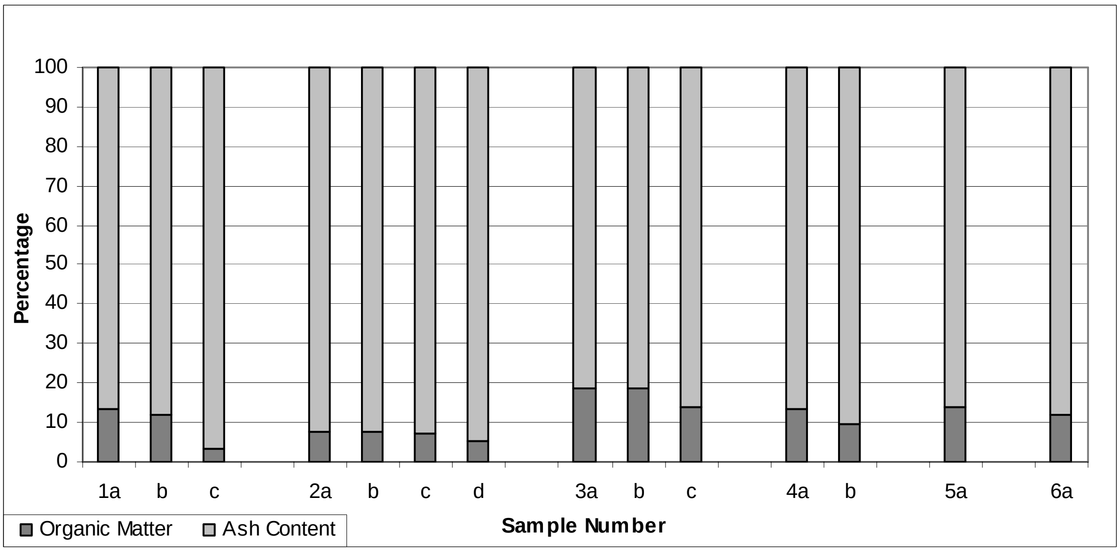


Figure 4.14. Organic matter and Ash Content for wetland J3

4.3.6. Bulk density

The soil samples which were taken for bulk density were very low, (the sample was taken adjacent to J3:3) the bulk density of the soil was 0.15g/cm³. The second bulk density sample was taken at J3:6 and had a reading of 0.17g/cm³. Both these samples are very low and deducing from this the soils have a high organic and can be classified as Histosols.

4.3.7. Soil and mottle colour

The soil and mottle colour was determined using the Munsell chart. Each soil sample was checked against the colour chart (in a wet state i.e. not air dried), added to this the mottle abundance as well as the mottle colour was recorded. The stoniness of the each soil sample was determined as noted before and in all but one sample, the samples taken from J3 could be classified as gritty (J3:1a, J3:1b, J3:6a), one sample was classified as very gritty (J3:1c). The soil colour according to the Munsell chart ranged from dark yellowish brown-black (10 yr 4/6-2.5/n) to very dark grey (2.5 yr 3/1) to black-very dark brown (10 yr 2/1-10 yr 3/2) to different shades of black (2.5/n, 5 y2.5/1, 7.5yr 2.5/1, and 10 yr 2/1). Only one soil sample was found to have mottles, the colour of which was brownish yellow (10 yr 6/8) . For an individual look at each sample colour please see Appendix B.

4.3.8. Vegetation

No vegetation samples were taken as the wetland was recently burnt at the time of the site visit.

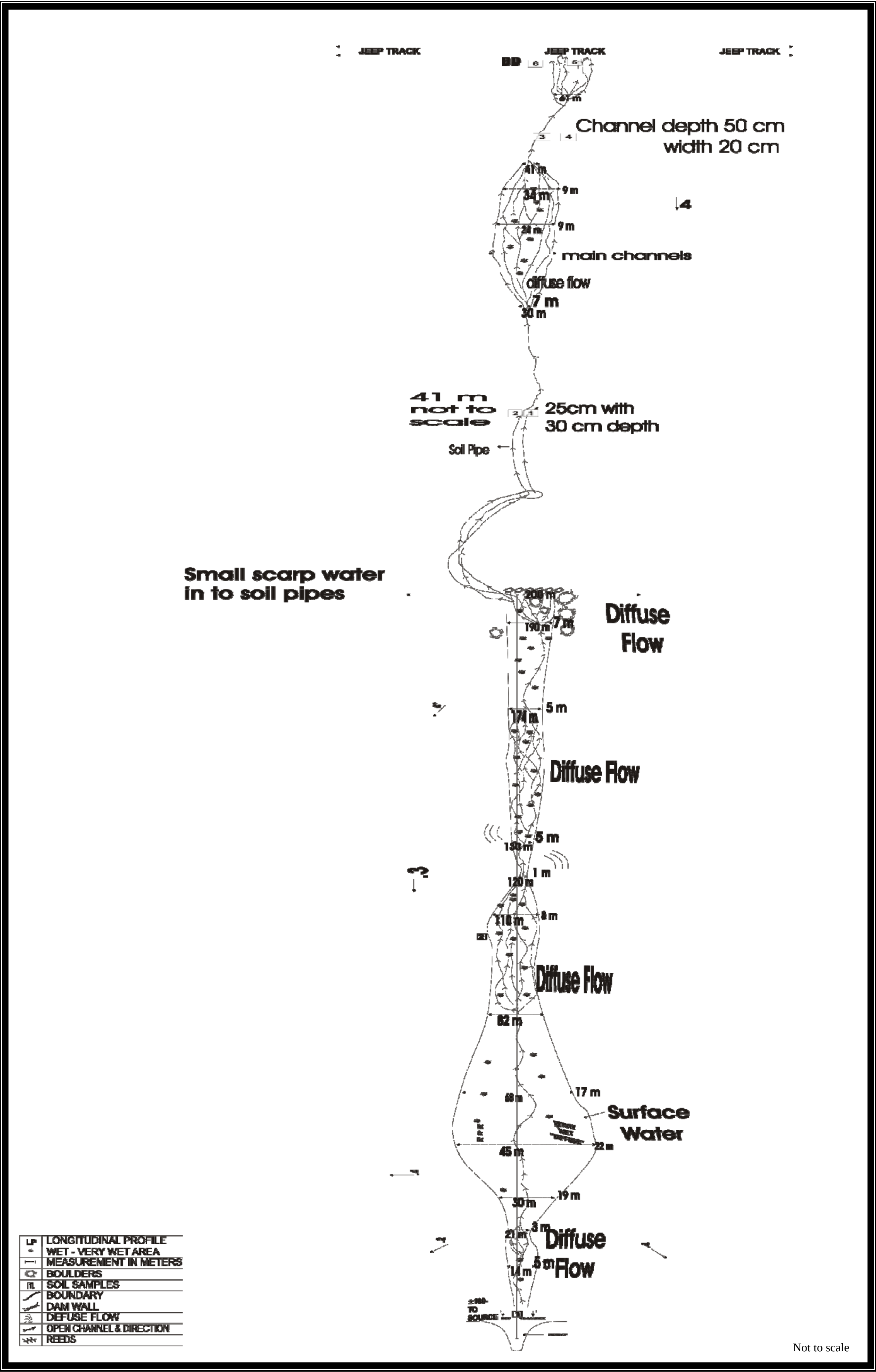
4.4. Wetland J4

4.4.1. Relief

Wetland J4 (Figure 4.15) is located in unit five of the hypothetical nine-unit land surface model (Dalyrymple et al., 1968) It must be noted at this point that J4 is a narrow wetland and can also be classified as a source seepage zone leading into wetland J5. The average gradient for J4 is 2.5°. Within wetland J4 there is a combination of channelled and diffuse flow. The channels are 10 to 30cm wide and 10 to 40cm deep, in certain sections in the proximity of the channel the area is wet, whereas in other sections the channel has a strong draining effect on the surrounding area. Side wall collapse was noted at wetland J4, thus indicating erosion which may be caused by the over flow of the channel during high rainfall events. At the end of J4 before is enters J5 there is a small water fall which was used as the divide between the two wetlands. It was noted that not all the water flow goes over the waterfall as part of the water flows around into a soil pipe which reappears at the start of J5.

4.4.2. Fine particle analysis

Due to the fact that J4 is a very narrow wetland/drainage line samples were only taken in the centre of the wetland. J4 forms part of J5 as it the top section. Sample J4:1 has a sand content of 50%, a silt content of 34% and a clay content of 17% (Figure 4.16). In sample J4:2 (is 100 meters from J4:1) the sand and silt fraction are very similar, 44% and 40% respectively, with clay being only 15%.


JEEP TRACK
JEEP TRACK
JEEP TRACK
Channel depth 50 cm
width 20 cm
41 m
34 m
9 m
9 m
main channels
diffuse flow
7 m
30 m
41 m
not to
scale
25cm with
30 cm depth
Soil Pipe
Small scarp water
in to soil pipes
Diffuse
Flow
190 m
7 m
5 m
174 m
Diffuse Flow
5 m
130 m
1 m
120 m
118 m
Diffuse Flow
82 m
17 m
Surface
Water
45 m
22 m
30 m
19 m
21 m
3 m
Diffuse
Flow
5 m
14 m
TO
SOURCE
LP LONGITUDINAL PROFILE
WET - VERY WET AREA
MEASUREMENT IN METERS
BOULDERS
SOIL SAMPLES
BOUNDARY
DAM WALL
DEFUSE FLOW
OPEN CHANNEL & DIRECTION
REEDS
Not to scale

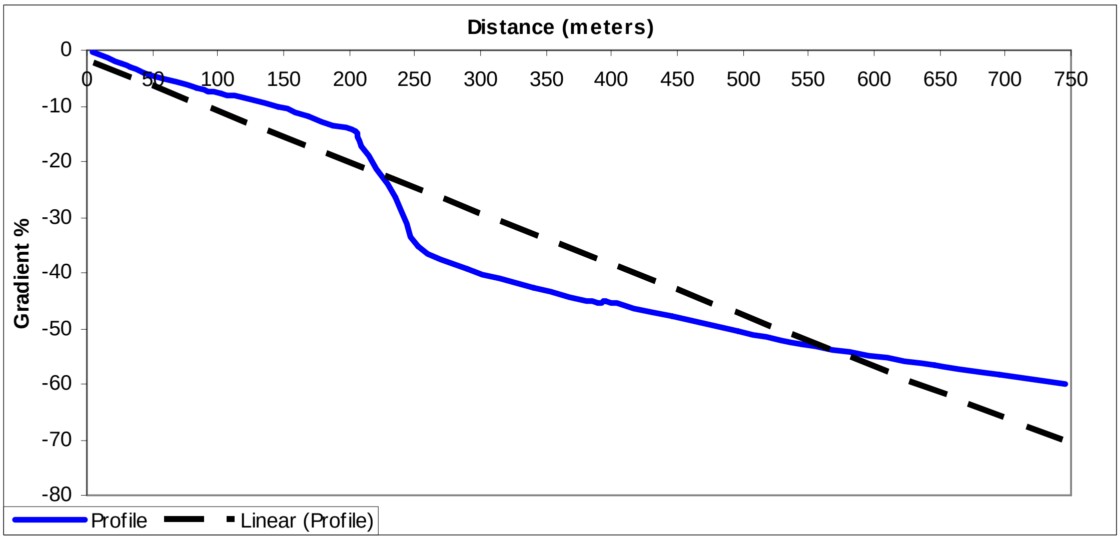


Figure 4.15. Field map (preceding page) and longitudinal profile of wetland J4-5.

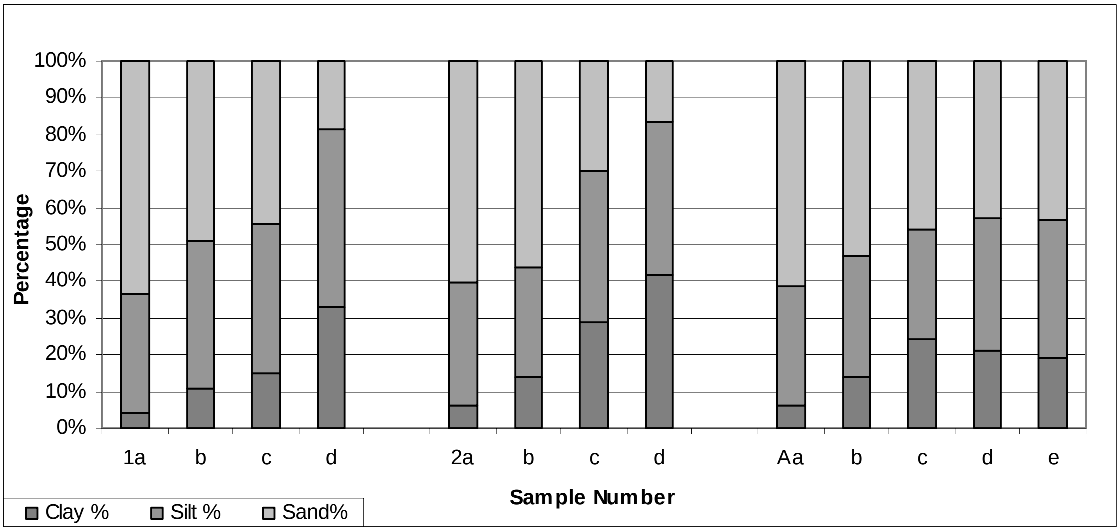


Figure 4.16. Fine particle analysis for J4

4.4.3. Soil moisture

The highest average soil moisture was recorded at sample J4:1 (93.1%), the lowest average soil moisture came from sample J4:A at 34.4% (Figure 4.17). The soil moisture content declines with depth. All the samples except J4:A were taken in the centre of the wetland. The average soil moisture for wetland J3 was 65.6% and the results from J4:1 and J4:2 indicates a high organic content in the upper 40cm of soil.

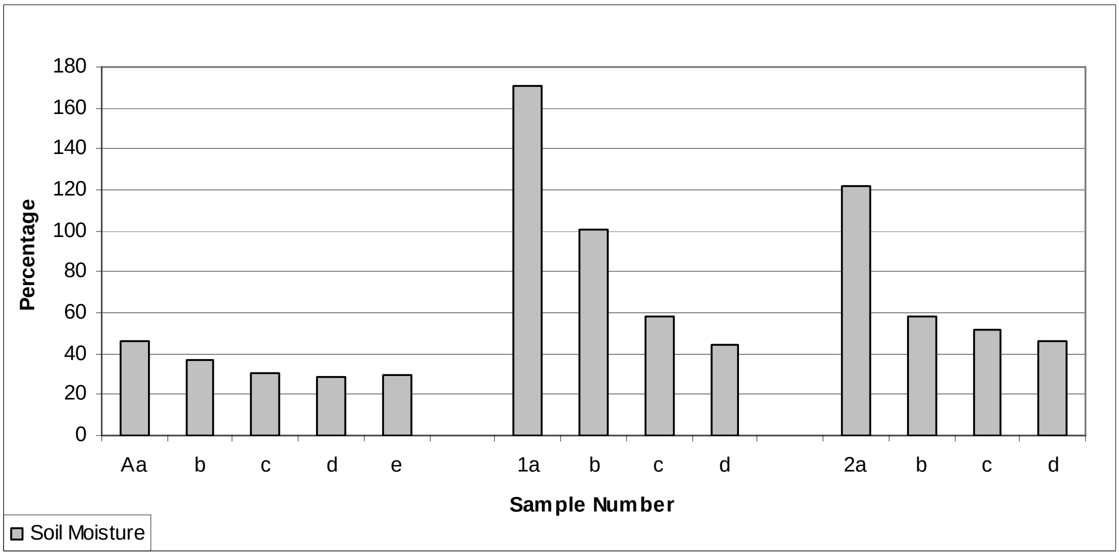


Figure 4.17. Soil moisture (dry mass) for wetland J4.

4.4.4. Soil pH

One pH sample was taken at the source of the wetland, as J4 flows into J5. The acidity in the soil profile ranges from medium acid (4.95 in J4:1a top 20cm) to slightly acid (5.48 in J4:1d bottom 1m). Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.5 and values in Figure 4.18.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE #
pH between 4.5 & 5.0	Medium Acid	J4:1
pH between 5.0 & 5.5	Slightly Acid	J4:1d

Table 4.5. Acidity descriptions for wetlands J4

4.4.5. Organic matter and ash content

The average organic matter for wetland J4 is 9.5%. In sample J4:A the average organic matter is 6.5%. Organic matter in J4:A decreases from 9.5% in the top 15cm to 7% in the lower 1.2m. In sample J4:1 the average organics is 11.9%. The organic matter decreases from 19% in the top 20cm to 8% in the bottom 1m. J4:2 average is 10.1%, with the highest organic matter recorded in the top 20cm (19.5%) and the lowest in the bottom 1m (5%). Ash content proportions are given in Figure 4.19.

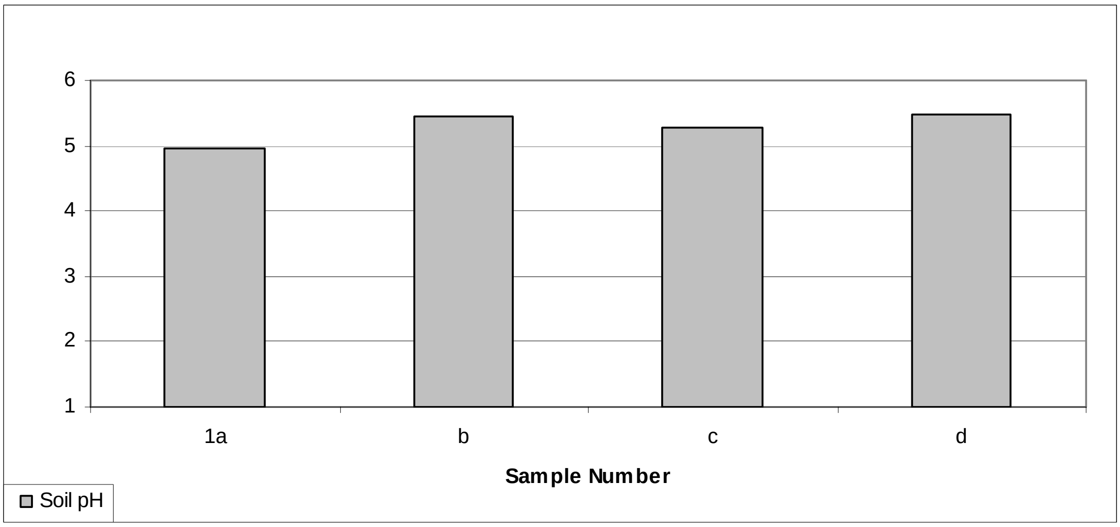


Figure 4.18. Soil pH for wetland J4

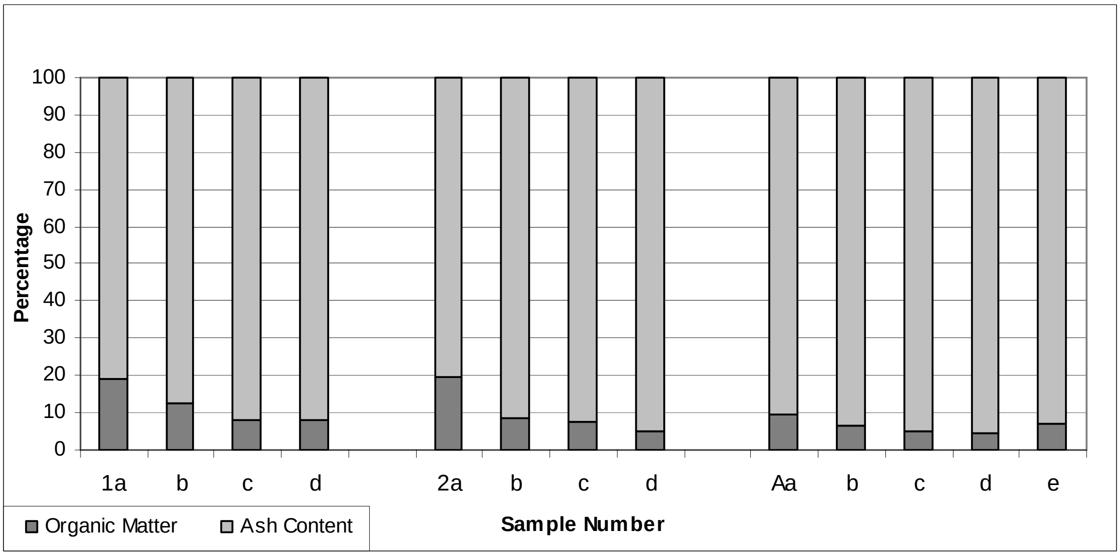


Figure 4.19. Organic and ash content proportions for wetland J4.

4.4.6. Bulk Density

No bulk density samples were taken at J4.

4.4.7. Soil and mottle colour

The soil and mottle colour and stoniness was determined by the method used above. Two J4 samples could be classified as having few small stones (J4:Aa and J4:Ac) and two samples were classified as having medium small stones (J4:Ad and J4:Ae). The soil colour according to the Munsell chart ranged from dark yellowish brown-strong brown (10 yr 4/6-7.5 yr 4/6) to black-reddish brown (7.5 yr 2.5/1-5 yr 4/3) to brown-dark grey (7.5 yr 4/4-7.5 yr 4/1) to different shades of black (7.5yr 2.5/1, 10 yr 2/1, 5 yr 2.5/1, 7.5 yr 4/2). The mottle colour for J4 ranged from reddish brown-yellowish brown (5 yr 4/4-10 yr 5/8) to strong brown-olive yellow (7.5 yr 5/6-10 yr 5/8), to olive (5 y 4/4). The average mottle abundance for J4 was 18%. Colours for individual samples are provided in Appendix B.

4.4.8. Vegetation

General vegetation characteristics were noted in and around the wetland are outlined in Table 4.6.

Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	Schoenaplectus sp (*Cyperaceae*)
Styppeiochloa gynoglossa (*Poaceae*)	cf Scabiosa (*Dipsacaceae*)	Carex autro-africana (*Cyperaceae*)
	cf Hibiscus (*Malvaceae*)	Eleocharis dregeana (*Cyperaceae*)
	Senecio decurrens (*Asteraceae*)	
	Cyrtanthus breviflorus (*Amaryllidaceae*)	
One sample of a Vascular plant or Tracheophyte was found: Gunnera perpensa (*Haloragaceae*).		

Table 4.6. Dominant grasses, forbs and sedges found in J4 (with the family name in italic).

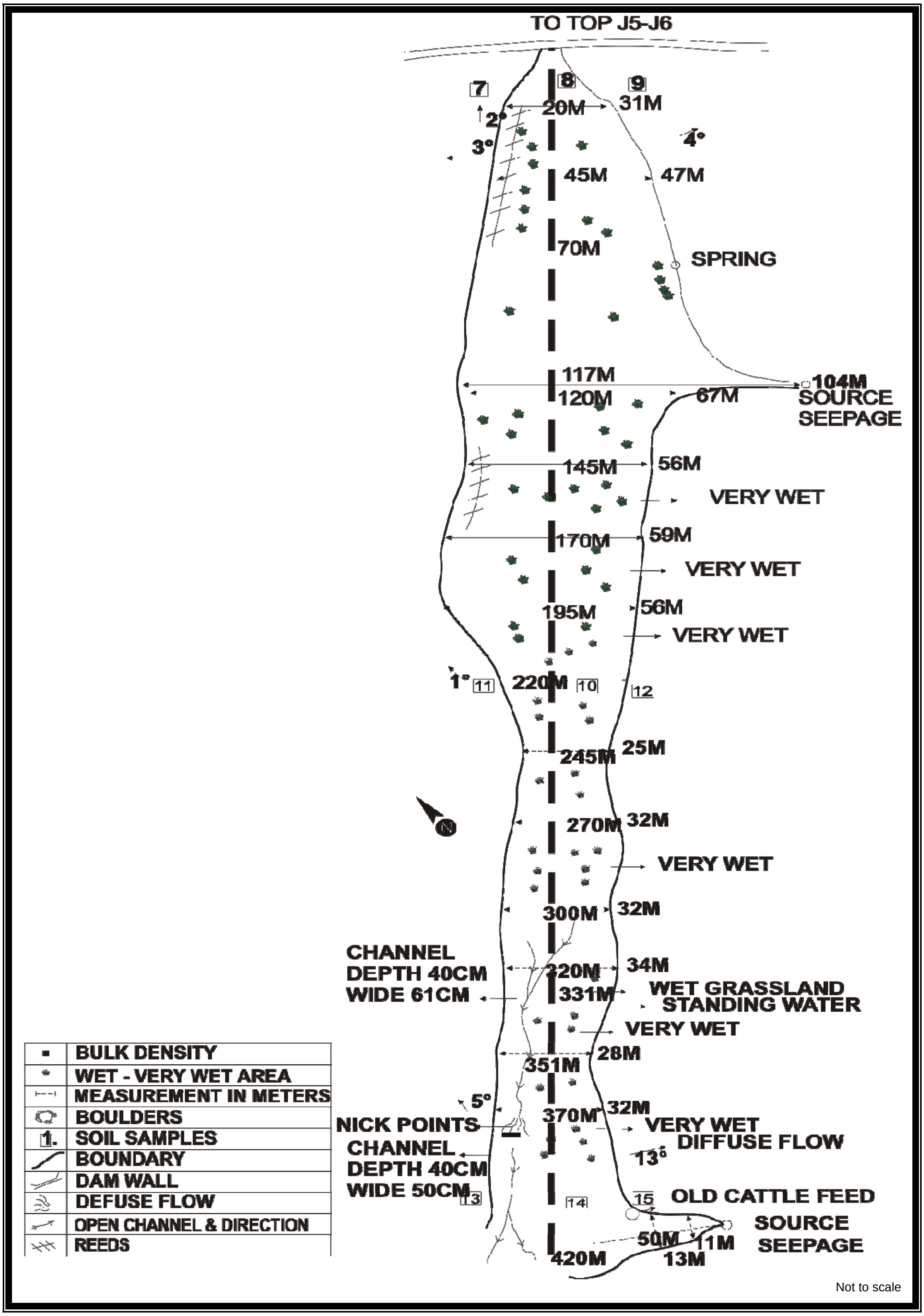
4.5. Wetland J5

4.5.1. Relief

Wetland J5 begins in unit 6 (foot slope) and ends in unit 7 (valley bottom) of the nine-unit land surface model. A jeep track crosses J5 on its transition from foot slope and valley bottom (Figure 4.20). Wetland J5 is characterised by a number of small channels which meander the wetland. The channel depth ranges from 30 to 50cm and the channel width ranged from 20 to 25cm. In the part above the jeep track two small channels join to form one channel which drains the upper part of the wetland. Ten meters before the jeep track the channel becomes diffuse flow and due to the jeep track forming a restriction on the movement of water, thus causing a dam effect above the jeep track.

The lower section (after the jeep track) is located in unit 7 of the nine-unit land surface model. The area directly below the jeep track is characterised by diffuse flow across the wetland, it is only 300m from the jeep track that channelized flow was noted. Below this, two small channels which flowed into a larger channel, the average dimensions of the channels were 10 to 20cm deep and 30 to 40cm wide. The larger channel has a nick point which then widens the channel to a depth of 40 cm and a width of 50cm, this channel then flows into a low order stream. It is interesting to note that the middle section between the two smaller channels is drier then the ‘outside’ edges of the wetland. This could be due to the draining effect which the channels have on the wetland.

The presence of hummocks was also noted, the size of which ranged from 30cm to 60cm high. The hummocks thus also had an influence as to where the water flows within the wetland. The hummocks in J5 were the deepest and most well established for all the wetlands studied. Average gradient for wetland J5 is 0.5° (half a degree).


TO TOP J5-J6
7
8
9
20M
31M
2°
3°
4°
45M
47M
70M
SPRING
117M
120M
104M
SOURCE
SEEPAGE
67M
145M
56M
VERY WET
170M
59M
VERY WET
195M
56M
VERY WET
1°
11
220M
10
12
245M
25M
270M
32M
VERY WET
300M
32M
CHANNEL
DEPTH 40CM
WIDE 61CM
320M
34M
331M
WET GRASSLAND
STANDING WATER
VERY WET
351M
28M
5°
NICK POINTS
370M
32M
VERY WET
DIFFUSE FLOW
CHANNEL
DEPTH 40CM
WIDE 50CM
13
13°
14
15
OLD CATTLE FEED
SOURCE
SEEPAGE
50M
11M
13M
420M
BULK DENSITY
WET - VERY WET AREA
MEASUREMENT IN METERS
BOULDERS
1.
SOIL SAMPLES
BOUNDARY
DAM WALL
DEFUSE FLOW
OPEN CHANNEL & DIRECTION
REEDS
Not to scale

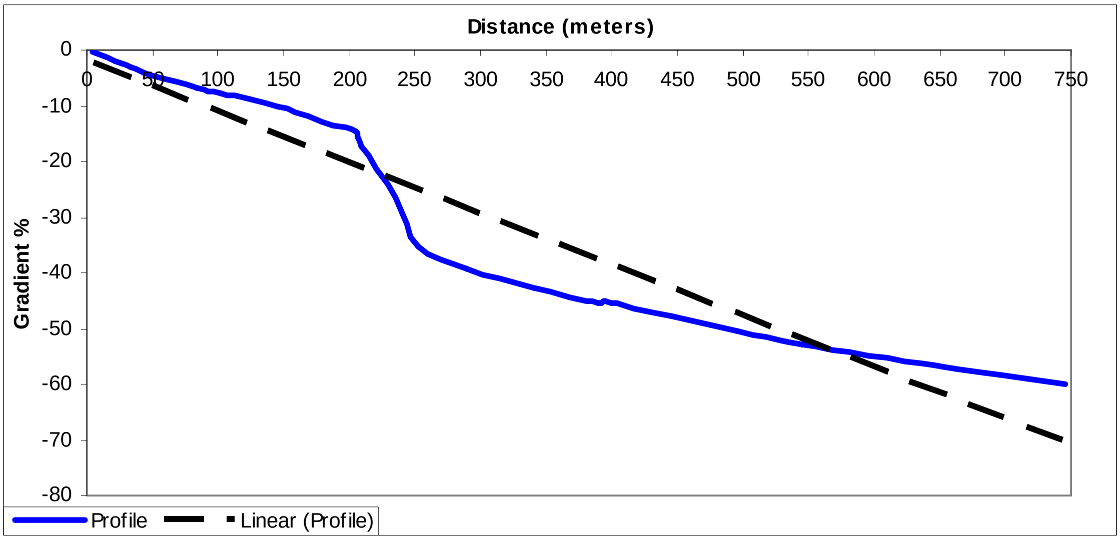


Figure 4.20. Field map (preceding page) and longitudinal profile of wetland J5.

4.5.2. Fine particle analysis

J5 continues downslope from J4 after a small scarp. Sample J5:1 (at the 'source' where the water resurfaces after entering the soil pipe from J4) the average sand fraction for J5:1 is highest at 57.5%, the silt fraction is 33.1% and the clay fraction is the lowest at 9.5% (Figure 4.21). In sample J5:2 (which is situated 3m to the left of sample J5:1 on Figure 4.20) the average sand fraction is again highest at 58%, with a silt fraction of 32%, and a low clay fraction of 10%. In sample J5:3 (which is 50m from J5:1 in the centre of the wetland) the sand fraction is 66.5%, the silt fraction 28.2%, and the clay fraction is lowest at 5.3%. Sample J5:4 (is 9m to the right of J5:3), the sand fraction is highest at 67.8%, with a silt fraction of 26.9%, and a clay fraction of 5.3%. Sample number J5:5 (is at the centre of the wetland 21m from J5:3, close to the Jeep track which crosses the wetland), the sand and silt fraction are very close together, with sand at 48.8% and silt at 40.5%, clay is low at 10.8%. In sample J5:6 (which is 6m to the left of J5:5) the sand fraction is highest at 49.1%, the silt fraction is 35.6% and the clay fraction is lowest at 15.3%. At sample J5:7 (on the lower section of the wetland, on the opposite side of the Jeep track, J5:7 is 20m to the left of J5:8 which is at the centre at the wetland) the sand fraction is 43.9%, silt fraction is 39.2% and the clay fraction is 17%. In sample J5:8 (which is at the centre of the wetland) has a sand fraction of 63.7%, a silt fraction of 27.3% and a clay fraction of 9%. At sample J5:9 (J5:9 is 20m to the right of J5:8) the sand fraction is 54.4%, the silt fraction is 28.9% and the clay fraction is 16.7%. J5:10 is 200m from J5:8 to the centre of the wetland, has a sand fraction 55.3%, and a silt fraction of 27.2%, with a clay fraction of 17.5%. In sample J5:11 which is 20m to the right of J5:10, with a sand fraction of 62.3%, a silt fraction of 26%, and a clay fraction 11.7%. Sample J5:12 is 20m to the right of J5:10 and has a sand fraction of 78.1%, a silt fraction of 17%, and a low clay fraction of 5%. In sample J5:13 is 200m from J5:10 and 20m to the left of J5:14. Sample J5:13 has an average sand fraction of 57.5%, a silt fraction of 25.5%, and a clay fraction of 17%. Sample J5:14 which is at the centre of the wetland 200m from sample J5:10 has an average sand fraction of 43.2% a clay fraction of 29% and silt fraction of 27.8%. In sample J5: 15 is 20m to the right of J5:14, has a sand fraction of 70.2%, a silt fraction of 18.1%, and a clay fraction of 11.8%. It should be noted that the clay fraction of the soil increases with depth, whereas the sand fraction decreases.

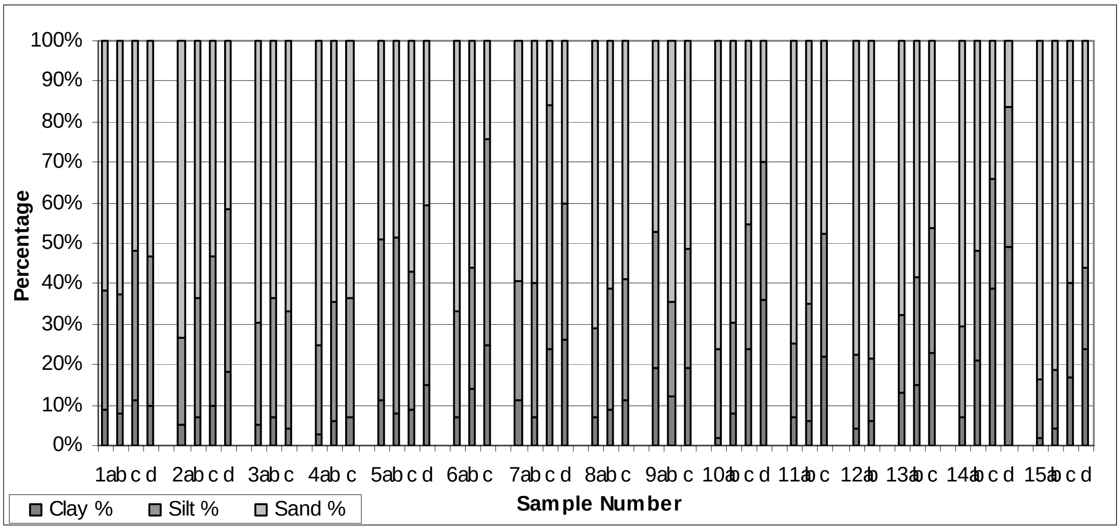


Figure 4.21. Fine particle size analysis for J5.

4.5.3. Soil moisture

The highest average soil moisture was recorded at sample J5:12 (225%), the lowest average soil moisture came from sample J5:13 at 30.9% (Figure 4.22). The soil moisture content declines with depth. As can be expected the samples which were taken down the centre of the wetland have more moisture then the samples from the outer edges of the wetland. The average soil moisture for wetland J5 was 84%. As previously mentioned in the case of peat soils it is well know that values of up till 200% may be found, (Briggs,1977; Goudie 1990), thus the results from J5 indicates a high organic content in a number of the soil sample pits.

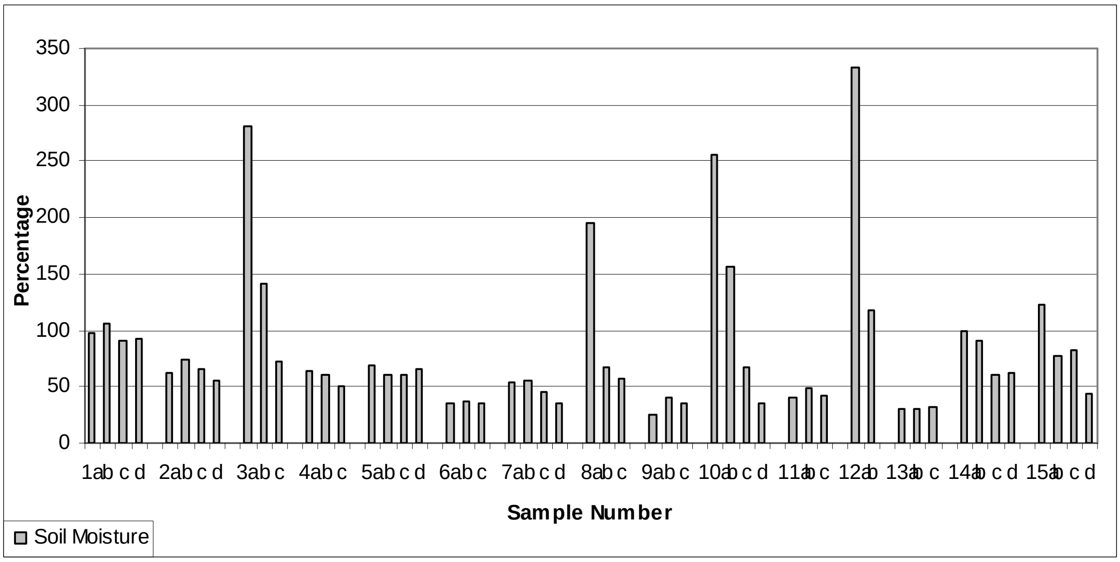


Figure 4.22. Soil moisture (dry weight) for wetland J5.

4.5.4. Soil pH

Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.7. The acidity in the soil ranges from 5.29 in J5:1 to 5.63 in J5:8 and all samples taken can be classified as slightly acidic and very slightly acidic. Samples were taken longitudinally down the wetland and at a 20cm interval in each sample pit (Figure 4.23). There seems to be no sequence/pattern/correlation in the sample pits related to the depth of the sample and the pH value.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE #
pH between 5.0 & 5.5	Slightly Acid	J5:1, J5:3,J5:10,J5:14,
pH between 5.5 & 6.0	Very Slightly Acid	J5:5, J5:8.

Table 4.7. Acidity descriptions for wetlands J5.

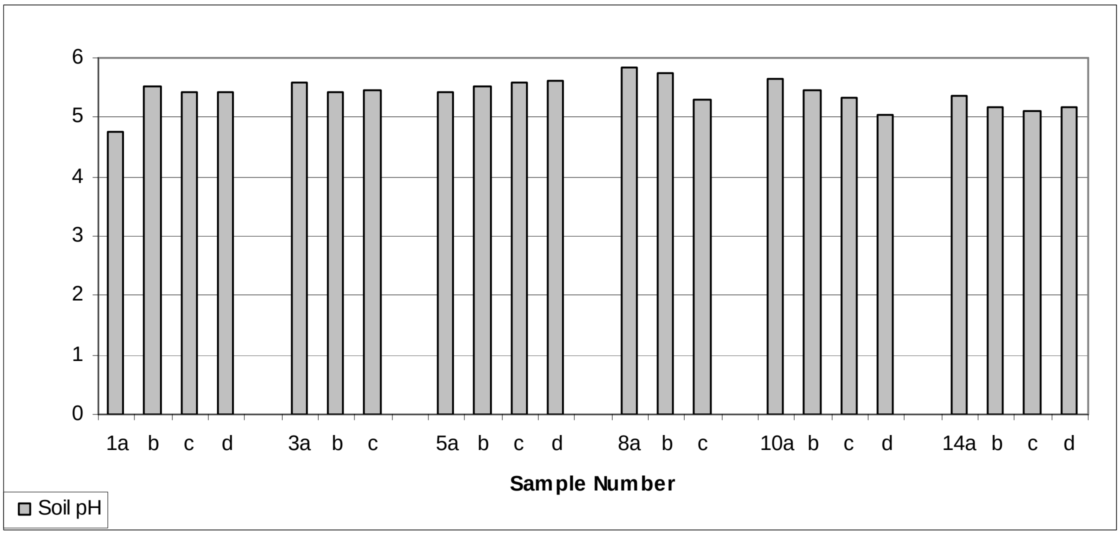


Figure 4.23. Soil pH for wetland J5.

4.5.5. Organic matter and ash content

The average organic matter for wetland J5 is 12.1%. In sample J5:1 the average organic matter is 12.7%. The organic matter in J5:1 increases from 11.9% in the top 20cm to 13.5% in the lower 80cm. In sample J5:2 the average organics is 11.5%. The organic matter decreases from 16% in the top 20cm to 7.5% in the bottom 80cm. J5:3 average is 17.4%, with the highest organic matter recorded in the top 20cm (26.6%) and the lowest in the bottom 1m (8%). Sample J5:4 organic matter average is 8.3%, with the highest recorded organic content again at 20cm (8.9%) and the lowest at 60cm (7%). J5:5 has an average organic content of 8.5%, with the highest recorded organic content at 20cm (10%) the organic content of the soil decreases to 7.5% in the lower 80cm. In sample J5:6 the average is 8.3%, The organic matter decreases from 13% in the top 20cm to 6% in the bottom 60cm. In sample J5:7 the average organics is 9%. The organic matter decreases from 13.5% in the top 20cm to 4.5% in the bottom 1m. J5:8 average is 15%, with the highest organic matter recorded in the top 20cm (25%) and the lowest in the bottom 60cm (8.5%). Sample J5:9 organic matter average is 12.2%. The organic matter in J5:9 increases from 12% in the top 20cm to 12.5% in the lower 60cm. J5:10 has an average organic content of 14.1%, with the highest recorded organic content at 20cm (26%) the organic content of the soil decreases to 2.5% in the lower 1.2m. In sample J5:11 the average is 11.5%. The organic matter decreases from 16% in the top 20cm to 6.5% in the bottom 60cm. In sample J5:12 the average organics is 20.9%. The organic matter decreases from 28.7% in the top 20cm to 13% in the bottom

60cm. J5:13 average is 12.3%, with the highest organic matter recorded in the top 20cm (14%) and the lowest in the bottom 60cm (10.5%). In sample J5:14 the average organics is 8.7%. The organic matter decreases from 13.9% in the top 20cm to 4.9% in the bottom 1.2m. J5:15 average is 11.7%, with the highest organic matter recorded in the top 20cm (18.4%) and the lowest in the bottom 1.5cm (6%). Ash content proportions are given in Figure 4.24.

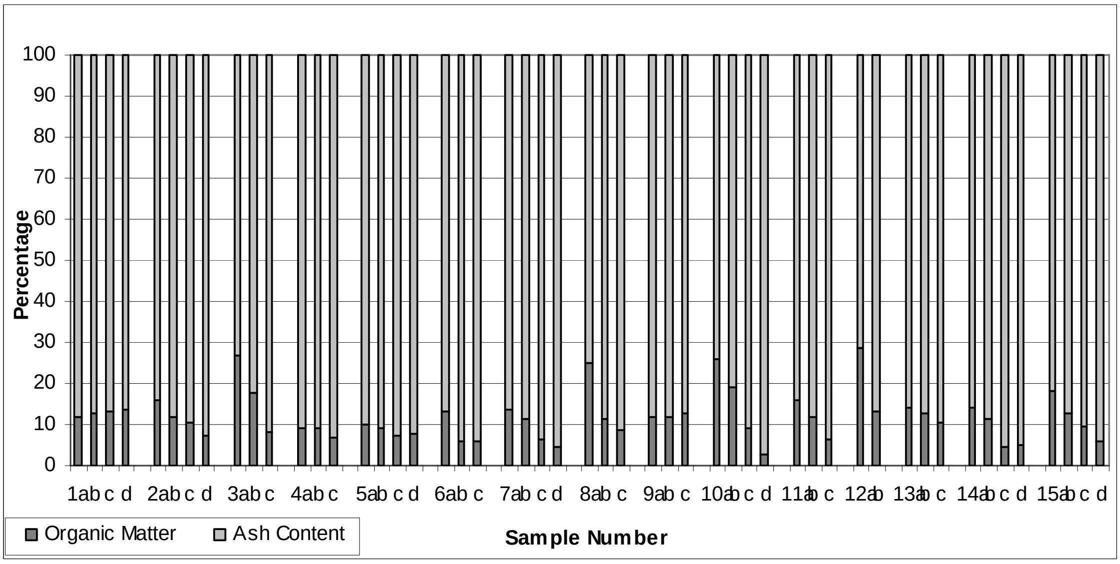


Figure 4.24. Organic matter and ash content proportions for wetland J5.

4.5.6. Bulk density

The soil samples taken had low bulk density values, (the sample was taken adjacent to J5:5) the bulk density of the soil was 0.61g/cm³. The second bulk density sample was taken near J5:6 and had a reading of 0.78g/cm³. Both these samples are low and deducting from this the soils have a high organic and can be classified as Histosols and Andisols.

4.5.7. Soil and Mottle Colour

In all the samples taken from J5 one sample was classified as sandy (J5:8a), three samples were classified as having few small stones (J5:9a, J5:13a, J5:14a), one sample was classified as being block (J5:11c), two samples were classified as being gritty (J5:15a, J5:15b). The soil colour according to the Munsell chart ranged from light olive brown (2.5 yr 5/4), very dark brown (10 yr 2/2), very dark greyish brown (10 yr 3/2), dark reddish brown (5 yr 3/3) to a number of different shades of black (5 y 2 2.5/1, 7.5 yr 2.5/1, 10 yr 2/1,2.5/n). The mottle colour for J5 ranged from yellowish red (5 yr 4/6), strong brown (7.5 yr 5/6), brownish yellow-light grey (10 yr 6/8-10 yr 7/1), bluish grey (gleyed, 4/10B). The average mottle abundance for J5 was 11%. For an individual look at each sample colour see Appendix B.

4.5.8. Vegetation

The dominant vegetation within and adjacent to the wetland is outlined in Table 4.8.

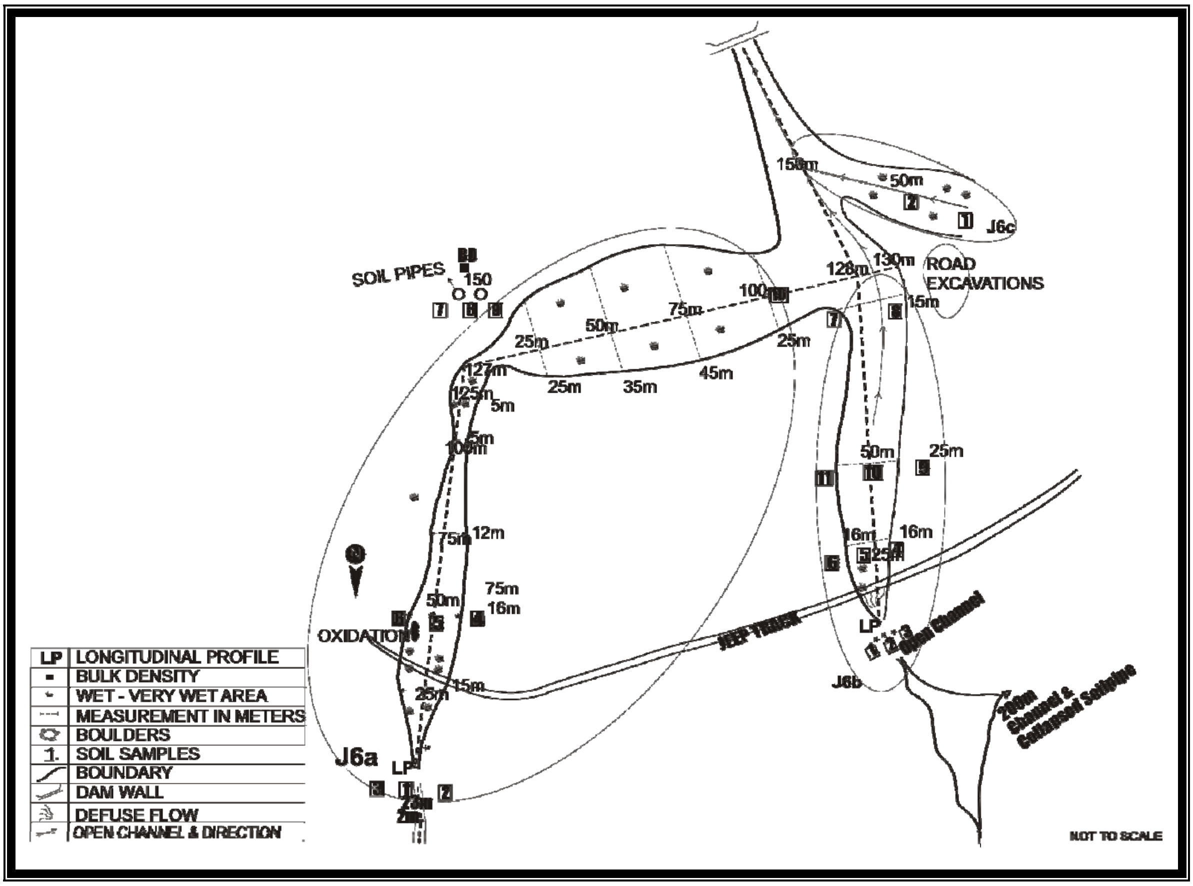
Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	Schoenaplectus sp (*Cyperaceae*)
Styppeiochloa gynoglossa (*Poaceae*)	cf Scabiosa (*Dipsacaceae*)	Carex autro-africana (*Cyperaceae*)
	cf Hibiscus (*Malvaceae*)	Eleocharis dregeana (*Cyperaceae*)
	Senecio decurrens (*Asteraceae*)	
	Cyrtanthus breviflorus (*Amaryllidaceae*)	
One sample of a Vascular plant or Tracheophyte was found: Gunnera perpensa (*Haloragaceae*).		

Table 4.8. Dominant grasses, forbs and sedges found in J5 (with the family name in italic)

4.6. Wetland J6a

4.6.1. Relief

Wetland sections J6a, J6b and J6c, form arms or sections of the same wetland (Figure 4.25) and findings for each arm of J6 are presented separately. Longitudinal profiles were taken through the larger sections J6a and J6b and are presented in Figures 4.25 and 4.26 respectively.



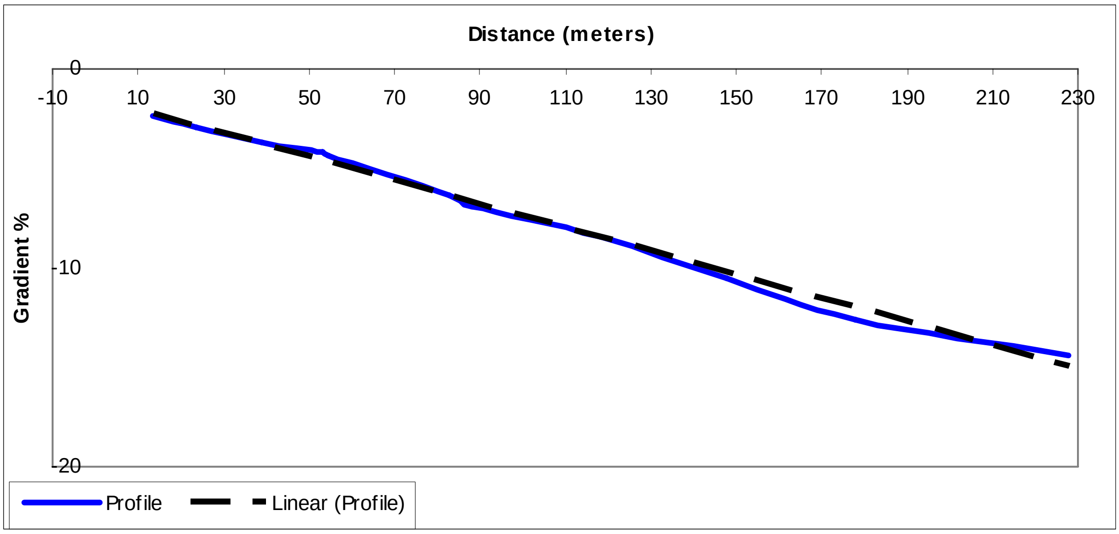


Figure 4.25. Field map of wetland J6 and long profile through J6a

J6a is characterised by overland flow with no channels in the wetland. The source for J6a arises from a soil pipe which is 23 meters above the jeep track, the section above the jeep track is very narrow and can be classified as a drainage line. It is only 8 meters from the jeep track that the water flow spreads out, where the track channels the water, after which the water is again spread out. The lower section of J6a has an average gradient of 2°. As previously mentioned J6a is characterised by overland/sheet flow, added to this was an area of 5 x 2.5 m where a red colour indicated that oxidation had taken place, this site was unique in the sense that it was the largest oxidation patch found in all the wetlands studied.

4.6.2. Fine particle analysis

Sample J6a:1 was taken at the source and centre of the wetland arm above the Jeep track which crosses the wetland. Within sample J6a:1 the sand fraction is the highest (45.6%) and the silt fraction is second at 43% with clay being the lowest at 11.3% (Figure 4.26). In sample J6a:2 (which is 4 meters to the right of sample J6a:1 on Figure 4.25) once again the sand fraction is highest at 75.4%, the slit fraction is 18.6%, and the clay fraction being lowest at 6%. In sample J6a:3 (which is 4 meters to the left of sample J6a:1) the sand fraction again the highest at 45.6%, with silt being second with a percentage of 43% and clay being the lowest at 11.3%. In sample J6a:4 (which is 50 meters from J6a:1 in the right of J6a:5) the sand fraction is highest at 45% with the silt fraction being 36.1% and clay the lowest at 18.8%. At sample J6a:5 (which is in the centre of the wetland 8 meters from of sample J6a:4) the sand fraction is highest at 41.4% with the silt fraction being 36.8% and clay the lowest at 21.8%. At sample J6a: 6 (which is 8 meters to the left of sample J6a:5) the sand fraction is the highest at 41% and clay the lowest at 18.2%, the slit fraction within the sample is 40.8%.

Sample J6a:7 (which is 100 meters from J6a:5, is to the right of J6a:8 which is at the centre of the wetland), the sand fraction is highest at 39.4% with the silt fraction being 30.8% and clay the lowest at 29.8%. Sample J6a:8 (was taken at the centre of the wetland 8 meters to the right of J6a:7), the sand fraction is the highest (41.7%) and the silt fraction is second at 32% with clay being the lowest at 26.3%. In sample J6a:9 (which is 8 meters to the right of sample J6a:8) once again the sand fraction is highest at 46.8%, the slit fraction is 31.8%, and the clay fraction being lowest at 21.3%. In sample J6a:10 (which is 100 meters to the right of sample J6a:8, in the wetland which contents J6a and J6b) in this sample the clay fraction is highest at 37%, the sand fraction is 35%, and the silt fraction is lowest at 28%.

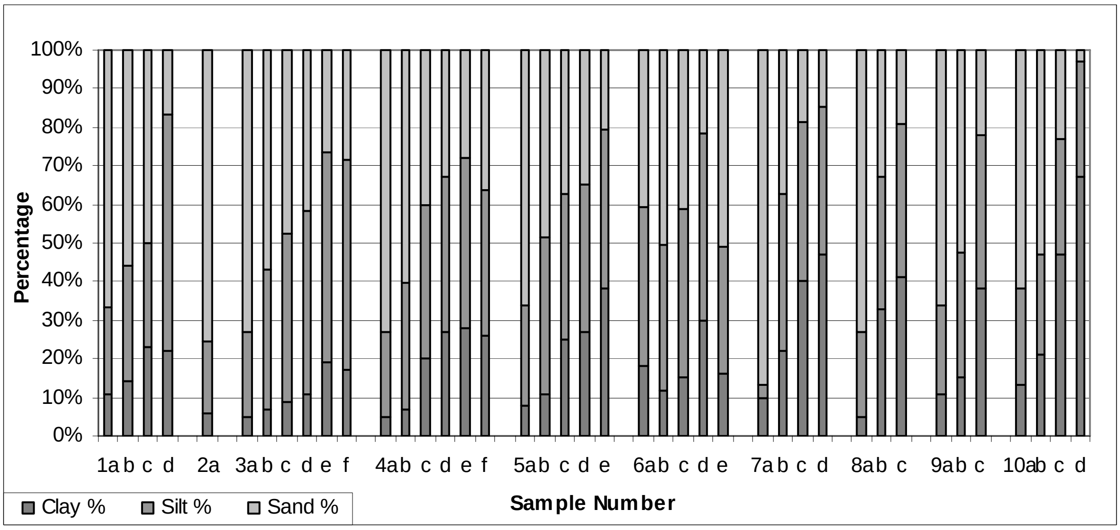


Figure 4.26. Fine particle size analysis for wetland J6a.

4.6.3. Soil moisture

The highest average soil moisture was recorded at sample J6a:6 (192.6%), the lowest average soil moisture came from sample J6a:2 at 38.7% (Figure 4.27). Soil moisture content generally declines with relation to depth. Average soil moisture for wetland J6a was 74.6%. As previously mentioned in the case of peat soils the results from J5 indicates a high organic content in a number of the soil sample pits.

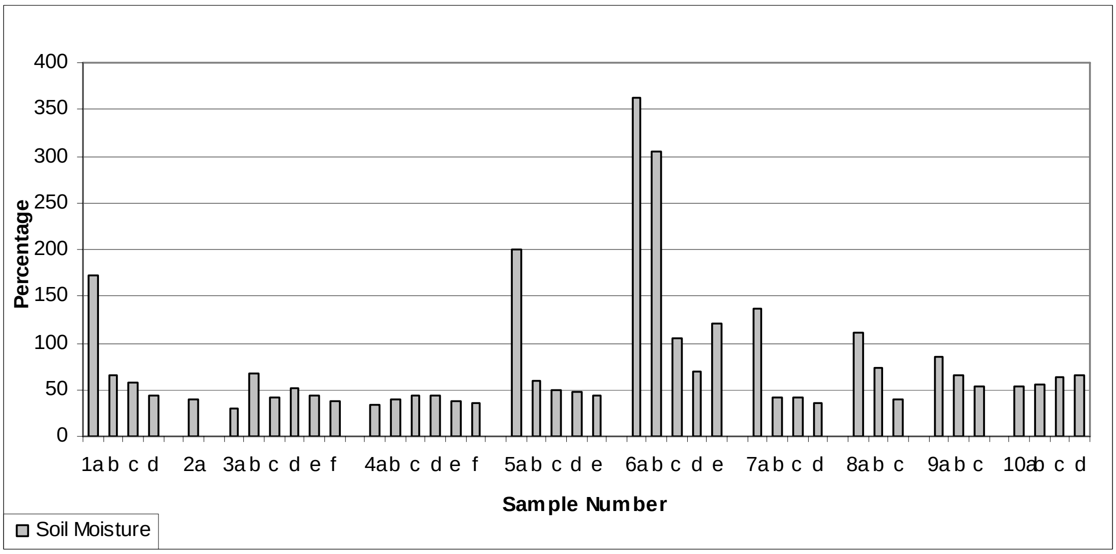


Figure 4.27. Soil moisture for wetland J6a.

4.6.4. Soil pH

Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.9 and values provided in Figure 4.28. The acidity in the soil ranges from slightly acid (5.27 in J6a:1) to very slightly acid (6.69 in J6a:10) (Figure 4.28). Samples were taken longitudinally down the wetland and at a 20cm interval in each sample pit (Figure 4.28). The average of each sample pit was then derived to give a broader over view of the wetland. There seems to be no sequence /pattern /correlation in the sample pits related to the depth of the sample and the pH value.

pH RANGE	**ACIDITY/ALKALINE CATEGORY**	**SAMPLE #**
pH between 4.0 & 4.5	Strongly Acid	
pH between 4.5 & 5.0	Medium Acid	
pH between 5.0 & 5.5	Slightly Acid	J6a:1,J6a:5
pH between 5.5 & 6.0	Very Slightly Acid	J6a:8,J6a:10

Table 4.9. Acidity descriptions for wetland J6a

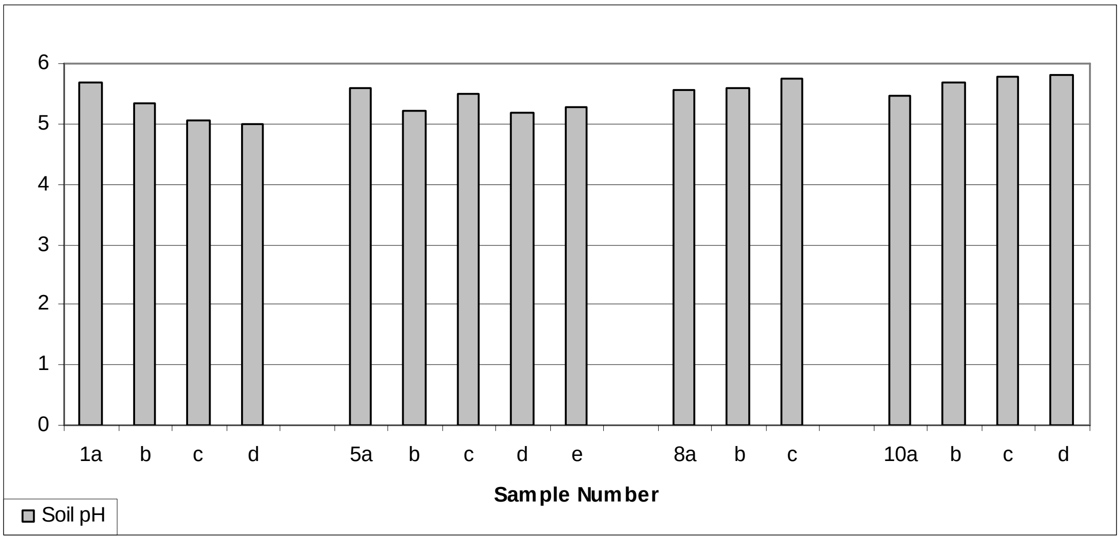


Figure 4.28. Soil pH for J6a.

4.6.5. Organic matter and ash content

The average organic matter for wetland J6a is 12.2%. In sample J6a:1 the average organic matter is 9.5%. The organic matter in J6a:1 decreases from 17.8% in the top 20cm to 4% in the lower 1m. In sample J6a:2 the organic matter is 14% no further soil sample could be removed. For J6a:3 the average is 7.9%, with the highest organic matter recorded in the top 20cm (12%) and the lowest in the bottom 1.5m (5%). Sample J6a:4 the organic matter average is 10.1%, with the highest recorded organic content again at 20cm (14.8%) and the lowest at 1.5m (6.9%). J6a:5 has an average organic content of 11.1%, with the highest recorded organic content at 20cm (20.5%) the organic content of the soil decreases to 6% in the lower 1m. In sample J6a:6 the average is 14.7%. The organic matter decreases from 17% in the top 20cm to 13% in the lower 1.2m. In sample J6a:7 the average organics is 12.6%. The organic matter decreases from 24.5% in the top 20cm to 7.5% in the bottom 80cm. J6a:8 average is 11.8%, with the highest organic matter recorded in the top 20cm (18%) and the lowest in the bottom 60cm (6%). Sample J6a:9 organic matter average is 13.5%. The organic matter in J6a:9 decreases from 17% in the top 20cm to 10% in the lower 60cm. J6a:10 has an average organic content of 17.5%, with the highest recorded organic content at 20cm (20.5%) the organic content of the soil decreases to 16% in the lower 50cm. Ash content proportions are given in Figure 4.29.

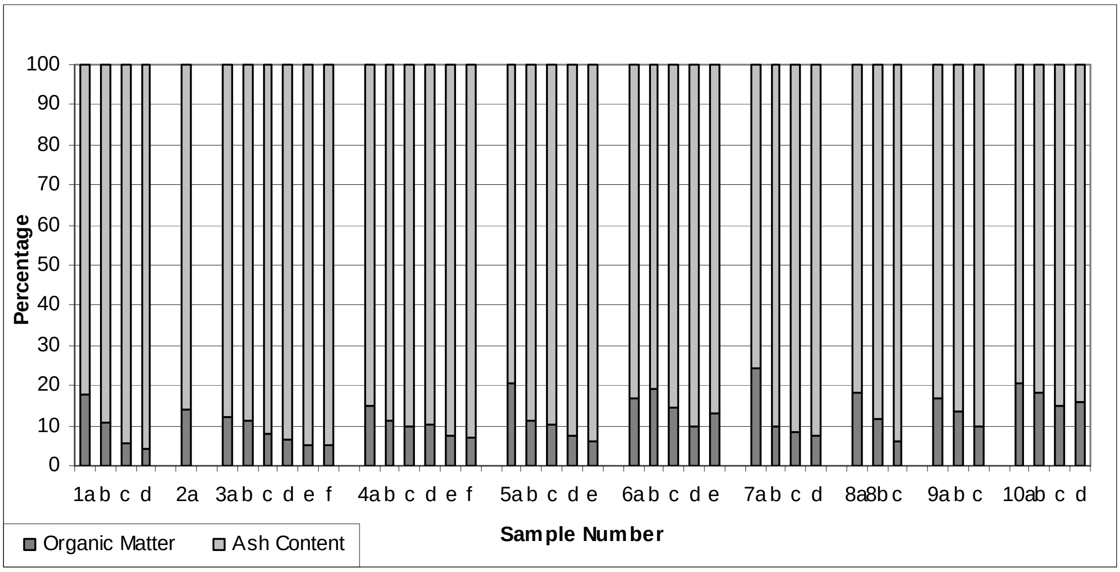


Figure 4.29. Organic matter and ash content proportions for wetland J6a.

4.6.6. Bulk density

The samples taken for bulk density revealed low values, (a sample was taken 20m west of J6a:5 outside the wetland) the bulk density of the soil was 0.69g/cm³. The second bulk density sample was taken in the wetland at J6a:8 and had a reading of 0.30g/cm³. Both these samples are low and deducting from this the soils have a high organic and can be classified as Histosols.

4.6.7. Soil and mottle colour

The soil and mottle colour was determined as before and in the samples taken from J6a one sample was noted as having medium stones (J6a:3c), three samples were noted as having few small stones (J6a:7a, J6a:7c, J6a:7d). The soil colour according to the Munsell chart ranged from dark yellowish brown (10 yr 4/4) to bluish black (2.5 5/5 pb) to reddish black (2.5 yr 2.5/1) to black (5 yr 2.5/1). The mottle colour for J2 ranged from yellowish red (5 yr 4/6) to strong brown (7.5 yr 5/6). The average mottle abundance for J6a was 7%. For an individual look at each sample colour please see Appendix B.

4.6.8. Vegetation

The dominant vegetation within and adjacent to wetland J6a is outlined in Table 4.10.

Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	Schoenaplectus sp (*Cyperaceae*)
Styppeiochloa gynoglossa (*Poaceae*)	cf Hibiscus (*Malvaceae*)	Carex autro-africana (*Cyperaceae*)
	Ranunculus multifudus (*Ranunculaceae*)	Eleocharis (*Cyperaceae*)
	Helichrysum aureonitens (*Asteraceae*)	

Table 4.10. Dominant grasses, forbs and sedges found in J6a (with the family name in italic)

4.7. Wetland J6b

4.7.1. Relief

As with J6a, J6b is also intersected by the jeep track in the upper section of the wetland (Figure 4.25). The source of J6b is a collapsed soil pipe with a length of approximately 200 meters. Unlike J6a, J6b has a well defined channel in the lower reaches of the wetland, attributes to the less wet condition of the wetland. The channel width ranged from 20 cm to 1.5 meters wide, the depth of the channel range from 10cm to 90cm. The gradient of wetland J6b is 2°. Wetland J6a intersects J6b approximately 150 meters from the jeep track, where the wetland drains in to a deep channel of 90cm deep and 1.5 meters wide. Thirty meters from the intersection of J6a and J6b, J6c links into the wetland system.

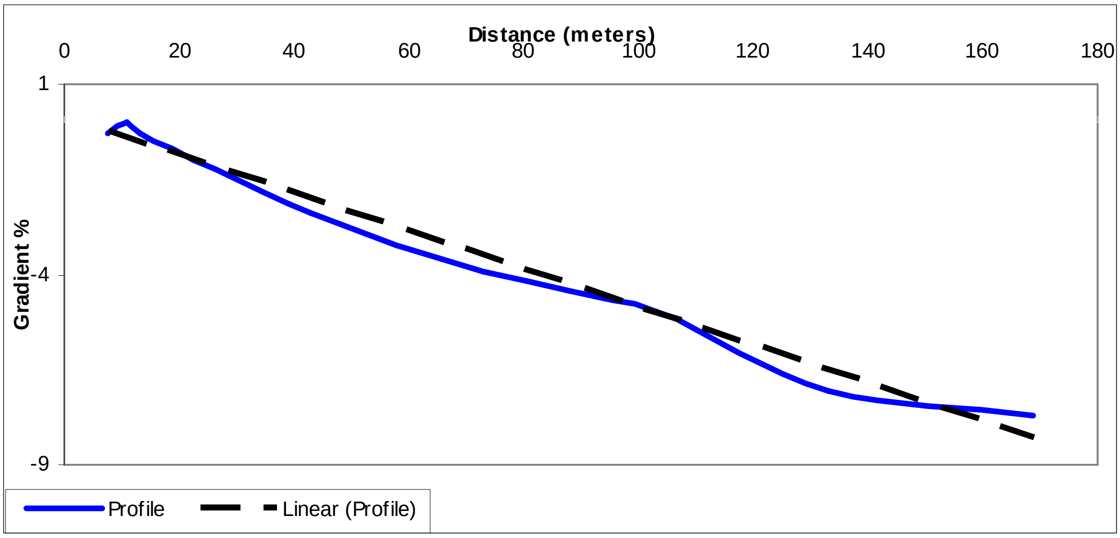


Figure 4.30. Longitudinal profile of wetland J6b as shown on Figure 4.25.

4.7.2. Fine particle analysis

Sample J6b:1 was taken 2 meters to the left of J6b:2 which is at the centre of the wetland arm above the Jeep track which crosses the wetland. Within sample J6b:1 the sand fraction is the highest (58.4%) and the silt fraction is second at 32.2% with clay being the lowest at 9.4% (Figure 4.31). In sample J6b:2 (which is 2 meters to the right of sample J6b:1 on Figure 4.25, and at the centre of the wetland) once again the sand fraction is highest at 61.5%, the slit fraction is 26.8%, and the clay fraction being lowest at 11.7%.

In sample J6b:3 (which is 2 meters to the right of sample J6b:2) the sand fraction again the highest at 56.5%, with silt being second with a percentage of 35.5% and clay being the lowest at 8%. In sample J6b:4 (which is 20 meters from J6b:2 and 10m to the right of J6b:5) the sand fraction is highest at 53.6% with the silt fraction being 33% and clay the lowest at 13.4%. At sample J6b:5 (which is in the centre of the wetland 10 meters to the left of sample J6b:4) the sand fraction is highest at 54.4% with the silt fraction being 31.2% and clay the lowest at 14.48%. At sample J6b: 6 (which is 10 meters to the left of sample J6b:5) the sand fraction is the highest at 59.7% and clay the lowest at 9.4%, the slit fraction within the sample is 30.9%. Sample J6b:7 (which is 50 meters from J6b:5, which is at the centre of the wetland), the sand fraction is highest at 54.6% with the silt fraction being 26.7% and clay the lowest at 18.8%. Sample J6b:8 (7 meters to the left of J6b:7), the sand fraction is the highest (36.7%) and the silt fraction is second at 33.9% with clay being the lowest at 29.4%. In sample J6b:9 (which is 7 meters to the right of sample J6b:7) once again the sand fraction is highest at 55.2%, the slit fraction is 26%, and the clay fraction being lowest at 18.8%.

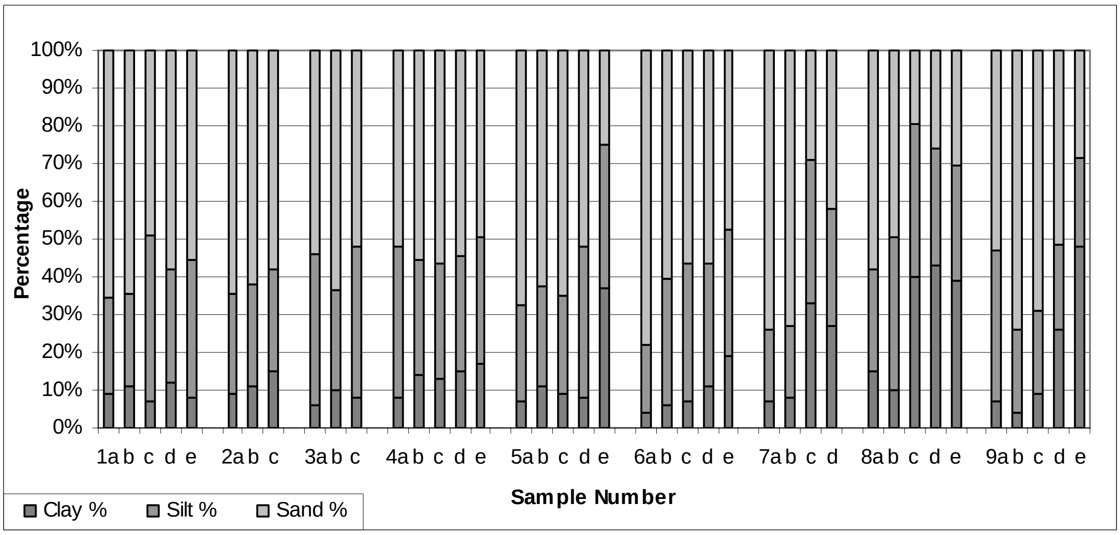


Figure 4.31. Fine particle size analysis for wetland J6b.

4.7.3. Soil moisture

The highest average soil moisture was recorded at sample J6b:3 (103.8%), the lowest average soil moisture came from sample J6b:8 at 35.2% (see also Figure 4.32). The average soil moisture for wetland J6b was 69.5%. As previously mentioned in the case of peat soils it is well know that values of up till 200% may be found, (Briggs 1977 & Goudie 1990).

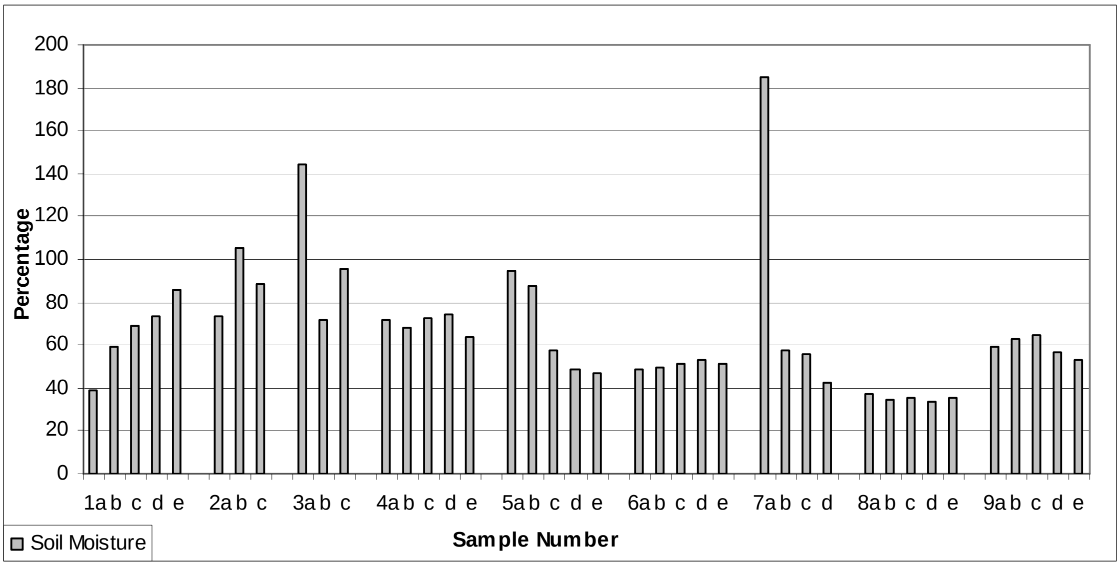


Figure 4.32. Soil moisture (dry mass) for wetland J6b.

4.7.4. Soil pH

Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.11. Acidity in the soil ranges from 5.58 in J6b:2 to 5.92 in J6b:5 (Figure 4.33). The samples were taken longitudinally down the wetland and at a 20cm interval in each sample pit. The average of each sample pit was then derived to give a broader overview of the wetland. There seems to be no sequence in the sample pits related to the depth of the sample and the pH value.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE #
pH between 5.5 & 6.0	Very Slightly Acid	J6b:2, J6b:5, J6b:7

Table 4.11. Acidity descriptions for wetland J6b

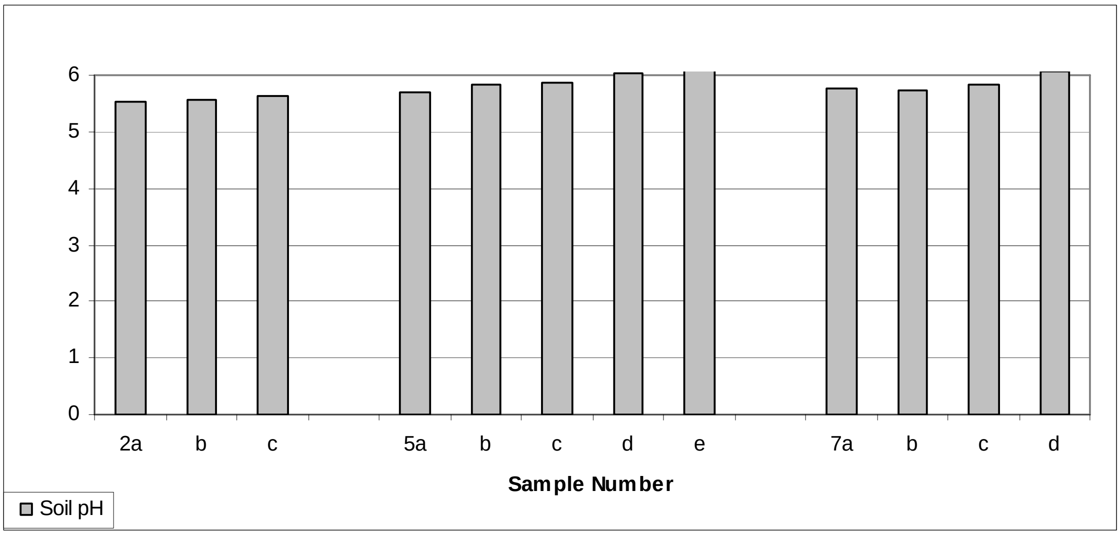


Figure 4.33. Soil pH for wetland J6b.

4.7.5. Organic matter and ash content

The average organic matter for wetland J6b is 12.3%. In sample J6b:1 the average organic matter is 13.7%. The organic matter in J6b:1 increases from 10.5% in the top 20cm to 13% in the lower 1m. In sample J6a:2 the organic matter is 12.3%. The organic matter decreases from 12.5% at 20cm to 11.5% at 60cm depth. J6b:3 average is 11.8%, with the highest organic matter recorded in the top 20cm (14.5%) and the lowest in the bottom 1m (10%). Sample J6b:4 organic matter average is 16.1%, with the highest recorded organic content again at 20cm (18.5%) and the lowest at 1m (12.5%). J6b:5 has an average organic content of 11.3%, with the highest recorded organic content at 20cm (17.5%) the organic content of the soil decreases to 6.5% in the lower 1m. In sample J6b:6 the average is 11.9% and organic matter decreases from 15.5% in the top 20cm to 10% in the bottom 1m. In sample J6b:7 the average organics is 14%. Organic matter decreases from 29.5% in the top 20cm to 7% in the bottom 80cm. J6b:8 average is 7.6%, with the highest organic matter recorded in the top 20cm (12%) and the lowest in the bottom 80cm (3%). Sample J6b:9 organic matter average is 12.3%. The organic matter in J6b:9 decreases from 15% in the top 20cm to 10% in the lower 1m. Ash content proportions are given in Figure 4.34.

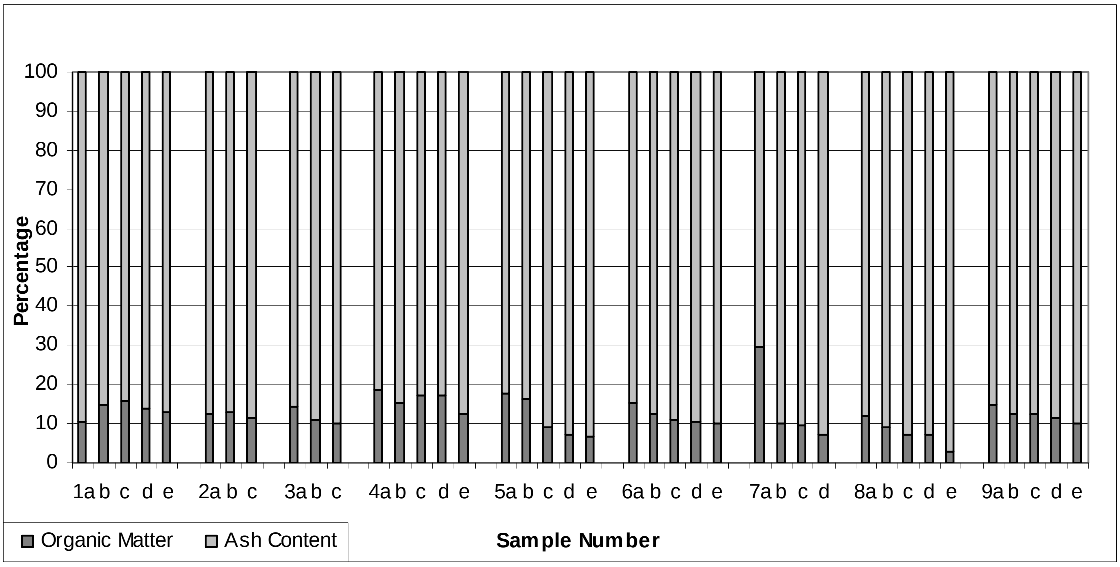


Figure 4.34. Organic matter and ash proportional content for J6b.

4.7.6. Bulk density

Bulk density readings were taken at J6a.

4.7.7. Soil and mottle colour

In all the samples taken from J6b two samples were noted as being gritty (J6b:3a and J6b:3b), one sample was classified as having few small stones (J6b:1e), one sample was classified as having many small to medium stones (J6b:3c), and one sample was noted as having few very small stones in the soil (J6b:5d). The soil colour according to the Munsell chart ranged from dark yellowish brown to black (10 yr 4/4-10 yr 2/2) to strong brown (7.5 yr 5/8) to dark reddish brown (5 yr 3/3) to a number of different shades of black (10 yr 2/1, 7.5 yr 2.5/1, 2.5 y 2.5/1), olive yellow (2.5 y 6/6), greenish black (10 y 2.5/1). The mottle colour for J6b ranged from yellowish red (5 yr 5/6) to strong brown (7.5 yr 5/6), olive yellow (2.5 yr 6/8), reddish yellow (7.5 yr 6/8). The average mottle abundance for J6b was 18%. For an individual look at each sample colour please see Appendix B.

4.7.8. Vegetation

The dominant vegetation within and adjacent to wetland J6b is outlined in Table 4.12.

Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	Schoenaplectus sp (*Cyperaceae*)
Styppeiochloa gynoglossa (*Poaceae*)	cf Hibiscus (*Malvaceae*)	Carex autro-africana (*Cyperaceae*)
	Ranunculus multifudus (*Ranunculaceae*)	Eleocharis (*Cyperaceae*)
	Helichrysum aureonitens (*Asteraceae*)	

Table 4.12. Dominant grasses, forbs and sedges found in J6b (with the family name in italic)

4.8. Wetland J6c

4.8.1. Relief

Wetland J6c (Figure 4.25) is a small seepage wetland which drains into the larger wetland system. The wetland is characterised by a minimal amount over land flow as well as an accumulation of organics. The area is well vegetated, with a gradient of 2°. The lower section of the wetland system has a channel of 4 m wide and 50 cm deep which drains finally into a dam. The dam did not hold a significant amount of water as observed during field visits, and is mostly fully sedimented and well vegetated.

4.8.2. Fine particle analysis

Sample J6c:1 was taken at the centre of the third arm which enters the wetland. Within sample J6c:1 the sand fraction is the highest (43.5%) and the silt fraction is second at 32.7% with clay being the lowest at 23.8% (Figure 4.35). In sample J6c:2 (which is 27 meters from J6c:1 and at the centre of the wetland) once again the sand fraction is highest at 59.6%, the slit fraction is 23.9%, and the clay fraction being lowest at 16.5%.

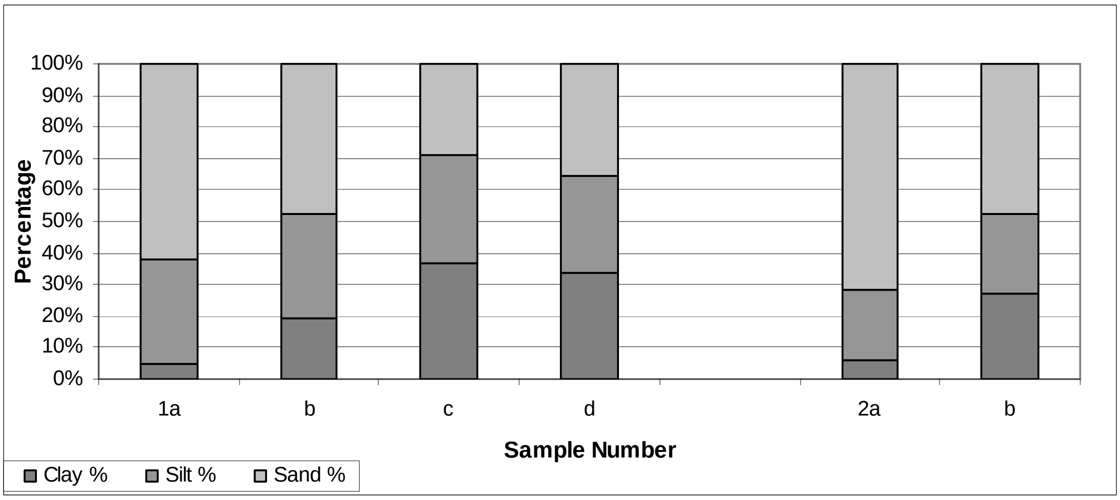


Figure 4.35. Fine particle size analysis for J6c.

4.8.3. Soil Moisture

The highest average soil moisture was recorded at sample J6c:2 (213.45%), the lowest average soil moisture came from sample J6c:1 at 88.86%. Soil moisture declines with depth (Figure 4.36). Average soil moisture for wetland J6c was 151.1%. As previously mentioned, values of up till 200% may be found in peat soils (Briggs, 1977; Goudie 1990).

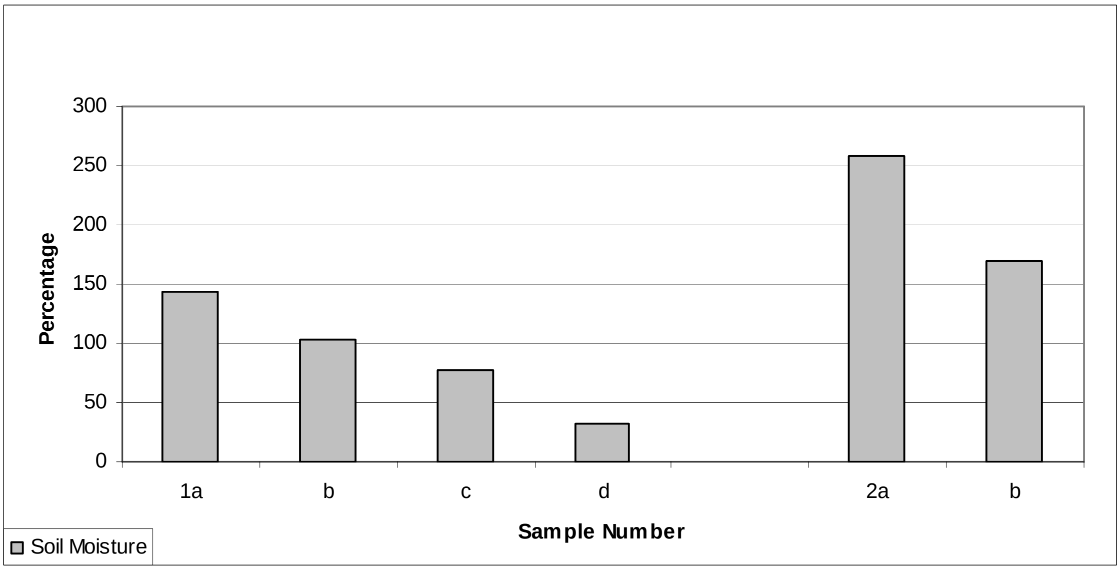


Figure 4.36. Soil moisture for J6c.

4.8.4. Soil pH

Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.13. The acidity in the soil ranges from slightly acid (5.26 in J6c:1) to very slightly acid (5.57 in J6c:2) (Figure 4.37). The samples were taken longitudinally down the wetland and at a 20cm interval in each sample pit. The average of each sample pit was then derived to give a broader over view of the wetland. There seems to be no sequence /pattern /correlation in the sample pits related to the depth of the sample and the pH value.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE #
pH between 5.0 & 5.5	Slightly Acid	J6c:1
pH between 5.5 & 6.0	Very Slightly Acid	J6c:2

Table 4.13. Acidity descriptions for wetland J6c.

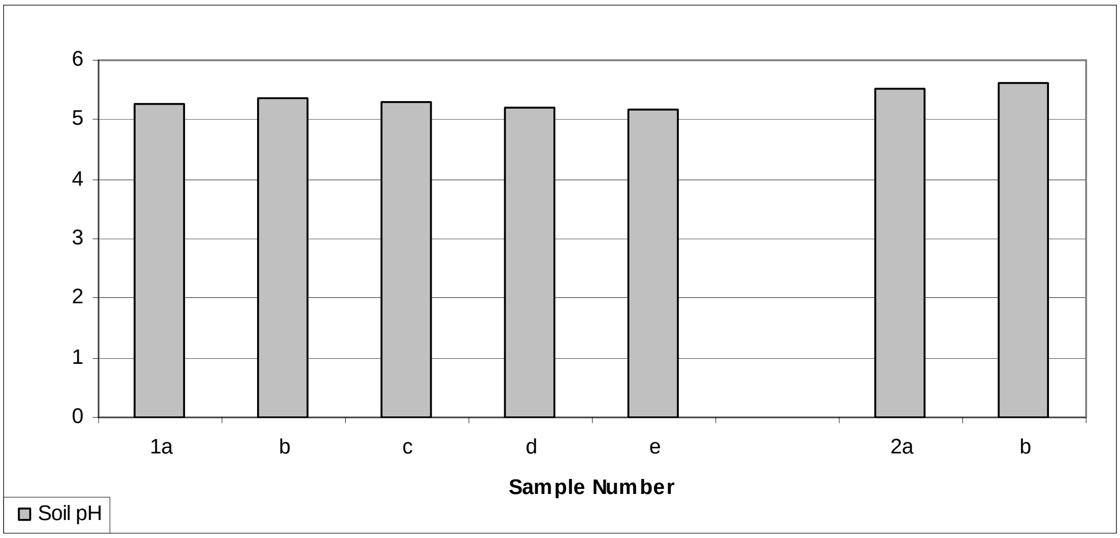


Figure 4.37. Soil pH for wetland J6c.

4.8.5. Organic matter and ash content

The average organic matter for wetland J6c is 16%. In sample J6c:1 the average organic matter is 13%. Organic matter in J6c:1 decreases from 24.5% in the top 20cm to

3% in the lower 1m. In sample J6c:2 the organic matter is 19%. The organic matter decreases from 23% at 20cm to 15% at 2m depth. Ash content proportions are given in Figure 4.38.

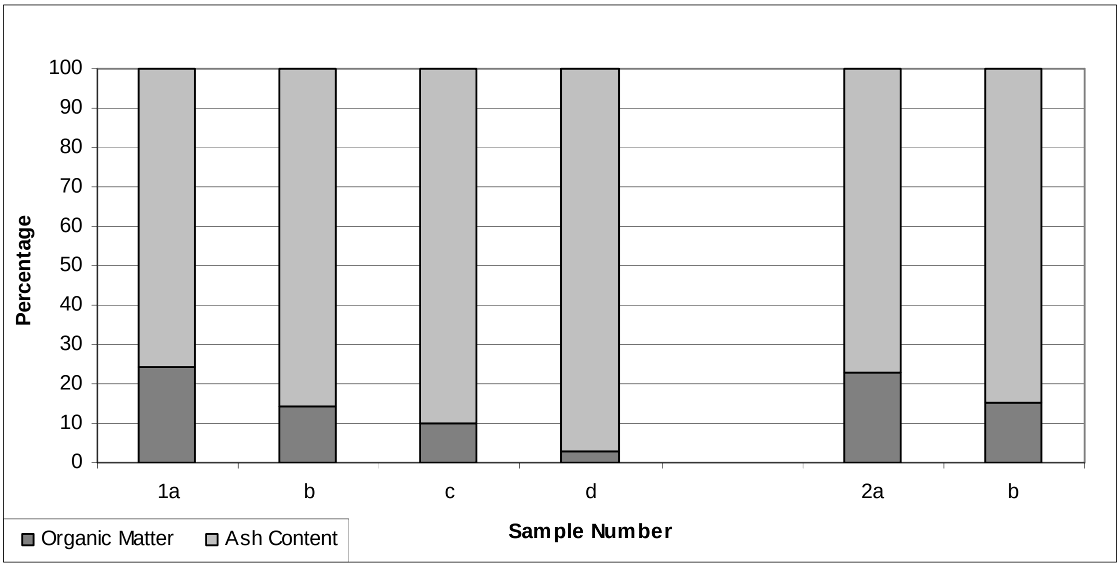


Figure 4.38. Organic matter and ash content proportions for wetland J6c.

4.8.6. Bulk Density

In wetland J6 bulk density readings were only taken at section J6a.

4.8.7. Soil and mottle colour

Soil colour according to the Munsell chart for J6c ranged from greenish grey-black (6/10Y-10 yr 2/1) to very pale brown-greenish grey-brownish yellow (10 yr 7/6-6/10Y-10 yr 6/8) to black (7.5 yr 2.5/1,10 yr 2/1). No mottles were found in J6c. For an individual look at each sample colour see Appendix B.

4.8.8. Vegetation

As conducted above, vegetation is outlined in Table 4.14.

Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum pilosellum (*Asteraceae*)	Schoenaplectus sp (*Cyperaceae*)
Styppeiochloa gynoglossa (*Poaceae*)	cf Hibiscus (*Malvaceae*)	Carex autro-africana (*Cyperaceae*)
	Ranunculus multifudus (*Ranunculaceae*)	Eleocharis (*Cyperaceae*)
	Helichrysum aureonitens (*Asteraceae*)	

Table 4.14. Dominant grasses, forbs and sedges found in J6c (with the family name in italic)

4.9. Wetland J7

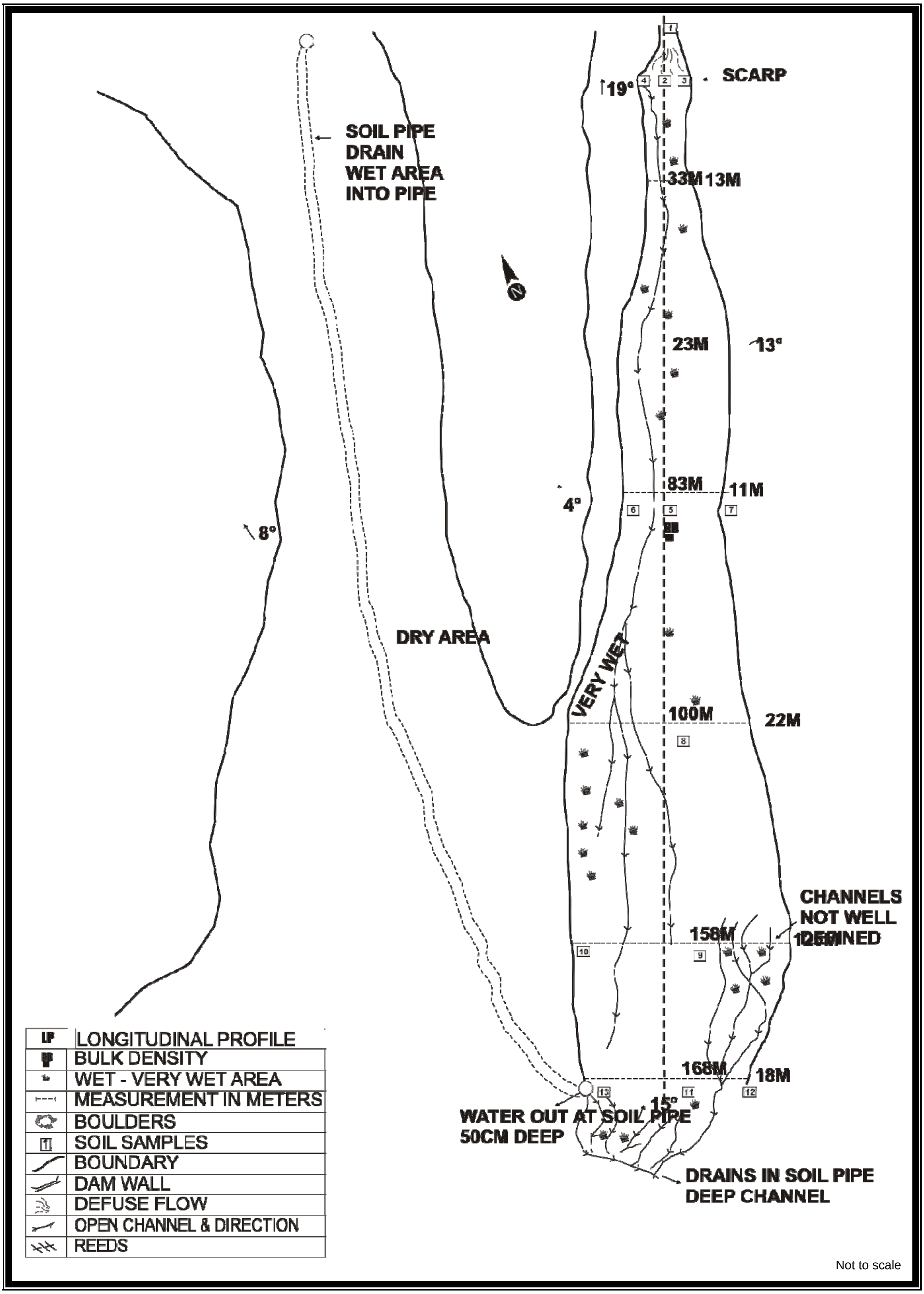
4.9.1. Relief

J7 is situated within unit one (plateau) of the nine-unite land surface model (Dalyrymple et al., 1968) and is situated between two scarps one at the start of the wetland and one where the wetland drains into soils pipes. The gradient of J7 is 4°. The source for the wetland is a soil pipe discharging on to the surface. A small rock wetland is created by soil pipe discharge, which then proceeds over a scarp and on to the wetland area which was studied. Hummocks were noted in the wetland ranged from 5cm to 15cm high. It was also noted that there was a great deal of animal movement in the wetland. The only channel which was noted in J7 was three small channels which ranged in depth from 10cm to 30cm and with a width of 20cm, which drained into a soil pipe. J7 drains into a number of soil pipes. Adjacent to J7 there is a partly collapsed soil pipe, thus creating a partly exposed gully/channel which dischargers into the same soil pipe system as J7.

4.9.2. Fine Particle Analysis

Sample J7:1 (Figure 4.39) was taken at the source and centre of the wetland above the nick point leading to the rest of the wetland. Within sample J7 the sand fraction is the highest (82%) and the silt fraction is second at 14% with clay being the lowest at 4% (Figure 4.40). In sample J7 (which is 6 meters from J7:1 on Figure 4.39) once again the sand fraction is highest at 70.8%, the slit fraction is 24.2%, and the clay fraction being lowest at 5%. In sample J7:3 (which is 8 meters to the right of sample J7:2) the sand fraction again the highest at 64.7%, with silt being second with a percentage of 21.5% and clay being the lowest at 13.8%. In sample J7:4 (which is 8 meters the left of J7:2) the sand fraction is highest at 62.8% with the silt fraction being 24.8% and clay the lowest at 12.4%. At sample J7:5 (which is in the centre of the wetland 83 meters from of sample J7:2) the sand fraction is highest at 75.3% with the silt fraction being 19.7% and clay the lowest at 5%. At sample J7:6 (which is 8 meters to the left of sample J7:5) the sand fraction is the highest at 58% and clay the lowest at 11.8%, the slit fraction within the sample is 30.2%.

Sample J7:7 (which is 8 meters to the right of J7:5), the sand fraction is highest at 73.7% with the silt fraction being 20.5% and clay the lowest at 5.8%. Sample J7:8 (was taken at the centre of the wetland 100 meters from J7:5), the sand fraction is the highest (59.3%) and the silt fraction is second at 34.7% with clay being the lowest at 6%. In sample J7:9 (which was taken at the centre of the wetland 58 meters from J7:8) once again the sand fraction is highest at 63.2%, the slit fraction is 29.6%, and the clay fraction being lowest at 7.2%. In sample J7:10 (which is 6 meters to the left of sample J7:9) in this sample the clay fraction is highest at 71.4%, the sand fraction is 24.4%, and the silt fraction is lowest at 4.2%. In sample J7:11 (which was taken at the centre of the wetland 10 meters from J7:9) once again the sand fraction is highest at 51.1%, the slit fraction is 33.9%, and the clay fraction being lowest at 15%. In sample J7:12 (which is 4 meters to the right of sample J7:11) in this sample the clay fraction is highest at 63.3%, the sand fraction is 30.7%, and the silt fraction is lowest at 6%. In sample J7:13 (which is 4 meters to the left of sample J7:11) in this sample the clay fraction is highest at 61.5%, the sand fraction is 29.2%, and the silt fraction is lowest at 9.3%.


SCARP
19°
SOIL PIPE
DRAIN
WET AREA
INTO PIPE
33M
13M
23M
13°
83M
11M
4°
8°
DRY AREA
VERY WET
100M
22M
CHANNELS
NOT WELL
DEFINED
158M
168M
18M
15°
WATER OUT AT SOIL PIPE
50CM DEEP
DRAINS IN SOIL PIPE
DEEP CHANNEL
LONGITUDINAL PROFILE
BULK DENSITY
WET - VERY WET AREA
MEASUREMENT IN METERS
BOULDERS
SOIL SAMPLES
BOUNDARY
DAM WALL
DEFUSE FLOW
OPEN CHANNEL & DIRECTION
REEDS
Not to scale

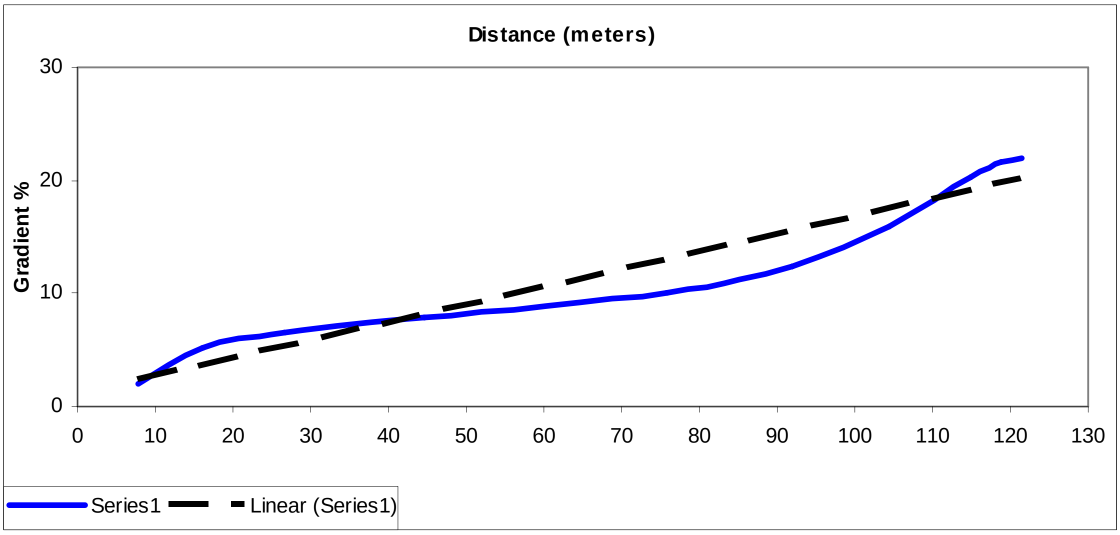


Figure 4.39. Field map (previous page) and longitudinal profile of wetland J7.

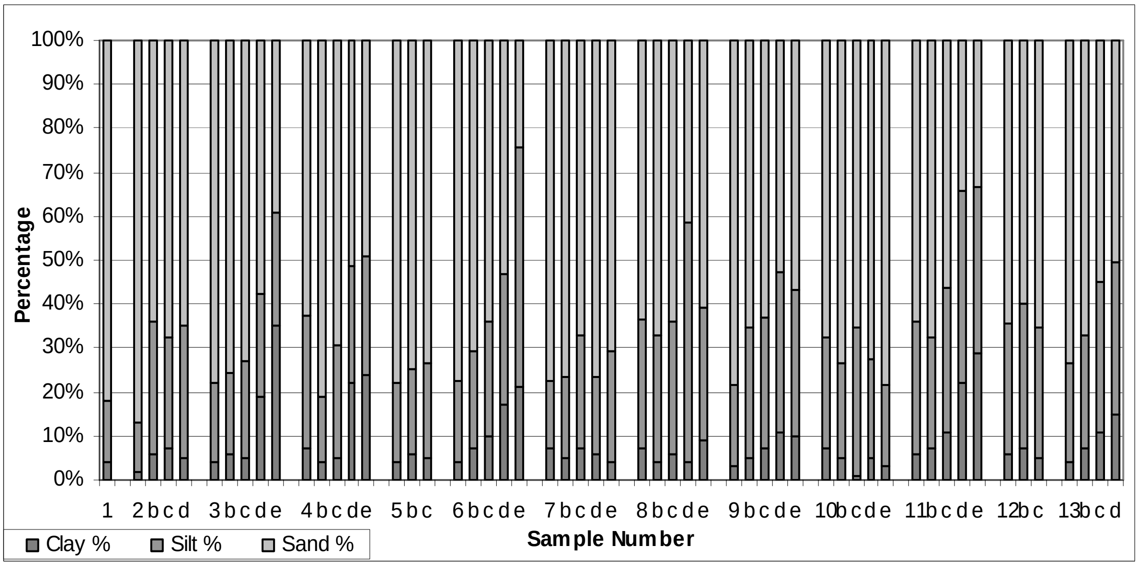


Figure 4.40. Fine particle size analysis for J7

4.9.3. Soil Moisture

The highest average soil moisture was recorded at sample J7:10 (225.4%), the lowest average soil moisture came from sample J7:3 at 44.4%. Soil moisture content generally declines with relation to depth (Figure 4.41). The average soil moisture for wetland J7 was 96.6%. As mentioned previously, peat soils with values of up till 200% may be found, (Briggs, 1977; Goudie 1990), thus the results from J7 indicate a high organic content in a number of the soil sample pits.

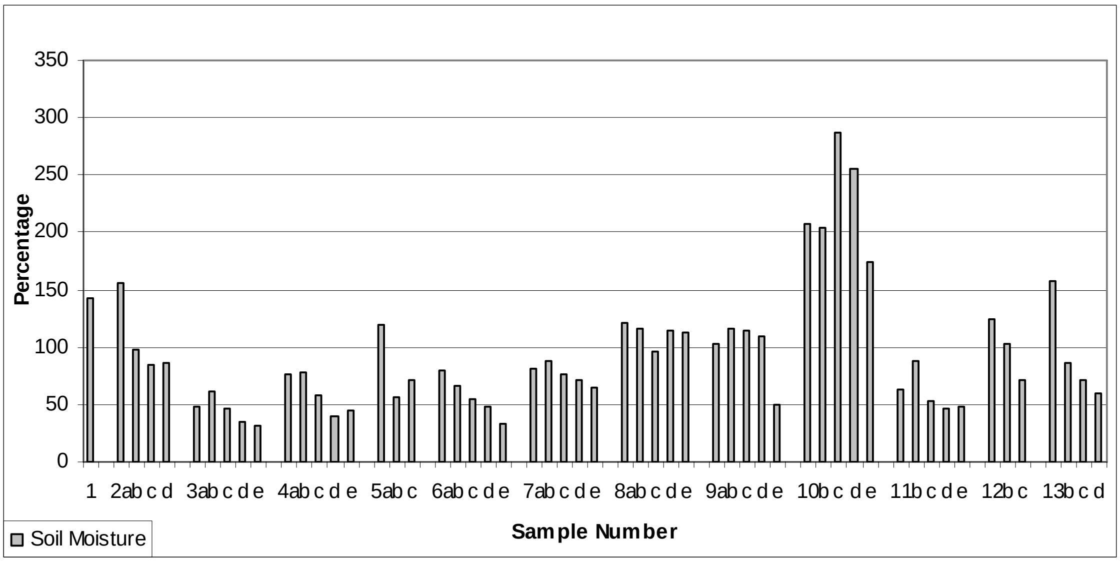


Figure 4.41. Soil moisture (dry weight) for wetland J7.

4.9.4. Soil pH

Acidity descriptions of the wetlands (following Lake, 2000) are outlined in Table 4.15. Acidity in the soil ranges from very slightly acid (5.59 in J7:9) to very slightly alkaline (6.02 in J7:1) (Figure 4.43). The samples were taken longitudinally down the wetland and at a 20cm interval in each sample pit. The average of each sample pit was then derived to give a broader overview of the wetland. There seems to be no apparent pattern in the sample pits related to the depth of the sample and the pH value.

pH RANGE	ACIDITY/ALKALINE CATEGORY	SAMPLE #
pH between 5.5 & 6.0	Very Slightly Acid	J7:2,J7:5,J7:9, J7:13
pH between 6.0 & 6.5	Very Slightly Alkaline	J7:1

Table 4.15. Acidity descriptions for wetland J7

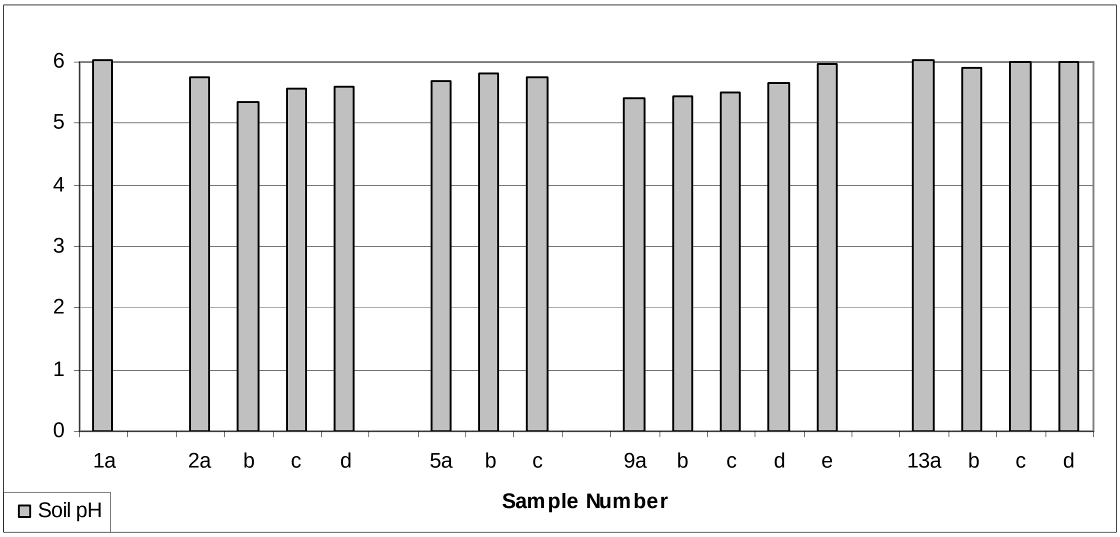


Figure 4.42. Soil pH for wetland J7.

4.9.5. Organic matter and ash content

The average organic matter for wetland J7 is 15.1%. In sample J7:1 the organic matter is 16%. In sample J7:2 the organic matter is 16.5%. The organic matter decreases from 22.5% at 20cm to 15% at 1m depth. J7:3 average is 11.7%, with the highest organic matter recorded in the top 20cm (19.5%) and the lowest in the bottom 1.2m (6.5%). Sample J7:4 organic matter average is 12.7%, with the highest recorded organic content again at 20cm (21.5%) and the lowest at 1m (9%). J7:5 has an average organic content of 14.5%, with the highest recorded organic content at 20cm (20%) the organic content of the soil decreases to 13% in the lower 60cm. In sample J7:6 the average is 10%, organic matter decreases from 20.5% in the top 20cm to 3% in the bottom 1.1m. In sample J7:7 the average organics is 13.5% and decreases from 18% in the top 20cm to 9.5% in the bottom 1.2m. J7:8 average is 17.7%, with the highest organic matter recorded in the top 20cm (22%) and the lowest in the bottom 1.2m (17%). Sample J7:9 organic matter average is 16.9% and decreases from 26% in the top 20cm to 10% in the lower 2m. In sample J7:10 the organic matter is 24.9% and decreases from 31% at 20cm to 18% at 1.5m depth. J7:11 average is 13%, with the highest organic matter recorded in the top 20cm (22%) and the lowest in the bottom 1m (8.5%). Sample J7:12 organic matter average is 14.7%, with the highest recorded organic content again at 20cm (17%) and the lowest at 60cm (11.5%). J7:13 organic matter average is 15.4%, with the highest recorded organic content again at 20cm (28%) and the lowest at 80cm (9%).Ash content proportions are given in Figure 4.43.

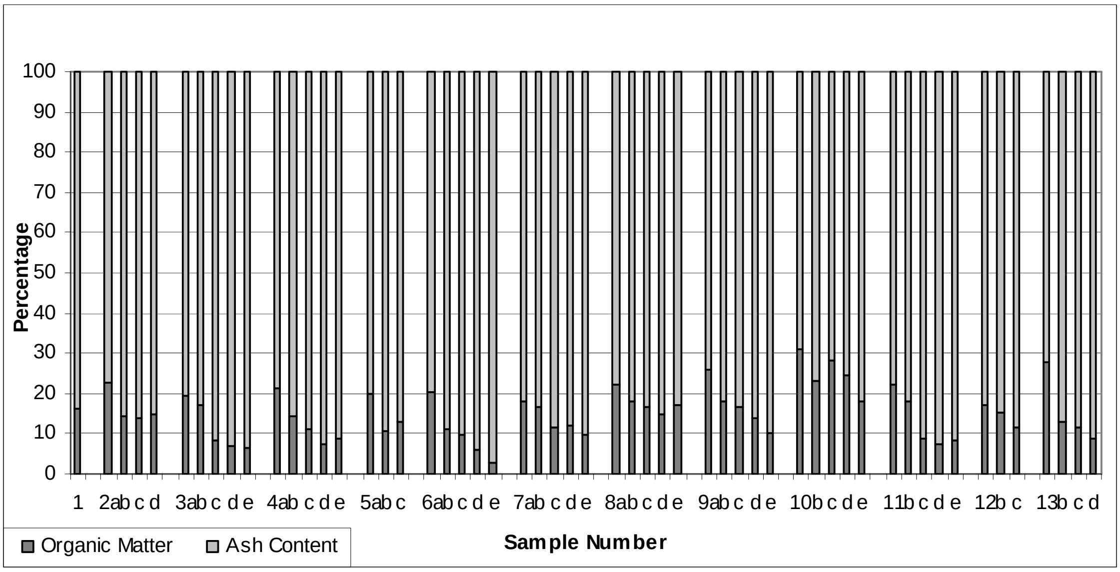


Figure 4.43. Organic matter and ash content proportions for wetland J7.

4.9.6. Bulk density

A sample was taken adjacent to J7:5 inside the wetland, the bulk density of the soil was found to be 0.32g/cm³. A second bulk density sample was taken outside J7, 10m to the east of J7:5 and had a value of 0.42g/cm³. Due to the fact that both samples have low values, it may be postulated that the soils are rich in organic matter and can be classified as Histosols.

4.9.7. Soil and mottle colour

In all the samples taken from J7 nine samples noted as having few small stones (J7:1, J7:2a, J7:2b, J7:2d, J7:3b, J7:3e, J7:4e, J7:5b, J7:6b), two samples were noted as having many small stones (J7:3a, J7:3d), one sample was noted as having very small stones (J7:13c). The soil colour according to the Munsell chart ranged from dark yellowish brown (10 yr 4/6) to black-bluish black (10 yr 2/1-2.5 5/5 pb) to pale yellow-yellow-black (5 y 8/3-2.5 y 7/6-10 yr 2/41) to pale olive-dark yellowish brown (5 yr 6/5-10 yr 3/6), very dark greyish brown (10 yr 3/2), to number of different shades of black (10 yr 2/1, 7.5 yr 2.5/1, 2.5/n, 2.5 y 2.5/1). The mottle colour for J7 ranged from yellowish red (5 yr 4/6) to strong brown (7.5 yr 4/6) to olive yellow (2.5 yr 6/6), brownish yellow (10 yr 6/8),very pale brown (10 yr 8/3). The average mottle abundance for J7 was 6%. For an individual look at each sample colour see Appendix B.

4.9.8. Vegetation

As conducted above, vegetation is outlined in Table 4.16.

Grasses	Forbs	Sedges
Miscanthus capense (*Granineae*)	Helichrysum auronitens (*Asteraceae*)	Ficinia spp. (*Cyperaceae*)
Harpochloa flax (*Poaceae*)	Ranunculus multifudus (*Ranunculaceae*)	
Alloteropsis senialata (*Poaceae*)	Gerbera ambigua (*Asteraceae*)	
Eragrostis (*Poaceae*)		
Diheteropogon filifolius (*Poaceae*)		
A sample of a Vascular plant or Tracheophyte was found: Gunnera perpensa (*Haloragaceae*).		

Table 4.16. Dominant grasses, forbs and sedges found in J4-6 (with the family name in italics.

This chapter has focused on the results from the various laboratory and infield tests which were preformed on the seven wetlands. The following chapter will centre on the discussion of the results.

Chapter 5: Discussion

In this chapter the result from the previous chapter are discussed and conclusions drawn as to the significance which the finding may have in relation to the study objectives. None of the wetlands had particularly unique (previously undiscovered) features and all the data captured were within standard expected totals for palustrine wetlands. One interesting aspect was the role of soil pipes in wetland drainage, both into and out of the systems that appears not to be documented before although Longmore (2001) notes pipes within wetlands. A brief discussion of each measured attribute follows.

5.1. Relief

Water movement into, through and over soil is of paramount importance in soil erosion. It encompasses the infiltration, percolation and retention of water within wetlands and the effects which this has (Bryan, 2000). As stated by Bryan (2000) the transport of sediment from hillslopes to valleys where it is accessible to fluvial processes is of central importance in geomorphology. Added to this is the fact that the study area is located in a high rainfall area, thus rain splash and runoff energy are the active erosive agents which move the sediment down the slopes into the lowlands. It is this sediment from hillslopes which accumulates on low relief/gradient areas which in turn can create areas of impeded water movement thus allowing the water time to infiltrate the soil profile. It can also cause the water to be forced over a wider area. Due to the steep gradients surrounding most wetlands a large amount of sediment is deposited in the wetland, explaining the high sand content in the top 20cm. Although not all wetlands studied have a 0° gradient, within the landscape position the wetland had the lowest relief of the area thus creating areas where water and sediment accumulates and thus infiltrates into the soil profile.

5.2. Particle size distribution

In wetland J1 the samples which were taken in the depressional wetland had the highest overall clay content of all the wetlands and samples taken. This could be due to the surrounding area trapping the hillslope sediment before it enters the depression wetland. In all the wetlands studied, it was found that the clay content of the soil increases with depth, where as the sand content decrease with depth. Another finding was in wetland J2, J3, J4, J6a, J6b, J6c, the clay content is higher in the upper 20cm of the soil profile when moving down the longitudinal profile of the wetland, towards the wetland outlet. Thus in J2, J3, J4, J6a, J6b, J6c, the sand content decreases towards the outlet of the wetland. In wetlands J5, J7 the clay content increases toward the middle of the wetland and decreases towards the outlet. In J5 and J7 the sand content decrease towards the middle of the wetland and then increases again towards the outlet. The reason for the clay content being highest lower down the profile may be due to clay migration and filtration into the soil profile as the water moves downwards as noted by Bryan (2000).

5.3. Soil moisture

In wetland J2 and J6b the soil moisture increases from 20cm to 40cm and then decreases lower down the profile. However in the remaining wetlands the highest moisture content was measured at the surface (0-20cm) of the wetland. On occasions values well over 100% were recorded this may be due to the high organic matter, thus the added ability of the soil to store water, indicating the effectiveness of organic matter to store water. It is also interesting to note that the soil samples with the highest moisture content were also the samples with the highest organic matter percentage and the lowest inorganic (mineral) content. Thus the conclusion can be drawn that the areas of high organic matter have an increased potential to store water. There is a band of water movement between 40-60cm within the soil profile, increased moisture content in this area. This may be due to the increase in clay further down the profile creating an impermeable layer.

5.4. Soil pH

Wetland soils occur over a wide range of pH, organic soils in wetlands are often acidic in nature (Mitsch and Gosselink, 2000). The CO_2 that builds up during the decomposition of organic matter lowers the pH explaining the low pH of wetland soils (Smith and Pizalotto, 2000). The pH of the study site corresponds well with other findings in the KwaZulu-Natal Drakensberg. Mitchell's (1998) work in the Cobham area of the Drakensberg found pH values of 4.45 to 5.54, and van der Merwe (1955) found the pH to vary between 5.6 and 6.6 in the Little 'Berg (in Killick, 1961). Thus the site covered in the current study corresponds with the two previous studies. Average values and provided in Table 5.1.

pH RANGE	**ACIDITY/ALKALINE CATEGORY**	**WETLAND(s)**
pH between 4.0 & 4.5	Strongly Acid	
pH between 4.5 & 5.0	Medium Acid	J1
pH between 5.0 & 5.5	Slightly Acid	J4, J5, J6a, J6c
pH between 5.5 & 6.0	Very Slightly Acid	J2, J6b
pH between 6.0 & 6.5	Very Slightly Alkaline	J7

Table 5.1. Averages for the acidity descriptions for the wetlands investigated

The acidity in the soil ranges form medium acid (4.81 in J1) to very slightly alkaline (6.02 in J7). The samples were taken longitudinally down the wetland and at a 20cm interval in each sample pit. The average of each sample pit was then derived to give a broader over view of the wetland. In wetland J1, J2, J6a, J6c the acidity of the soil decreases from the source of the wetland to the outlet. In wetland J5 the acidity of the soil decreases from the source however, the acidity then increases toward the exit. Wetland J7 is very slightly alkaline (6.02) at its source then the acidity increases faintly toward the middle of the wetland and again returns to near very slightly alkaline (5.99). There appears to be no sequence in the sample pits related to the depth of the sample and the pH value.

5.5. Organic matter and ash content

Organic matter in soil plays an important role in determining soil water-holding capacity, soil structure, binds potentially harmful toxins, and retains carbon from the atmosphere, it also provides along-term store of nutrients needed by plants (Trumbore, 1997; Schumacher, 2002). As organic matter is important within the soil profile it is of interest to observe the amount of organic matter within the soil samples taken thereby attaining an enhanced perception of not only the geomorphology of the wetlands but also the health and functioning within the wetlands.

As presumed from literature, the higher the organic matter fraction, the higher the ability of that soil to store water and retain carbon/toxins from the atmosphere (Bauder, 1999; Trumbore, 1997; Schumacher, 2002; Veseth, 1989). Although none of the wetlands (soil samples) studied had values of over 35% organic matter the values were consistent with that of wetland soils in the KwaZulu-Natal Drakensberg (Longmore, 2001). The average organic matter for all the wetlands studied is 11%. Wetlands which have an organic matter content of higher then 10% are, J3 (11.85%), J5 (12.14%), J6a (12.27%), J6b (12.33%), J6c (16%), J7 (15.19%). There are a number of individual soil samples which have a organic matter content of higher then 20% specifically sample, J5:3a (26.6%), J5:8a (25%), J5:10a (26%), J5:12a (28.7%), J6a:5a (20.5%), J6a:7a (24.5), J6a:10a (20.5%), J6c:1a and 2a (24.5% and 23% respectively, J7:2a (22.5%), J7: 4a (21.5%), J7:6a (20.5%), J7:8a (22%), J7:9a (26%) J7:10a (31%), J7:11a (22%), J7:13 (28%). Most of the above mentioned soil samples are to the middle of the wetland in the permanent zone, thus contributing to the water holding capacity of the wetland. Linked to the water holding capacity is flood attenuation, which is one of the functions of wetlands, the wetlands furthermore perform a water purification function as the organic matter traps any toxins which may be present in the rain water. Organic matter within soil samples indicates that the organic matter decreased with depth, but increased towards the centre/middle sections of the wetlands.

Organic carbon in soil indicates whether the soil is mineral or organic (Kotze, et al. 1996). The conversion of organic matter content to organic carbon has in the past been a widely discussed topic. Traditionally, for soils, a conversion factor of 1.724 has been used to convert organic matter to organic carbon based on the assumption that organic matter contains 58% organic C (i.e., g organic matter/1.724 = g organic C) (Nelson and Sommers, 1996). Despite this there is no universal conversion factor as the factor varies from soil to soil and from soil horizon to soil horizons within the same soil, and will vary depending upon the type of organic matter present in the sample (Schumacher, 2002). Other Conversion factors range form 1.9 to as high as 2.5 (McVay and Rice, 2002; Nelson and Sommers, 1996; Soil Survey Laboratory Methods Manual, 1992). Broadbent (1953) recommended the use of 1.9 to convert organic matter to total organic carbon for surface soils and 2.5 for the conversion of subsurface soils. Dean (1974) uses a conversion factor of 2.13 for organic matter to organic carbon, Dean also suggests a small overestimate may occur in some particularly clay-rich sediments. For this study the conversion factor of Mitsch and Gosselink (2000) were used as both these researchers are well respected for their knowledge on wetlands and wetland soils. Mitsch and Gosselink (2000) suggest a conversion factor of 2, thus for the estimate of organic carbon when organic matter content is know,

$$\%C_{org} = \%OM/2$$

Where $\%C_{org}$ = percentage of organic carbon

%OM = percentage of organic matter

The above formula is a guildeline and the conversion is for an estimate of organic carbon in the soils sampled. It must be noted that there are a large number of variables which may influence the results of the organic matter to organic carbon conversion, such as exposure time, sample size, and position in the furnace Heiri (2001), these variable however are not within the scope of the present study.

Organic carbon results show that none of the wetlands in their totality can be classified as organic soils, however there are certain areas which have 10% organic carbon. These areas are generally to the centre/middle of the wetland.

5.6. Bulk density

Organic soils have a lower bulk density and higher water holding capacity then mineral soils. As stated by Mitsch and Gosselink (2000) the bulk density of well decomposed organic soils is generally 0.2 to 0.3g/cm³. All the bulk density measurement which were taken was very low ranging form 0.17- 0.96 in J3 and J2 respectively, thus indicating a high porosity as well as high organic matter content of the soils. According to (Smith and Pizalotto, 2000) as plant material decomposes, bulk density increases thus when analysing the data it can be noted that the wetland study site have poorly decomposed plant material as the bulk density is very low. Bulk density decreased with increased organic matter content.

5.7. Observations

Most of the wetlands studied were discharge site, as water flowed out of the soil profile onto the surface area. J1 which had no know outlet is the only wetland which can be classified as a recharge wetland. All the wetlands were well vegetated. The trampling of wetland areas by animals is a cause of concern due to the fact that this increases the erosive qualities of wetland soils during high rainfall events (more lose soil). Due to the small size of the wetlands their individual effect of flood attenuation may be minimal, however when added together they may have a valuable role to play, not only in flood attenuation but also in water quality.

5.8. Geomorphic attributes or features

As set out in the aims and objectives in Section 1.8, geomorphic attributes of the wetlands were identified and these are as follows.

5.8.1. Low relief

All but two of the wetlands within the study area are the lowest point in the landscape, and thus the area where water and sediment will accumulate. The wetlands within the study area are surrounded by steep slopes and rough topography. Although not all wetlands studied have a 0° gradient, the gradients of the wetlands ranged between 0° and 9°. The gradients were still low enough to slow the movement of water sufficiently to trap sediment.

5.8.2. Soil piping

Piping develops spontaneously by outlet sapping where soil water potential is positive and high hydraulic gradients produce seepage forces that can eject particles and enlarge fabric macro pores. Forces close to the surface can usually eject only small particles from soils of low cohesion, so true piping is usually found only in saturated dispersed clays, loess and organic soils (Bryan, 2000). It is thus postulated that the main deposition of sediments is through hill slope runoff.

As noted above, one interesting finding is that all but one wetland flow into a soil pipe before entering a low order stream. Also, J6a, b, c, J5 and J7 source from a soil pipe. Although soil pipes may occur within wetlands (e.g. Longmore, 2001) to the author's knowledge the role which soil pipes play n regard to drainage, into as well as out of wetlands, has not been document before. Further research is necessary to determine why this area is known for its soil piping.

5.8.3. Sediment traps

Due to the high percentage of sand in the top 20cm it can be hypothesized that sediment from the hillslopes is deposited in the wetland areas as the water losses its velocity. This is again due to the low relief of the wetlands in the landscape.

5.8.4. Surface roughness

The hummocks and surface roughness in the wetland help with the slowing down of storm water as it enters the wetland. This in turn ensures the infiltration, percolation and retention of water in the wetland, thereby ensuring low flow for the catchment.

5.8.5. Channelling within wetland

A number of wetlands had channels draining them, the smaller channels had minimal effect on the surrounding area, however the larger channel in wetland J6b had a very significant effect on the surrounding wetland areas. The channels are the primary means by which water exits the wetlands, it must be noted that the channels are not permanent and change from season to season.

5.8.6. Organic matter accumulation

As previously stated the organic matter increases towards the middle of the wetland, which may in the long term have an effect on the relief of the wetland, due to the accumulation of organics in the middle of the wetland. In doing so areas of lower relief will be created, thus the water will be forced to flow in such areas, which again in turn may cause micro channelling within the wetland.

5.8.7. Geological barriers (scarps)

Three wetlands (J4, J5 and J7) had geological barriers in the form of scarps, the effect of the barriers are more significant above the barrier, due to the fact that water dams up behind the barrier. Small scale barriers within the wetlands were not noted.

However, the small scarp may give rise to a broken topography with associated rapid run-off and high erosion hazard below the scarp (Rydgren, 1996.).

5.9. Testing J. Longmore's hydro-geomorphologic classification:

Longmores classification of the wetlands according to hydro-geomorphic attributes was tested to see the compatibility of the classification to different catchments. Longmore (2001) identified five different wetland classes in the upper Mooi River Catchment area, these classes can be defined as follows:

- **Bench**: which can either be confined or unconfined to a depression, from here another distinction can be made namely rock or soil based.
- **Basin**: which can either be situated in a headwater position or have a variable terrain position (throughflow basin), a distinction can be made again between channelled (straight, meandering and channelled islands) and un-channelled.
- **Valley Side Slope**: this class can be divided into linked or isolated which again can be divided into convex or concave slope, another distinction can be made here channelled or un-channelled.
- **Confined Valley** (flood plain not well developed low order stream): here the wetlands are divided as follows, headwater position or variable terrain (throughflow wetland) further divided into channelled (straight, meandering and channelled islands) or un-channelled.
- **Unconfined Valley** (floodplain well developed high order stream):here the distinction is made between valley side slope (bordering/in close proximity to wetland) or valley side (significant distance away from wetland >100m), which is divided into channelled (straight, meandering and channelled island) or diffuse flow.

Longmore (2001) classified each wetland type according the following descriptors: landscape position, landform characteristics, morphometry, size, hydrology, nature of substratum, and dominant vegetation characteristics. For an in depth look into the classification system see Longmore (2001).

The wetlands studied here can be classified into the following classification types.

5.9.1. Wetland J1

Landscape position: Bench

Category: Shelf wetland

Landform characteristics: relatively flat, with both micro and macro- topographical variations.

Morphometry: wetland restricted to depressions (commonly referred to as Tarns).

Size: very small wetland, encompassed by a frame reference of less the 100 x 100m. Characterized by a diameter of more than five meters, but less than or equal to 35 meters.

Hydrology: Water depth: Depths between 20cm and 50cm.

Water permanence: Variable – temporary to permanent.

Water balance: Primary sources of water input:
- precipitation
- Overland flow
- Groundwater discharge

Primary sources of water output:
- evaporation
- Evapotranspiration
- Groundwater recharge
- Overflow of tarn side walls.

Nature of Substratum: Soil depth 1m on consolidated sheetrock base. Organic matter content for the surface horizons range from 8.5% to 15.2%. Organic carbon estimate range from 4.3% to 7.6%.

Vegetation: Found in J1: Styppeiochloa gynoglssa, Mentha aquatica, Eleocharis dregeana, Miscanthus capense, Helichrysum pilosellum, cf Hibiscus, Senecio decurrens as well as one sample of a Vascular plant or Tracheophyte was found: cf Hypoxis rigidula.

5.9.2. Wetland J2

Landscape position: Valley side slope

Category: Isolated

Landform characteristics: slope is slightly concave. However the gradient of the wetland is below the suggested 5%. The surface is smooth, with micro-topographical variability.

Morphometry: wetland gradient not steep, however surrounding gradient steep, especially towards the low order stream.

Size: Relatively small in aerial extent. Encompassed by a frame of references less then the micro-scale wetlands (i.e. > 500m x 500m), J2 size is 105m².

Hydrology: Water depth: Depths between 20cm and 50cm.

Water permanence: Variable – temporary to permanent.

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.

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Nature of Substratum: Contrary to classification solum depth was up to 80cm, and not as classification states 10-20cm. Organic carbon below 5%.

Vegetation: Miscanthus capense, Helichrysum pilosellum, Schoenaplectus sp, Eleocharis dregeana, as well as Potamogeton thunbergi, Gunnera perpensa, Mentha aquatica are common.

5.9.3. Wetland J3

Landscape position: Valley side slope

Category: Isolated.

Landform characteristics: Slope is concave. Gradient is relatively steep 9°. Micro-topographical variability exists.

Morphometry: Isolated from valley bottom wetlands. However the wetland does flow into a low order stream.

Size: Relatively small in aerial extent. Encompassed by a frame of references less then the micro-scale wetlands (i.e. > 500m x 500m), J3 size is 516m².

Hydrology: Water depth: Standing water found, water is temporarily ponded in micro-topographical depression.

Water permanence: Generally below 10cm.

Water balance: Primary sources of water input: precipitation

Overland flow

Groundwater discharge

Primary sources of water output: evaporation

Evapotranspiration

Groundwater recharge

Surface runoff, subsurface flow.

Nature of Substratum: Contrary to classification solum depth was up to 1m, and not as classification states 10-20cm. Organic carbon higher in some sample then the prescribed 5%.

Vegetation: Seasonal to temporary hydrophytic vegetation, Potamogeton thunbergi, Gunnera perpensa, Mentha aquatica are common (according to Longmore 2001). However, due to the fact that J3 was burnt on before site visit no samples were taken.

5.9.4. Wetland J4

Landscape position: Confined valley wetlands

Category: Source seepage zone

Landform characteristics: Narrow, with a gradient of 2.5%, a scarp intersects the wetland after which it is labelled J5.

Morphometry: Linear and fairly narrow.

Size: well over 2000m², meso- to macro scale.

Hydrology: Water depth: Variable but does not exceed 20cm.

Water permanence: Seasonal to permanent.

Water balance: Primary sources of water input: subsurface, toeslope seepage

precipitation

Overland flow

Groundwater discharge

Primary sources of water output: evaporation

Evapotranspiration

Groundwater recharge

Surface, subsurface runoff.

Nature of Substratum: Solum depth in the order of 1m. Organic carbon in the order of 9%.

Vegetation: Miscanthus capense, Helichrysum pilosellum, Schoenaplectus sp, Styppeiochloa gynoglossa, cf Scabiosa, Carex autro-africana, cf Hibiscus, Eleocharis dregeana, Senecio decurrens, Cyrtanthus breviflorus, Gunnera perpensa.

5.9.5. Wetland J5

Landscape position: Unconfined valley wetlands

Category: Diffuse

Landform characteristics: very flat with a negligible gradient. Not associated with a significant river channel, un-channelled flat wetland.

Morphometry: the lateral extent of the wetland is limited by valley sides slopes.

Size: Relatively large in the order of 15km².

Hydrology: Water depth: Standing water depth variable, in the order of 10-30cm.

Water permanence: permanent

Water balance: Primary sources of water input: precipitation

Overland flow

Groundwater discharge

Runoff & seepage from valley side slopes

Primary sources of water output: evaporation

Evapotranspiration

Groundwater recharge

Overland and subsurface flow.

Nature of Substratum: generally deep sediment deposits up to 200cm. Organic carbon high up 14% in permanently wet zones.

Vegetation: Miscanthus capense, Helichrysum pilosellum, Schoenaplectus sp, Styppeiochloa gynoglossa, cf Scabiosa, Carex autro-africana, cf Hibiscus, Eleocharis dregeana, Senecio decurrens, Cyrtanthus breviflorus, Gunnera perpensa, as well as Phragmites spp., Typha spp and Cyperus spp.

5.9.6. Wetland J6a,b,c

Landscape position: Confined valley wetlands

Category: Headwater

Landform characteristics: A gradient of 3%, confined to valley bottoms.

Morphometry: Linear, valley side slope define the wetlands catchment area. One large channel draining the wetland.

Size: well over 9000m², meso- to macro scale.

Hydrology: Water depth: Variable but does not exceed 50cm.

Water permanence: Seasonal to permanent.

Water balance: Primary sources of water input: subsurface, toeslope seepage
precipitation
Overland flow
Groundwater discharge

Primary sources of water output: evaporation
Evapotranspiration
Groundwater recharge
Surface, subsurface runoff.

Nature of Substratum: Solum depth in the order of 1.5m. Organic carbon as high as 14%.

Vegetation: Miscanthus capense, Helichrysum pilosellum, Schoenaplectus sp, Styppeiochloa gynoglossa, cf Scabiosa, Carex autro-africana, cf Hibiscus, Eleocharis dregeana, Senecio decurrens, Cyrtanthus breviflorus, Gunnera perpensa.

5.9.7. Wetland J7

Landscape position: Basin wetland

Category: Headwater basin

Landform characteristics: The landform is best described as basinal.

Morphometry: Generally slightly concave.

Size: 2300m²

Hydrology: Water depth: rarely exceed 20cm, generally below 10cm.

Water permanence: Permanent.

Water balance: Primary sources of water input: precipitation
Surface & subsurface flow
Groundwater discharge

Primary sources of water output: evaporation

Evapotranspiration

Groundwater recharge

Surface runoff, subsurface flow

Nature of Substratum: Contrary to classification solum depth up to 2m. Organic carbon may be a high as 15%.

Vegetation: Miscanthus capense, Helichrysum auronitens, Ficinia spp., Harpochloa flax, Ranunculus multifudus, Alloteropsis senialata, Gerbera ambigua, Eragrostis, Diheteropogon filifolius, Gunnera perpensa.

5.9. Findings of the classification

Notwithstanding the role of piping, all the wetlands studied could be placed into one of the classification types, however, some difficulty was experienced with nature of substratum as the current study found the soil depth to be deeper then that of the classification. Added to this the organic carbon content was also higher then that of the classification. Criteria appear simple and easy to understand, however the field worker needs a basic understanding of wetlands and geomorphological processes within and surrounding wetlands in the classification area.

Several additional points can be made:

- Although there is some need in the refinement of the water balance as it may be difficult for an untrained person to decide on primary sources of water input and output within a wetland. This could be done by listing the physical appearance on the wetland surface.
- The vegetation study should be expanded as to give a wider range of vegetation which may be found within a certain wetland type.
- Schematic sketches are very useful, however these may cause confusion regarding wetlands which may be border cases such as J6a,b,c.
- It is also suggested that the classification is used on other catchments to test the adaptability to different environments. An effort should also be made to

circulate the classification to institutions and governmental departments to ensure the use of the classification and prevent the creation of another classification which focuses on the same wetland types.

Chapter 6: Conclusion

The findings contained in this study have highlighted the connection between wetlands and the surrounding landscape and hydrological conditions. A concise overview of the findings reported in this study together with the implication of the findings and the opportunities for further research follows.

6.1. Dominant factors which influence the origin and maintenance of wetlands

Observations made in field and analyses in the laboratory have shown that wetland origin and maintenance in the study area may well be attributed to the following factors:

6.1.1. Climatic factors

As noted before the study area is situated within a high rainfall zone relative to other areas in South Africa (Schulze, 1979). This increases the amount of water available for infiltration into the wetland, added to this the lower temperatures in the high altitude zone reduce the evaporation and evapo-transpiration potential of the wetlands (Ellery et al.,2005). This adds to the water budget of the wetland Mitsch and Gosselink (2000) thereby enhancing the potential of organic matter accumulation within wetlands as well as the added potential for sediment movement down the side slopes into the wetland.

6.1.2. Landscape position

The position of the wetlands within the landscape setting plays an important role in where wetlands will form and the maintenance of the wetlands. The setting of the wetland influences the size, due to the restrictive nature of the valley sides and the hillslopes surrounding the wetland (Semeniuk, 1987; Semeniuk and Semeniuk, 1995). Due to the steep hillslopes of the watershed as well as the high rain fall, the sediment yield to the wetlands is enlarged (Bryan, 2000). Wetlands are inclined to form in areas of low relief and well as in depressions. Slope wetlands predominantly form in areas of discharge and do not store water, whereas wetlands situated in depressions or valley bottoms act as storage units, for low flow.

6.2. Wetland characteristics

The geomorphology within wetlands strongly influences the local pattern of water movement, surface and sub-surface (Bedford and Preston, 1988). Certain of the wetlands studied appeared to act as sediment sinks, thereby supporting a water purification role with the landscape (Kotze, et al., 2005). Due the position of the wetlands they trap sediment which moves down the slopes before it can enter the low order stream thus removing sediment which would have landed up in a high order river further down the catchment.

6.2.1. Water movement within wetlands

The small channel systems found within the wetlands appeared to have been formed by three different forces namely: soil pipe collapse, faunal initiation, or overland flow processes. With the collapse of soil pipes channels are created which may drain the wetland, the smaller channels have a minimal effect on the surrounding wetland areas. However the larger channels have a pronounced effect in drying out the area it flows through. Generally when soil pipes collapse they create larger channels, which are more effective in drying out the wetland, and transport the water and sediments out and into the river channel.

Pertaining to faunal initiation, observations are that the continuous movement of large or small herbivores on certain path within wetlands can create depression which may become areas of preferential water movement. Added to the larger herbivore are rodents which barrow in the wetlands looking for food, thereby creating cavities and barrows which can be enlarged by overland flow and later form channels within the wetlands.

As stated before the surface roughness (hummocks) of the wetlands play an important role not only in channelling the water, but also in slowing down the velocity of the over land flow. The above statement may seem contradictory, as the hummocks create areas of lower relief thus creating channels, for water movement. However, during large rainfall events the water exceeds the channels between the hummocks and the hummocks then slows the velocity of the water down as the water passes over the hummocks.

6.2.2. Organic matter accumulation

Wetland hydrology also controls the accumulation of organic matter through its influence on the primary productivity, and decomposition organic matter (Mitsch and Gosselink, 2000). Due to the anaerobic conditions within a wetland decomposition is slow and organic accumulation high. In the study it was found that the permanent wet areas are also the areas where the most organic matter was found. These areas are to the centre of the wetlands, generally the areas with lowest relief (Ellery, et al., 2005). However, over time organics may accumulate within this area, thus the area may become raised, thereby changing the water flow within the wetland.

6.3. Hydro-geomorphic classification

It is with the help of a classification systems that addresses geomorphic issues that proper enlightened management decisions can be made. There has been a need in wetland classification to look at the surrounding areas, as well as the wetland itself. Decisions are often made with only ‘half’ the information (Semeniuk and Semeniuk, 1995). Thus only ‘half’ of the problem will be addressed. Often wetland rehabilitation managers do not have the basic environmental understandings to make informed decisions about rehabilitation works needed. With this classification managers can broaden their view on wetlands and come to the understanding of what processes occur where in the wetland setting. Added to this the managers will be forced to look further than the wetland boundaries, to the surrounding landscape and thereby developing an understanding of the geomorphological interactions between terrestrial and aquatic systems (Kotze, 1999).

It must be noted at this point that Longmore’s (2001) classification is not basic. To apply the classification, some knowledge of geomorphology and wetland functions is required, yet it is simple enough to be used effectively.

However, some information will be lost such as information pertaining to water balance, as there are no clear surface descriptions given as well as depth and organic content of the soil as few managers have the necessary skills and equipment to gather the information. Within the classification there is a need to refine certain aspects such as the water balance of the wetlands, as well as the vegetation sections, this has been discussed in previous chapters.

Despite the fact that Longmores (2001) classification comes at a time when there has been an increase in wetland classifications (Dini and Cowan, 2000; Kotze, et al., 2001: Ellery, et al., 2005; Ewart-Smith, et al., 2006), Longmores (2001) classification is the only one which focuses on the hydro-geomorphology of palustrine wetlands.

6.4. Incorporation into management systems

As mentioned above the fact that Longmores' classification is the only palustrine classification currently available to field and academic staff it is of utmost importance that the classification is incorporated into management systems, thereby creating a larger data base of palustrine wetlands within South Africa, and thus addressing the paucity of geomorphological research in palustrine wetlands. It is also important to identify reference or bench mark wetlands.

The wetlands researched are pristine, and thus they provide a good bench mark against which other wetlands can be compared for a number of purposes such as assessment, training, mitigation, restoration, and classifications (Brinson, 1993).

Both on and off site management of wetlands is necessary, as changes in the land use above a wetland may have very pronounced effect on the wetland and its functioning. Therefore, the classification by Longmore is respectable as it not only focuses on the wetland but also on the surrounding area, thereby creating a holistic frame work from which to classify.

Bridging the distance between academic staff and managers is not an easy one and changes will have to be at grass roots level. Public perception that a wetland is a wetland and no differences exist between different types of wetlands must be changed. The only way to do this will be through an intensive education plan probably starting at school level. Perceptions start at a young age, as children will become the managers and leaders of tomorrow. This however is not the solution which is needed today. When incorporating a classification system into a management plan every effort must be made to ensure that the final user of the classification has the necessary skill to apply the classification.

However, before the roll out phase of the classification can begin the classification system must first be accepted by the academic society, thereby ensuring there is no reinvention of the wheel.

6.5. The need for further research

Wetlands can not be researched from any one single discipline, due to the nature and the interaction which wetlands have with the natural and man made environments, wetlands should be looked at from a multi-disciplinary field (Longmore, 2001). Despite the fact that wetland research has been undertaken by many researches there is still a wide area in which more information should be collected and interpreted. Wetlands are dynamic environments which change continually thus further research into a clearer understanding in the geomorphology of wetlands, can only benefit wetland extension workers. A number of key areas where more research has been identified and are as follows:

- Investigation is necessary relating to the organic carbon of wetlands, the effect which regular burning has on it, and the accumulation rates. As well as the distribution of organic carbon across the country.
- More research is necessary relating to the hydrogeomorphic contribution of soil pipes into, within and out of wetlands.
- Further investigation is required to determine to what extent fauna impacts on wetlands and the micro topography within the wetlands.

- There is a need for long term research into hillslope sediment delivery processes and the effect this may have on the formation and maintenance of wetlands (over land flow and sediment transport into wetlands) as well as the effect which this may have on the vegetation in the wetland.

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APPENDIX A

Laboratory analysis
for
Wetlands J1-J7

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
J1										
1a	20 cm	41	36.9	22.1	39.1	64.1	89.7	10.3	5.2	4.75
1b	40 cm	48	33.8	18.2	40.0	66.7	90.6	9.4	4.7	4.83
1c	60 cm	59	34.1	6.9	39.8	66.0	91.7	8.3	4.2	4.75
1d	80 cm	67	30.8	2.2	28.1	39.1	95.5	4.5	2.2	4.89
2a	20 cm	21	32.7	46.3	24.1	31.8	90.2	9.8	4.9	4.89
2b	40 cm	23	36.5	40.5	23.9	31.4	90.6	9.4	4.7	4.89
2c	60 cm	30	43.9	26.1	24.7	32.8	94.1	5.9	3.0	5.07
2d	80 cm	34	48.1	17.9	23.7	31.0	95.2	4.8	2.4	4.77
3a	20 cm	8	18.3	73.7	46.8	87.9	84.8	15.2	7.6	4.98
3b	40 cm	20	26.6	53.4	35.7	55.5	92.1	7.9	4.0	4.92
3c	60 cm	35	26.9	38.1	34.2	52.1	93.0	7.0	3.5	4.88
J1										
A1	15 cm	44	33.7	22.3	31.3	45.6	91.5	8.5	4.3	
A2	30 cm	60	34.3	5.7	30.8	44.6	94.0	6.0	3.0	
A3	60 cm	66	34	0	35.1	54.0	93.5	6.5	3.3	
A4	80 cm	65	35	0	23.4	30.5	95.0	5.0	2.5	
A5	1 m	63	37	0	24.9	33.2	98.0	2.0	1.0	
B1	15 cm	26	30.1	43.9	35.1	54.0	86.0	14.0	7.0	
B2	30 cm	36	40.6	23.4	32.2	47.5	91.5	8.5	4.2	
B3	45 cm	48	44.2	7.8	28.0	39.0	93.0	7.0	3.5	
C1	15 cm	16	21.9	62.1	31.8	46.5	89.5	10.5	5.3	
C2	30 cm	23	25.4	51.6	32.3	47.8	91.5	8.5	4.3	
C3	45 cm	37	33.1	29.9	28.8	40.4	93.0	7.0	3.5	
C4	90 cm	39	22.9	38.1	26.9	36.8	95.0	5.0	2.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
J2										
1a	20 cm	12	25.4	62.6	43.3	76.5	91.0	9.0	4.5	5.47
1b	40 cm	21	39.9	39.1	29.1	41.1	95.0	5.0	2.5	5.38
2a	20 cm	13	29.2	57.8	23.5	30.8	91.5	8.5	4.3	
2b	40 cm	25	26.7	48.3	20.9	26.4	94.5	5.5	2.8	
2c	60 cm	22	32.8	45.2	22.5	29.1	95.5	4.5	2.3	
2d	80 cm	29	27.1	43.9	22.6	29.2	96.5	3.5	1.8	
3a	20 cm	14	25.9	60.1	30.3	43.6	96.0	4.0	2.0	
3b	40 cm	27	43.6	29.4	31.7	46.5	94.0	6.0	3.0	
3c	80 cm	25	38.1	36.9	27.5	37.9	96.0	4.0	2.0	
4a	20 cm	20	30.3	49.7	33.5	50.3	94.5	5.5	2.7	5.43
4b	40 cm	24	33.6	42.4	34.2	52.1	95.1	4.9	2.5	5.78
4c	60 cm	32	33.9	34.1	28.0	38.9	95.0	5.0	2.5	5.76
5a	20 cm	21	36.3	42.7	28.2	39.2	95.0	5.0	2.5	
5b	40 cm	23	41.1	35.9	26.1	35.3	95.5	4.5	2.2	
5c	60 cm	35	34.1	30.9	25.7	34.6	95.5	4.5	2.2	
6a	20 cm	16	26.3	57.7	25.1	33.4	93.4	6.6	3.3	
6b	40 cm	25	33.4	41.6	26.8	36.7	94.6	5.4	2.7	
6c	80 cm	22	39.9	38.1	24.4	32.2	95.5	4.5	2.3	
7a	20 cm	24	37.8	38.2	30.1	43.1	92.6	7.4	3.7	5.57
7b	40 cm	23	37.4	39.6	31.0	44.9	93.1	6.9	3.4	5.89
7c	60 cm	36	41.5	22.5	24.2	31.9	95.5	4.5	2.2	6.01

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
J3										
1a	15 cm	8	29.7	62.3	57.3	134.0	86.5	13.5	6.8	
1b	30 cm	25	29.7	45.3	45.3	82.7	88.0	12.0	6.0	
1c	1 m	17	26.6	56.4	28.6	40.1	96.5	3.5	1.8	
2a	15 cm	9	22.4	68.6	49.9	99.6	92.5	7.5	3.7	
2b	30 cm	7	21.8	71.2	27.5	38.0	92.5	7.5	3.7	
2c	45 cm	11	25.4	63.6	27.1	37.1	93.0	7.0	3.5	
2d	80 cm	19	32.9	48.1	26.3	35.6	94.5	5.5	2.7	
3a	15 cm	7	21.7	71.3	62.1	164.0	81.5	18.5	9.2	
3b	30 cm	22	29.5	48.5	57.9	137.6	81.5	18.5	9.2	
3c	1 m	28	33.5	38.5	57.6	135.6	86.0	14.0	7.0	
4a	15 cm	5	21.8	73.2	37.2	59.3	86.5	13.5	6.7	
4b	30 cm	12	25.6	62.4	35.9	56.1	90.5	9.5	4.7	
5a	15 cm	15	26.1	58.9	50.0	100.1	86.0	14.0	7.0	
6a	15 cm	8	22.2	69.8	31.8	46.6	88.0	12.0	6.0	
J4										
1a	20 cm	4	32.7	63.3	54.9	121.7	81.0	19.0	9.5	4.95
1b	40 cm	11	39.9	49.1	36.8	58.3	87.5	12.5	6.3	5.44
1c	60 cm	15	40.6	44.4	34.0	51.6	92.0	8.0	4.0	5.28
1d	80cm-1m	33	48.3	18.7	31.6	46.2	92.0	8.0	4.0	5.48
2a	20 cm	6	33.8	60.2	63.1	170.6	80.5	19.5	9.8	
2b	40 - 60 cm	14	29.8	56.2	50.1	100.2	91.5	8.5	4.3	
2c	60 - 80 cm	29	41	30	36.6	57.8	92.5	7.5	3.7	
2d	80cm - 1m	42	41.7	16.3	30.6	44.2	94.9	5.1	2.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
Aa	15 cm	6	32.7	61.3	31.7	46.4	90.5	9.5	4.7	
Ab	40 cm	14	33.1	52.9	27.1	37.2	93.5	6.5	3.3	
Ac	60 cm	24	29.9	46.1	23.6	30.8	95.0	5.0	2.5	
Ad	80 cm	21	36.4	42.6	22.2	28.5	95.5	4.5	2.3	
Ae	1.2 m	19	37.8	43.2	22.6	29.2	93.0	7.0	3.5	
J5										
1a	20 cm	9	29.4	61.6	49.5	98.0	88.1	11.9	6.0	4.77
1b	40 cm	8	29.2	62.8	51.4	106.0	87.5	12.5	6.3	5.53
1c	60 cm	11	37	52	47.7	91.4	87.0	13.0	6.5	5.42
1d	80 cm	10	36.6	53.4	47.9	92.0	86.5	13.5	6.7	5.43
2a	20 cm	5	21.8	73.2	38.4	62.4	84.0	16.0	8.0	
2b	40 cm	7	29.3	63.7	42.4	73.7	88.0	12.0	6.0	
2c	60 cm	10	36.5	53.5	39.9	66.4	89.4	10.6	5.3	
2d	80 cm-1m	18	40.3	41.7	35.5	55.1	92.5	7.5	3.7	
3a	20 cm	5	25.5	69.5	73.8	281.0	73.4	26.6	13.3	5.59
3b	40 cm	7	29.6	63.4	58.6	141.7	82.5	17.5	8.8	5.44
3c	80 cm	4	29.4	66.6	42.2	72.9	92.0	8.0	4.0	5.45
4a	20 cm	3	21.8	75.2	39.0	64.0	91.0	9.0	4.5	
4b	40 cm	6	29.3	64.7	37.8	60.7	91.1	8.9	4.5	
4c	60 cm	7	29.5	63.5	33.4	50.2	93.0	7.0	3.5	
5a	20 cm	11	40.1	48.9	40.7	68.7	90.0	10.0	5.0	5.43
5b	40 cm	8	43.6	48.4	37.9	60.9	91.0	9.0	4.5	5.52
5c	60 cm	9	34.1	56.9	37.9	61.0	92.5	7.5	3.7	5.59
5d	80 cm	15	44.2	40.8	39.4	64.9	92.5	7.5	3.8	5.61
6a	20 cm	7	26.1	66.9	26.1	35.4	87.0	13.0	6.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
6b	40 cm	14	29.7	56.3	27.4	37.8	94.0	6.0	3.0	
6c	60 cm	25	50.9	24.1	25.9	35.0	94.0	6.0	3.0	
7a	20 cm	11	29.5	59.5	34.8	53.4	86.5	13.5	6.8	
7b	40-60 cm	7	33.1	59.9	35.6	55.3	88.5	11.5	5.7	
7c	80 cm	24	60.1	15.9	31.6	46.2	93.5	6.5	3.3	
7d	1 m	26	33.9	40.1	26.2	35.5	95.5	4.5	2.2	
8a	20 cm	7	22.1	70.9	66.2	195.6	75.0	25.0	12.5	5.85
8b	40 cm	9	29.8	61.2	40.0	66.7	88.5	11.5	5.8	5.74
8c	60 cm	11	30.1	58.9	36.1	56.5	91.5	8.5	4.3	5.29
9a	20 cm	19	33.7	47.3	20.0	25.0	88.0	12.0	6.0	
9b	40 cm	12	23.4	64.6	28.4	39.6	88.0	12.0	6.0	
9c	60 cm	19	29.6	51.4	25.9	35.0	87.5	12.5	6.3	
10a	20 cm	2	21.8	76.2	71.9	256.5	74.0	26.0	13.0	5.65
10b	40 - 60 cm	8	22.3	69.7	61.0	156.7	81.0	19.0	9.5	5.47
10c	60 - 80 cm	24	30.7	45.3	40.2	67.3	91.0	9.0	4.5	5.33
10d	1.2 m	36	34.1	29.9	25.9	34.9	97.5	2.5	1.3	5.05
11a	20 cm	7	18.4	74.6	28.6	40.1	84.0	16.0	8.0	
11b	40 cm	6	29.2	64.8	32.7	48.7	88.0	12.0	6.0	
11c	60 cm	22	30.4	47.6	29.9	42.6	93.5	6.5	3.2	
12a	20 cm	4	18.2	77.8	76.9	332.8	71.3	28.7	14.4	
12b	60 cm	6	15.7	78.3	54.0	117.5	87.0	13.0	6.5	
1.2m no sample came out bed-rock										
13a	20 cm	13	19.1	67.9	22.9	29.7	86.0	14.0	7.0	
13b	40 cm	15	26.6	58.4	23.6	31.0	87.5	12.5	6.3	
13c	60 cm	23	30.7	46.3	24.4	32.2	89.5	10.5	5.3	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
14a	20 -40 cm	7	22.5	70.5	50.0	99.9	86.1	13.9	7.0	5.35
14b	40 -60 cm	21	27.2	51.8	47.7	91.2	88.5	11.5	5.8	5.17
14c	60 -80 cm	39	27.1	33.9	37.7	60.4	95.5	4.5	2.2	5.1
14d	80 cm- 1.2m	49	34.5	16.5	38.5	62.5	95.0	5.0	2.5	5.16
15a	20 cm	2	14.5	83.5	55.2	123.2	81.6	18.4	9.2	
15b	40 -60 cm	4	14.7	81.3	43.8	77.8	87.1	12.9	6.5	
15c	60 - 80 cm	17	23.1	59.9	45.0	81.7	90.5	9.5	4.7	
15d	80 -1.5m	24	19.9	56.1	30.6	44.1	94.0	6.0	3.0	
J6a										
1a	0 -40 cm	11	22.4	66.6	63.3	172.2	82.2	17.8	8.9	5.7
1b	40 -80 cm	14	30.1	55.9	39.3	64.9	89.2	10.8	5.4	5.34
1c	80 -1 m	23	27.1	49.9	36.4	57.1	94.5	5.5	2.7	5.06
1d	1 - 2 m	22	61.1	16.9	30.3	43.4	96.0	4.0	2.0	4.98
2a	0 20 cm	6	18.6	75.4	27.9	38.7	86.0	14.0	7.0	
3a	0 -20 cm	5	21.8	73.2	23.3	30.4	88.0	12.0	6.0	
3b	20 -40 cm	7	36.3	56.7	40.3	67.6	89.0	11.0	5.5	
3c	40 -60 cm	9	43.6	47.4	29.8	42.5	92.0	8.0	4.0	
3d	60 -80 cm	11	47.2	41.8	34.0	51.5	93.5	6.5	3.2	
3e	80 -1 m	19	54.5	26.5	30.6	44.1	95.0	5.0	2.5	
3f	1 -1.5 m	17	54.8	28.2	27.1	37.2	95.0	5.0	2.5	
4a	0 -20 cm	5	21.9	73.1	25.0	33.3	85.1	14.9	7.4	
4b	20 -40 cm	7	32.7	60.3	28.5	39.8	88.9	11.1	5.5	
4c	40 -60 cm	20	39.9	40.1	30.5	43.9	90.0	10.0	5.0	
4d	60 -80 cm	27	40.3	32.7	30.7	44.2	89.6	10.4	5.2	
4e	80 -1 m	28	44.2	27.8	27.8	38.5	92.5	7.5	3.8	
4f	1 -1.5 m	26	37.8	36.2	26.5	36.1	93.0	7.0	3.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
5a	0 -20 cm	8	25.7	66.3	66.7	200.1	79.5	20.5	10.2	5.58
5b	20 -40 cm	11	40.7	48.3	37.6	60.2	89.0	11.0	5.5	5.23
5c	40 -60 cm	25	37.9	37.1	33.4	50.2	89.5	10.5	5.3	5.49
5d	60 -80 cm	27	38	35	31.9	46.8	92.5	7.5	3.7	5.17
5e	80 -1m	38	41.6	20.4	30.7	44.4	94.0	6.0	3.0	5.28
6a	0 -20 cm	18	41.4	40.6	78.3	361.8	83.0	17.0	8.5	
6b	20 -40 cm	12	37.6	50.4	75.3	305.7	81.0	19.0	9.5	
6c	40 -60 cm	15	43.7	41.3	51.3	105.2	85.5	14.5	7.3	
6d	60 -80 cm	30	48.3	21.7	41.2	70.1	90.0	10.0	5.0	
6e	80 -1.2m	16	32.9	51.1	54.6	120.4	87.0	13.0	6.5	
7a	0 -20 cm	10	3.3	86.7	57.9	137.4	75.5	24.5	12.3	
7b	20 -40 cm	22	40.6	37.4	29.4	41.7	90.0	10.0	5.0	
7c	40 -60 cm	40	41.3	18.7	29.5	41.9	91.5	8.5	4.3	
7d	60 -80 cm	47	38.1	14.9	26.6	36.3	92.5	7.5	3.7	
8a	0 -20 cm	5	21.8	73.2	52.5	110.6	82.0	18.0	9.0	5.56
8b	20 -40 cm	33	34.2	32.8	42.2	73.1	88.5	11.5	5.7	5.6
8c	40 -60 cm	41	39.9	19.1	28.3	39.5	94.0	6.0	3.0	5.74
9a	0 -20 cm	11	22.7	66.3	45.8	84.4	83.0	17.0	8.5	
9b	20 -40 cm	15	32.7	52.3	39.2	64.6	86.5	13.5	6.8	
9c	40 -60 cm	38	40.1	21.9	34.6	52.9	90.0	10.0	5.0	
10a	0 -10 cm	13	25.4	61.6	34.6	53.0	79.5	20.5	10.3	5.47
10b	10 -30 cm	21	26.2	52.8	35.3	54.6	81.7	18.3	9.2	5.68
10c	30 -40 cm	47	30.2	22.8	39.0	63.9	85.0	15.0	7.5	5.77
10d	40 -50 cm	67	30.3	2.7	39.4	65.0	84.0	16.0	8.0	5.82

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
J6b										
1a	0 -20 cm	9	25.6	65.4	28.0	38.9	89.5	10.5	5.3	
1b	20 -40 cm	11	24.7	64.3	37.3	59.4	85.0	15.0	7.5	
1c	40 -60 cm	7	43.9	49.1	41.0	69.4	84.0	16.0	8.0	
1d	60 -80 cm	12	30.2	57.8	42.4	73.6	86.0	14.0	7.0	
1e	80 -1 m	8	36.4	55.6	46.2	85.9	87.0	13.0	6.5	
2a	0 -20 cm	9	26.5	64.5	42.5	73.8	87.5	12.5	6.3	5.54
2b	20 -40 cm	11	26.8	62.2	51.2	105.0	87.0	13.0	6.5	5.57
2c	40 -60 cm	15	27.2	57.8	46.9	88.2	88.5	11.5	5.7	5.62
3a	0 -20 cm	6	39.9	54.1	59.1	144.5	85.5	14.5	7.3	
3b	20 -80 cm	10	26.6	63.4	41.8	71.8	89.0	11.0	5.5	
3c	80 -1m	8	40.1	51.9	48.8	95.3	90.0	10.0	5.0	
4a	0 -20 cm	8	40.1	51.9	41.7	71.6	81.5	18.5	9.3	
4b	20 -40 cm	14	30.3	55.7	40.5	68.1	84.5	15.5	7.7	
4c	40 -60 cm	13	30.4	56.6	42.2	72.9	83.0	17.0	8.5	
4d	60 -80 cm	15	30.7	54.3	42.6	74.3	83.0	17.0	8.5	
4e	80 -1m	17	33.3	49.7	38.8	63.5	87.5	12.5	6.3	
5a	0 -20 cm	7	25.4	67.6	48.8	95.1	82.5	17.5	8.8	5.71
5b	20 -40 cm	11	26.5	62.5	46.7	87.6	83.5	16.5	8.2	5.82
5c	40 -60 cm	9	26.1	64.9	36.7	57.9	91.0	9.0	4.5	5.87
5d	60 -80 cm	8	40.1	51.9	32.6	48.4	93.0	7.0	3.5	6.02
5e	80 -1 m	37	38.1	24.9	31.8	46.6	93.5	6.5	3.3	6.2
6a	0 -20 cm	4	18.2	77.8	32.9	49.1	84.5	15.5	7.8	
6b	20 -40 cm	6	33.4	60.6	33.0	49.1	87.5	12.5	6.3	
6c	40 -60 cm	7	36.6	56.4	34.1	51.7	89.0	11.0	5.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
6d	60 -80 cm	11	32.7	56.3	34.5	52.7	89.5	10.5	5.3	
6e	80 -1 m	19	33.6	47.4	33.9	51.4	90.0	10.0	5.0	
7a	0 -20 cm	7	18.9	74.1	64.9	185.2	70.5	29.5	14.8	5.75
7b	20 -40 cm	8	19.1	72.9	36.6	57.8	90.0	10.0	5.0	5.73
7c	40 -60 cm	33	37.9	29.1	35.8	55.9	90.5	9.5	4.7	5.83
7d	60 -80 cm	27	30.8	42.2	29.7	42.2	93.0	7.0	3.5	6.08
8a	10 cm	15	27.1	57.9	26.9	36.8	88.0	12.0	6.0	
8b	20 cm	10	40.4	49.6	25.8	34.8	91.0	9.0	4.5	
8c	40 cm	40	40.7	19.3	26.2	35.5	93.0	7.0	3.5	
8d	50 cm	43	30.8	26.2	25.3	34.0	93.0	7.0	3.5	
8e	80 cm	39	30.7	30.3	26.0	35.1	97.0	3.0	1.5	
9a	0 -20 cm	7	39.9	53.1	37.4	59.7	85.0	15.0	7.5	
9b	20 -40 cm	4	21.8	74.2	38.8	63.3	87.5	12.5	6.3	
9c	40 -60 cm	9	22.1	68.9	39.3	64.9	87.5	12.5	6.3	
9d	60 -80 cm	26	22.6	51.4	36.2	56.8	88.5	11.5	5.8	
9e	80 -1 m	48	23.7	28.3	34.5	52.8	90.0	10.0	5.0	
J6c										
1a	0 -20 cm	5	32.9	62.1	58.9	143.2	75.5	24.5	12.3	5.26
1b	40 -60 cm	19	33.3	47.7	50.8	103.1	85.5	14.5	7.3	5.37
1c	60 -80 cm	37	34.2	28.8	43.7	77.5	90.0	10.0	5.0	5.3
1d	80 -1m	34	30.5	35.5	24.0	31.6	97.0	3.0	1.5	5.2
	1 -1.5m									5.18
2a	0 -20 cm	6	22.4	71.6	72.1	258.2	77.0	23.0	11.5	5.52
2b	20 -2m	27	25.4	47.6	62.8	168.7	85.0	15.0	7.5	5.62

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
J7										
1	15 cm	4	14	82	58.8	142.6	84.0	16.0	8.0	6.02
2a	20 cm	2	11.1	86.9	61.0	156.2	77.5	22.5	11.3	5.76
2b	40 -60 cm	6	30.2	63.8	49.3	97.0	85.5	14.5	7.3	5.34
2c	60 -80 cm	7	25.4	67.6	45.9	84.8	86.0	14.0	7.0	5.56
2d	80 cm - 1m	5	30.1	64.9	46.5	87.0	85.0	15.0	7.5	5.6
3a	20 cm	4	18.2	77.8	32.1	47.3	80.5	19.5	9.8	
3b	40 - 60 cm	6	18.4	75.6	38.2	61.9	83.0	17.0	8.5	
3c	60 - 80 cm	5	21.9	73.1	32.1	47.2	91.5	8.5	4.3	
3d	80 cm - 1m	19	23.2	57.8	25.7	34.7	93.0	7.0	3.5	
3e	1m-1.2m	35	25.9	39.1	23.7	31.1	93.5	6.5	3.3	
4a	0 - 20cm	7	30.3	62.7	43.5	76.9	78.5	21.5	10.8	
4b	20 -40 cm	4	14.7	81.3	43.6	77.3	85.5	14.5	7.3	
4c	40 -60 cm	5	25.5	69.5	36.5	57.4	89.0	11.0	5.5	
4d	60 -80 cm	22	26.6	51.4	28.3	39.4	92.5	7.5	3.7	
4e	80 - 1m	24	27.1	48.9	30.8	44.4	91.0	9.0	4.5	
5a	0 -20 cm	4	18.2	77.8	54.3	118.8	80.0	20.0	10	5.7
5b	20 -40 cm	6	19	75	36.3	57.1	89.5	10.5	5.3	5.8
5c	40 -60 cm	5	21.8	73.2	41.8	71.8	87.0	13.0	6.5	5.75
6a	0 - 20 cm	4	18.6	77.4	44.4	79.8	79.5	20.5	10.2	
6b	20 -40 cm	7	22.2	70.8	39.8	66.2	89.0	11.0	5.5	
6c	40 - 80 cm	10	25.9	64.1	35.3	54.5	90.5	9.5	4.7	
6d	80 - 1m	17	29.8	53.2	32.4	48.0	94.0	6.0	3.0	
6e	1- 1.1m	21	54.5	24.5	24.7	32.8	97.0	3.0	1.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
7a	0 -20 cm	7	15.6	77.4	44.7	80.8	82.0	18.0	9.0	
7b	20 -40 cm	5	18.4	76.6	46.8	87.8	83.5	16.5	8.2	
7c	40 -60 cm	7	25.7	67.3	43.4	76.5	88.5	11.5	5.8	
7d	60 -80 cm	6	17.2	76.8	41.4	70.7	88.0	12.0	6.0	
7e	80 -1.2m	4	25.4	70.6	39.5	65.3	90.5	9.5	4.7	
8a	0 -20 cm	7	29.6	63.4	54.8	121.1	78.0	22.0	11.0	
8b	20 - 40 cm	4	29.1	66.9	53.6	115.7	82.0	18.0	9.0	
8c	40 - 60 cm	6	30.1	63.9	49.2	96.9	83.5	16.5	8.3	
8d	60 - 80 cm	4	54.5	41.5	53.4	114.7	85.0	15.0	7.5	
8e	80 - 1.2 m	9	30.3	60.7	52.8	112.1	83.0	17.0	8.5	
9a	0 -30 cm	3	18.6	78.4	50.5	102.1	74.0	26.0	13.0	5.4
9b	30 -60 cm	5	29.7	65.3	53.8	116.4	82.0	18.0	9.0	5.43
9c	60 -90 cm	7	30.1	62.9	53.3	114.2	83.5	16.5	8.2	5.49
9d	90 -1.2m	11	36.3	52.7	52.2	109.1	86.0	14.0	7.0	5.65
9e	1.2 - 2m	10	33.3	56.7	33.2	49.6	90.0	10.0	5.0	5.96
10a	0 -30 cm	7	25.4	67.6	67.4	207.2	69.0	31.0	15.5	
10b	30 -60 cm	5	21.8	73.2	67.1	203.5	77.0	23.0	11.5	
10c	60 -90 cm	1	33.6	65.4	74.2	286.8	71.9	28.1	14.1	
10d	90 -1m	5	22.3	72.7	71.9	256.1	75.5	24.5	12.3	
10e	1 -1.5m	3	18.7	78.3	63.5	173.6	82.0	18.0	9.0	
11a	0 -20 cm	6	29.9	64.1	38.6	62.9	78.0	22.0	11.0	
11b	20 -40 cm	7	25.6	67.4	46.7	87.7	82.0	18.0	9.0	
11c	40 - 60 cm	11	32.7	56.3	34.8	53.4	91.0	9.0	4.5	
11d	60 -80 cm	22	43.7	34.3	31.9	46.8	92.5	7.5	3.7	
11e	80 - 1m	29	37.6	33.4	32.3	47.7	91.5	8.5	4.3	
12a	0 -20 CM	6	29.7	64.3	55.5	124.6	83.0	17.0	8.5	

SITE NO.	DEPTH	% CLAY	% SILT	% SAND	% WET WEIGHT	% DRY WEIGHT	% ASH CONTENT	% ORGANIC MATTER	% ORGANIC CARBON	SOIL pH
12b	20 -40 cm	7	32.9	60.1	50.7	102.9	84.5	15.5	7.8	
12c	40 -60 cm	5	29.6	65.4	41.7	71.5	88.5	11.5	5.7	
b-rock visible palr yellow										
13a	0 -20 cm	4	22.6	73.4	61.2	157.6	72.0	28.0	14.0	6.04
13b	20 - 40 cm	7	25.9	67.1	46.5	86.8	87.0	13.0	6.5	5.9
13c	40 - 60 cm	11	34	55	41.4	70.7	88.5	11.5	5.7	5.99
13d	60 -80 cm	15	34.4	50.6	37.1	59.0	91.0	9.0	4.5	6.01

APPENDIX B

Munsell colour chart soil descriptors for Wetlands J1-J7

	DEPTH	LITTER LAYER	ORGANIC HORIZONS	STONINESS	MUNSELL COLOUR WET	MUNSELL DESCRIPTION	MUNSELL MOTTLE	MOTTLING DESCRIPTION	MOTTLING ABUNDANCE
J 1									
1a	20 cm	Y	H,Om		2.5 y 2.5/1	black	7.5 yr 5/6	strong brown	7%
1b	40 cm		Om, F		2.5 y 2.5/1	black	10 yr 5/8	yellowish brown	3%
1c	60 cm				2.5/n	black	7.5 yr 6/8	reddish yellow	40%
1d	80 cm				10 y 2.5/1	greenish black	7.5 yr 5/8	strong brown	60%
2a	20 cm	N	Om,R	granular	10yr 3/2	very dark grayish brown	7.5 yr 4/6	strong brown	1%
2b	40 cm		R	granular	10yr 3/2	very dark grayish brown			
2c	60 cm		R	blocky	10 yr 3/4	dark yellowish brown	7.5 yr 4/6	strong brown	30%
2d	80 cm			gran/blocky	7.5 yr 3/1	very dark gray	7.5 yr 4/6	strong brown	7%
3a	20 cm	Y	n/c,R,H		2.5/n	black			
3b	40 cm		n/c,R,M		10 yr 2/1	black	7.5 yr 5/6	strong brown	1%
3c	60 cm		R		2.5 y 2.5/1	black	5 yr 4/6	yellowish red	5%
A1	15 cm	Y			5 pb 4/1	dark bluish gray	7.5 YR 4/6	strong brown	10%
A2	30 cm				5 y 4/1	dark gray	7.5 YR 4/6	strong brown	5%
A3	60 cm				2.5 y 4/1	dark gray	7.5 YR 5/6	strong brown	10%
A4	80 cm			little gritty	2.5 y 4/1 & 4/2	dark gray&drk grayish brown	7.5 YR 5/8	strong brown	40%
A5	1 m			little gritty	5 y 5/1 - 5 y 4/1	gray - dark gray	7.5 YR 5/6	strong brown	40%
B1	15 cm		R		2.5/n	black	5 yr 4/6	reddish brown	5%
B2	30 cm		R, n/c		2.5 yr 3/1	very dark gray	7.5 yr 4/6	strong brown	20%
B3	45 cm	bed-rock	n/c		10 yr 4/2	dark grayish brown	7.5 yr 5/8	strong brown	50%
C1	15 cm		R, n/c		2.5/n	black	5 yr 4/6	yellowish red	5%
C2	30 cm		R, n/c		10 yr 2/1	black	5 yr 4/6	yellowish red	10%
C3	45 cm				2.5yr2.5/1-10yr3/2	black-v.dark grayish brown	7.5 yr 5/6	strong brown	40%
C4	90 cm				2.5y2.5/1-10yr5/4	black-yellowish brown	7.5 yr 5/8	strong brown	30%
J2									
1a	20 cm	Y	F,H,Om,R	sandy	10yr4/4-/5y2.55/1	dark yellowish brown/black			
1b	40 cm		F,H,Om,R		2.5/5pb	bluish black	7.5 yr 5/6	strong brown	1%
2a	20 cm		n/s,R	few small stones	10 yr 4/4	dark yellowish brown	7.5 yr 4/6	strong brown	1%
2b	40 cm		n/s,R	small stones	7.5 yr 3/1	dark brown	7.5 yr 5/8	strong brown	1%
2c	60 cm		n/s		7.5 yr 3/1	very dark brown	7.5 yr 5/8	strong brown	1%
2d	80 cm				10 yr 3/2	very dark graish brown	7.5 yr 5/6	strong brown	5%
3a	20 cm	Y	O,Oh,R	sandy	10yr6/6-/-5yr2.5/1	brownish yellow-black			
3b	40 cm		n/c,R		2.5/n	black	5yr 4/6	yellowish red	10% (glayed?)
3c	80 cm		R		2.5/n	black	5yr 4/6	yellowish red	15%
4a	20 cm		F,Om,R		7.5 yr 2.5/1	black	7.5 yr 4/6	strong brown	5%
4b	40 cm		R		5 yr 3/1	very dark gray	5 yr 3/4	dark reddish brown	3%

	DEPTH	LITTER LAYER	ORGANIC HORIZONS	STONINESS	MUNSELL COLOUR WET	MUNSELL DESCRIPTION	MUNSELL MOTTLE	MOTTLING DESCRIPTION	MOTTLING ABUNDANCE
4c	60 cm		R		7.5 yr 3/1	very dark gray	5 yr 4/6	yellowish red	3%
5a	20 cm		F,R		5 yr 2.5/1	black	5 yr 4/6	yellowish red	15%
5b	40 cm		R		2.5 yr 2.5/1	reddish black	5yr 4/6	yellowish red	15%
5c	60 cm				7.5 yr 3/1	very dark gray	7.5 yr 5/6	strong brown	10%
6a	20 cm		F,R	agrates	7.5 yr 2.5/1	black			
6b	40 cm		n/s, R	agrates	7.5 yr 2.5/1	black			
6c	80 cm		n/s	agrates	7.5 yr 2.5/2	very dark brown			
7a	20 cm		F,R	agrates	10 yr 3/1	very dark gray	7.5 yr 5/6	strobg brown	1%
7b	40 cm		R		7.5 yr 2.5/2	very dark brown			
7c	60 cm				19 yr 3/4	dark yellowish brown			
J3									
1a	15 cm	Y	O,Op,Of-Oh	gritty	2.5/n	black			
1b	30 cm		Op	gritty	5 y 2.5/1	black			
1c	1 m	bed-rock	Op	very gritty	5 y 2.5/1	black			
2a	15 cm		R		5 y 2.5/1	black			
2b	30 cm		R		7.5 yr 2.5/1	black			
2c	45 cm				10 yr 2/1	black			
2d	80 cm				2.5 yr 3/1	very dark gray	10 yr 6/8	brownish yellow	
3a	15 cm	Y	O,Op,F.H,Of-Oh		2.5/n	black			
3b	30 cm		O,Op,F.H,Of-Oh		2.5/n	black			
3c	1 m		n/c,Om-Oh		5y 2.5/1	black			
4a	15 cm	Y	R		10 yr 2/1	black			
4b	30 cm	b-rock	R		10yr2/1-10yr3/2	black-very dark brown			
5a	15 cm	b-rock	Op		10yr4/6-2.5/n	dark yellowish brown-black			
6a	15 cm	b-rock	R	gritty	7.5yr2.5/1	black			
J4									
Aa	15 cm	n	n/s, R	few small stones	7.5 yr 2.5/1	black	5 yr 4/4-10 yr 5/8	reddish brown-yellowish brown	5%
Ab	40 cm		R		5 yr 2.5/1	black	7.5 yr 5/6- 2.5 yr 6/8	strong brown- olive yellow	50%
Ac	60 cm		n/c v. littlr	few small stones	7.5yr 4/4-7.5yr4/1	brown-dark gray	2.5 yr 6/8	olive yellow	10% histo
Ad	80 cm			med.small stones	7.5 yr 4/2	brown	5 y 4/4	olive	30% histo
Ae	1.2 m			med.small stones	7.5yr 4/2	brown	5 y 4/4	olive	30% histo
1a	20 cm	Y	Of,O,Op,F		10 yr 2/1	black			
1b	40 - 60 cm		Oh,O,n/c		10yr 2/1	black			

	DEPTH	LITTER LAYER	ORGANIC HORIZONS	STONINESS	MUNSELL COLOUR WET	MUNSELL DESCRIPTION	MUNSELL MOTTLE	MOTTLING DESCRIPTION	MOTTLING ABUNDANCE
1c	60 - 80 cm		Op,F,O		5yr2.5/1--10yr2/1	black			
1d	80cm - 1m		O,F		5 yr 2.5/1	black	10yr4/6-/ 5gy5/1	ark yellowish brown/greenish gray	
2a	20 cm	Y	O,F,R		5yr2.5/1~7.5yr2.5/1	black			
2b	40 cm		O,F,n/c,R		5yr2.5/1~7.5yr2.5/1	black			
2c	60 cm		n/c		7.5yr2.5/1~5yr4/3	black~reddish brown	7.5yr5/6	strong brown	10%
2d	80cm-1m				10yr4/6~7.5yr4/6	dark yellowish brown~strong brown	7.5yr5/8	strong brown	5%
J5									
1a	20 cm	Y	O,Om,R,Op		5y2 2.5/1	black			
1b	40 cm		Om,R.O,Op		5y 2.5/1	black			
1c	60 cm		n/c,Oh		7.5yr 2.5/1	black			
1d	80 cm		Oh		7.5yr 2.5/1	black			
2a	20 cm	Y	Om,F,R		10yr 2/2	very dark brown			
2b	40 cm		Om,F,R		10yr 2/1	black			
2c	60 cm		R		5yr 3/2	dark reddish brown			
2d	80 cm-1m				5yr 3/3	dark reddish brown			
3a	20 cm	Y	O,Om,Of,R		7.5yr 2.5/1	black			
3b	40 cm		Of-Om		10yr 2/1	black			
3c	80 cm		Om-Oh		10yr 2/1	black			
4a	20 cm	Y	R,Om		7.5yr 2.5/1	black			
4b	40 cm		R,n/c		7.5yr 5/2	very dark brown			
4c	60 cm				5yr 2.5/1	black	7.5yr 5/6	strong brown	1%
5a	20 cm	Y	R,Om,n/c		10yr 2/1	black			
5b	40 cm		R,Om,n/c		5yr 2.5/1	black	5yr 4/6	yellowish red	1%
5c	60 cm		R,Oh,n/c		5yr 2.5/1	black			
5d	80 cm		Oh		7.5yr 2.5/1	black			
6a	20 cm	Y	R		10yr 3/2	very dark grayish brown			
6b/c	40 cm		R		10yr 2/2	very dark brown	10yr6/8~10yr7/1	brownish yellow~light gray	60%
6c/b	60 cm				10yr2/2	very dark brown	10yr6/8~10yr7/1	brownish yellow~light gray	10%
7a	20 cm	Y	Om,R		7.5yr 2.5/1	black			
7b	40-60 cm		R		5yr 2.5/1	black			
7c	80 cm				10yr3/3~10yr2/2	dark brown~very dark brown			
7d	1 m				10yr2/1	black	7.5yr 5/8	strong brown	10%
8a	20 cm		Of,O,Om,R	sandy	10yr 3/2	very dark grayish brown			
8b	40 cm		O,R		2.5/N	black	10yr 7/6	yellow	5%

	DEPTH	LITTER LAYER	ORGANIC HORIZONS	STONINESS	MUNSELL COLOUR WET	MUNSELL DESCRIPTION	MUNSELL MOTTLE	MOTTLING DESCRIPTION	MOTTLING ABUNDANCE
8c	60 cm		n/c		2.5/N	black			
9a	20 cm		Om,R	few sml st	2.5y 5/4	light olive brown			
9b	40 cm		R		10yr 3/2	very dark grayish brown			
9c	60 cm		R		10yr 3/2	very dark grayish brown			
10a	20 cm	Y	Om,O,Of,R		10yr 2/1	black			
10b	40 - 60 cm		O,Of,R		10yr 2/1	black			
10c	60 - 80 cm		Of-Oh		2.5/N	black			
10d	1.2 m				10yr 2/1	black	4/10B	bluish gray (gley)	
11a	20 cm	Y	Om,R		7.5yr 2.5/1	black			
11b	40 cm		R		7.5yr 2.5/2	very dark brown			
11c	60 cm			blocky	10yr 3/2	very dark grayish brown			
12a	20 cm	Y	O,Of,R		2.5y 2.5/1	black			
12b	60 cm		O,Of,R		10yr 2/1	black			
no sample came out bed-rock									
13a	20 cm	Y	R	few sml st	7.5yr 2.5/1	very dark brown			
13b	40 cm		R		10yr 2/2	very dark brown			
13c	60 cm		R		10yr 2/2	very dark brown			
14a	20 -40 cm		Op,H,F,R	few sml st	10yr 2/1	black			
14b	40 -60 cm		R,n/c		2.5y 2.5/1	black	7.5yr 5/8	strong brown	5%
14c	60 -80 cm		n/c		10yr 4/3~10yr 3/2	dark yellowish brown~very dark brown	10yr 6/8	yellowish brown	5%
14d	80 cm- 1.2m				10yr 2/1~10yr 6/8	black~brownish yellow	7.5yr 4/6	strong brown	10%
15a	20 cm	Y	Op,n/c,R	gritty	10yr 2/1	black			
15b	40 -60 cm		n/c,R	gritty	7.5yr 2.5/1	black	10yr 6/8	yellow brown	5%
15c	60 - 80 cm		Oh		7.5yr 2.5/1	black			
15d	80 -1.5m	b-rock			10yr 3/1	very dark gray			
J6a									
1a	0 -40 cm		F,Of,R		10yr2.5/1	greenish black	10y6/2	greenish gray	
1b	40 -80 cm		F,Of-Om,R		5yr2.5/1	black			
1c	80 -1 m		n/c		5yr5/6~7.5yr5/4	yellowish red~brown			
1d	1 - 2 m		n/c		7.5yr4/6~5yr2.5/1~5yr5/3	str. Brown~black~reddish brown			
2a	0 20 cm		Om,R		10yr3/3	dark brown			
3a	0 -20 cm		F,R		10yr4/6	dark yellowish brown			
3b	20 -40 cm		F,R		10yr2/2	very dark brown			

	DEPTH	LITTER LAYER	ORGANIC HORIZONS	STONINESS	MUNSELL COLOUR WET	MUNSELL DESCRIPTION	MUNSELL MOTTLE	MOTTLING DESCRIPTION	MOTTLING ABUNDANCE
3c	40 -60 cm		R	med. St	10yr3/1~2.5yr4/4	very dark gray~reddish brown			
3d	60 -80 cm				2.5yr4/4~10yr3/2	reddish brown~very dark grayish brown			
3e	80 -1 m				7.5yr3/1~5yr5/6	very dark gray~yellowish red			
3f	1 -1.5 m				2.5yr4/6	red			
4a	0 -20 cm		R		10yr3/3	dark brown			
4b	20 -40 cm		R		10yr3/3	dark brown			
4c	40 -60 cm				2.5yr2.5/1	black	7.5yr4/6	strong brown	5%
4d	60 -80 cm				2.5yr2.5/1	black	7.5yr5/6	strong brown	5%
4e	80 -1 m				7.5yr2.5/1	black	10yr6/8	brownish yellow	5%
4f	1 -1.5 m				10yr2/1	black			
5a	0 -20 cm		F,n/c,R		5yr2.5/1	black			
5b	20 -40 cm		n/c		10yr2/1	black			
5c	40 -60 cm				10yr2/1~2.5/N	black~black			
5d	60 -80 cm				10yr2/1~2.5/N	black~black			
5e	80 -1m				10yr3/3~7.5yr2.5/1	dark brown~black			
6a	0 -20 cm		Of,H		10yr3/1~5yr4/6	dar greenish gray~yellowish red			
6b	20 -40 cm		Of,H		10yr2.5/1~5yr4/6	greenish black~yellowish red			
6c	40 -60 cm		Op,H		2.5/10B~5yr4/6	bluish black~yellowish red			
6d	60 -80 cm		Oh		2.5/10B	bluish black			
6e	80 -1.2m		Oh		10y2.5/1	greenish black			
7a	0 -20 cm	Y	F,H,R	few sml st	10yr2/2	black			
7b	20 -40 cm		R		2.5/10B	bluish black	7.5yr4/6	strong brown	5%
7c	40 -60 cm		R	few sml st	7.5yr2.5/1	black	7.5yr4/6	strong brown	5%
7d	60 -80 cm			few sml st	7.5yr2.5/1	black	7.5yr5/6	strong brown	5%
8a	0 -20 cm	Y	n/c,F,R		10yr2/2	very dark brown			
8b	20 -40 cm		n/c,F,R		2.5y2.5/1	black	7.5yr4/6	strong brown	10%
8c	40 -60 cm		R		2.5y2.5/1~10yr6/1	black~gray	5yr5/8	yellowish red	10%
9a	0 -20 cm	Y	H,F,R		10yr2/1	black			
9b	20 -40 cm		F,R		10yr2/1	black	5yr5/8	yellowish red	10%
9c	40 -60 cm				10yr3/1	very dark brown	5yr5/8	yellowish red	5%
10a	0 -10 cm	Y	F,R		2.5y2.5/1	black			
10b	10 -30 cm		R		2.5y2.5/1	black			
10c	30 -40 cm		R		2.5y2.5/1	black			
10d	40 -50 cm				2.5y2.5/1	black	7.5yr7/8	reddish yellow	10%
J6b									
1a	0 -20 cm		Om,R		2.5yr6/6~2.5yr2.5/1	olive yellow~reddish black			

	DEPTH	LITTER LAYER	ORGANIC HORIZONS	STONINESS	MUNSELL COLOUR WET	MUNSELL DESCRIPTION	MUNSELL MOTTLE	MOTTLING DESCRIPTION	MOTTLING ABUNDANCE
1b	20 -40 cm				2.5yr2.5/1	reddish black	2.5yr6/8	olive yellow	
1c	40 -60 cm		R		10yr2/1	black	7.5yr4/6	strong brown	2%
1d	60 -80 cm		R		2.5yr2.5/1	reddish black			
1e	80 -1 m			few sml st	7.5yr2.5/1	black			
2a	0 -20 cm		Om,R		10yr2/1	black			
2b	20 -40 cm		Oh		2.5y2.5/1	black			
2c	40 -60 cm	b-roc			2.5y6/6	olive yellow			
3a	0 -20 cm		Om,Op	gritty	2.5y2.5/1	black			
3b	20 -80 cm		Om-Oh	gritty	7.5yr2.5/1	black			
3c	80 -1m		Om-Oh	mny sml-med st	10y2.5/1	greenish black	5yr5/6	yellowish red	1%
4a	0 -20 cm		Om,R		7.5yr2.5/1~10yr4/4	black~dark yellowish brown	7.5yr4/6	strong brown	30%
4b	20 -40 cm		Om,R		10yr4/4~10yr2/2	dark yellowish brown~black	5yr4/6	yellowish red	20%
4c	40 -60 cm				5yr2.5/1	black	5yr4/6	yellowish red	1%
4d	60 -80 cm				7.5yr2.5/1	black	7.5yr5/8	strong brown	5%
4e	80 -1m				10yr2/1	black			
5a	0 -20 cm	Y	Om,R		2.5y2.5/1	black			
5b	20 -40 cm		Om,R		7.5yr2.5/1	black	5yr5/8	yellowish red	5%
5c	40 -60 cm		Om		10yr4/3~2.5/N	brown~black			
5d	60 -80 cm			fes v sml st	2.5y2.5/1~10yr4/4	black~dark yellowish brown			
5e	80 -1 m				7.5yr5/8~7.5yr4/6	strong brown(2x)			
6a	0 -20 cm	Y	Om,R		10yr4/4	dark yellowish brown			
6b	20 -40 cm		Om,R		10yr3/2~10yr3/6	very dark grayish brown~dark yellow brown			
6c	40 -60 cm		R		10yr3/6	dark yellowish brown			
6d	60 -80 cm		R		5yr3/3	dark reddish brown			
6e	80 -1 m				5yr3/4	dark reddish brown			
7a	0 -20 cm	Y	Om,Of,R		10yr2/1	black	5yr3/3	dark reddish brown	2%
7b	20 -40 cm		Om		10yr2/1	black	5yr3/3	dark reddish brown	2%
7c	40 -60 cm		n/c,Om		10yr2/1	black	7.5yr4/6	strong brown	30%
7d	60 -80 cm		Om		2.5y2.5/1	black	7.5yr6/8	reddish yellow	30%
8a	10 cm	Y	Om,R		7.5yr2.5/1	black	7.5yr4/6	strong brown	2%
8b	20 cm		R		7.5yr2.5/1	black	7.5yr5/6	strong brown	10%
8c	40 cm		Om,R		2.5y2.5/1	black	7.5tr5/8~10yr5/8	strong brown~yellowish brown	50%
8d	50 cm				10yr4/4	dark yellowish brown	7.5tr5/8~10yr5/8	strong brown~yellowish brown	70%
8e	80 cm				10yr4/4	dark yellowish brown	7.5tr5/8~10yr5/8	strong brown~yellowish brown	70%
9a	0 -20 cm	Y	Om,R		10yr3/2	very dark grayish brown			
9b	20 -40 cm		Om,R		2.5y2.5/1	black	7.5yr5/8	strong brown	10%

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9c	40 -60 cm				2.5y2.5/1	black	7.5yr5/8~2.5y7/8	strong brown~yellow	5%
9d	60 -80 cm				7.5yr2.5/1	black	7.5yr5/6	strong brown	1%
9e	80 -1 m		Oh		2.5/N	black			
J6c									
1a	0 -20 cm	Y	Op,Om,R		7.5yr2.5/1	black			
1b	40 -60 cm		Op,Om,R		10yr2/1	black			
1c	60 -80 cm				10y/2.5~6/5GY~10yr7/6	black~greenish gray~very palr brown			
1d	80 -1m				10yr7/6~6/10Y~10yr6/8	very pale brown~greenish gray~brownish yellow			
1e	1 -1.5m				10yr7/6~6/10Y~10yr6/8	very pale brown~greenish gray~brownish yellow			
2a	0 -20 cm	Y	O,Of,F,R		6/10Y~10yr2/1	greenish gray~black			
2b	20 -2m		Op		6/10Y~10yr2/1	greenish gray~black			
J7									
1	15 cm	b-roc	F.R,H,n.c	few sml st	5yr 2.5/1	black			
2a	20 cm		R,H,n/c	few sml st	5yr 2.5/1	black	5yr 4/6	yellowish red	1%
2b	40 -60 cm		R,n/s	few sml st	7.5yr 2.5/1	black	7.5yr 4/6	strong brown	1%
2c	60 -80 cm		H		10yr 2/1	black	10yr 6/8	brownish yellow	3%
2d	80 cm - 1m		H	few sml st	10yr 2/1	black			
3a	20 cm		R	many sml st	10yr 3/4	dark yellowish brown			
3b	40 - 60 cm		R	few sml st	10yr 3/3	dark yellowish brown			
3c	60 - 80 cm		R		7.5yr 4/6	strong brown			
3d	80 cm - 1m			many sml st	10yr 4/6	dark yellowish brown	2.5yr 6/6~7.5yr 5/8	olive yellow ~ strong brown	10%
3e	1m-1.2m			few sml st	7.5yr 5/8	strong brown	2.5yr 6/6	olive yellow	5%
4a	0 - 20cm		R		10yr 2/2	very dark brown			
4b	20 -40 cm		R		10yr 2/1	black			
4c	40 -60 cm		R		7.5yr 2.5/1	black			
4d	60 -80 cm				7.5yr 3/2	dark brown	10yr 6/8~7.5yr 5/8	brownish yellow~strong brown	20%
4e	80 - 1m			few sml st	2.5/N ~7.5yr 4/6	black ~ strong brown			
5a	0 -20 cm		Om,R		7.5yr 2.5/1	black	5yr 4/6	yellowish red	1%
5b	20 -40 cm		Om,R	few sml st	10yr 2/1	black	10yr 6/6~5yr 4/6	brownish yellow~yellowish red	7%
5c	40 -60 cm			few sml/med st	10yr 2/1	black	7.5yr5/8~10yr7/8	strong brown~yellow	7%
6a	0 - 20 cm		Om,R		10yr 2/1	black			
6b	20 -40 cm		R	few sml st	10yr4/6~7.5yr2.5/1	dark yellow brown~black	7.5yr 6/8	reddish yellow	5%
6c	40 - 80 cm				10yr2/1~10yr5/6	black~yellowish brown	7.5yr 5/6	strong brown	5%
6d	80 - 1m	b-roc			5yr6/5 ~ 10yr3/6	palr olive~dark yellowish brown			
6e	1- 1.1m	b-roc			10yr5/3~7.5yr6/8~5yr6/5	brown~reddish yellow~pale olive			

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7a	0 -20 cm		Om,R		7.5yr 2.5/1	black			
7b	20 -40 cm		Om,R		10yr2/2	very dark brown			
7c	40 -60 cm				7.5yr3/3	dark brown	10yr 8/3	very pale brown	1%
7d	60 -80 cm				10yr2/2~10yr4/4	very dark brown~dark yellowish brown			
7e	80 -1.2m				10yr3/3	dark brown			
8a	0 -20 cm		Om,R		10yr 2/1	black			
8b	20 - 40 cm		n/c,R		2.5/N	black			
8c	40 - 60 cm		n/c		2.5/N	black			
8d	60 - 80 cm		n/c		2.5/N	black			
8e	80 - 1.2 m		n/c		2.5/N	black			
9a	0 -30 cm		Om,R,F		7.5yr 2.5/1	black	5yr 5/8	yellowish red	5%
9b	30 -60 cm		Om,R		10yr2/1~2.5/5pb	black~bluish black	5yr 5/8	yellowish red	10%
9c	60 -90 cm		Om		10yr2/1~2.5/5pb	black~bluish black	7.5yr5/6	strong brown	5%
9d	90 -1.2m				10yr2/1~2.5/5pb	black~bluish black			
9e	1.2 - 2m	b-roc			5y8/3~2.5y7/6~10yr2/1	pale yellow~yellow~black			
10a	0 -30 cm	Y	Of,Om,R,F		10yr2/1	black	7.5yr5/6	strong brown	15%
10b	30 -60 cm		Of,Om,R		10yr2/1	black			
10c	60 -90 cm		Of-Om		10yr2/1~2.5/5pb	black~bluish black			
10d	90 -1m		Om-Oh		10yr2/1	black			
10e	1 -1.5m		Om-Oh		10yr3/2~10yr2/1	very dark brown~black			
11a	0 -20 cm		Om,R		7.5yr2.5/1	black			
11b	20 -40 cm		Om,R		10yr2/1	black			
11c	40 - 60 cm		R		7.5yr2.5/1	black	7.5yr4/6	strong brown	15%
11d	60 -80 cm				10yr 3/2	very dark grayish brown	7.5yr5/8	strong brown	2%
11e	80 - 1m				10yr 3/2	very dark grayish brown	7.5yr5/8	strong brown	1%
12a	0 -20 CM		Om,F,R		10yr2/2	very dark brown			
12b	20 -40 cm		Om,F,R		7.5yr3/1	very dark gray	7.5yr5/6	strong brown	1%
12c	40 -60 cm	b-roc	Om,F,R		7.5yr3/1	very dark gray	10yr6/8	brownish yellow	1%
b-rock visible pale yellow									
13a	0 -20 cm	Y	Om,F,R		10yr2/1	black			
13b	20 - 40 cm		Om,F,R		2.5y2.5/1	black			
13c	40 - 60 cm		R	very sml st	2.5y2.5/1	black	10yr5/8	yellowish brown	5%
13d	60 -80 cm				10yr2/1~10yr4/4	black~dark yellowish brown			