# NATURAL MECHANISMS OF EROSION PREVENTION AND STABILISATION IN A MARAKELE PEATLAND; IMPLICATIONS FOR CONSERVATION MANAGEMENT

by

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**DECEMBER 2016**

**DECLARATION**

I declare that **NATURAL MECHANISMS OF EROSION PREVENTION AND STABILISATION IN A MARAKELE PEATLAND; IMPLICATIONS FOR CONSERVATION MANAGEMENT** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. Photos taken by other people have been credited as such. I further declare that I have not previously submitted this work, or part of it, for examination at Unisa for another qualification or at any other higher education institution.

A Bootsma ________________ 18 August 2017

Antoinette Bootsma Date

**SUMMARY**

The Matlabas mire, an actively peat accumulating wetland, is located in the headwaters of the Matlabas River, Marakele National Park, Limpopo Province, South Africa. Various seepage zones and artesian peat domes are contained in this peatland that consists of two tributaries of which the western one is partially channelled.

The occurrence of decaying peat domes and desiccated areas with terrestrial vegetation, as well as the apparent erosion on the western tributary, have raised concerns on the health of this wetland.

A network of piezometers was installed in the mire and results confirm that the system is fed primarily from seepage from the slopes of the catchment. Chemical analysis and temperature recorded indicate an isolated groundwater source of which the water does not mix with surface water. This is linked with isotope analysis of the age of peat in various sections of the mire.

Erosion was attributed to anthropogenic changes in the catchment. Management recommendations include rehabilitation and reinstating the driving forces that support the mire.

**Keywords**

Mire, ecohydrology, Marakele National Park, Matlabas River catchment, wetland rehabilitation, vegetation classification, artesian peat domes, desiccation of peat, wetland management.

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# Glossary

| | |
|---|---|
| Aeolian | The process of wind erosion and deposition |
| Artesian spring | When the groundwater, under pressure, finds its way to the land surface |
| Colluvium | Material which accumulates at the foot of a steep slope |
| Ecohydrology | An interdisciplinary field studying the interactions between water and ecosystems |
| Endorheic | A closed drainage basin that retains water and allows no outflow to other external bodies of water |
| Fluvial | Found in a river |
| Geomorphology | The study of the physical features of the surface of the earth and their relation to its geological structures |
| Hydrogeomorphology | An interdisciplinary science that focuses on the interaction and linkage of hydrologic processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions |
| Isohypse | A line on a map connecting points of both equal height and equal barometric pressure |
| m.a.s.l. | Meters Above Sea Level |
| Pedology | Soil science |
| Phytosociology | The branch of science which deals with plant communities, their composition and development, and the relationships between the species within them |
| Quadrat | Sample plot |
| YBP | Years Before Present |

# CHAPTER 1: Introduction

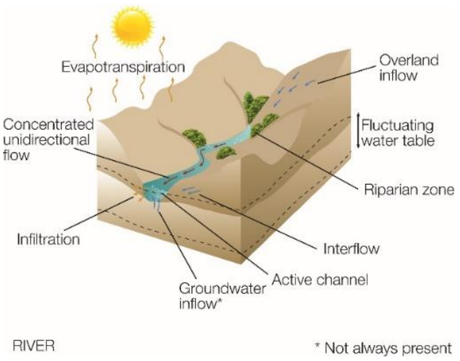
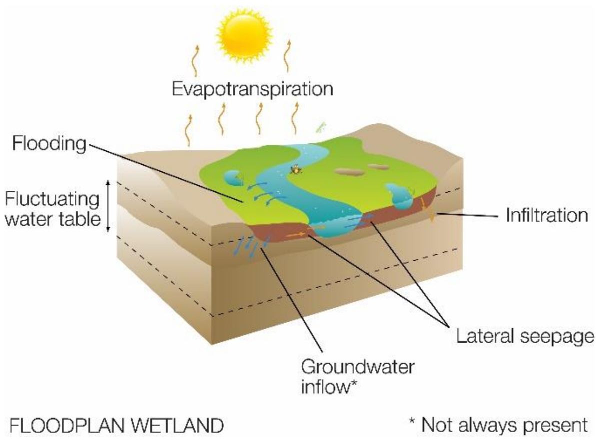
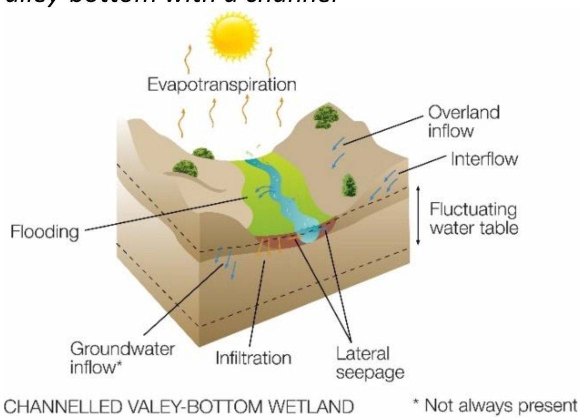
## 1.1 BACKGROUND

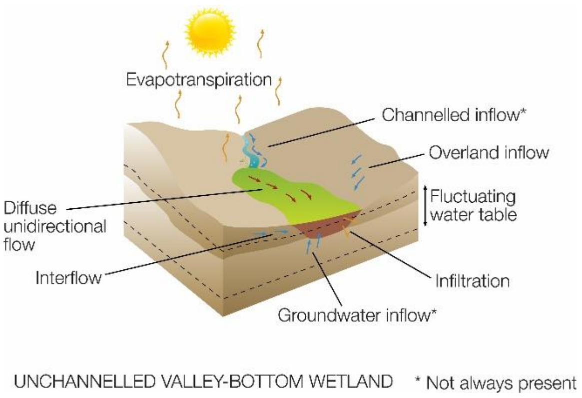
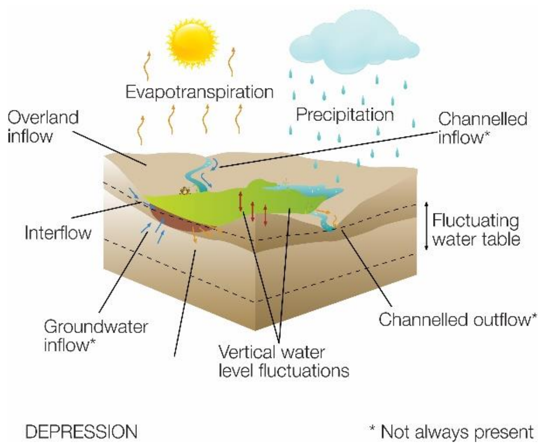
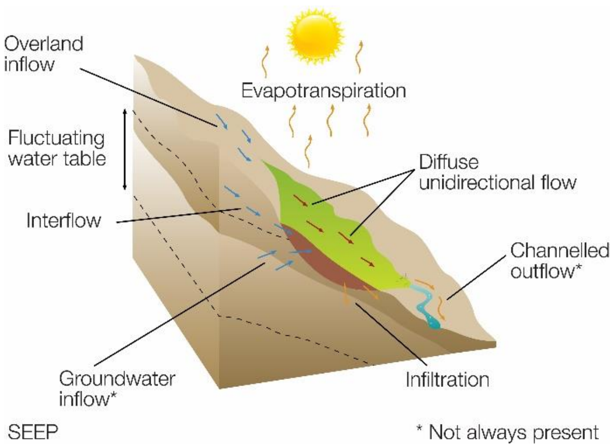
The Ramsar Convention on Wetlands define wetlands as: *areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres* (Ramsar, 1971). In a local context, the South African National Water Act (NWA) defines wetlands as follows: *land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil* (NWA, 1988).

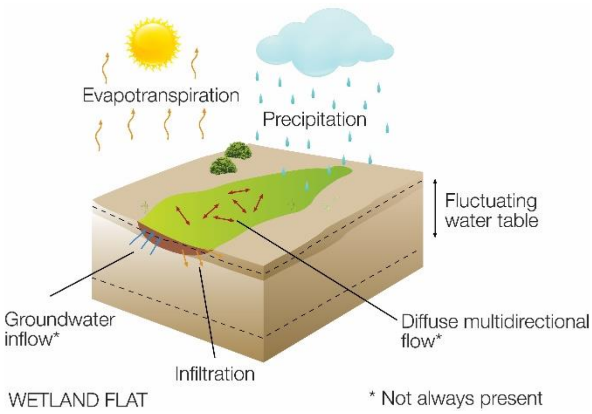
The way in which water moves through the landscape (hydrology) and its interplay with the landform characteristics and processes (geomorphology) are the two most important features that determine the characteristics of inland wetlands (Ollis *et al.,* 2013). Wetland nomenclature and classification has followed many avenues. Two main international scientifically-based wetlands classification systems, developed for the purpose of wetlands inventory and management, have gained broad acknowledgement. One was developed by Cowardin and colleagues in 1979 for the needs of the United States government, and the second, more comprehensive system was adopted by the Ramsar Convention on Wetlands in 1996 (Brinson, 2011).

In South Africa the Water Research Commission together with the South African National Biodiversity Institute commissioned the development of a National Wetland Classification System for the South African National Wetland Inventory in 2005, to encompass the broad definition of wetlands as defined by the Ramsar Convention (Ollis *et al.,* 2013). A description of inland wetland types that follow from this work is set out in Table 1 below. These functional wetland units, known as hydrogeomorphic units, are currently used in the South African National Wetland Inventory and form the basis of wetland analysis in South Africa (Ollis *et al.,* 2013).

**Table 1:** Wetland types (adapted from Kotze *et al*., 2007; Ollis *et al.,* 2013)

| **Wetland hydrogeomorphic types** | **Description of hydrological and geomorphological processes. Ollis *et al.,* 2013** |
|---|---|
| *Riparian habitat*   | Linear fluvial, eroded landforms which carry channelized flow on a permanent, seasonal or ephemeral/episodic basis. The river channel flows within a confined valley (gorge) or within an incised macro-channel. The "river" includes both the active channel (the portion which carries the water) as well as the riparian zone. |
| *Meandering floodplain*   | Linear fluvial, net depositional valley-bottom surfaces which have a meandering channel which develop upstream of a local (for example resistant dyke) base level, or close to the mouth of the river (upstream of the ultimate base level, the sea). The meandering channel flows within an unconfined depositional valley, and ox-bows or cut-off meanders – are usually visible at the 1:10 000 scale (i.e. observable from 1:10 000 orthomaps).<br><br>The floodplain surface usually slopes away from the channel margins due to preferential sediment deposition along the channel edges and areas closest to the channel. This can result in the formation of backwater swamps at the edges of the floodplain margins. |
| *Valley-bottom with a channel*   | Linear fluvial, net depositional valley-bottom surfaces which have a straight channel with flow on a permanent or seasonal basis. Episodic flow is thought to be unlikely in this wetland setting. The straight channel tends to flow parallel with the direction of the valley (i.e. there is no meandering), and no ox-bows or cut-off meanders are present in these wetland systems. The valley floor is, however, a depositional environment such that the channel flows through fluvially-deposited sediment. These systems tend to be found in the upper catchment areas. |

| Wetland hydrogeomorphic types | Description of hydrological and geomorphological processes. Ollis *et al.,* 2013 |
|---|---|
| *Valley-bottom without a channel*<br><br> | Linear fluvial, net depositional valley-bottom surfaces which do not have a channel. The valley floor is a depositional environment composed of fluvial or colluvial deposited sediment. These systems tend to be found in the upper catchment areas, or at tributary junctions where the sediment from the tributary smothers the main drainage line. |
| *Depressional pans*<br><br> | Small (deflationary) depressions which are circular or oval in shape; usually found on the crest positions in the landscape. The topographic catchment area can usually be well-defined (i.e. a small catchment area following the surrounding watershed). Although often apparently endorheic (inward draining), many pans are “leaky” in the sense that they are hydrologically connected to adjacent valley-bottoms through subsurface diffuse flow paths. |
| *Seepage wetlands*<br><br> | Seepage wetlands are the most common type of wetland (in number), but probably also the most overlooked. These wetlands can be located on the mid- and footslopes of hillsides; either as isolated systems or connected to downslope valley-bottom wetlands. They may also occur fringing depressional pans. Seepages occur where springs are decanting into the soil profile near the surface, causing hydric conditions to develop; or where through flow in the soil profile is forced close to the surface due to impervious layers (such as plinthite layers; or where large outcrops of impervious rock force subsurface water to the surface). |

| Wetland hydrogeomorphic types | Description of hydrological and geomorphological processes. Ollis *et al.,* 2013 |
|---|---|
| *Flat wetland*   | In areas with weakly developed drainage patterns and flat topography, rainfall may not drain off the landscape very quickly, if at all, due to the low relief. In such areas (commonly characterized by aeolian deposits or recent sea floor exposures) the wet season water table may rise close to, or above, the soil surface, creating extensive areas of shallow inundation or saturated soils. In these circumstances the seasonal or permanently high groundwater table creates the conditions for wetland formation. |

Factors such as climate, soil types and vegetation further affect the ability of wetlands to provide ecosystem services as well as their sensitivity to impacts, both natural and anthropogenic (Kotze *et al*. 2007; Macfarlane *et al.,* 2008).

Ecosystem services provided by wetlands include direct and indirect benefits, such as the following described by Macfarlane *et al*., (2008):

Direct benefits:

- Cultural benefits;
- Cultural heritage;
- Tourism and recreation; and
- Education and research.

- Provisioning benefits;
  - Provision of water for humans;
  - Provision of harvestable resources;
  - Provision of cultivated foods;
- Biodiversity maintenance;
  - Provision of habitat for a diversity of fauna and flora species, both generalist and rare; and
  - Provision of migration corridors between terrestrial and aquatic habitats.

Indirect benefits:

- Water quality enhancement benefits;
  - Sediment trapping;
  - Phosphate assimilation;
  - Nitrate assimilation;
  - Toxicant assimilation;
  - Erosion control;
- Flood attenuation;

- Streamflow regulation; and
- Carbon storage.

Peatlands are a category of wetlands characterised by organic soils. Joosten and Clarke (2002) define peat as *a sedentarily accumulated material comprising at least 30% (dry mass) of dead organic matter.* Furthermore, a wetland can only be classified as a peatland if it has peat at least 30 cm deep (Backéus, 1988). Nomenclature of peatlands is dominated by northern hemisphere countries where peat is most common. Terms associated with peat wetlands (i.e. peatlands) may have different definitions. For example, the term "mire" can refer to either a bog or a fen. A bog is a peatland that receives water only by precipitation and is cut off from any other water source including groundwater (Joosten and Clarke, 2002). A bog is also a term used for semi-aquatic vegetation occurring on acidic peat (Backéus, 1988). Fen is a term descriptive of peatlands that receive their primary water input from precipitation, surface inflow and especially groundwater inflow (Joosten and Clarke, 2002). The term mire refers to an actively peat accumulating wetland (Sjörs, 1948, cited in Joosten and Clarke, 2002), as opposed to a wetland which had accumulated peat in the past but in which no new peat formation occurs.

Peatlands constitute an important natural resource worldwide (Strack, 2008). Peatlands are an important source of clean water which is a threatened non-renewable resource (Joosten and Clark, 2002). In South Africa peatlands are used unsustainably for grazing by livestock (Du Preez and Brown, 2011) and subsistence farming (Grundling *et al*., 1998), while some are mined for the mushroom and horticulture industries (Grundling and Grobler, 2005).

Mires occur in broad, extensive stretches in the northern hemisphere where the rainfall, temperature and landscape are most conducive to their formation (Strack, 2008). Mires are uncommon in areas with high rates of evaporation and transpiration. This is especially true for the southern hemisphere where they are found in areas with relatively high annual precipitation or where concentrated groundwater discharge is present (for example springs) as a result of geological features (Lopez and Smith, 1995; Meadows, 1988). Approximately 50% of the world's wetlands are mires, but less than 1% of mires occur in the southern hemisphere (Grundling and Grobler, 2005).

Peat accumulates over thousands of years due to anaerobic (anoxic) conditions, which prevent a rapid decomposition of organic material including the roots of sedges, *Phragmites*, or even trees (Maltby and Barker, 2009). In the Northern Hemisphere, under cold climatic conditions, peat is often formed by *Sphagnum* moss (Gorham, 1995). Peat formed by *Sphagnum* moss is not common in South Africa (Venter, 2003).

Groundwater-fed mires in South Africa usually have peat layers that are often highly decomposed. In these types of mires, both surface water flow and subsurface flows are often critical in maintaining moisture levels in peat deposits and maintaining their function. This is because the groundwater contribution through the peat is limited by the very low hydraulic conductivity of the deeper, more decomposed peat (Grundling *et al*., 2013, Grundling, 2014a). Peat formation is largely dependent on the availability of water from surface or groundwater sources, which in turn corresponds with climatic patterns (Joosten and Clark, 2002).

Several South African peatlands are older than some peatlands in the northern hemisphere. For example, the Mfabeni fen (located along the coast of northern KwaZulu Natal, South Africa) is approximately 45 000 years old (Grundling *et al.,* 2013). Most South African peatlands experienced significant peat accumulation in the Holocene period, from 11 000 years ago to the present. This trend was also observed in northern hemisphere peatlands (Meadows, 1988). Peat accumulation was favoured during this period because of wetter global conditions (Beilman *et al.,* 2009).

Long-term loss of natural wetlands globally averages between 54–57% since 1900 AD but may have been as high as 87% since 1700 AD (Davidson, 2014). Losses have been more significant for inland than coastal wetlands. The rate of wetland loss in Europe has slowed and in North America has remained low since the 1980's. However, the rate has remained high in Asia and Africa, where large-scale and rapid conversion of coastal and inland natural wetlands is continuing (Davidson, 2014). In South Africa the loss of wetlands, and particularly peatlands, has been attributed to commercial exploitation, peat fires (Grundling and Grobler, 2005) and habitat transformation by agriculture, forestry and urban expansion (SANBI, 2011; Rivers-Moore and Cowden, 2012).

In this study, the Matlabas mire, a peatland in the headwaters of the Motlhabatsi River was investigated. The Motlhabatsi River drains into the headwaters of the Matlabas River which forms an important component of the Marakele National Park (MNP) (SANPARKS, 2008) (Figure 1). The mire occurs in a valley with steep slopes within a rugged mountainous area and can be described as a valley-bottom hillslope seepage wetland complex (Kotze *et al.,* 2007; Ollis *et al.,* 2013), with seasonal and permanent wetland zones. In the best preserved parts of the mire a shallow water layer is always flowing over the surface, even in very dry periods. A hydrological pilot study (conducted in May 2011) identified prominent discharge zones which, together with occurrence of peat layers and artesian springs, bear strong evidence of geological/geomorphological control and sustained groundwater input. The peatland was found to be under stress (for example erosion, desiccated peat) from past land use practices including overgrazing and possibly road construction. Degradation of Marakele and other Waterberg wetlands are of concern as these headwater systems are important water discharge areas ensuring sustained flow to ecosystems further downstream.


**Figure 1.** Overlooking the Matlabas mire taken from the high eastern plateau (photo by M. Bootsma)

### 1.2 PROBLEM STATEMENT

The Matlabas mire consists of two sections. The western part shows clear signs of erosion and peat desiccation while the eastern part is nearly pristine with some erosion evident in its lower reaches. The current threat of gully erosion in the eastern section of the mire is expected to cause large sections of the mire to become dry, resulting in the dehydration and resultant loss of the peat and the mire.

Historic aerial images of the Matlabas mire indicate the presence of channels in the south-eastern portion of the mire as far back as 1956. Current channels are more pronounced. Effective rehabilitation planning for the managers and scientists of the Park requires an assessment of how natural erosion stabilisation processes have been modified and whether erosion control should be implemented.

In order to provide scientifically based recommendations on the rehabilitation processes to be implemented it is imperative that the ecohydrology of the mire is understood. An ecohydrological approach to wetland rehabilitation is based on an understanding of the underlying hydrological systems that influence wetlands at a landscape level. A qualitative analysis of the interplay between landscape position and characteristics of water recharge and discharge, connected with key vegetation and pedological factors provide insights into the processes that keep an ecosystem functioning (Grootjans and Van Diggelen, 2009; Grootjans and Jansen, 2012).

## 1.3 RESEARCH OBJECTIVES

### *Hypothesis*

The current accelerated erosion phase is a result of recent changes to the erosion control mechanisms that stabilised naturally occurring erosion.

### *Research Questions*

In order to develop possible answers and solutions for the current erosion and degradation of the peat in the Matlabas mire the following research questions have been formulated:

- What soils are characteristic of the different wetness zones of the mire?
- What vegetation communities occur on the mire?
- What are the surface water characteristics of the mire?
- How do surface water, soil and vegetation relate to each other?
- What are the characteristics of current erosion features in the mire?

In order to describe and analyse erosion stabilisation processes that ultimately inform management recommendations, particularly regarding the ecohydrology of the Matlabas mire, the ultimate objectives are to understand the drivers and responders of the Matlabas mire. For that reason, special attention will be given to those parameters that are associated with drivers and responders of the mire, including the vegetation classes, ground- and surface water composition, and temperature characteristics of the soil, which may give an insight in groundwater movement (Grootjans and Jansen, 2012). It is further important to view the drivers and responders in relation to man-made structures that may have altered natural processes in the mire.

### *Specific objectives were to:*

- Ascertain the chemical characteristics of the ground - and surface water
- Classify vegetation communities in the mire
- Determine how temperature relates to the basic chemical characteristics of water in the mire
- Describe how water moves within the soil profiles
- Suggest models of water flow in the mire to illustrate current processes affected by erosion.

# CHAPTER 2: Study Area

## 2.1 THE LOCATION OF THE MARAKELE MIRE

The Marakele mire is located within the headwaters of the Matlabas River within the southern parts of the Marakele National Park (MNP), Limpopo Province, South Africa (Figure 2). The MNP is located in quarter degree square 2427BC (SACS, 1980). The MNP is dominated by the Waterberg Mountain in the south-eastern part of the park, with undulating to flat plains characterizing the northwest. The MNP covers an area of approximately 290.51 km² and has been managed as a national park since 1988, but was only officially proclaimed a national park in Government Notice 248 of 11 February 1994 published in Government Gazette No. 15483. The park currently forms part of the Waterberg Biosphere. Before 1988 the area was utilised as a farm with cultivated areas and cattle (Van Staden, 2002). The Marakele mire lies on the farm Kransberg R 593 (SANPARKS, 2014).

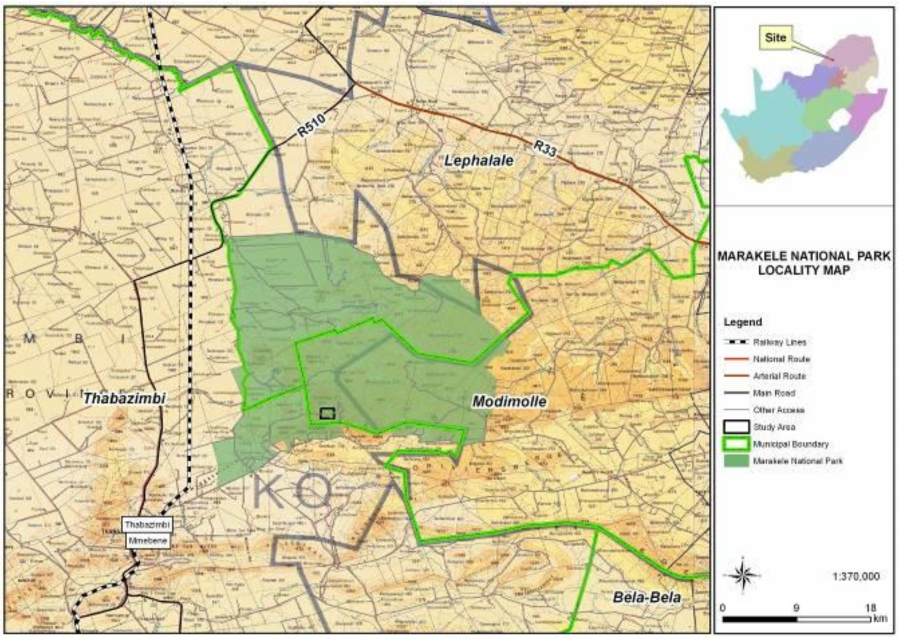



**Figure 2.** Location of the Marakele National Park with the position of the study area indicated by the black rectangle

## 2.2 CLIMATE

The Matlabas Valley falls in the Waterberg Mountain Bushveld vegetation unit, with a rainfall that varies from 556 - 630 mm per annum, mainly during the summer months, between November and March (Figure 3). The region experiences warm summers with temperatures of up to 32°C and cool, dry winters with frost in the low-lying areas (Mucina and Rutherford, 2006).

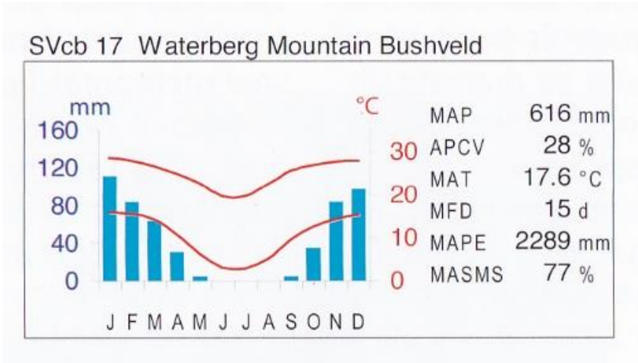



**Figure 3:** Climate diagram of the Waterberg Mountain Bushveld in which the Marakele mire is located (Mucina and Rutherford, 2006)

## 2.3 GEOLOGY AND SOILS

The underlying parent rock of the study area is sandstone of the Aasvoëlkop Formation, Matlabas Subgroup (Waterberg Supergroup) (with shale and mudstone); and Sandriviersberg Formation, Kransberg Subgroup (Waterberg Supergroup) (SACS 1980 cited in Van Staden, 2002).

The soils that have developed on the parent materials range from shallow to deep sandy soils on sandstone, and clayey soils on diabase and mudstone (Van Staden, 2002). Land type classes for the MNP include Ib, Ac, Fa, and Ad (Mucina and Rutherford, 2006).

The wetlands in the MNP occur mainly in the intermediate to higher lying areas (1000 - 2200 m.a.s.l.) that receive higher rainfall compared to the lower lying areas (600 - 1000 m.a.s.l.). The distribution and characteristics of these wetlands are strongly controlled by geologic features (Grundling *et al.,* 2013). These dykes and fault/fracture zones weathered faster than the surrounding sandstone and formed preferential flow paths for groundwater. Groundwater seeps from these paths into valleys resulting in different wetland types including channelled and unchanneled valley-bottom and hillslope seepage wetlands (Grundling *et al*., 2013). Wetlands mainly occur in valleys arranged in a prominent kite-like pattern as a result of diabase dykes intruding along faults/fractures striking west-northwest to east-southeast and northeast-southwest into Waterberg Group sandstones (Figure 4).

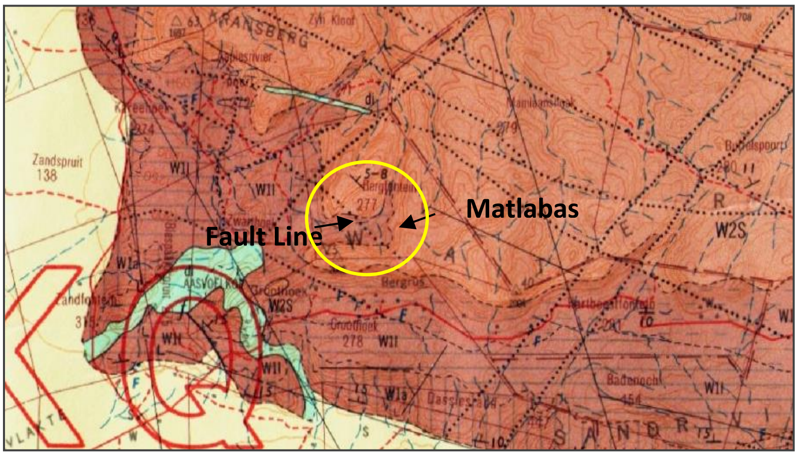



**Figure 4.** Southeast to northwest fault lines (indicated by the dotted line) and the northeast to southwest oriented valleys (indicated by the dark red shaded area). Source: 1:250 000 Geological Map 2426 Thabazimbi (SACS, 1980). The yellow circle indicates the location of the Matlabas valley

### 2.4 HYDROLOGY

The MNP is an important catchment area for a number of large rivers, including the Matlabas, Mamba and Sterkstroom Rivers, which eventually drain into the Limpopo River. These rivers form three main hydrological systems in the MNP and are therefore important areas for river recharge and water quality maintenance (SANPARKS, 2008). The Matlabas mire drains into the Motlhabatsi River to the north. This river confluences with the larger Mamba River to form the Matlabas River. The Matlabas River eventually drains into the Limpopo River which decants into the Indian Ocean at Xai Xai in Mozambique.

The main regional hydrological features are presented in Figure 5 below. An interesting feature of the watercourses in this area is the west-northwest to east-southeast and northeast-southwest patterns of their alignment, which follows geological structures.

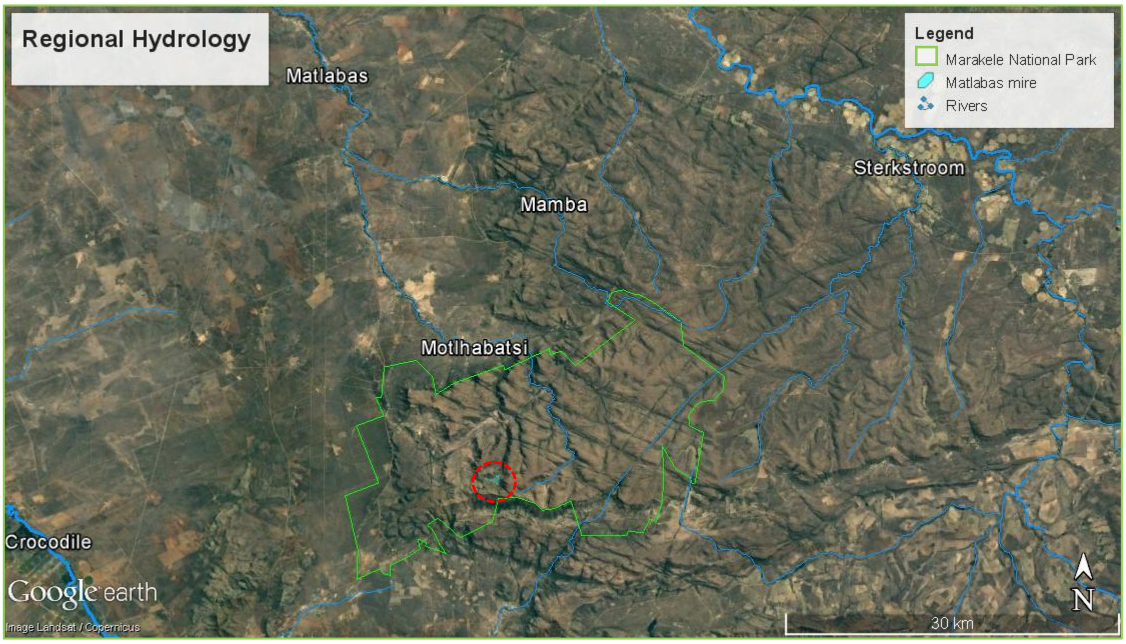



**Figure 5.** Surface water hydrology patterns relative to the Marakele National Park. The Matlabas mire is located in the red dashed circle

## 2.5 VEGETATION

The MNP is situated in the Savanna Biome (Rutherford and Westfall, 1994). The Acock's (1988) vegetation classification reflects several vegetation units in the park, including Sour Bushveld (Veld Type 20), Mixed Bushveld (Veld Type 18), Sourish Mixed Bushveld (Veld Type 19) and North-Eastern Mountain Sourveld (Veld Type 8). Sweet Bushveld (Veld Type 17) is found along the banks of the Matlabas River. This classification is still used to describe habitats in the park in popular media aimed at tourists.

Van Staden (2002) recognized 24 vegetation communities in the MNP. The Matlabas valley falls within the vegetation unit classified as *Faurea saligna-Acacia caffra Woodland* (Figure 6).

Van Staden and Bredenkamp (2005) classified the major vegetation community along the Matlabas, Mamba and Sterkstroom rivers as the *Andropogon huilensis-Xyris capensis* vegetation community. This community is differentiated by the following diagnostic plant species; *Syzygium cordatum, Cliffortia linearifolia, Andropogon huilensis, Aristida junciformis, Arundinella nepalensis, Ischaemum fasciculatum, Miscanthus junceus, Ascolepis capensis, Cyperus thorncroftii, Drosera madagascariensis,* *Fuirena pubescens, Helichrysum aureonitens, Hypericum lalandii, Monopsis decipiens, Sebaea leiostyla, Verbena bonariensis* and *Xyris capensis.*

Mucina and Rutherford (2006) describe three vegetation units for the MNP: The Waterberg-Magaliesberg Summit Sourveld (Gm 29) which surrounds the Matlabas valley, pockets of Northern Afromontane Forest (FOz 2) and Waterberg Mountain Bushveld (SVcb17) in which the Matlabas valley falls.

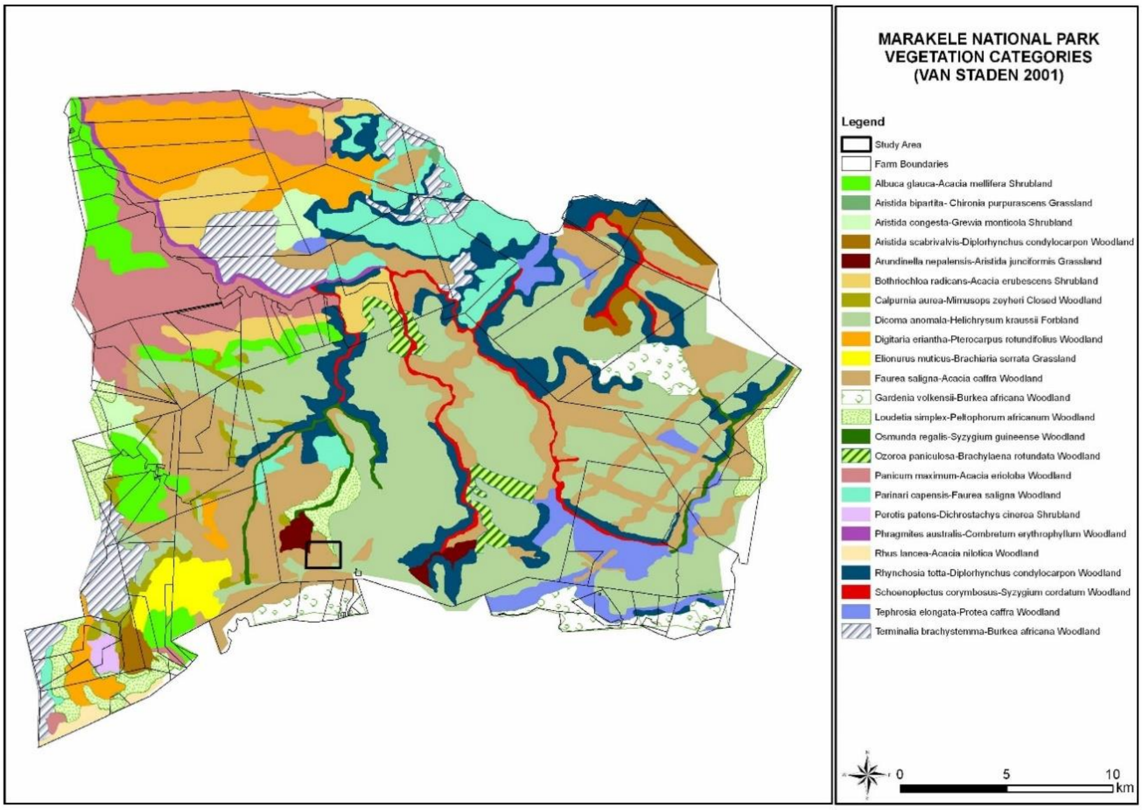


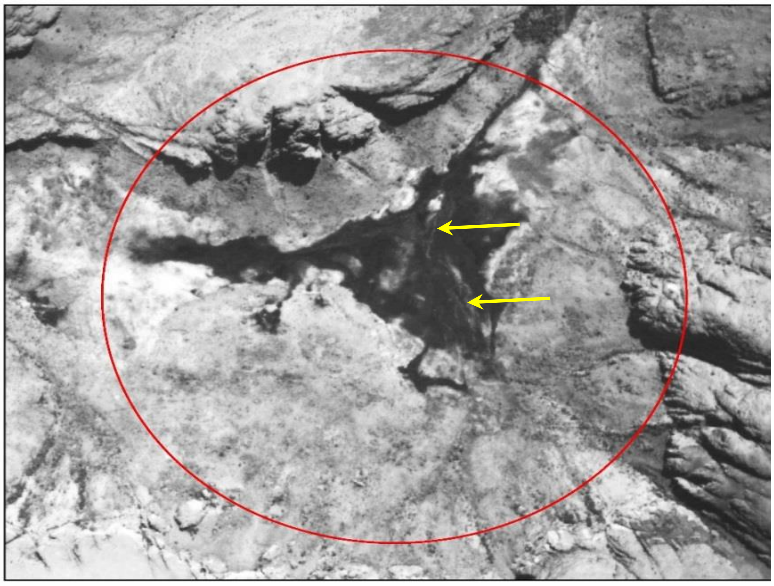

**Figure 6.** Vegetation units for the MNP. The Matlabas valley is denoted by the black square in the lower section of the park (Van Staden, 2002).

### 2.6 FAUNA

The MNP places an emphasis on maintaining biodiversity and ecological processes, with the emphasis on red data taxa, mega herbivores and large carnivores (SANPARKS, 2008). Since its proclamation in 1994, MNP has become an important refuge for rare and endangered species such as the Cape Vulture (*Gyps coprotheres*), Black Rhinoceros (*Diceros bicornis*), the Roan Antelope (*Hippotragus equines*) and the Waterberg Cycad (*Encephalartos eugenemaraisii*). (Bezuidenhoudt and van Staden, 2009). The vegetation along the Matlabas River forms an important winter refuge area for game particularly during the dry season. This vegetation is crucial to sustain adequate numbers of prey species for large predators such as lion and spotted hyena (SANPARKS, 2008).

### 2.7 EROSION FEATURES

The development of erosion features in the largely pristine eastern section of the Matlabas mire have raised questions regarding the appropriate management protocol that should be implemented. Aerial images of the mire taken in 1956, before the road to the south and east of the mire was built, indicate some channel formation. Since the construction of the road with its associated culverts and change of land use from farming to conservation, channel formation in the eastern section of the mire has increased as shown in the aerial image taken in 1972 (Figure 7).



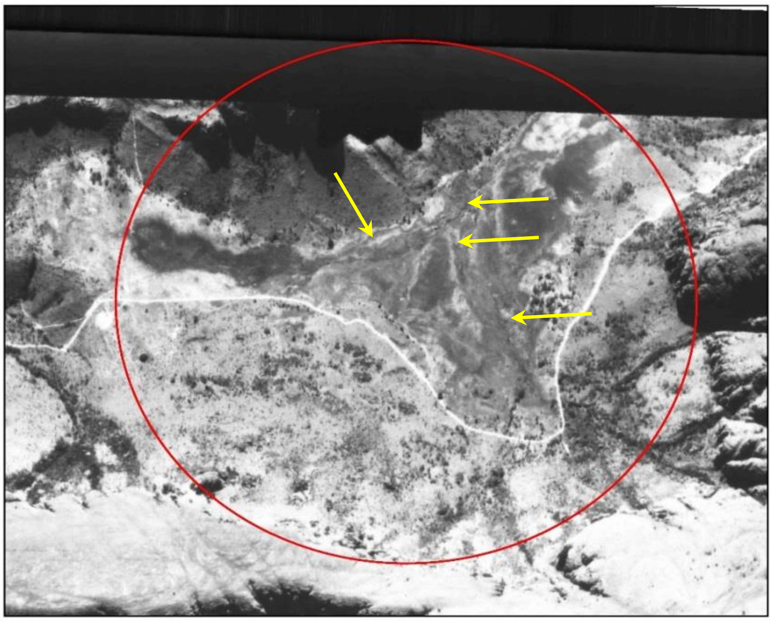


**Figure 7.** Aerial photograph of the Matlabas mire taken in 1956 (top) and 1972 (bottom) reflecting the presence of channel formation indicated by the yellow arrows.

# CHAPTER 3: Methods

### 3.1 GEOMORPHOLOGY AND HYDROGRAPHY

Height contours were recorded with a Trimble R8 GNSS surveying system, using RTK DGPS with a roving receiver and a static receiver based at a nearby trigonometric beacon. Contour lines with 50 cm intervals were obtained (accuracy 8 – 15 mm[1]). Data for 290 points were obtained. Elevation data, together with accurate GPS points were used to derive height contours throughout the mire to create an accurate spatial reference. Based on this map data was gathered to describe the hydrology.

Two components of surface water flow were described: channelled flow and the direction of flow of diffuse surface water outside of the channels. Channelled surface water was visually plotted on aerial imagery and classified as either permanent or intermittent. Position of channels on imagery was cross-referenced between the following years: 2003, 2012 and 2015. Analysis of these years provided a reference between regional precipitation patterns (drier and wetter years), and was largely influenced by the availability of clearly visible aerial images.

Flow direction of dispersed surface water was visually estimated by dropping a piece of debris onto the water and tracking its direction with a hand held compass. This was done during both wet and dry seasons. Data was recorded with a Garmin GPSmap 76CSx GPS. Flow direction was adjusted for a declination of 15°44'[2]. Adjusted flow direction was then converted to arrows and plotted on the map using ESRI ArcMap software (ESRI, 2011) and KML files (Google Earth, 2013). Direction of surface water flow outside of the channels was superimposed with contour data, and instances were highlighted where the direction of surface water flow did not follow the contours.

### 3.2 EROSION FEATURES

The location of erosion features was accurately plotted during the survey of height contours (8 - 15 mm). Characteristics such as the depth and width of the gullies were measured infield and recorded in an Excel spreadsheet.

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[1] http://trl.trimble.com/dscgi/ds.py/Get/File-750663/022516-130A_TrimbleR8s_DS_US_0716_LR.pdf accessed 2016.11.19

[2] http://www.magnetic-declination.com accessed 2012.06.07

### 3.3 TEMPERATURE AND RAINFALL

Average daily temperature [°C] (a calculation of 24 hourly values) and Total Daily Rainfall (in mm, calculated for a 24 hour period starting from 0100 to 2400 hours) was logged by the Thabazimbi Towers weather station (LAT (S): 24.29937, LONG (E): 27.70002), managed as part of the Agricultural Research Council-Institute for Soil Climate and Water Agro-Climatology Programme (Agro-Climatology Staff, 2016).

### 3.4 VEGETATION CLASSIFICATION

A total of 54 sample plots (4 $m^2$) were placed on a stratified random basis (Brown *et al.*, 2013) throughout the Matlabas mire (Figure 8). Species area curves following the methodology described in Magurran (2004) conducted in the Marakele mire during the vegetation analysis indicated that 1x1 m quadrats were insufficient to describe the diversity of plant species. Due to the small area covered by homogenous vegetation units, larger quadrats would have spanned ecotones (vegetation gradients). This was undesirable as data would not reflect clear vegetation communities. Therefore 2x2 m quadrats were considered as optimal sample sizes for the current study and has proved an effective size for vegetation classification of wetlands (Sieben, 2011; Pretorius, 2011). Sampling focus was on the eastern section of the mire since it is in a more natural state and the aim of the project is to understand the natural processes preventing erosion. A grid that divided sample plots into 100 squares was used to estimate percentage cover abundance. The percentage cover abundance score was converted to the Braun Blanquet abundance classes (Werger, 1974; Westhoff and Van der Maarel, 1978). In each sample plot all the species were identified while environmental data on the soil type and aspect were also recorded.

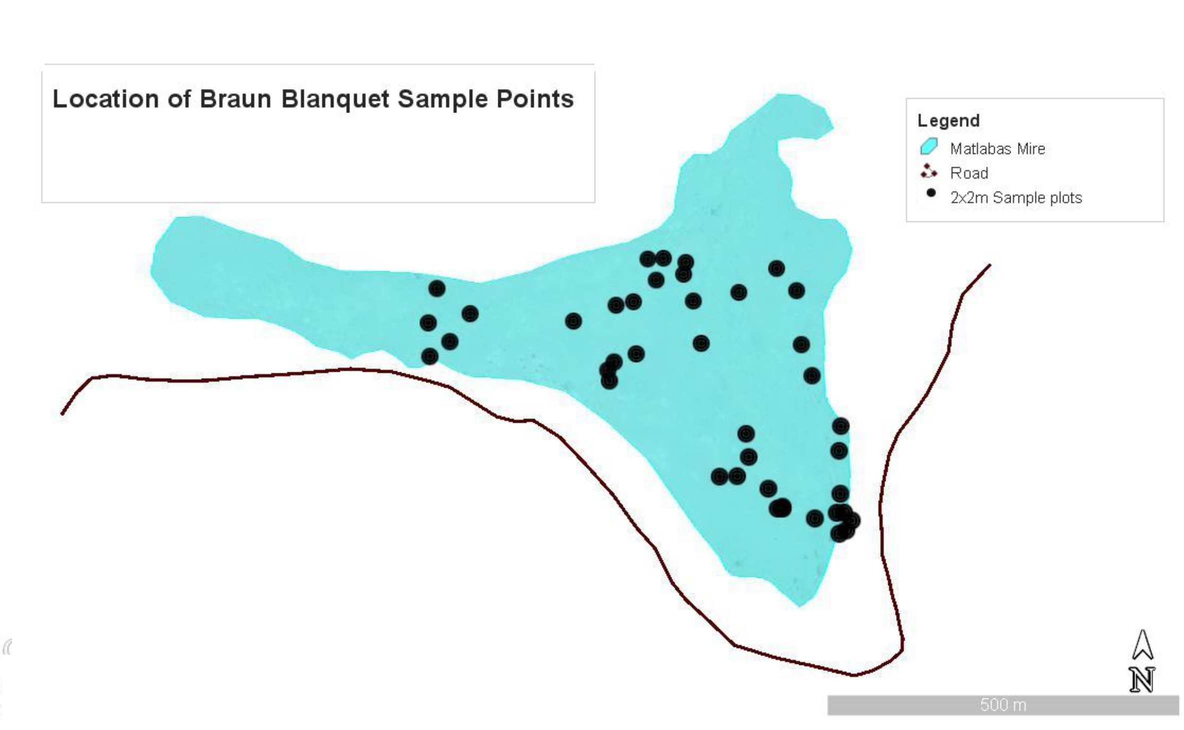



**Figure 8.** Position of the vegetation survey sample plots

The floristic and habitat data were captured in an Excel spreadsheet and was then imported into the JUICE 7.0 (Tichy, 2002) vegetation classification software programme. The modified TWINSPAN (Hill, 1979; Rolecěk *et al*., 2009) classification was performed using Whittaker's beta-diversity to derive a first approximation of the plant communities for the study area. Pseudo-species cut levels were set at 0-5-25-50-75. The phytosociological table was refined according to Braun-Blanquet procedures as described by Brown *et al*. (2013). The plant communities were described in terms of their characteristic and dominant species, distribution and broad habitat.

### 3.5 LOCATION OF TRANSECTS

Four transects were placed to include variations in vegetation gradients and hydrological zonation as well as being inclusive of landscape elements such as elevated domes and water channels. Soil profiles, as well as groundwater composition, was described and analysed at intervals along the four transects (Figure 9). For soil coring an Edelman corer and a Russian peat auger was used. The humification grade was assessed in the field according to the Von Post humification scale (Von Post, 1922).

### 3.6 TEMPERATURE PROFILES

Temperature profiles were measured in April 2012 (end of summer) and in August 2013 (end of winter). The timing of temperature measurements was independent from other measurements and results were not directly correlated with other data. The location of temperature measurements also did not strictly follow the transects along which other sampling was conducted. To investigate trends in temperature gradients, the measurements were done across, as well as along, contours and through landscape features of interest such as vegetation communities and the domes.

The measurements were carried out using a 2 m long probe that was placed vertically into the soil layers. Readings were taken at every 20 cm and correlated with the presence of sand, clay or peat by interpreting the sound of the probe moving through the substrate as well as the resistance experienced by the operator.

### 3.7 GROUNDWATER LEVEL AND WATER PRESSURE

The wells and piezometers were made from 50 mm diameter PVC pipes, ranging between 5.18 m and 0.97 m in length. Slots of about 1 mm wide, 20 mm deep and 20 mm apart were cut into the lower 20 cm of the pipes for piezometers and along the whole length of the pipe for wells. Pipes were then covered with geotextile screening to allow water to move into the pipes.

Well and piezometer nests were installed along each transect in the eastern section of the mire in such a way that nests were located in representative vegetation zones (Figure 9). The pipes were placed vertically into the soil profile so that 40 cm of pipe protruded above the soil surface. The tops of the pipes were capped between sampling events.

Piezometer nests were installed with two tubes of different lengths so that the bottoms of the tubes were in different substrate layers, for example, sand and peat layers. The differences in water pressure between the two tubes reflected the direction of water flow within the soil profile. An example of a piezometer nest is shown in Figure 10 below.

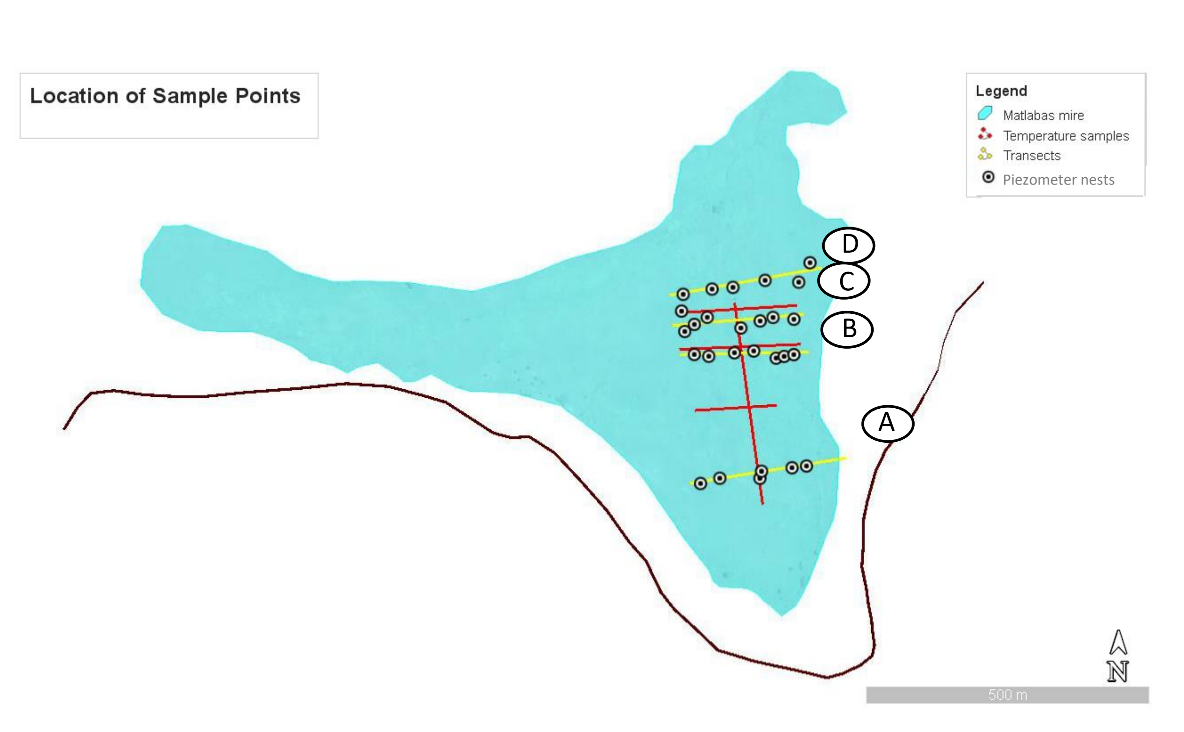



**Figure 9.** Position of transects A, B, C and D, together with position of piezometer nests and alignment of soil temperature measurements

**Figure 10.** An example of a piezometer nest made up of three PVC pipes forming a well and two piezometers that extend to various depths of the substrate

Water levels within the wells and piezometers were monitored manually on a monthly basis from 2011 to 2013 to obtain 24 months of consecutive readings. Data from two months were chosen to be representative of the wet season (March 2012) and the dry season (June 2012). These months were chosen following calculation in Excel spreadsheets of averages of all months across the dataset.

### 3.8 CHEMICAL COMPOSITION OF WATER

Water was extracted from each well and piezometer pipe as well as other parts of the mire so as to obtain samples representative of different layers of the substrate. The pipes were first emptied to ensure that no contaminated water was sampled. After about 24 hours, when clean water from the substrate (groundwater) had again filled the pipes, water samples were collected in 250 ml PVC bottles. PVC bottles were rinsed with the sample water, filled to the brim and stored in a cooler box. The samples (69 samples from June 2011 and 61 samples from January 2013) were analysed for macro-ionic composition at the Agricultural Research Council's Institute for Soil Climate and Water. The analysis was done according to APHA *et al*., (1985a) for the following parameters; pH, Electric Conductivity (EC), metal cations ($Ca^{+2}$, $Mg^{+2}$, $K^{+}$, $Na^{+}$, $Fe^{II(III)}$) and main anion concentrations ($HCO_3^-$, $Cl^-$, $SO_4^{-2}$, $NO_3^-$). The metal cations concentrations were obtained by emission spectroscopy using an inductively coupled plasma source (APHA *et al.,* 1985b). The main anion concentrations were determined by a Dionex ion chromatograph with the conductivity measurement method (APHA *et al.* 1985c). $HCO_3^-$ was analysed titrimetrically and for $SiO_2$ with a Wirsam AES XRF. The accuracy of the concentrations of the different main cations and anions were verified using an electrical balance (EB) (Appelo and Postma, 2005).

### 3.9 DATA ANALYSIS

The delineation of wetland boundaries presented here was based on vegetation gradients visible on aerial images. Although the presence of seepage wetlands to the south of the mire and the road are noted their extent has not been accurately determined. Since the focus of the research was on the body of the mire itself, adjacent seepage wetlands were not included in all the maps, nor were they sampled for any of the parameters analysed in the mire.

Field and laboratory data were imported into Excel spreadsheets and sorted into tables. Graphs were derived from interpretation of these tables and converted to images. Outlier data were removed from the dataset.

The floristic data from each sample plot were captured into the vegetation database Turboveg for Windows in the program Juice 7.0 (Tichy, 20002; Hennekens, 1996). Data was exported into Excel speadsheets showing percentage cover abundance and Braun Blanquet abundance classes (Werger, 1974; Westhoff and Van der Maarel, 1978).

Maps were drawn in Google Earth software based on visible landscape characteristics and data relevant to sample plots.

# CHAPTER 4: Results

## 4.1 VEGETATION

The results of the TWINSPAN classification are indicated in the phytosociological table (Table 2 and Figure 11). A total number of five plant communities were identified, located on both peat and mineral soils. These five communities can be further grouped into three major communities and two sub-communities as listed below:

1. *Kyllinga melanosperma–Miscanthus junceus* community
   - 1.1 *Kyllinga melanosperma–Miscanthus junceus* community - *Arundinella nepalensis* sub-community
   - 1.2 *Kyllinga melanosperma–Miscanthus junceus* community - *Digitaria brazzae* sub-community
2. *Pteridium aquilinum* community
3. *Andropogon eucomis–Aristida canescens* community
   - 3.1 *Andropogon eucomis–Aristida canescens* community - *Helichrysum nudifolium* sub-community
   - 3.2 *Andropogon eucomis–Aristida canescens* community - *Panicum dregeanum* sub-community

The complete phytosociological data including all species recorded is presented in Appendix A.

**Table 2:** The phytosociological table for species recorded in the Matlabas mire

| | 1 | | | | | | | | | | | | | | | | | | | | | | 2 | | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1 | | | | | | | | | 1.2 | | | | | | | | | | | | | | | | | 3.1 | | | | | | | | | 3.2 | | | | | | | | | | | | | | | | | |
| Releve number | 36 | 48 | 53 | 52 | 32 | 51 | 49 | 14 | 54 | 15 | 47 | 45 | 12 | 6 | 13 | 11 | 35 | 8 | 7 | 10 | 17 | 9 | 16 | 1 | 2 | 3 | 4 | 30 | 42 | 40 | 39 | 44 | 31 | 41 | 43 | 50 | 23 | 22 | 5 | 27 | 24 | 34 | 21 | 46 | 18 | 33 | 38 | 25 | 26 | 28 | 37 | 19 | 29 | 20 |
| **Species group A** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Miscanthus junceus* | | | + | . | + | . | | . | | . | | | . | | | | | | | | | | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Kyllinga melanosperma* | . | | | . | . | | | | | + | | . | | r | | | . | | | . | | + | | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Thelypteris confluens* | . | . | | . | . | . | . | | | . | | . | | . | | | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group B** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Arundinella nepalensis* | | + | | | | . | . | + | . | . | . | . | . | . | . | . | | . | . | . | + | . | . | . | . | . | . | . | . | 2 | 2 | . | 2 | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum nudifolium* | . | | + | | . | + | | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | 1 | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Pycnostachys reticulata* | | . | | | . | | | | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | 1 | + | . | 1 | 1 | . | 1 | . | . | . | . | . | . | 4 | . | . | . | . | . | . | . | . | 1 | . | 1 | . |
| *Rhynchospora* sp. | . | | | | + | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Ascolepis capensis* | | . | + | | + | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group C** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Digitaria brazzae* | . | . | . | . | . | . | . | . | . | . | . | . | | + | . | | . | . | | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . |
| *Nidorella auriculata* | . | . | . | . | . | . | . | . | . | + | . | . | . | + | + | | . | r | | . | r | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum epapposum* | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | + | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Phragmites australis* | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Miscanthidium junceum* | . | . | . | . | . | . | . | . | . | | . | | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group D** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Pteridium aquilinum* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 5 | 5 | 5 | 4 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Triumfetta pilosa var tomentosa* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | + | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Oldenlandia herbacea* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | + | r | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum aureonitens* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Oxalis obliquifolia* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | + | + | . | . | . | . | . | . | . | . | . | + | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group E** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Aristida canescens* | | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | 4 | 2 | 2 | 4 | 2 | 1 | 4 | 4 | 2 | 2 | . | 2 | 4 | 4 | 4 | 2 | 4 | 2 | 2 | 1 | 4 | 2 | 4 | 4 | 2 | 2 |
| *Andropogon eucomus* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | 1 | . | . | . | . | . | . | . | 1 | . | + | . | . | 2 | . | . | . | . | + | . | . | . | . |
| *Chironia purpurascens* subsp. *Purpurascens* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | + | . | . | . | 1 | . | . | . | . | . | . | . | 1 | . | r | 1 | . | . | . | 1 | 2 | 2 | . | r |
| **Species group F** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Helichrysum nudifolium* var. *nudifoli* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | 2 | 1 | 2 | . | 1 | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | 1 | . |
| *Avena fatua* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | 1 | . | . | 1 | . | . | . | . | . | . | . | 4 | . | . | 2 | . | . | . | . | 1 | . | . | . |
| *Xyris capensis* | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | . | . | . | 1 | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum aureonitens* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | + | . | 1 | . | 1 | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . |
| *Drosera collinsiae* | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | . | 4 | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . |
| **Species group G** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Panicum dregeanum* | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | 2 | + | . | 5 | 1 | 1 | 1 | 4 | 4 | 2 | 2 | 2 | 2 | 5 | 1 | 5 | . | 4 |
| *Senesio* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | 2 | . | . | . | . | . | . | . | 1 | 1 | 1 | . | 1 | . | r | . | . | + | . | 1 | . | + | + | + |
| *Eragrostis racemosa* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | + | . | 2 | . | . | 1 | . | . | 1 | 2 | . | . |
| *Commelina africana* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | + | + | + | . | . | + | 1 | . | . | . | . | . | . | . | . | . | . |
| *Pseudognaphalium undulatum* | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | 1 | . | 2 | + | . | . | + | . | . | . | . | 1 | . | . | 1 | . |

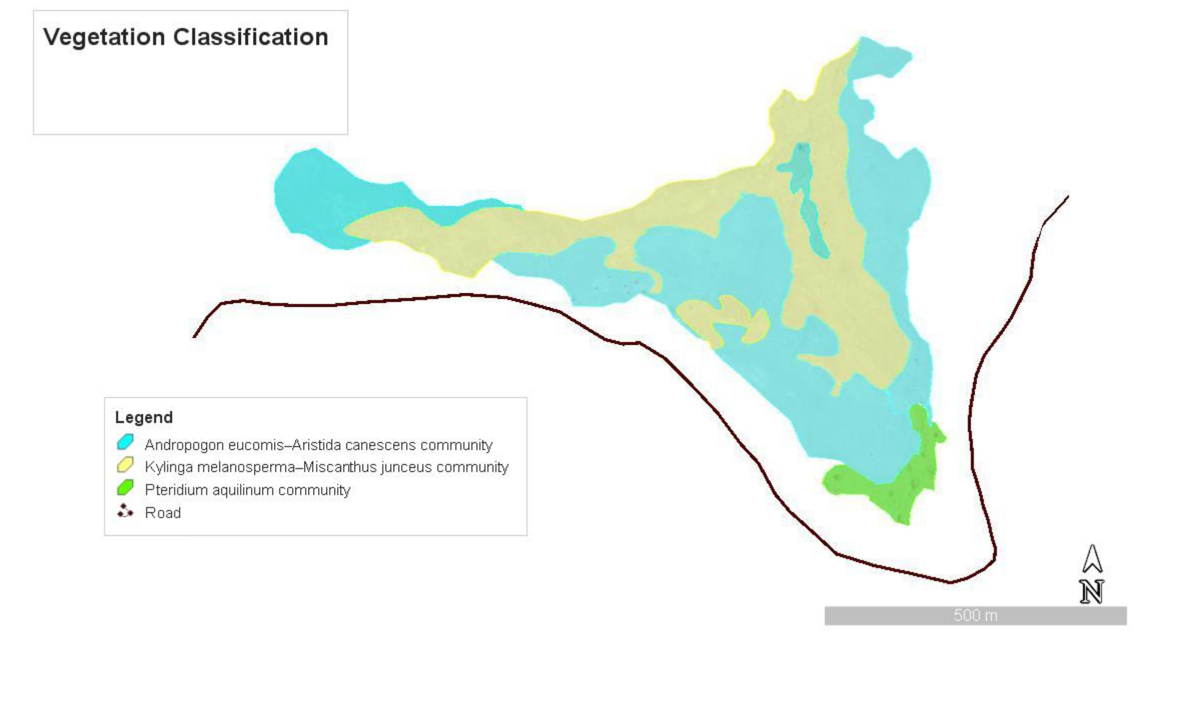



**Figure 11**. Distribution of the three major vegetation communities:

### 1. *Kyllinga melanosperma–Miscanthus junceus* community

This plant community is characterised by the presence of species from species group A and include the forbs *Miscanthus junceus, Kyllinga melanosperma* and *Thelypteris confluens.*

This community is the wettest of the three major communities identified. It is characterised by visible surface water and the thickest peat deposits. Tussocks of *Miscanthus junceus* can be up to 30 cm between the water surface and the top of the tussock (where the grass stems and leaves start to spread). These tussocks, together with rhizomes of the fern *Thelypteris confluens* and the sedge *Kyllinga melanosperma* (species group A) make this vegetation unit very functional in terms of dispersing water flow and trapping sediments (Figure 12).

**Figure 12.** The *Kyllinga melanosperma–Miscanthus junceus* major community is characterised by tall grasses, ferns and sedges that form thick tussocks and rhizomes that are very effective in dispersing water and trapping sediments

This community can be divided into two sub-communities, both of which are closely related to the presence of peat soil. The first subcommunity (*Kyllinga melanosperma–Miscanthus junceus* community - *Arundinella nepalensis* sub-community) included *Campylopus pyriformis, Nidorella auriculata, Isolepis costata, Rhynchospora sp.,* and *Digitaria brazzae* (species group B). This subcommunity has some affinity with the *Andropogon eucomis–Aristida canescens* community *Helichryum nudifolium* sub-community (species group F). This is due to the microhabitats within the mire which form mosaics of species distribution within, and sometimes across, broader gradients.

Analysis of the synoptic table reflected the following characteristics of this group (Table 3):

**Table 3:** Results from the synoptic table for the *Kyllinga melanosperma–Miscanthus junceus* community - *Arundinella nepalensis* sub-community

| *Kyllinga melanosperma –Miscanthus junceus* community - ***Arundinalla nepalensis*** **sub-community (species group B)** | |
|---|---|
| Diagnostic species | Constant species |
| *Ascolepis capensis, Helichrysum nudifolium, Rhynchospora* sp. | *Arundinella nepalensis, Kyllinga melanosperma, Miscanthus junceus, Pycnostachys reticulata* |

The second subcommunity (*Kyllinga melanosperma–Miscanthus junceus* community - *Digitaria brazzae* sub-community) included *Digitaria brazzae, Nidorella auriculata, Helichrysum epapposum, Phragmites australis* and *Miscanthidium junceum* (species group C).

Analysis of the synoptic table reflected the following characteristics of this group (Table 4):

**Table 4:** Results from the synoptic table for the *Kyllinga melanosperma–Miscanthus junceus* community - *Digitaria brazzae* sub-community

| *Kyllinga melanosperma –Miscanthus junceus* community - ***Digitaria brazzae*** **sub-community (species group C)** | |
|---|---|
| Diagnostic species | Constant species |
| *Miscanthus junceus, Nidorella auriculata* | *Kyllinga melanosperma* |

A stand of *Phragmites australis* occurs within this subcommunity, on thick peat deposits (Figure 13). This stand of reeds is unique to the mire. *Phragmites australis* is not recorded in any other location although the data analysis was not at a detailed enough resolution to identify this feature as forming part of the diagnostic or constant species in the subcommunity.

**Figure 13.** The stand of *Phragmites australis* reeds only occurs in one place in the mire (top). Special precautions had to be taken to prevent the creation of erosion pathways in the mire (bottom) (photo by P. Grundling)

### *2. Pteridium aquilinum* community

This vegetation community occurs along the outer edge of the wetland and is characterised by species poor *Pteridium aquilinum* dominated patches (species group D). This community is located exclusively on mineral soil. Various small forbs were recorded in this unit but could not be identified since no inflorescences were evident (Figure 14).

Analysis of the synoptic table reflected the following characteristics of this group (Table 5):

**Table 5:** Results from the synoptic table for the *Pteridium aquilinum* major community

| ***Pteridium aquilinum*** major community (species group D) | |
|---|---|
| Diagnostic species | Constant species |
| *Helichrysum aureonitens, Oldenlandia herbacea, Oxalis obliquifolia, Pteridium aquilinum, Triumfetta pilosa* var. *tomentosa* | – |

**Figure 14.** Dominant patch of the fern *Pteridium aquilinum* occurs along the outer edge of the wetland and is characterised by low species richness.

### *3. Andropogon eucomis–Aristida canescens community*

This moist grassland vegetation community is an interface between the wet grassland (*Kyllinga melanosperma–Miscanthus junceus* major community) and terrestrial habitat. This community had the largest number of species containing common wetland species as well as species generally associated with terrestrial conditions (species group E). This community largely corresponds to the presence of mineral soil.

The elevated peat domes occurred predominantly in this major community (Figure 15). Species composition of the domes was not uniform enough to cluster into distinct groups. Species recorded on domes that were in the process of desiccation reflected pioneer species including *Rubus cuneifolius* and *Gomphocarpus physocarpus*. Wetter domes reflected species such as *Chrysophyllus* sp. and *Thelypteris confluens*. Peat domes are elevated to approximately 1 m above the surrounding landscape and are between 30 m and 9 m in width.

Two sub-communities occur as subsets of the major community. The first subcommunity (*Andropogon eucomis–Aristida canescens* community *Helichrysum nudifolium* sub-community) included *Helichrysum nudifolium* var. *nudifolium*, *Avena fatua, Xyris capensis, Helichrysum aureonitens* and *Drosera collinsiae* (species group F). Some affinity is seen with the *Kyllinga melanosperma–Miscanthus junceus* community - *Arundinella nepalensis* sub-community discussed above.

Analysis of the synoptic table reflected the following characteristics of this group (Table 6):

**Table 6:** Results from the synoptic table for the *Andropogon eucomis–Aristida canescens* community-*Helichrysum nudifolium* sub-community

| *Andropogon eucomis –Aristida canescens* community - ***Helichryum nudifolium*** sub-community (species group F) | |
|---|---|
| Diagnostic species | Constant species |
| *Aristida canescens* | *Pycnostachys reticulata* |

The second subcommunity (*Andropogon eucomis–Aristida canescens* community - *Panicum dregeanum* sub-community) included *Panicum dregeanum, Senesio* sp., *Eragrostis racemosa Commelina Africana* and *Pseudognaphalium undulatum* (species group G).

Analysis of the synoptic table reflected the following characteristics of this group (Table 7):

**Table 7:** Results from the synoptic table for the *Andropogon eucomis–Aristida canescens* community - *Panicum dregeanum* sub-community

| *Andropogon eucomis–Aristida canescens* community - ***Panicum dregeanum*** sub-community (species group G) | |
|---|---|
| Diagnostic species | Constant species |
| *Panicum dregeanum, Senesio sp.* | *Aristida canescens* |

**Figure 15.** Peat domes can raise more than 1 metre above the surrounding *Andropogon eucomis–Aristida canescens* grassland community (top and bottom) (bottom photo by P. Grundling).

## 4.2 GEOMORPHOLOGY AND HYDROGRAPHY

*Elevation contour lines*

The Matlabas mire consists of two sections: the western section (6 ha) and the eastern section (8 ha). The western section drains from the west (from 1621 m.a.s.l.) to east with a slope of 4%. Two seepage wetlands are intersected by the road that runs along the southern edge of the mire (Figure 16). The mire is located close to the watershed of the main east-west stretching valley. The eastern section of the mire drains primarily to the north (from 1614 m.a.s.l.) with a slope of 5%. The elevation at the confluence of the two sections is approximately 1577 m.a.s.l. Elevation contours at 0.5 m intervals are presented in Figure 16 (details are provided in Appendix B).

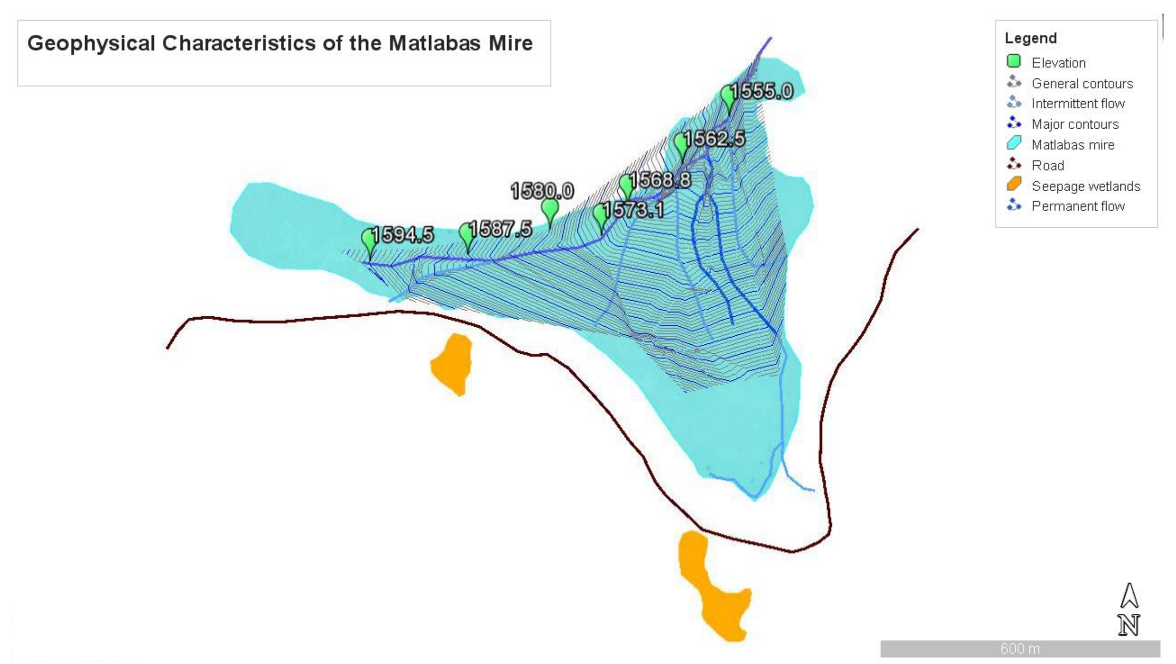



**Figure 16.** The two seepage wetlands and contours drawn at 0.5 m intervals relative to the road and intermittent and permanent surface water flow

The Matlabas mire is characterised by a series of elevated peat domes. The peat domes are located primarily in the southern part of the mire. The alignment of most peat domes (northwest - southeast) appears to correspond to the position of a fault line indicated in the 1:250000 Geological Map. Most domes are situated along this fault line, but some are also aligned in an east - west direction. This could point to the presence of another fault line (Figure 17).

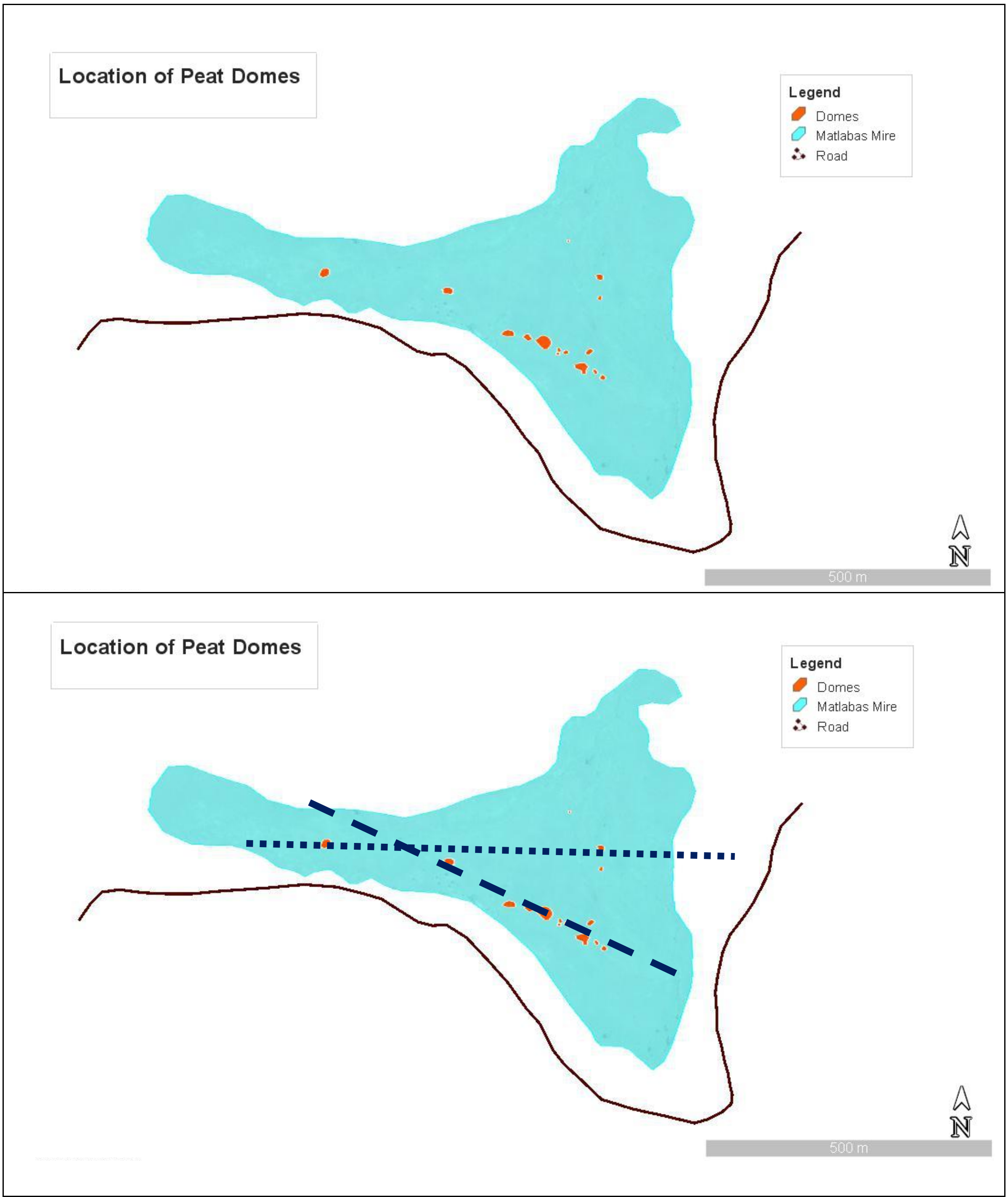



**Figure 17.** The top figure shows the position of the elevated peat domes (in orange). The bottom figure again shows the location of the elevated peat domes in relation to the position of the fault line (blue dashed line, (northwest - southeast) indicated on the Geological Map. Most domes are situated along this fault line, but some are also aligned in east - west direction. This could point to the presence of another fault line (blue dotted line).

*Surface water flow*

Six channels with intermittent water flow were recorded. Permanent water flow was recorded in two channels and a section of a third.

The direction of diffuse water flow, outside of these channels, was recorded in the April, 2012 (36 points) and the January 2013 (22 points) in the eastern wetland section (Figure 18). The direction of water flow generally runs across gradients and drains towards the low lying areas of the landscape. However, in each transect in which readings were taken, deviations from this trend were evident (Figure 19). Unchannelled flow was recorded primarily in the *Kyllinga melanosperma–Miscanthus junceus community* corresponds to the peat soils. The *Miscanthus junceus* grass forms large tussocks that are elevated above the water surface, in some instances by as much as 30 cm. The spaces between tussocks form channels in which water flows on the surface. The presence of erosion channels also influenced the direction of water flow. Data for the diffuse water flow is provided in Appendix C.

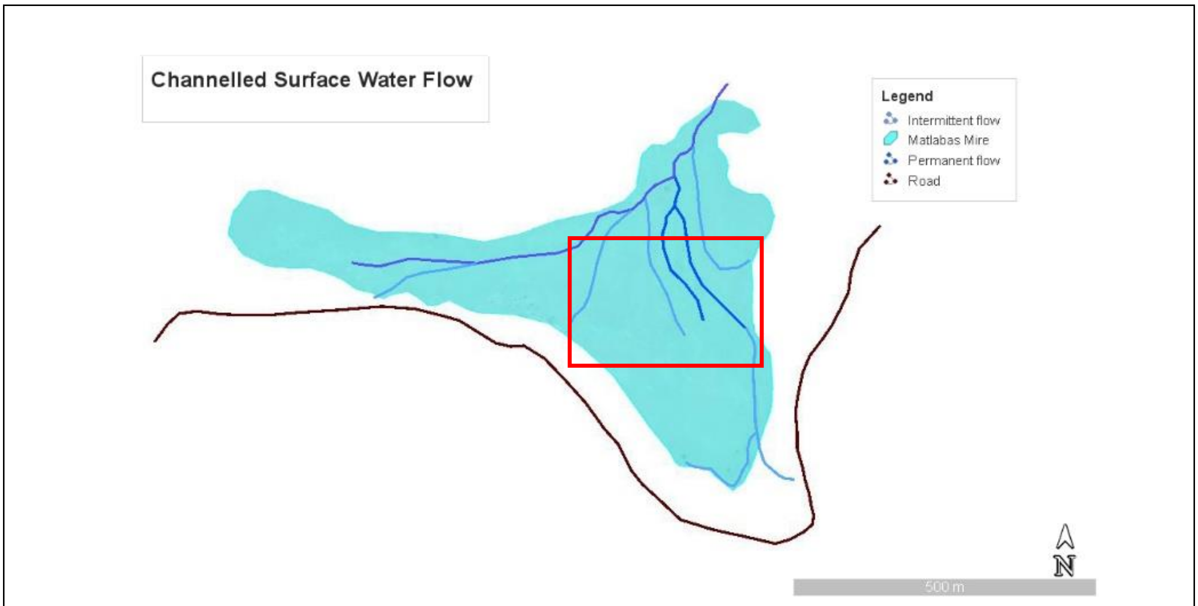



**Figure 18:** Direction of unchannelled water flow was sampled in the eastern section of the mire as indicated by the red square. Data recorded in this area is presented visually below

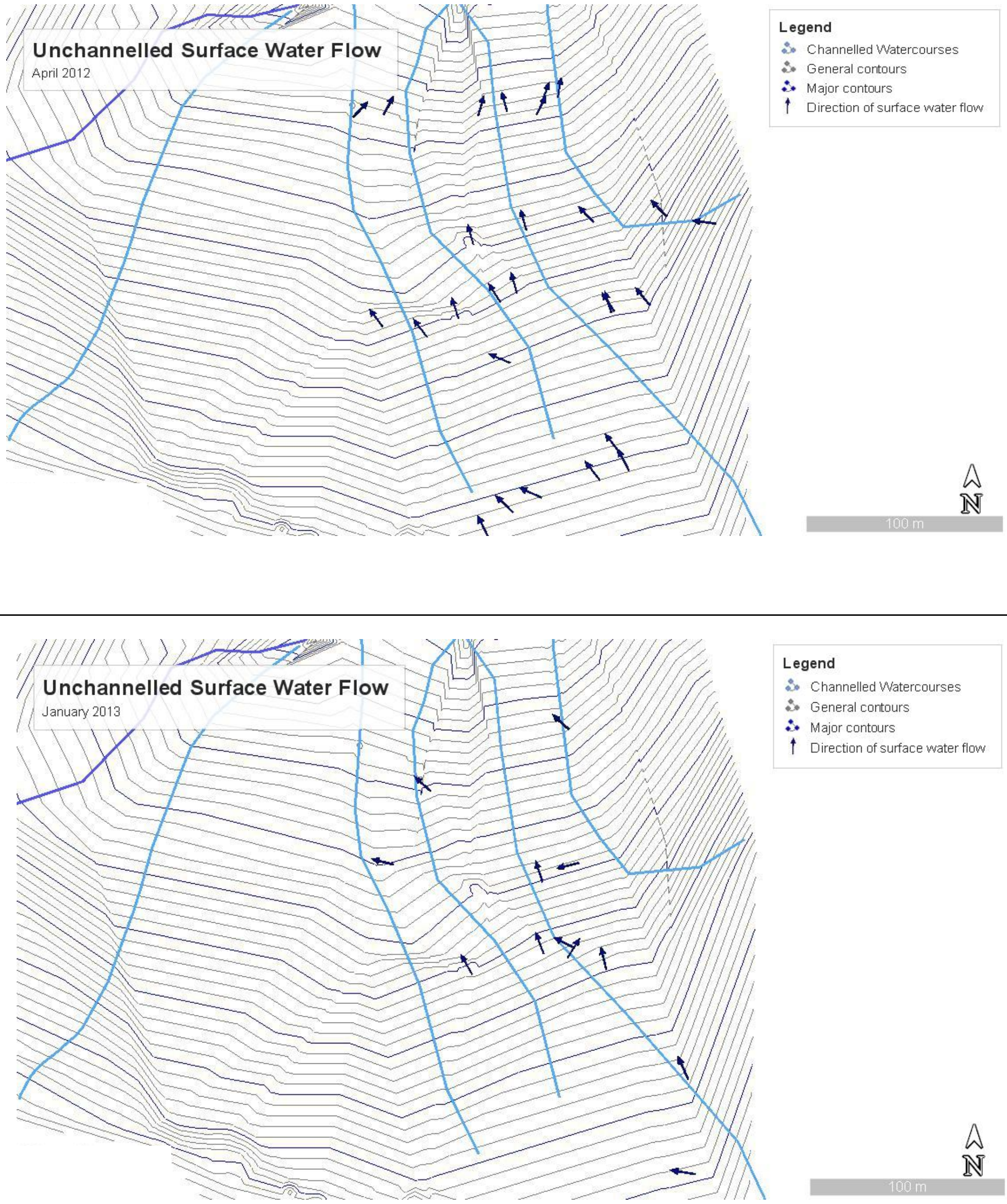



**Figure 19.** Direction of unchannelled water flow is indicated by the blue arrows, relative to contours and channelled water flow in the dry season (top) and the wet season (bottom)

### 4.3 SOILS AND SOIL EROSION

Peat soils cover a total of 14 ha (22% of the larger wetland extent of 64 ha), with an average peat thickness of 1.5 m (maximum 4 m thick) in the eastern part where the survey transects were located (Figure 20). The inferred peat volume for the overall system is 150 000 m$^3$. The peat is mostly a grass-sedge peat that is highly fibrous. Finer grained peat occurs at the surface with coarser layers in some domes. Sand and gravel occur in layers particularly below the peat domes.

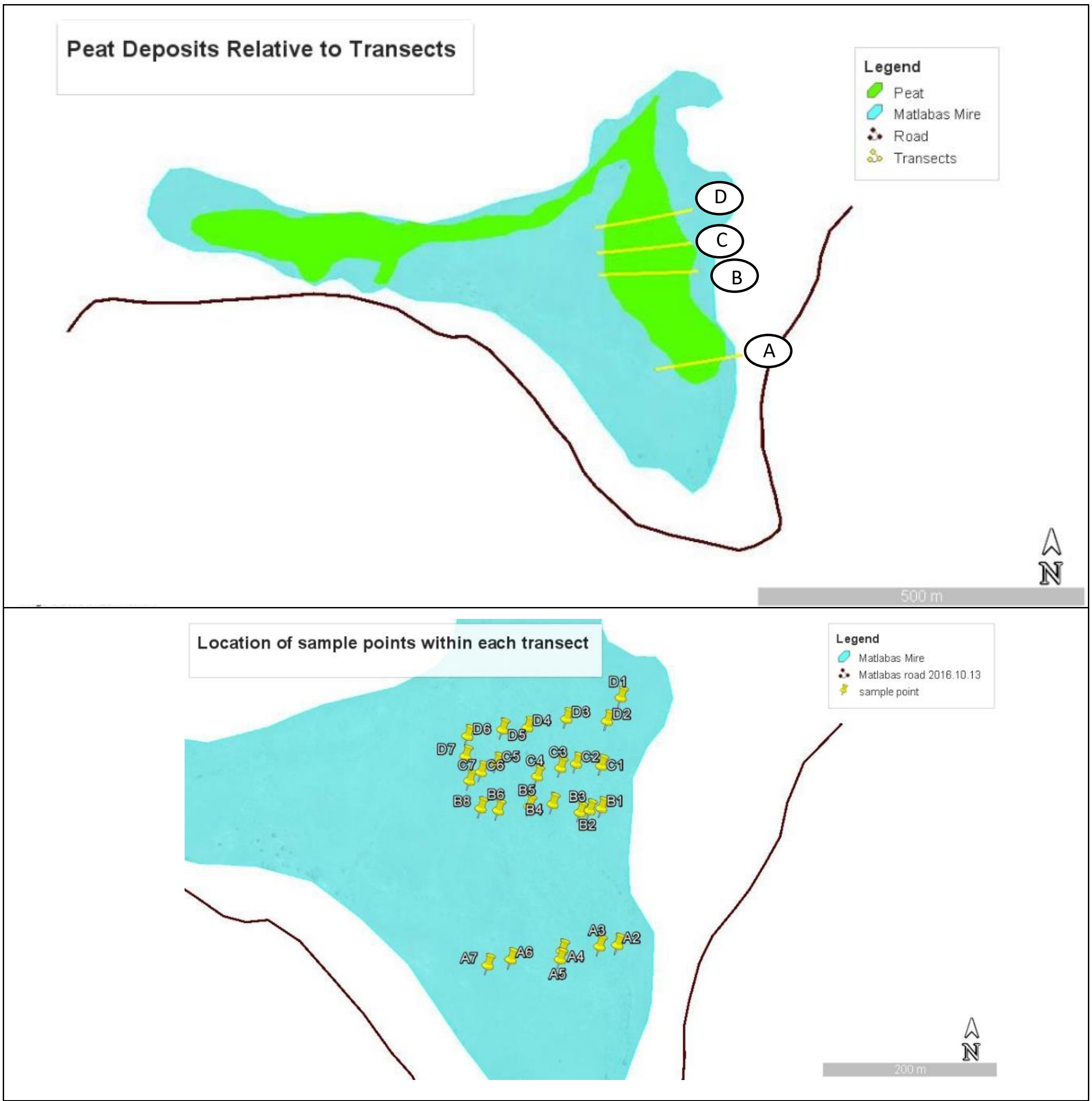



**Figure 20**. Extent of peat deposits and peat distribution relative to the mineral soils of the mire mire and the position of transects (top). The position of sample points within each transect (bottom)

In each transect soil profiles were described. Peat layers described according to the Von Post humification scale (Von Post, 1922) were grouped together. Similarly, different clay and sand layers were grouped together to show layers with comparable influence on subsurface water flow. For example sand offers less resistance to water flow than clay. Figure 21 below shows the generalised diagrams of soil layers recorded in each profile. In this diagram it is evident that sand and soil layers form consecutive layers as deposition events occurred in the mire. These patterns in soil structure are relevant to water flow paths within the soil profile as discussed below.

Full data sets can be seen in Appendix D.

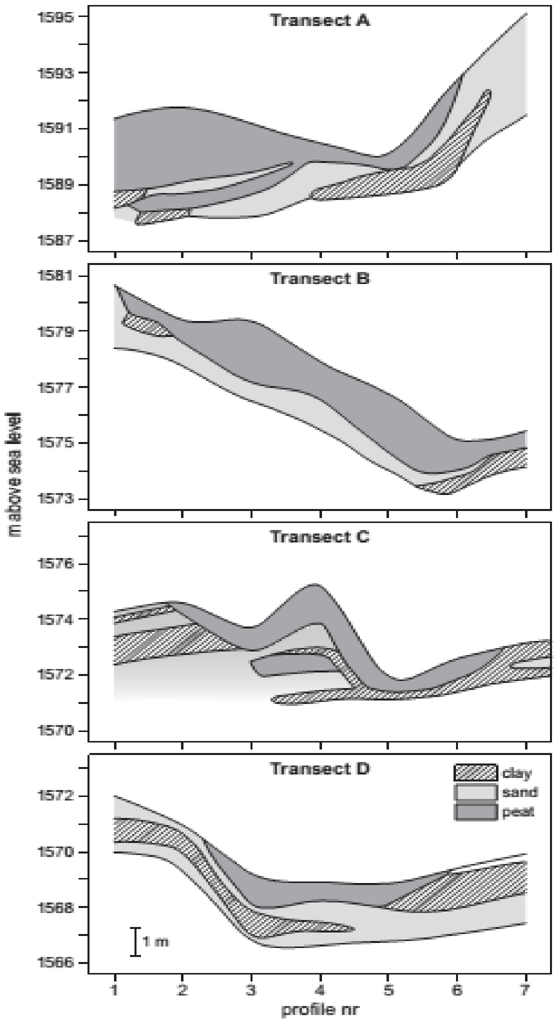



**Figure 21.** Soil profiles in transects A, B, C and D. In this graph left is east and terrestrial and right is west and the middle of the mire.

Erosion is most prominent in the western section of the mire which has a gentler slope (4%) compared to less erosion in the eastern section which has a steeper slope (6%). Factors that contribute to this difference in erosion formation includes the high energy surface water flows from the slopes of the mire's catchment. The location of the road adjacent to the mire (cutting through two seepage wetlands) further increases the energy of surface water flow by intercepting seepage water from the slopes of the catchment. Some of this intercepted water is drained through culverts and released onto the surface of the mire downslope of the road. Intercepted water no longer flows into the mire as lateral seepage within the soil profile, but now enters the mire as high energy surface water runoff. The energy of surface water increases beyond the attenuation capacity of vegetation. As a consequence, less water is available to maintain peat moisture and the resulting desiccation further reduces surface roughness. Elephants, which do not occur naturally in this area, are a further contributing factor. They disturb large patches of vegetation for mud baths which further decreases local vegetation cover and contributes to erosion in the mire. Accelerated erosion occurs particularly in areas where vegetation is disturbed by elephants or burnt too frequently.

The positions of current erosion gullies and head-cuts are presented in Figure 22 below. Details of coordinates, depths and descriptions of each erosion feature are presented in Appendix E.

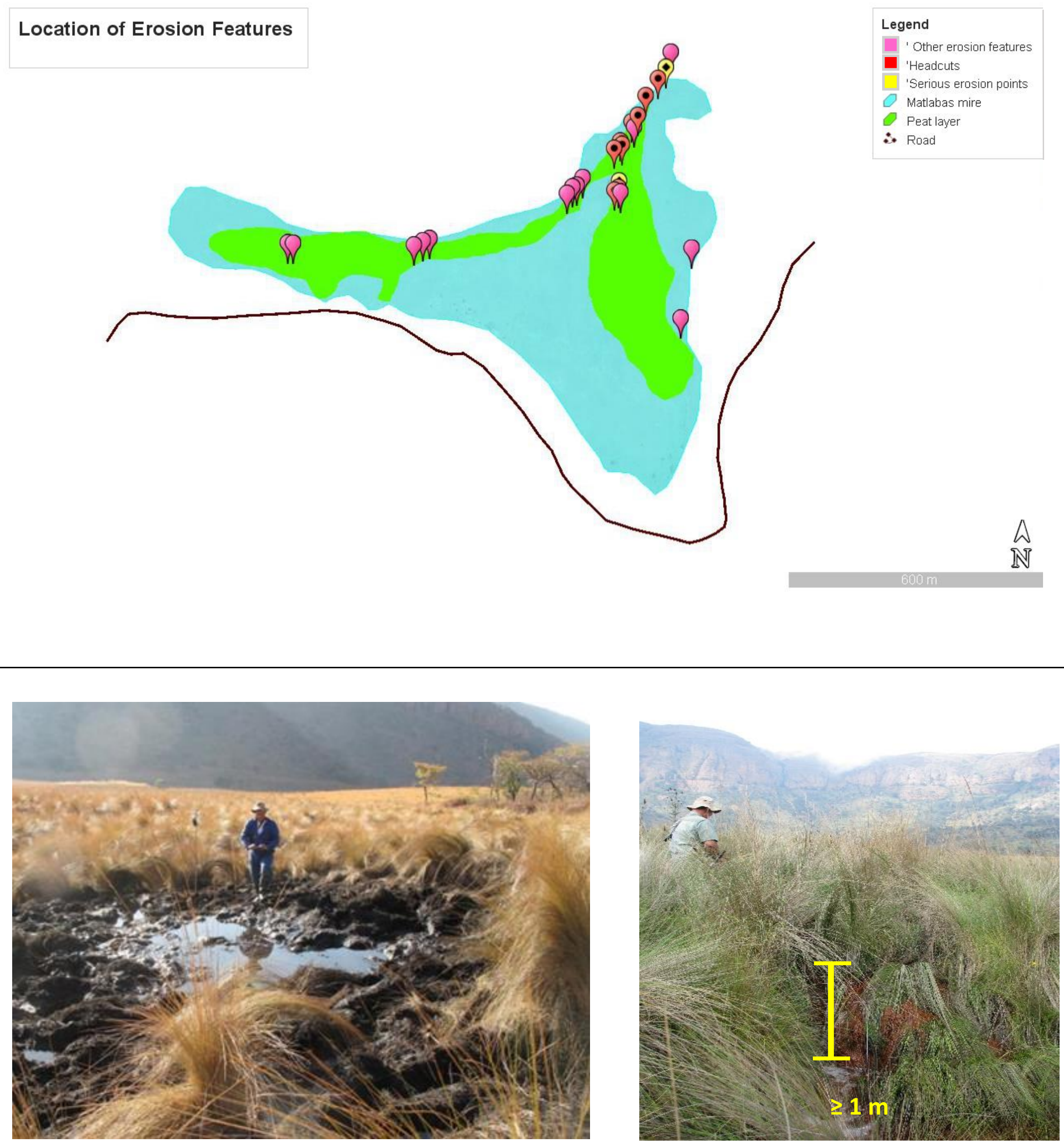



**Figure 22.** Locations of erosion features in the Matlabas mire (top). Serious erosion problems were identified based on the width and depth of the feature. In some instances the headcut erosion drops more than a metre to the current channel (right) Sometimes elephants use the *Andropogon eucomis–Aristida canescens* grassland community for mud bathing (left) (photo by P. Grundling).

### 4.4 PRECIPITATION 2011-2013

The highest rainfall recorded in 2011, 2012 and 2013 was recorded during the months of October to April (Figure 23). In this period, the rainfall was above an average of 5.5 mm per 24 hour period in a month and is therefore considered as the wet season. During the months from May to September, rainfall below 0.25 mm (average per 24 hour period in a month) was recorded. This period is considered as the dry season. Rainfall data is presented in Appendix F.

Rainfall 2011 | Rainfall 2013

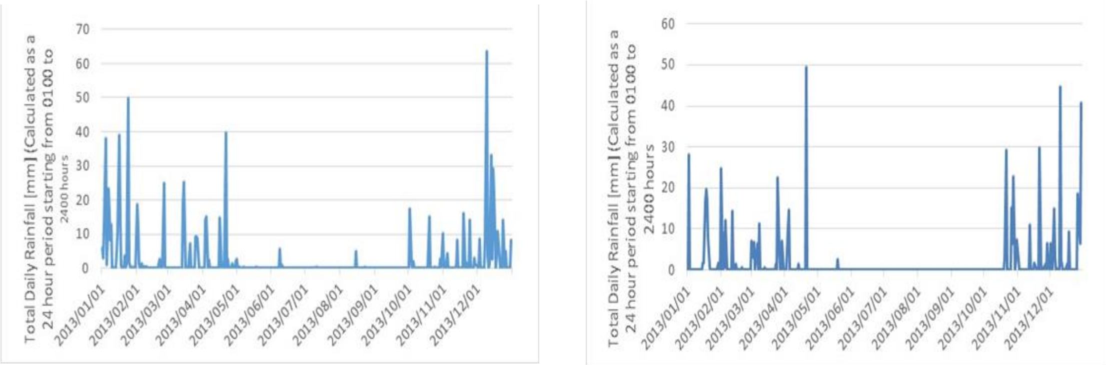



**Figure 23.** Rainfall recorded in 2011 (left) and 2013 (right).

### 4.5 TEMPERATURES 2011-2013

The average daily temperature recorded from 2011 to 2013 ranged from a high of 19.45°C to a low of 5.08°C (Figure 24). Maximum daily temperatures reached a high of 22.76°C and minimum night temperatures reached a low of -1.72°C. February was generally the warmest month and July the coldest. The average annual temperature in 2011 to 2013 was between 15.05°C and 16.17°C. Ambient temperature data is presented in Appendix G.

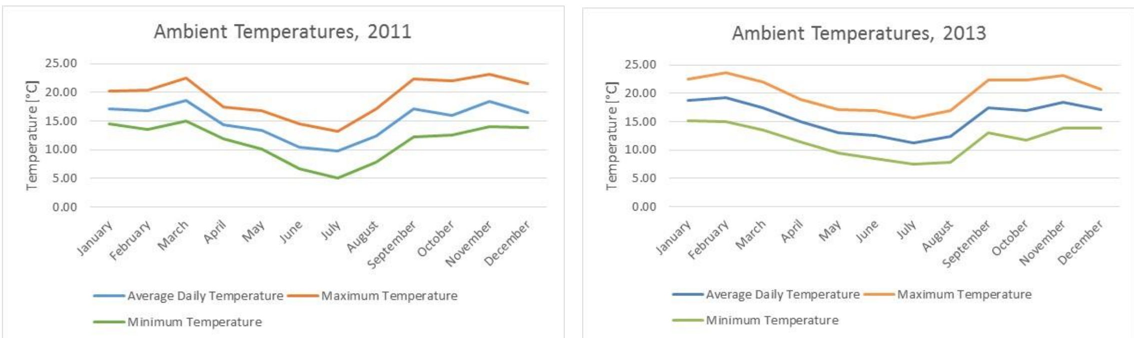
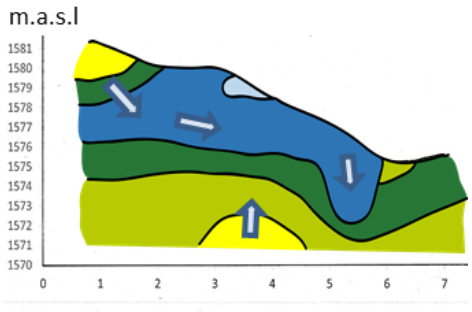
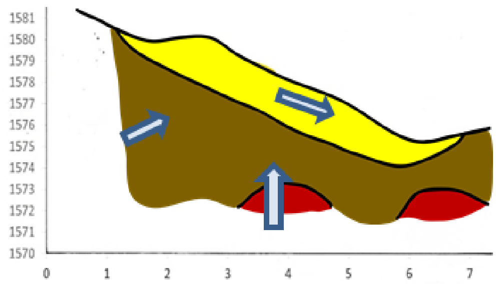



**Figure 24.** Ambient daily temperatures recorded in 2011 (left) and 2013 (right).

Temperature gradients were measured in the soil profile at the end of summer (April 2012) and again at the end of winter (August 2013). The summer measurements showed two points to be particularly warm. The first point corresponds to the area between the third and fourth points on transect B, namely B3 and B4, at a depth of 140 cm below the soil surface. This point is located immediately upslope from the *Phragmites australis* reed stand. The second point is located at site B6 (at a depth of 186 cm below the soil surface). During the winter measurements a warmer area was again located in the area between B3 to B5 (at an approximate depth of 140 cm below the soil surface) (Figure 25). Both summer and winter temperatures were recorded as this relates to water flow patterns in dry and wet seasons.

A longitudinal transect that connects points A2 crosses transect B at the edge of the *Phragmites australis* reed stand, a point between transects B and C, C3 and a point between D3 and D4 was also assessed for temperature gradients. A high temperature (16.3°C) was recorded at point A2 at about 2.5 m below the soil surface (Figure 25). Soil temperature data is shown in detail in Appendix H.

| Temperatures in transect B from east to west, wet period 2012 | Temperatures in transect B from east to west, dry period 2012 |
|---|---|
|   |   |

Temperatures in longitudinal transect from north to south, wet period 2012

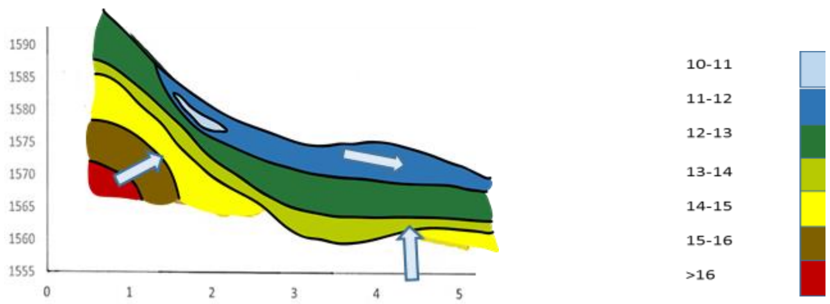



**Figure 25.** Temperatures recorded in transect B in the wet and dry seasons (top). In this graph left is east and terrestrial and right is west and the middle of the mire. Temperature profile recorded along a longitudinal section of the mire from north (terrestrial) to south (towards the middle of the

mire) (bottom). Arrows represent water movement, often within the broader isohypse classes as presented in Appendix I.

## 4.6 WATER PRESSURE

In each graph data is presented to show the more terrestrial habitat in the east (left) and the centre of the mire in the west (right) (Figure 26). Small upward or downward movements of water within each isohypse class are not shown in the graphs below due to the resolution of these graphs that show general trends. However, these finer resolution movements are reflected in Table 50 in Appendix I.

*Transect A*

In transect A water pressure in deeper layers is always higher than in shallow layers in both wet and dry seasons.

*Transect B*

Water pressure readings and isohypse patterns in transect B show general water movement from the outer edges of the mire towards the centre of the mire. However, smaller patterns in this transect show upward water movement at point B4, underneath the reed patch.

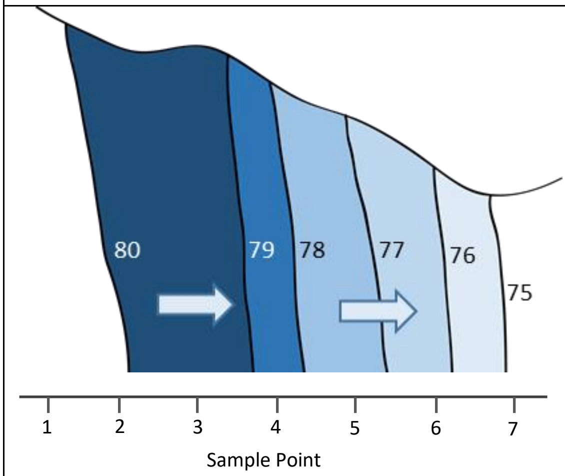
*Transect C*

At this transect, watercourses occur where water is carried along the surface from upslope seepage during wet seasons and precipitation events. Point C4 is located directly upslope from a raised peat dome. A watercourse runs immediately downslope from point C5. Water pressure readings show mainly lateral movement of water from the terrestrial sides of the mire towards the watercourse. Water also moves from the peat dome towards the watercourse in wet and dry seasons.

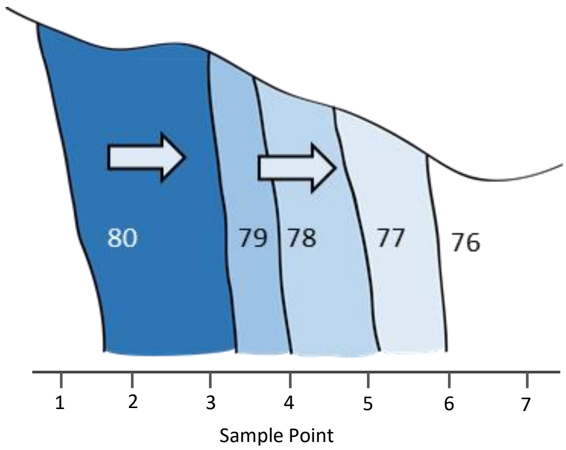
*Transect D*

Water pressure readings in transect D indicate lateral water flowing from the sides towards the central part of the transect where it is discharged at points D3 and D4. Downward movement of water is recorded at point D5 during both wet and dry season. This corresponds to a point where the soil profile does not have a clay layer below the peat or sand layers.

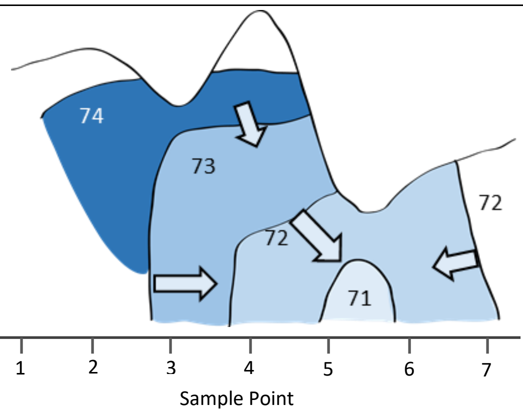
Water pressure in transect B. Wet period, March 2012



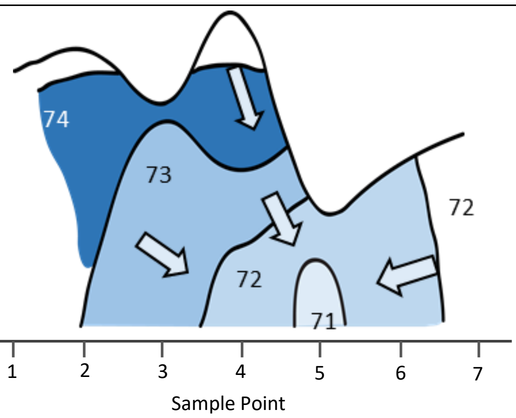

Water pressure in transect B. Dry period June 2012



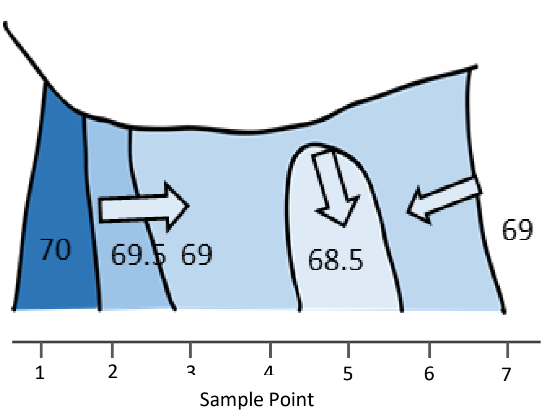

Water pressure in transect C. Wet period, March 2012




Water pressure in transect C. Dry period June 2012




Water pressure in transect D. Wet period, March 2012




Water pressure in transect D. Dry period June 2012

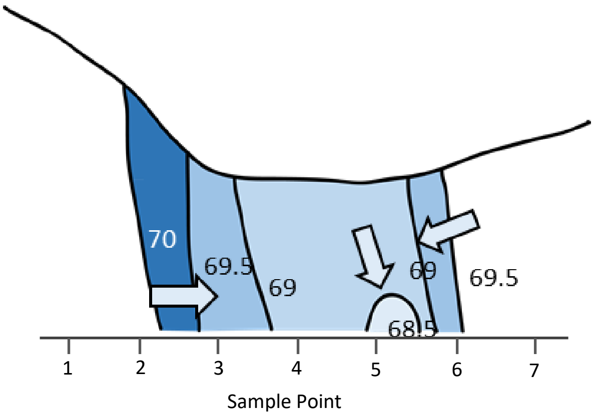



**Figure 26.** Water pressure in transects B, C and D during a wet period (March 2012) and a drier period (June 2012). In this graph left is east and terrestrial and right is west and the middle of the mire. Although the water pressure in the wet period is higher than in the dry period, the direction of groundwater flow is the same.

## 4.7 CHEMICAL COMPOSITION OF WATER

Detailed results of water composition are presented in Appendix J.

*Transect A*

Ammonium ($NH4^+$) levels in transect A are relatively low, ranging from 0.02 to 0.68 mg/l in summer and 0.2 to 2.2 mg/l in winter. The slightly elevated concentrations recorded in the dry season are consistent with concentration of minerals by evaporation.

The pH values appear to be very similar for wet and dry seasons (within 0.2 on average, with a maximum difference of 0.57 at A3 well). Too few measurements are available for the dry season to make reliable conclusions. It is possible that representative trends will become apparent should further sampling be done.

Calcium (Ca) levels appear to be lower in the dry season than in the wet season. Points A1 and A6 have the highest calcium levels (and also the highest bicarbonate levels). These two points are also the closest to the surrounding terrestrial and mountain areas.

Chloride ($Cl^-$) concentrations are higher during the dry season with the exception of Point A4 (Figure 27). Sodium (Na) concentrations reflect the pattern also seen in chloride concentrations. Point A1 has a relatively high chloride and sodium concentration in the wet season. This may be attributed to it relative dryness, although the other dry point, A7, does not reflect high concentrations of either of these two parameters. It is possible that the slope closest to Point A1 (the eastern slope) has higher concentrations of sodium and chloride than the slope associated with Point A7 (the southern slope).

Chloride wet period (summer 2013) | Chloride dry period (winter 2011)

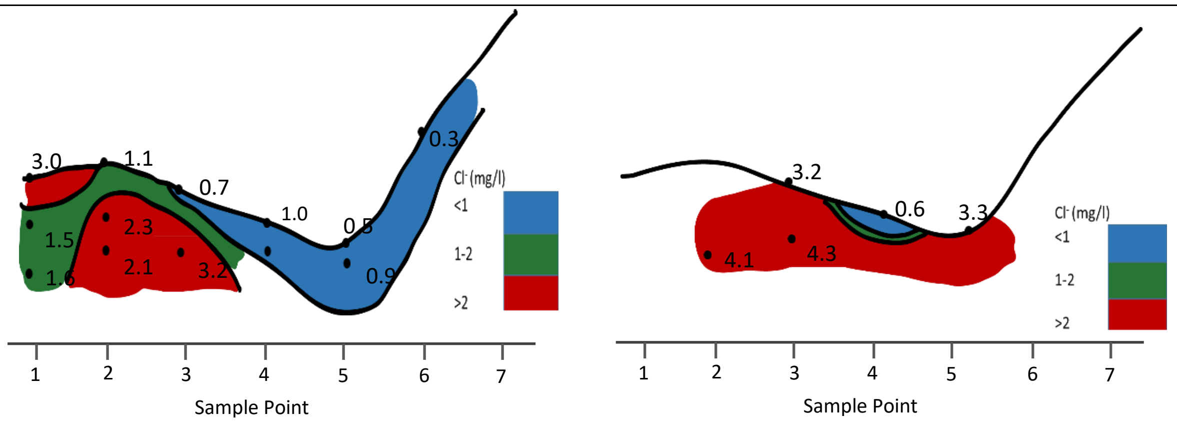



**Figure 27.** Chloride concentration in mg/l in the groundwater in transect A in a wet and a dry period. In this graph left is east and terrestrial and right is west and the middle of the mire

*Transect B*

Bicarbonate ($HCO3^-$) concentrations in transect B, particularly in the dry season, increased towards the centre of the mire and with soil depth.

The patterns observed in ammonium and calcium concentrations are very similar. Calcium and ammonium rich water in transect B generally occurs deeper in the profile, rather than at the surface as in transect A (Figure 28). During the dry season a high concentration of calcium and ammonium is recorded at point B6 (3.94 m below the soil surface) and at point B5 approximately 0.62 m below the soil surface and above the clay layer where infiltration occurs.

Chloride concentrations recorded in the dry season decreased with depth to a lowest concentration at point B6 at a depth of 3.94 m below the soil surface (Figure 28). Sodium concentrations, on the other hand, show the opposite pattern. Sodium is seen to increase with depth and reflects the same pattern as calcium and ammonium at points B5 and B6.

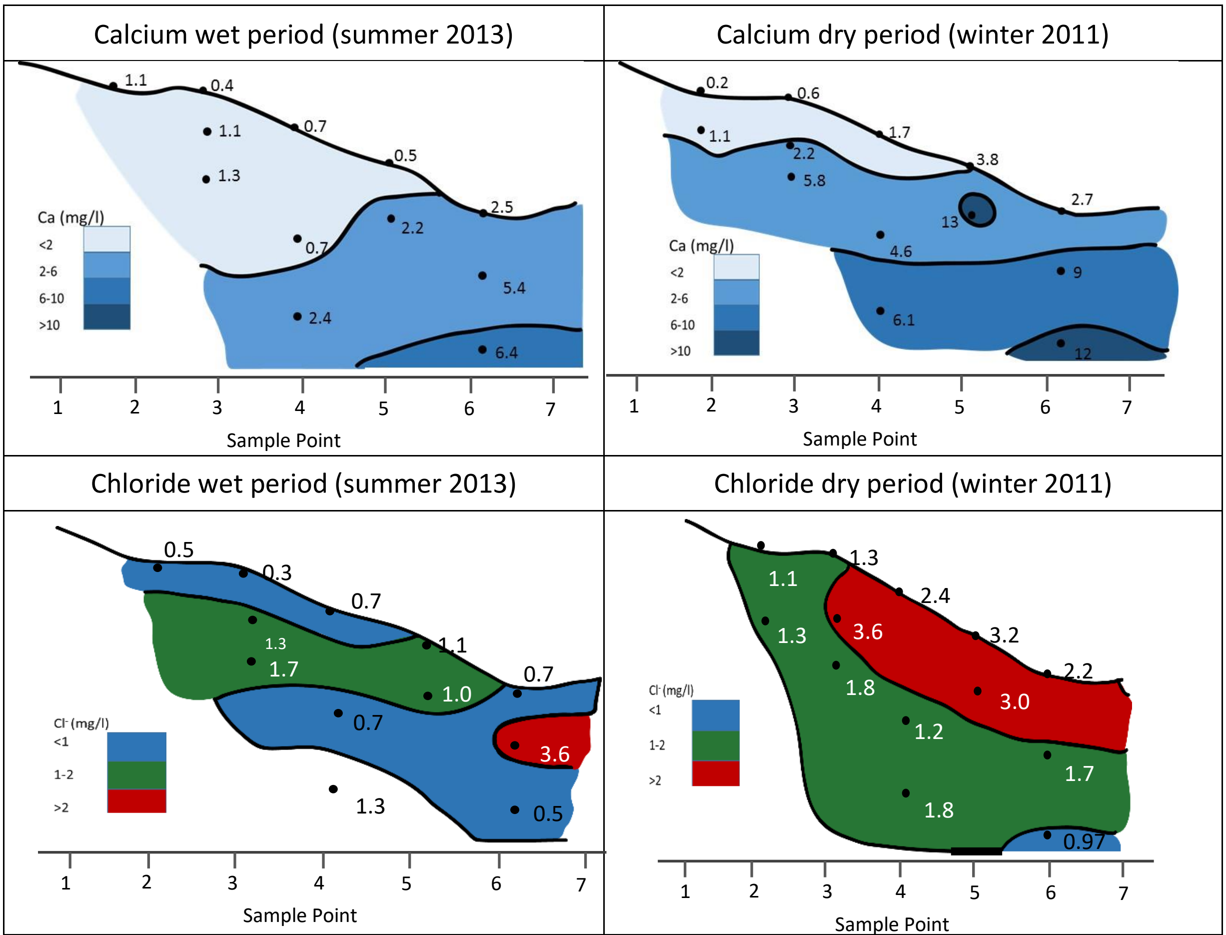



**Figure 28**. Calcium (upper) and chloride (lower) concentration mg/l in transect B in the groundwater in a wet and a dry period. In this graph left is east and terrestrial and right is west and the middle of the mire

*Transect C*

Ammonium concentrations in transect C are slightly higher in the dry season than in the wet season. A particularly high concentration was recorded at the surface at point C5 during the dry season sample event.

The pH concentrations in summer and winter are very similar, with lower pH readings recorded deeper in the soil profile with the exception of the surface water at point C3 which has a relatively elevated pH. The elevated peat dome through which this transect runs has a slightly lower pH than the surrounding area in the dry season.

Calcium and bicarbonate concentrations generally increase towards the centre of the mire and with depth. Winter concentrations are generally higher than summer concentrations. High calcium concentrations (and also bicarbonate and pH) were recorded under the central peat dome (at point C4) during the dry period. Chloride concentrations, particularly in the wet season, are lower in the deeper sections of the profile (Figure 29).

A relatively high concentration of nitrate (0.73 mg/l relative to the average of 0.16 mg/l) was recorded immediately below the peat dome in the wet season. Sulphate levels also showed this pattern with values between 1.80 mg/l to 0.69 mg/l, which is higher than in deeper layers.

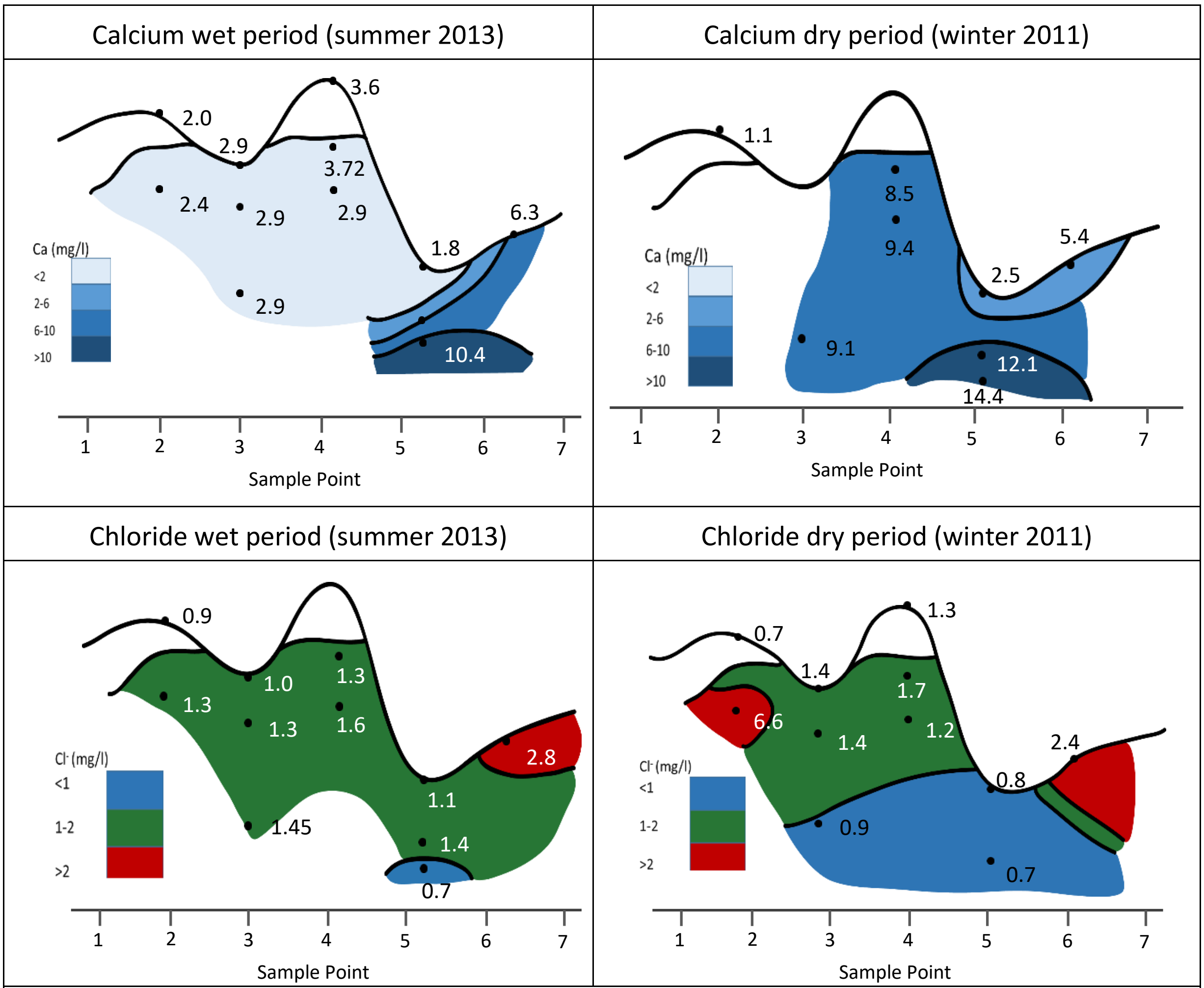



**Figure 29**. Calcium (upper) and chloride (lower) concentration in mg/l in transect C in the groundwater in a wet and a dry period. In this graph left is east and terrestrial and right is west and the middle of the mire

*Transect D*

The pH values are generally higher in the dry season with a particularly high value recorded at point D4, approximately 2.4 m below the soil surface. Calcium values are also generally higher in the dry season. However point D7, which occurs in the *Andropogon eucomis–Aristida canescens* community (a drier grassland unit), had high calcium concentrations. This pattern was also recorded in the sodium, bicarbonate and ammonium values. This point lies above a thick clay layer and relatively little water movement occurs here.

High concentrations of bicarbonate were recorded during the dry season at point D3 from approximately 2.73 m to 3.61 m below the soil surface. A high concentration of calcium was also recorded at this point (Figure 30).

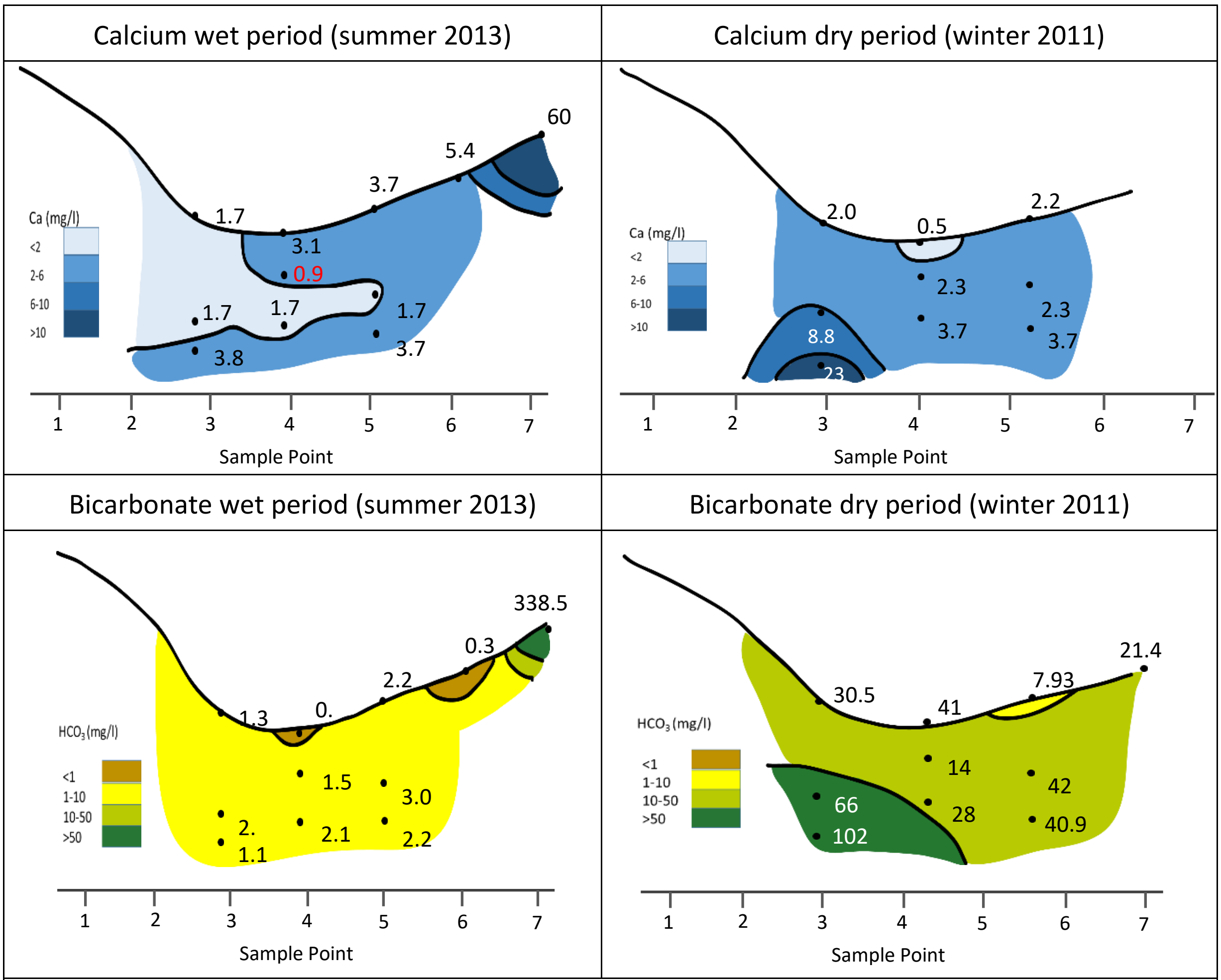



**Figure 30**. Calcium (upper) and bicarbonate (lower) concentration in mg/l in transect D in the groundwater in a wet and a dry period. In this graph left is east and terrestrial and right is west and the middle of the mire

# CHAPTER 5: Discussion

### 5.1 ORIGIN OF WATER FLOWS

In general, water level data show that the water moves laterally through the soil profile, from the terrestrial outer edges of the mire (located to the south and east) towards the centre (Figure 26). Water then drains to the north into the watercourse that drains into the Motlhabatsi River. This is supported by data presented in Elshehawi (2015) which describes water movement in the Matlabas mire as originating from precipitation and groundwater that has travelled only a short distance from the adjacent hillslopes where water has low concentrations of cations. Erosion channels increase the input of surface water into the intermittent and permanent water channels and decreases the degree to which water travels laterally within the soil surface.

Water entering the mire through direct precipitation is usually poor in mineral content (Van Wyk and Vermeulen, 2011). This water has a dilution effect in the upper soil layers and edges of the mire. For example several transects show a relatively low concentration of calcium in the top water layers after a wet period. However, the groundwater from the slopes is also very low in calcium and chloride. In transect B seepage water from the slopes is shown to dilute calcium and ammonium concentration (Figure 28). This can also be seen in transect D (Figure 30). After a dry period we see higher values, in particular in the upper layers. This is most likely due to evaporation, which concentrates minerals in soil moisture in the shallow layers. Piezometer readings also reflected lower water pressure during the drier months (Figure 26).

In transect B the chemistry, temperature and groundwater pressure data suggest that two distinct water sources are present in this section of the mire. During the dry season water at the deepest piezometer at point B6 is chemically distinct from water at the deepest piezometer at point B4. Piezometer readings show that water from the deeper part of the profile at B4 moves to the surface, whereas water from the deeper part of the profile at B6 does not. The shallower parts of the profile at B6 are similar in composition to points B2, B3 and B4, further supporting the suggestion that water from depth at B6 does not mix with shallow water at B6. This data indicates that a source of groundwater occurs in the deeper sections of transect B that is distinct from the water discharged at point B4 (Figure 28).

Transect C includes a peat dome which has dried out. Drying out of the peat dome resulted in a loss in base rich components causing lower pH levels (Smolders *et al.,* 2006). Acidification of decomposing peat sometimes leads to increased mineralisation and increased production of nitrate, which produces acid (Grootjans *et al*., 1986). This pattern is visible from the high nitrate concentrations (0.73 mg/l relative to the average of 0.16 mg/l) in the groundwater below the peat dome in the wet season. Oxidation of pyrite (FeS) further generates acid (Madaras *et al*., 2012). Sulphate concentrations in the wet season show increased levels consistent with the flow patterns of water in this transect (Figure 29). In other words, the acidity of water increases with an increase in depth at the dry peat dome. The chemical data therefore indicates that the recent deepening of the stream (erosion) has exposed soil layers to oxidation and infiltration of precipitation water, thus stimulating the production of acid components in the soil. Also the contour lines drawn from the water pressure graph clearly show that the peat dome has become an infiltration area that is losing water to the stream. Results therefore suggest that erosion in the mire has resulted in its drying out.

In transect D chemical values are also affected by the soil layers described in the previous chapter. High calcium, sodium, bicarbonate and ammonium levels were recorded at point D7. This point lies above a thick clay layer and relatively little water movement occurs here, effectively trapping and concentrating minerals due to evaporation in the shallow parts of the soil layer. The same effect is seen at point D3 where a slight upward movement is seen within the isohypse class to a value of -0.20 m.a.s.l. (refer to Table 50 in Appendix I). High concentrations of bicarbonate and calcium occur directly underneath a clay layer (Figures 21 and 30). This pattern supports the hypothesis that groundwater flows upwards from deeper levels in the mire.

### 5.2 CONCEPTUAL MODELS OF WATER FLOW IN THE MIRE

Water movement in transect A reflects seepage conditions from precipitation water that has infiltrated the southern and eastern slopes of the mire's catchment (Table 50, Appendix I). The big tussocks of the *Miscanthus junceus* grass and the thick rhizomes of the sedge and fern species disperse the surface flow pattern and slows down water velocity. During high flow events the tussocks and rhizomes disperse surface water flow into adjacent channels, preventing erosion in the main channel. Where this micro-topography is altered by, for example, trampling or erosion, water flow deviates from the contours to flow into preferential (erosive) flow channels which are visible from aerial images (Figure 19). Some trampling by grazers is natural and may result in erosion which is stable under natural conditions (as would be the case without the road, culverts and trampling by elephants).

In transect B clay layers in the soil profile present a barrier to mixing of water from different sources (Figures 21 and 28). Precipitation and seepage water recharges into the soil layer at point B5 (behind the reeds) (Table 50, Appendix I).

An exception to this pattern is the *Phragmites australis* reed patch where upward movement of groundwater from deep layers occurs (Table 50, Appendix I). This flow path may be the result of geomorphological features associated with the fault line that occurs along this part of the mire as shown in the conceptual model presented in Figure 31 below.

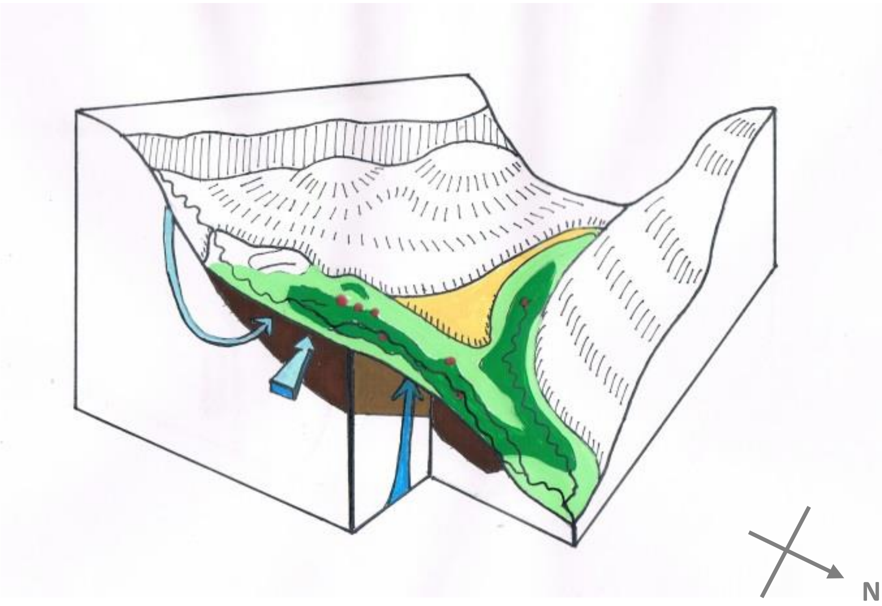
Water from a deep source (base flow) moves upward in the profile at point B6 but does not mix with water in the upper layers of the profile since it is blocked by the clay layer present at this point (Figure 21; Table 50, Appendix I).

In transect C seepage water moves along the upper layers of the soil profile towards the stream channels which are intersected by this transect, particularly towards point C5. This transect is in line with the location of the fault line indicated in the geological map (GS, 1974) and the aerial images for the area. It is possible that this fault line affects impermeable areas that result in the upward flow of water recorded in transect B (Table 50, Appendix I).

Water in transect D also reflects discharge of lateral water movement towards the stream channels intersected by this transect, particularly towards points D4 to D6. Some infiltration of precipitation water due to drainage was recorded within isohypse classes at point D5 (Table 50, Appendix I).

A conceptual model for water flow in the mire is presented in Figure 31 below. Transects B and C are used as representative examples and include the important findings discussed above. This model reflects an interpretation of groundwater levels, groundwater composition and temperature profiles which suggest that lateral groundwater from the valley flanks is the primary water source, which is very poor in dissolved minerals. Groundwater from deeper strata with more dissolved mineral discharges in lower sections of the mire, possibly forced to the surface due to the presence of a geological fault.

Conceptual model of transect B




Conceptual model of transect C

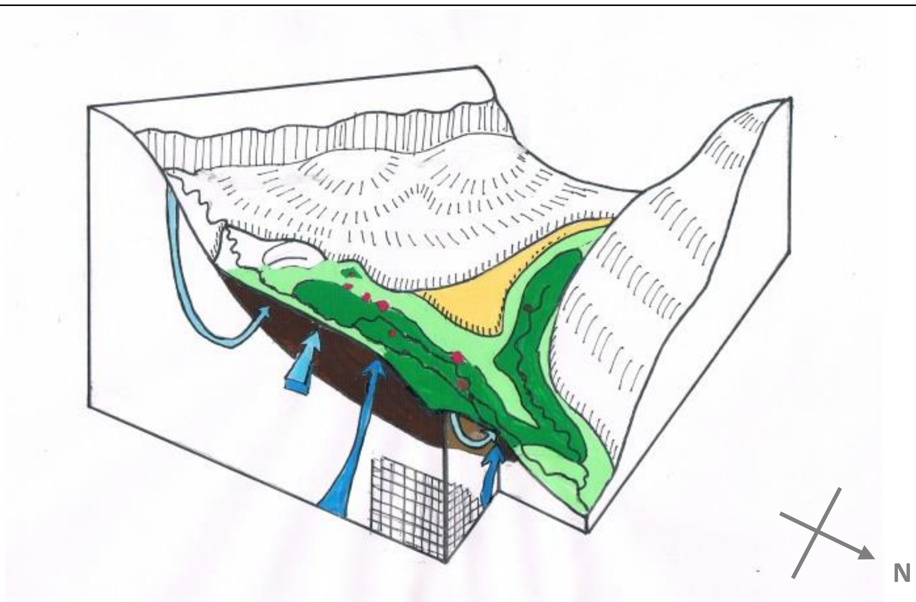



**Figure 31.** Arrows indicate the interpretation of different water sources that lead water to different parts of the mire in transects B and C. The differences in arrows are representative of differences in water sources and flows and is not related to quantified properties (for example, the width of the arrow is not related to flow volumes)

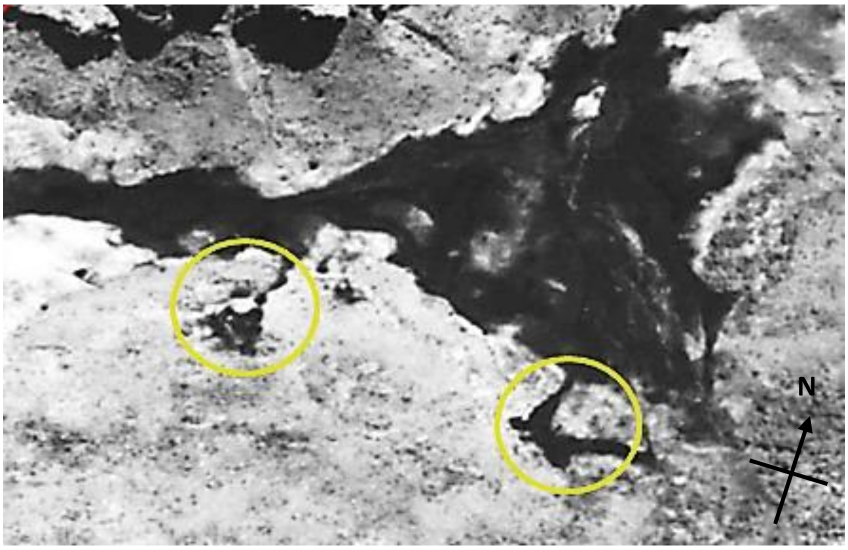
***Key***

- *Kyllinga melanosperma–Miscanthus junceus* community
- *Andropogon eucomis–Aristida canescens* community
- Terrestrial grassland
- Geological fault
- Peat soil
- Domes

## 5.3 CHANGES IN THE HYDROLOGY OF THE MIRE

Surface water movement in the mire has changed in response to changes in land use. Aerial images show the construction of the road along the southern and eastern boundary of the wetland between 1956 and 1972. This road cuts through two prominent seepage wetlands (Figure 32). Although seepage processes still occur in these areas the road has altered the volume of water which is retained in the soils and slowly released to downstream areas.

Aerial image from 1956




Aerial image from 1972


**Figure 32.** An aerial photograph of 1956 (top) reflect the absence of the road and the presence of two prominent seepage wetlands indicated by the circles. In 1972 (bottom) the road had been built and the seepage wetlands were hardly visible

The road also intercepts some of the water that naturally seeps into the southern and western sections of the mire. Water that would have entered the mire by seeping through the upper soil layers now runs along the surface, supplementing the streams.

The valley of the Matlabas mire is bordered by steep slopes where unsorted rock boulders and coarse fragments form highly permeable valley slopes that act as effective recharge areas for water flow towards the wetland. These hillslope processes are likely to be a significant contributor to flow into the system. The presence of the road has altered natural processes by intercepting seepage and surface water, thus changing the characteristics of the energy with which water enters the mire. This is not to the advantage of the mire since this water no longer infiltrates into the soil profile but runs along the surface and into the streams.

Furthermore, sand and gravel layers are evident beneath the peat or interbedded in the peat indicating historically alternating high flow events from the steep catchment. Preferential flow paths in the higher conductivity sand and gravel result in the development of subsurface pipes as finer materials are washed out. The roofs of these pipes eventually collapse forming various natural erosion features (for example gullies and headcuts) (Grundling 2014b).

The *Kyllinga melanosperma–Miscanthus junceus* vegetation community is very functional in the sense that species recorded here are characterised by thick tussocks and robust rhizomes that are able to attenuate surface water flow and stabilise the soil profile. This is seen in the unchannelled surface water flow where flow direction deviates from the slope, for example in transect B behind the reed patch between sites B4 and B5 (Figure 33). This is caused by the vegetation structure, where grass tussocks and rhizomes force water to flow in a more easterly direction along the contour rather than along the steeper slope perpendicular to the contour. Local trampling by animals or researchers could also be responsible for the formation of channels in the soil, thus forming preferential flow paths. It is possible that formation of such channels in response to trampling by animals may lead to channel formation. This, in conjunction with the collapse of subsurface pipes, may increase high energy water flows in critical areas of the mire. Natural erosion resulting from these processes would be stable in the absence of anthropogenic factors such as the road.

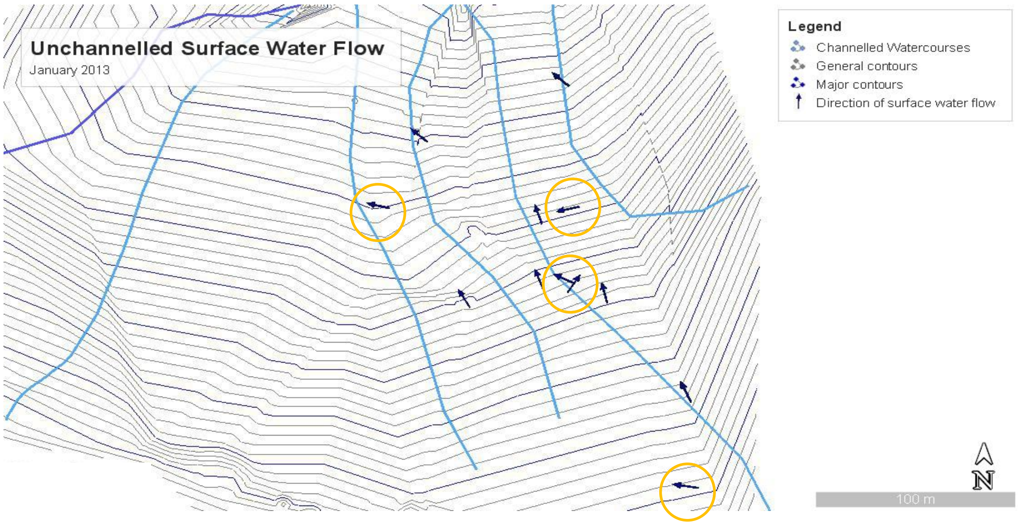



**Figure 33**. Surface water flow deviating from contours indicated by orange circles

The physical properties of peat are such that, once desiccation occurs, the peat becomes hydrophobic and denser (Strack, 2008). The resultant lowering of peat surfaces may create preferential flow paths which develop into erosion features during high flow events. Moist peat is also better able to attenuate high energy flows, whereas dried peat provides less resistance and surface water energy increases (Strack, 2008).

The road built along the edge of the mire may have resulted in a small change in hydrological processes which, together with natural factors such as collapsed subsurface pipes, trampling by grazers and climatic variations have allowed water flows to reach a critical point where the attenuating and natural re-wetting processes are not enough to stabilise erosion. Furthermore, the occasional damage to wetland vegetation caused by elephants is suggested to be unlikely in a natural setting. Since proclamation of the Marakele Nature Reserve elephants were introduced and confined to specific areas within the reserve. This localized impact may further tip the balance away from natural erosion stabilisation processes.

It is likely that, before the construction of the road, continued seepage water input from the slopes of the catchment sustained the peat moisture which, together with the resistant vegetation cover, was able to provide enough attenuation of high energy water flow to stabilize natural erosion. In this scenario the damage resulting from grazers naturally occurring in the area, and fires (which naturally occur every three to four years) would not result in erosion that could not be naturally stabilised.

The *Kyllinga melanosperma–Miscanthus junceus* plant community is further expected to contribute to peat formation in the context of the soil profiles which reflect natural sediment input events in the layers of sand and clay. It is possible to hypothesise that sand/clay layers that are sporadically washed into the mire may cover this plant community. Inundation creates anaerobic conditions resulting in slow decomposition rates and leads to peat accumulation. This hypothesis is supported by data that indicates a very fast rate of peat formation in the Matlabas mire compared to other peatlands in Southern Africa (Elshehawi 2015). However, this should be confirmed, particularly in terms of the effect of the road on the input of sediment loads.

The stand of *Phragmites autralis* reeds in transect B is a unique area in the mire. In Elshehawi (2015) the age of peat in the Matlabas mire was determined through radiocarbon analysis. The oldest sample of approximately 11 000 YBP was collected below the *Phragmites australis* reed patch. Samples from other sections of the mire show the age of the peat to be approximately 4 550 YBP.

The rate of peat accumulation in the last 4 550 years at point B4 was 1.43 mm per year compared to the 0.52 mm per year recorded for the rest of the mire (Figure 34). This rate is much faster than the 0.3 mm per year recorded in other South African peatlands during this period (Grundling *et al.,* 2013).

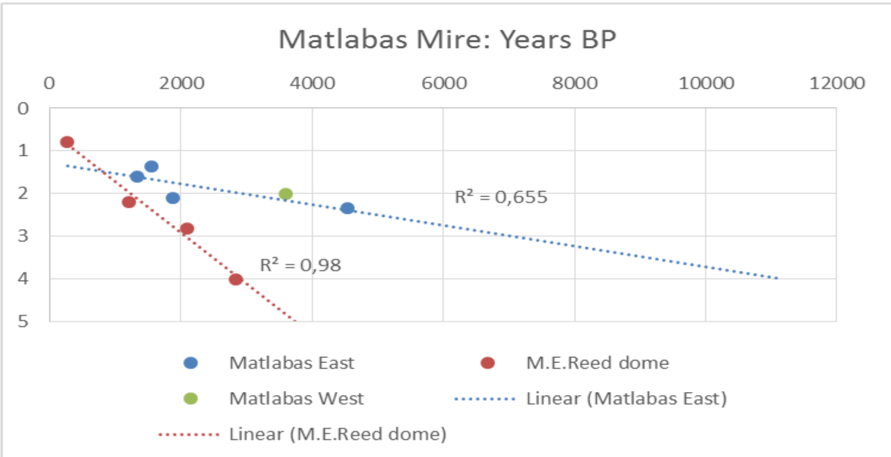



**Figure 34.** The age of peat deposits in the Matlabas mire together with the rate of peat accumulation recorded in Elshehawi (2015)

Elshehawi (2015) also reports that peat in the mire was formed primarily by C4[3] plant species, except for the area corresponding to points B3 and B4, where peat is formed primarily by C3[4] plants in shallower sections of the profile. This pattern indicates wetter and cooler conditions in this part of the mire which is also in keeping with colder, moister global temperatures 11 000 YBP (Ward *et al.*, 2008). This pattern is also described in Meadows (1988). Elshehawi (2015) suggests that it is the anoxic groundwater that provides anaerobic conditions in the peat, not the surface water. Because water is flowing over the surface, the anaerobic groundwater can penetrate the root zone, thus conserving the peat.

These observations support the hypothesis that groundwater from deeper layers flows upwards in this section of the mire to support continued peat accumulation and has done so for a very long time.

Patterns of water flow observed in the mire suggest that the peat domes were formed by an interplay of upward water pressure and barriers to water flow such as clay layers and geological faults. The recent drying of peat domes is hypothesised to be caused by erosion gullies that redirect water away from the domes.

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[3] A plant that utilizes the C4 carbon fixation pathway in which the CO2 is first bound to a phosphoenolpyruvate in mesophyll cell resulting in the formation of four-carbon compound (oxaloacetate) that is shuttled to the bundle sheath cell where it will be decarboxylated to liberate the CO2 to be utilized in the C3 pathway ((http://www.biology-online.org/dictionary/C3_plant accessed 2016.011.27)

[4] A plant that utilizes the C3 carbon fixation pathway as the sole mechanism to convert CO2 into an organic compound (i.e. 3-phosphogylycerate) (http://www.biology-online.org/dictionary/C3_plant accessed 2016.011.27)

# CHAPTER 6: Management Recommendations

Whilst the general condition of the mire is satisfactory, the increased erosion is of concern and the resulting peat desiccation should be arrested. Rehabilitation should aim at reinstating the driving forces sustaining the mire (Russell, 2009), namely the slow release of water into subsurface soil layers and also stabilising identified priority headcuts and gullies. Regular monitoring of the erosion in the mire and the success of erosion stabilisation structures should be included into the general park management schedule.

### 6.2 SETTING REHABILITATION PRIORITIES

Whilst the general condition of the mire is satisfactory, the increased erosion is of concern and the resulting peat desiccation should be arrested. Rehabilitation should aim at reinstating the driving forces sustaining the mire (Russell, 2009), namely the slow release of water into subsurface soil layers and also stabilising identified priority headcuts and gullies. Regular monitoring of the erosion in the mire and the success of erosion stabilisation structures should be included into the general park management schedule.

#### 6.2.1 REINSTATING DRIVING FORCES

The road intercepts water from the catchment and changes the energy with which it enters the mire. Particularly where the road has been incised into the hill side and intersects the seepage wetlands, structures should be put into place to promote the detention and infiltration of intercepted water into the soil profile and prevent high energy overland flow. These structures should aim to:

1) Slow down the stormwater runoff before subsequent transfer downstream (detention) and

2) Soak stormwater runoff into the ground, thereby physically reducing the volume of runoff on the surface and facilitating the incorporation of water into the soil profile (infiltration) (Armitage, *et al*., 2013).

To achieve this aim, filter strips and infiltration trenches should be considered along the road, particularly where the road cuts through the seepage wetlands. Filter strips are vegetated areas of land that are used to manage shallow overland stormwater runoff through filtration. Infiltration trenches are excavated trenches which are lined with a geotextile and backfilled with rock or other relatively large granular material (Armitage, *et al*., 2013).

Currently, culverts convey water from a stream into the mire. It is possible that improving the attenuation of water at the outlet of that culvert could further decrease high energy flows into the mire and promote infiltration into the soil profile.

### 6.2.2 STABILISING EROSION

A detailed rehabilitation plan should be informed by an up-to-date survey of the position and depth of erosion gullies and headcuts. The most critical headcuts and gullies should be identified for rehabilitation in collaboration with park management. The following principles should be addressed/considered (Russell, 2009):

- Is it necessary to divert water above the headcut?
- Is the headcut area sufficiently stable to be sloped and vegetated?
- If headcuts are not considered sufficiently stable for sloping and revegetation, central overflow structures should be constructed downstream to flood the headcut. Ensure that sufficient downstream impact protection is implemented.
- If a risk of the formation of lateral gullies is identified, water input into the gullies should be managed by diversion above the input site.
- Consider filling or stabilising the gullies by cutting back some of the bank to create a more gentle slope which can be revegetated. If filling is not considered suitable, create bands of robust, tall vegetation (for example vegetative bundles/vegetated sills) at regular intervals (for example every 5m) within the channel to slow down runoff and to increase the frequency with which the channel overspills as well as promoting sediment deposition in the channel.
- In peat soils, any structure built into a gully must extend downward into mineral subsoil, otherwise subsurface movement of water in the peat will undermine the structure. For the same reason, in order to key structures into the banks of a gully, mineral soils should be packed around solid surfaces.
- Monitor and manage damage to vegetation cover resulting from fires and large animals.

# CHAPTER 7: Conclusion

### 7.1 MOTIVATION AND APPROACH

The Matlabas mire, a peatland in the headwaters of the Motlhabatsi River, is an important feature of the MNP. This wetland has an estimated peat reserve of 150 000 $m^3$ which plays an important role in regulating ecological and hydrological processes in the Matlabas River, which contributes to the integrity of the Limpopo River. Furthermore, this peat deposit is also an important resource as a carbon sink which has been accumulating organic material for up to 11 000 years.

Several erosion features have been recorded in the lower reaches of the eastern section of this mire, possibly associated with land-use changes in the last six decades. These erosion gullies are expected to lay dry large sections of the mire, resulting in the dehydration and resultant loss of the peat. Effective rehabilitation planning for the managers and scientists of the Park required an assessment of the way in which natural erosion stabilisation processes have been modified and whether erosion control should be implemented.

In order to inform management recommendations, this research assignment set out to follow an ecohydrological approach to understand the underlying hydrological systems that drive the Marakele mire; in order to assess how natural erosion stabilization processes have been modified and whether erosion control should be implemented.

The specific research objectives were to:

- Ascertain the chemical characteristics of the ground - and surface water
- Classify vegetation communities in the mire
- Determine how temperature relates to the basic chemical characteristics of water in the mire
- Describe how water moves within the soil profiles
- Suggest models of water flow in the mire to illustrate current processes affected by erosion.

Chemistry, temperature and water movement in the soil profile was analysed. Soil, vegetation, surface water and erosion characteristics were described and their interaction shown in conceptual models.

### 7.2 SUMMARY OF RESULTS

Results of the analyses found that the mire is primarily sustained by lateral seepage water that hydrates the peat. However, upward movement of deeper, chemically distinct, groundwater was recorded. This distinct groundwater source appears to have supported high rates of peat accumulation for about 11 000 years. The hydrological drivers support a unique interplay of vegetation, soil and chemical responders.

Erosion was shown to be a natural process in the mire stabilised by the rough structure of the tussocks and rhizomes characteristic of the vegetation in the wettest parts of the mire. Sustained lateral seepage and groundwater input ensured that peat remained wet. Occasional sediment input provided an anaerobic environment that is conducive to further peat formation and erosion stabilisation (Figure 35).

However, since the construction of the road, erosion has become more pronounced. Currently the road intercepts some seepage water from the surrounding slopes. This slightly changes the energy of the water to produce surface water flows with a higher energy than is the case in an undisturbed scenario. This study shows that desiccation of peat and its subsequent physical and chemical breakdown is related to the current erosion channels. Furthermore, the nature of the peat changes as it becomes dryer (since the water redirects seepage water away from it along the edges of the mire). A critical point occurs where peat becomes hydrophobic and results in a further increase of the energy of surface water runoff.

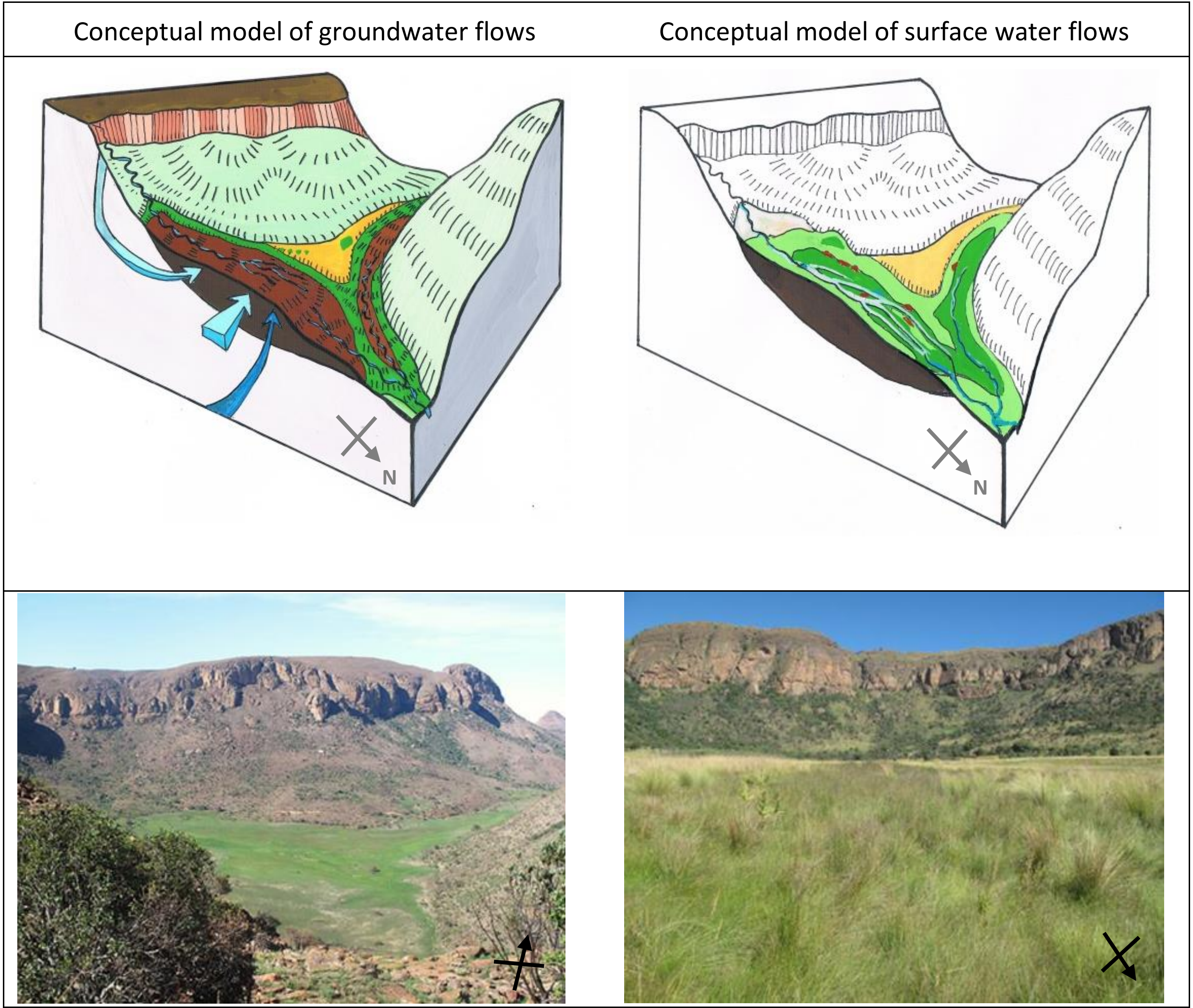


**Figure 35**. Schematic presentation of the hydrological system of the Matlabas mire showing lateral groundwater flows from different directions. A deep groundwater flow enters the valley from below (upper left). The surface water is dispersed over the peat surface by large tussocks (upper right).

***Key***

*Kyllinga melanosperma–Miscanthus junceus* community

*Andropogon eucomis–Aristida canescens* community

Terrestrial grassland

Peat soil

Domes

Results discussed above show that the hypothesis proposed is correct. The current erosion phase (accelerated erosion) is a result of recent changes from past erosion control mechanisms that stabilised naturally occurring erosion. Construction of the road has changed the water flowpaths to such a degree that natural erosion stabilisation processes are no longer effective. A small hydrological change resulting from the road therefore has a large ecological impact as feedback mechanisms collapse.

The result is that erosion formation accelerates beyond what the mire is able to balance through sediment input and sustained seepage water input from the slopes. It is therefore important that intervention should be undertaken to prevent further degradation of the mire.

From this body of work, management recommendations were formulated which will help SANPARKS to identify priorities and actions to ensure the continued persistence and effective function of the Matlabas mire. Rehabilitation should aim to firstly reinstate the hydrological drivers of the mire (sufficient subsurface lateral input of water to sustain the peat) and secondly to stabilise priority gullies and headcuts.

**7.3 DATA GAPS**

This research assessment followed an ecohydrological approach which encompasses several fields, including vegetation ecology and hydrology. An opportunity remains for further in-depth studies in these fields to produce research that is more statistically focused on the fields of phytosociology and hydrology.

In order to fill in knowledge gaps, future research should focus on the hydrogeomorphology and hydropedology of the mire, particularly on the effect of the geological faults on water movement in the mire. The nature of the groundwater source should be described and the possible effects of peat surface oscillation should be explored. It would also be interesting to see if there is any correlation with the C3 or C4 classification of plants that can be related to historic species distribution.

# CHAPTER 8: Acknowledgements

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I hope that the smell of the veld grass and vlei mud will evoke a special sense of peace and unity with the universe throughout your lives.

# CHAPTER 9: References

Acocks, J.P.H. 1988. Veld types of South Africa. *Memoirs of the botanical Survey of South Africa*, Vol 57:1-146.

Agro-Climatology Staff. 2016. ARC-ISCW Agro-Climatology Long-term Reports. In: *ARC-ISCW Climate Information System*. ARC-Institute for Soil, Climate and Water, Pretoria

American Public Health Association (APHA), American Water Works Association (AWWA), Water Pollution Control Federation (WPCF). 1985a. *Standard methods for the examination of water and waste water*. 16th ed. Washington, DC, US.

American Public Health Association (APHA), American Water Works Association (AWWA), Water Pollution Control Federation (WPCF), 1985b. Metals by emission spectroscopy using an inductively coupled plasma source. In: Franson, M.A.H., Clesceri, L.S., Greenberg, A.E., Trussel, R.R. (eds.): *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Pollution Control Federation (WPCF), Washington, DC, US, p. 3.

American Public Health Association (APHA), American Water Works Association (AWWA), Water Pollution Control Federation (WPCF), 1985c. Determination of anions by ion chromatography with conductivity measurement. In: Franson, M.A.H., Clesceri, L.S., Greenberg, A.E., Trussel, R.R. (eds.): *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Pollution Control Federation (WPCF), Washington, DC, US, p. 6.

Appelo, C.A.J., Postma, D. 2005. *Geochemistry, groundwater and pollution*, 2nd ed. A.A. Balkema, Amsterdam.

Armitage, N., Vice, M., Fisher-Jeffes, L., Winter, K., Spiegel, A. and Dunstan, J. 2013. Alternative Technology for Stormwater Management: The South African Guidelines for Sustainable Drainage Systems. WRC Report No. TT 558/13. Water Research Commission, Pretoria.

Bakéus, I. and Grab, S. 1995. Mires in Lesotho. In: Moen A., (ed.): *Gunneria 70- Regional variation and Conservation of Mire Ecosystems.* International Mire Conservation Group, Trondheim.

Beilman, D.W., MacDonald, G.M., Smith, L.C., and Reimer P.J. 2009. Carbon accumulation in peatlands of West Siberia over the last 2000 years. *Global Biogeochemical Cycles*. 23, GB1012, doi:10.1029/2007GB003112.

Bezuidenhoudt, H and van Staden, P.J. 2009. *Botanical assessment of the Apiesrivierpoort Forest*. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.514.5211&rep=rep1&type=pdf accessed 02.10.2015

Brinson, M. M. 2011. *Chapter 5 Classification of wetlands in Wetlands*: *Integrating multidisciplinary concepts*. Edited by B.A. Le Page, published by Springer

Brown, L. E., Johnston, K., Palmer, S.M. Aspray, K.L. Holden, J. 2013. River ecosystem response to prescribed vegetation burning on blanket peatland. *PLoS One,* 8 (11), e81023.ISSN1932-6203

Elshehawi, S. 2015*. Ecohydrological assessment and peat development of two South African peatlands: understanding the hydrological systems of Matlabas and Vazi-North peatlands.* M.Sc. thesis, University of Groningen, Netherlands.

Environmental Systems Research Institute (ESRI) 2011. ArcGIS Desktop: Version 9.3.1. Redlands, CA: Environmental Systems Research Institute.

Franson, M. A. H. 1995. American Public Health Association American Water Works Association Water Environment Federation, *Methods*, Vol 6:84.

Fritz, C., Campbell, D.I and Schipper, L.A. 2008. Oscillating peat surface levels in a restiad peatland, New Zealand—magnitude and spatiotemporal variability. *Hydrological Processes,* Vol. 22, Issue 17:3264-3274.

Davidson, N.C. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research,* Vol. 65(10):934-941 http://dx.doi.org/10.1071/MF14173 accessed 10.11.2016

Du Preez, P.J. and Brown, L.R. 2011. Impact of domestic animals on ecosystem integrity of Lesotho high altitude peatlands, in O. Grillo and G. Venora (eds.) *Ecosystems Biodiversity*. Intech, pp. 249-270, ISBN 978-953-307-417-7

Geological Survey (GS) (South Africa). Drawing Office 2426 Thabazimbi [cartographic material] / drawn in the Drawing Office of the Geological Survey, H. Hornsveld [cartography]; Department of Mines, Geological Survey. – Pretoria: Government Printer, 1974 / 1 map: col.; 47 x 93 cm., on sheet 79 x 99 cm. ( 1:250 000 geological series; 2426 )

Google Earth 2013: Marakele 24 26’ 58.59”S and 27 37’ 19.76” E Google Earth 10-03-2013, Accessed 20-04-2015)

Gorham, E. 1995. The biogeochemistry of northern peatlands and its possible responses to global warming. In: Woodwell, G. M., and Mackenzie, F. T. (eds) *Biotic Feedbacks in the Global Climatic System*. Oxford University Press, pp. 169-187.

Grootjans, A.P., Schipper, P.C. and Van der Windt, H.J. 1985. Influence of drainage on N-mineralization and vegetation response in wet meadows. *Acta Oecologia/ Oecologia Plantarum,* Vol. 7(21) 1:3-14.

Grootjans, A.P. and Jansen, A.J.M. 2012. An ecohydrological approach to wetland restoration: In: Grootjans A.P., Stanova, V., and Jansen, A. J.M. (eds.) *Calcareous Mires of Slovakia, Landscape settings, management and restoration prospects*. pp 21-28. KNNV Publishing, Zeist, the Netherlands.

Grootjans, A.P. and Van Diggelen, R. 2009. Hydrological Dynamics III: Hydro-Ecology. In: Maltby, E. and Barker, T. (eds) *The Wetlands Handbook*. Wiley-Blackwell

Grundling, P, Mazus, H. and Baartman, L. 1998. *Peat resources in northern KwaZulu-Natal wetlands: Maputaland*. Department of Environmental Affairs and Tourism, Pretoria.

Grundling, P. 2001. *The Quaternary peat deposits of Maputaland, northern KwaZulu-Natal, South Africa: categorisation, chronology and utilization*. Magister Scientiae Geology.Johannesburg: Rand Afrikaans University.

Grundling, P. and Grobler, R. 2005. Peatlands and Mires of South Africa. *Staflia 85, Zugleich Kataloge der OÖ. Landesmuseen*, Neue Serie 35, pp 379-396.

Grundling, P., Grootjans, A.P., Price, J.S. and Ellery, W.N. 2013. Development and persistence of an African mire; how the oldest South African fen has survived in a marginal climate. *Catena,* 100:176-183.

Grundling, P. 2014a. *Genesis and hydrological functioning of an African mire: understanding the role of peatlands in providing ecosystem services in semi-arid climates*. PhD thesis. University of Waterloo, Canada.

Grundling, P. 2014b. SANBI Wetland Assessment Report: Project Name: Marakele project

Hennekens, S.M. 1996. *TURBO(VEG): software package for input, processing, and presentation of phytosociological data*. User's guide. Version July 1996. IBN-DLO, Wageningen, and Lancaster University, Lancaster.

Hill, M.O. 1979. *TWINSPAN – A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of individuals and attributes*. Cornell University, Ithaca, N.Y.

Joosten, H. and Clarke, D. 2002. *Wise use of mires and peatlands–Background and principles including a framework for decision-making*. International Mire Conservation Group / International Peat Society.

Kotze, D. C. 1999: *A system for supporting wetland management decisions*. Ph.D. thesis. Pietermaritzburg: School of Applied Environmental Sciences, University of Natal.

Kotze, D.C., Marneweck, G.C, Batchelor, A.L. and Collins, N.B. 2007. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands*. WRC Report No. TT 339/09. Water Research Commission, Pretoria

Lopez, l. D. and Smith, L. 1995. Fluid flow in fault zones; Analysis of the interplay of convective circulation and topographically driven groundwater flow. *Water Resources Research,* Vol. 31, No 6:1489-1503.

Macfarlane, D.M., Kotze D.C., Ellery W.N., Walters D, Koopman, V, Goodman, P and Goge, C. 2008. *WET-Health: A technique for rapidly assessing wetland health*. WRC Report TT340/08 February 2008. Water Research Commission, Pretoria.

Madaras, M., Grootjans, A.P., Šefferová Stanová, V., Janáková, M., Laštůvka, Z. and Jansen, A. 2012. Fen meadows of Abrod; in urgent need of protection. Chapter 7. In: Grootjans, A.P., Jansen, A.M.J. & Stanova, V. (eds.) 2012. *Calcareous mires of Slovakia; landscape setting, management and restoration prospects.* KNNV Publishing, Zeist, the Netherlands. pp. 77-96.

Magurran, A.E. 2004. *Measuring biological diversity.* Blackwell Synergy.

Maltby, E. and Barker, T. 2009. *The Wetlands Handbook*. Wiley-Blackwell.

Meadows, M. E. 1988. Late Quaternary Peat Accumulation in Southern Africa. *Catena*, 15:459-472.

Mucina, L., and Rutherford, M. C. 2006. *Vegetation Map of South Africa, Lesotho and Swaziland, 1:1 000 000 scale sheet maps*. South African National Biodiversity Institute., Pretoria.

Ollis, D., Snaddon, K., Job., Mabona, N. 2013. *Classification System for Wetlands and other Aquatic Ecosystems in South Africa. User Manual: Inland Systems*. SANBI.

Pollard, S. and Du Toit, D. 2013. The emergence of a systemic view for the sustainable governance and use of wetlands in complex and transforming environments; Experiences from Craigieburn, South Africa. In: Wood, A., Dixon, A., McCartney, M. (eds*). Wetland Management and Sustainable Livelihoods in Africa*. Routledge Canada.

Pretorius, M.L. 2011. *A vegetation classification and description of five wetland systems and their respective zones on the Maputaland Coastal Plain*. MSc thesis. Pretoria: University of South Africa.

Ramsar 1971. *Convention on Wetlands of International Importance especially as Waterfowl Habitat.* Ramsar (Iran). 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987. http://www.ramsar.org/ accessed 28.04.2013

Rivers-Moore, N.A. and Cowden, C. 2012. *Wetlands and Ecological Management.* 20: 491. doi:10.1007/s11273-012-9271-5.

Roleček, J., Tichý, L., Zelený, D. and Chytrý, M. 2009. Modified TWINSPAN 986 classification in which the hierarchy respects cluster heterogeneity. *Journal of Vegetation Science,* 20:596-602.

Rutherford, M.C. and Westfall, R.H. 1994. Biomes of southern Africa: An objective categorization. *Memoirs of the botanical Survey of South Africa,* Vol. 63:1-94.

Russell, W. 2009. *WET-RehabMethods National guidelines and methods for wetland rehabilitation.* WRC Report TT 341/09. Water Research Commission, Pretoria.

Sjörs, H. 1948. Mire vegetation in Bergslagen, Sweden. *Acta Phytogeographica Suecica,* Vol. 21:1-299.

South Africa. 1988. National Water Act (NWA) 1988. South African National Water Act, No. 36 of 1988. https://www.dwa.gov.za/Documents/Legislature/nw_act/NWA.pdf accessed 05.02.2015

South African National Biodiversity Institute (SANBI) 2011. National Biodiversity Assessment 2011: *An assessment of South Africa's biodiversity and ecosystems. A synthesis Report*. South African National Biodiversity institute (SANBI) and Department of Environmental Affairs, Pretoria.

South African National Parks (SANPARKS) 2008. *Marakele National Park, Park Management Plan*. South African National Parks, Pretoria.

South African National Parks (SANPARKS) 2014. *Marakele National Park, Park Management Plan for the period 2014-2024*. South African National Parks, Pretoria

Sieben, E.J.J. 2011. *Compiling vegetation data in wetlands in KwaZuku-Natal, Free State and Mpumalanga, providing minimum data requirements and a sampling protocol.* WRC Project No. K8/789 Water Research Commission, Pretoria.

Smolders, A. J. P., Lamers, L. P. M., Lucassen, E. C. H. E. T., Van der Velde, G., and Roelofs, J. G. M. 2006. Internal eutrophication: How it works and what to do about it – a review. *Chemistry and Ecology,* Vol. 22, No. 2:93-111.

South African Commission for Stratigy (SACS). 1980. Lithostratigraphy of the Republic of South Africa, South West Africa/ Namibië and the Republics of Bophuthatwana, Transkei, and Venda. *Stratigraphy of South Africa. Part 1 (Comp. L.E. Kent).* Pretoria: Government Printer. (Handbook for Geological Survey in South Africa 8).

Strack, M. (Ed), 2008. *Peatlands and Climate Change*. International Peat Society Jyväskylä, Finland.

Tichý, L. 2002: JUICE, software for vegetation classification. *Journal of Vegetation Science,* Vol. 13: 451-453.

Van Staden, P.J. 2002. *An ecological study of the plant communities of Marakele National Park*. M.Sc. thesis. University of Pretoria, Pretoria.

Van Staden, P.J. and Bredenkamp, G.J. 2005. Major plant communities of the Marakele National Park. *Koedoe* 48(2): 59-70. Pretoria. ISSN 0075-6458.

Van Wyk, E. and Vermeulen, D. 2011. Characteristics of local groundwater recharge cycles in South African semi-arid hard rock terrains–rainwater input. *Water SA,* Vol. 37(2): 147–154.

Venter, C.E. 2003. *The vegetation ecology of Mfabeni peat swamp, St. Lucia, KwaZulu-Natal*. MSc Thesis. University of Pretoria.

Von Post, L. 1922 Sveriges gologiska undersöknings torvinventering och några avdess hittills vunna resultat. *Sv. mosskulturför. Tidskrift*, Vol. 1-27.

Ward K., J., Myers, D., A., Thomas, R., B. 2008. Physiological and growth responses of C3 and C4 plant responses to reduced temperatures when grown at low CO2 of the last ice age. *Journal of Integrative Plant Biology* 2008, Vol. 50 (11): 1388-1395

Werger, M.J.A. 1974. On concepts and techniques applied in the Zürich-Montpellier method of vegetation survey. *Bothalia,* Vol. 11: 309-323.

Westhoff, V. and Van der Maarel, E. 1978. The Braun-Blanquet approach. In: Whittaker, RH (ed.) *Classification of Plant Communities.* Junk, The Hague, pp. 289 - 374.

**APPENDIX A**: Vegetation Survey Data: Location of sample points and species cover abundance recorded at each point.

**Table 8**: Location of vegetation sample points

| Relevé number | Latitude | Longitude | | Relevé number | Latitude | Longitude |
|---|---|---|---|---|---|---|
| 1 | S24°27’44.58” | E27°36’13.98” | | 28 | S24°27’41.40” | E27°36’07.00” |
| 2 | S24°27’43.86” | E27°36’14.76” | | 29 | S24°27’29.62” | E27°36’05.06” |
| 3 | S24°27’43.44” | E27°36’14.34” | | 30 | S24°27’29.81” | E27°36’03.34” |
| 4 | S24°27’43.44” | E27°36’13.92” | | 31 | S24°27’31.14” | E27°36’01.86” |
| 5 | S24°27’43.74” | E27°36’12.60” | | 32 | S24°27’31.36” | E27°36’00.75” |
| 6 | S24°27’41.40” | E27°36’08.04” | | 33 | S24°27’32.34” | E27°35’58.04” |
| 7 | S24°27’40.32” | E27°36’08.80” | | 34 | S24°27’33.70” | E27°35’50.30” |
| 8 | S24°27’39.00” | E27°36’08.70” | | 35 | S24°27’32.00” | E27°35’51.50” |
| 9 | S24°27’28.68” | E27°36’05.28” | | 36 | S24°27’29.12” | E27°36’11.10” |
| 10 | S24°27’28.44” | E27°36’03.84” | | 37 | S24°27’34.30” | E27°36’02.00” |
| 11 | S24°27’28.50” | E27°36’02.82” | | 38 | S24°27’34.60” | E27°35’49.10” |
| 12 | S24°27’32.58” | E27°35’48.90” | | 39 | S24°27’30.50” | E27°36’12.30” |
| 13 | S24°27’30.54” | E27°35’49.38” | | 40 | S24°27’34.80” | E27°36’00.60” |
| 14 | S24°27’30.54” | E27°36’08.64” | | 41 | S24°27’35.30” | E27°36’00.20” |
| 15 | S24°27’31.08” | E27°36’05.70” | | 42 | S24°27’33.00” | E27°36’04.90” |
| 16 | S24°27’33.66” | E27°36’06.12” | | 43 | S24°27’31.40” | E27°36’05.10” |
| 17 | S24°27’35.94” | E27°36’00.30” | | 44 | S24°27’33.90” | E27°36’04.50” |
| 18 | S24°27’33.80” | E27°36’12.40” | | 45 | S24°27’31.67” | E27°35’51.68” |
| 19 | S24°27’35.60” | E27°36’13.00” | | 46 | S24°27’44.40” | E27°36’11.00” |
| 20 | S24°27’38.60” | E27°36’14.50” | | 47 | S24°27’33.40” | E27°36’10.10” |
| 21 | S24°27’40.00” | E27°36’14.30” | | 48 | S24°27’39.60” | E27°36’08.00” |
| 22 | S24°27’42.40” | E27°36’14.20” | | 49 | S24°27’39.60” | E27°36’07.30” |
| 23 | S24°27’44.40” | E27°36’14.40” | | 50 | S24°27’39.40” | E27°36’06.80” |
| 24 | S24°27’43.20” | E27°36’10.70” | | 51 | S24°27’36.10” | E27°36’06.90” |
| 25 | S24°27’43.10” | E27°36’10.70” | | 52 | S24°27’38.00” | E27°36’03.20” |
| 26 | S24°27’43.20” | E27°36’10.40” | | 53 | S24°27’29.40” | E27°36’05.50” |
| 27 | S24°27’42.10” | E27°36’09.90” | | 54 | S24°27’37.40” | E27°36’03.70” |

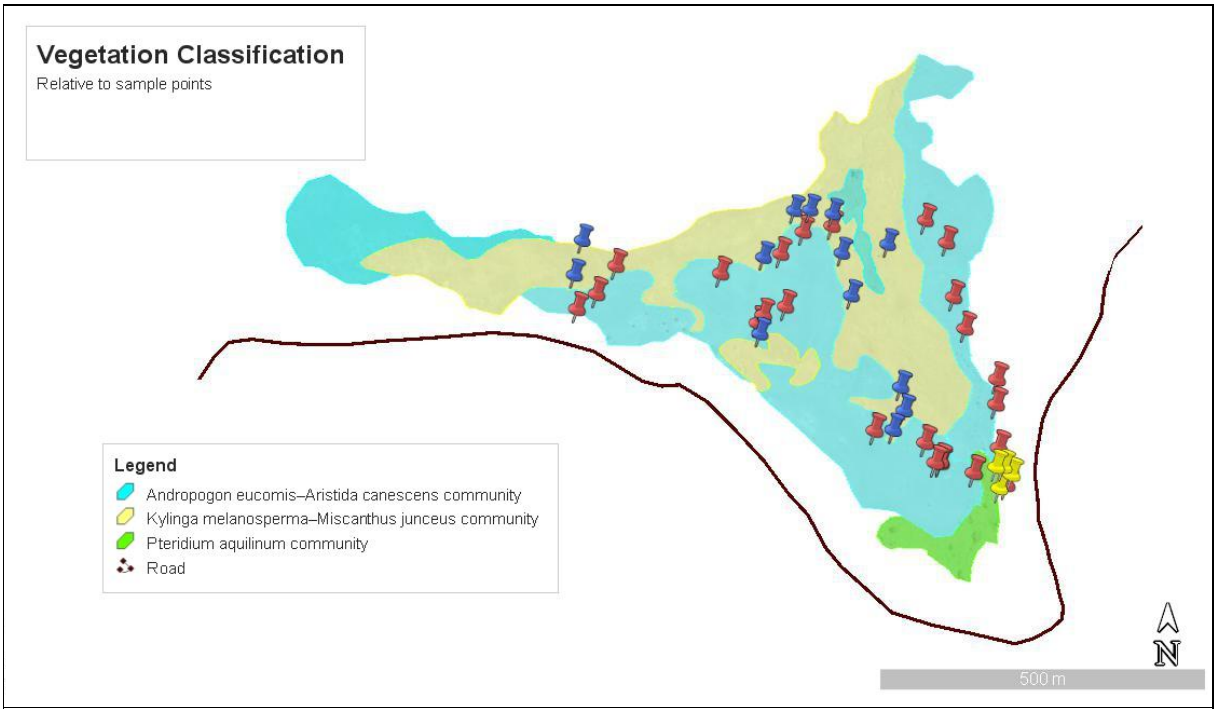


**Figure 36.** Location of sample plots in species group A (yellow), species group D (green) and species group E (blue).

**Table 9:** Phytocosiological table for all species recorded

| | 1 | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1 | | | | | | | | | 1.2 | | | | | | | | | | | | | | | | | | 3.1 | | | | | | | | | 3.2 | | | | | | | | | | | | | | | | | |
| Releve number | 36 | 48 | 53 | 52 | 32 | 51 | 49 | 14 | 54 | 15 | 47 | 45 | 12 | 6 | 13 | 11 | 35 | 8 | 7 | 10 | 17 | 9 | 16 | 1 | 2 | 3 | 4 | 30 | 42 | 40 | 39 | 44 | 31 | 41 | 43 | 50 | 23 | 22 | 5 | 27 | 24 | 34 | 21 | 46 | 18 | 33 | 38 | 25 | 26 | 28 | 37 | 19 | 29 | 20 |
| **Species group A** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Miscanthus junceus* | | | + | . | + | . | | . | | . | | | . | | | | | | | | | | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Kyllinga melanosperma* | . | | | . | . | | | | | + | | . | | r | | | . | | | . | | + | | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Thelypteris confluens* | . | . | | . | . | . | . | | | . | | . | | . | | | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group B** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Arundinella nepalensis* | | + | | | | . | . | + | . | . | . | . | . | . | . | . | | . | . | . | + | . | . | . | . | . | . | . | . | 2 | 2 | . | 2 | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum nudifolium* | . | | + | | . | + | | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | 1 | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Pycnostachys reticulata* | | . | | | . | | | | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | 1 | + | . | 1 | 1 | . | 1 | . | . | . | . | . | . | 4 | . | . | . | . | . | . | . | . | 1 | . | 1 | . |
| *Rhynchospora* sp. | . | | | | + | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Ascolepis capensis* | | . | + | | + | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group C** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Digitaria brazzae* | . | . | . | . | . | . | . | . | . | . | . | . | | + | . | | . | . | | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . |
| *Nidorella auriculata* | . | . | . | . | . | . | . | . | . | + | . | . | . | + | + | | . | r | | . | r | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum epapposum* | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | + | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Phragmites australis* | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Miscanthidium junceum* | . | . | . | . | . | . | . | . | . | | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group D** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Pteridium aquilinum* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 5 | 5 | 5 | 4 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Triumfetta pilosa var tomentosa* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | + | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Oldenlandia herbacea* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | + | r | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum aureonitens* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Oxalis obliquifolia* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | + | + | . | . | . | . | . | . | . | . | . | + | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| **Species group E** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Aristida canescens* | | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | 4 | 4 | 2 | 2 | 4 | 2 | 1 | 4 | 4 | 2 | 2 | . | 2 | 4 | 4 | 4 | 2 | 4 | 2 | 2 | 1 | 4 | 2 | 4 | 4 | 2 | 2 |
| *Andropogon eucomus* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | 1 | . | . | . | . | . | . | . | 1 | . | + | . | . | 2 | . | . | . | . | + | . | . | . | . |
| *Chironia purpurascens* subsp. *Purpurascens* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | + | . | . | . | 1 | . | . | . | . | . | . | . | 1 | . | r | 1 | . | . | . | 1 | 2 | 2 | . | r |
| **Species group F** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Helichrysum nudifolium* var. *nudifoli* | . | . | . | . | . | . | . | . | . | . | . | . | | . | | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | 2 | 1 | 2 | . | 1 | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | 1 | . |
| *Avena fatua* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | 1 | . | . | 1 | . | . | . | . | . | . | . | 4 | . | . | 2 | . | . | . | . | 1 | . | . | . |
| *Xyris capensis* | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | . | . | . | 1 | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum aureonitens* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | 1 | . | + | . | 1 | . | 1 | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . |
| *Drosera collinsiae* | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | . | 4 | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . |
| **Species group G** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Panicum dregeanum* | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | 2 | + | . | 5 | 1 | 1 | 1 | 4 | 4 | 2 | 2 | 2 | 2 | 5 | 1 | 5 | . | 4 |
| *Senesio* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | 2 | . | . | . | . | . | . | . | 1 | 1 | 1 | . | 1 | . | r | . | . | + | . | 1 | . | + | + | + |
| *Eragrostis racemosa* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | + | . | 2 | . | . | 1 | . | . | 1 | 2 | . | . |
| *Commelina africana* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | + | + | + | . | . | + | 1 | . | . | . | . | . | . | . | . | . | . |
| *Pseudognaphalium undulatum* | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | 1 | . | 2 | + | . | . | + | . | . | . | . | 1 | . | . | 1 | . |

| Species group H (species with low fidelity) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Scadoxus* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Diospyros* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Swertia welwitschii* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Sizygium cordata* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Scleria* sp | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | + | . | . | . | 1 | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . |
| *Campylopus pyriformis* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | + | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Cephalaria zeyheriana* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Rubus cuneifolius* | . | . | . | . | . | . | . | . | | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Hypericum landii* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Persicaria serrulata* | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Sporobolis* sp. | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Isolepis costata* | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Juncus oxycarpus* | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Fimbristylis* sp. | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Cyperus denudatus* | . | . | . | . | . | . | . | . | . | . | | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . |
| *Trachypogon spicatus* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Eragrostis gummiflua* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | 4 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Pycreus nitidus* | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Eragrostis* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Chrysophyllus* sp. | . | . | | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Sopubia simplex* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . |
| *Loudetia simplex* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . |
| *Antherotoma debilis* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | | . | + | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Chamaecrista comosa* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . |
| *Gomphocarpus physocarpus* subsp. *gomphocarpa* | . | . | . | . | . | . | . | . | + | . | . | . | . | . | + | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Cymbopogon validus* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | 5 | . | . | . | . | . | . | . |
| *Bulbostylis buchananii* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . |
| *Epilobium capense* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Sebaea leiostyla* | . | . | . | . | + | . | . | . | . | . | . | . | . | r | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Pycreus unioloides* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Bulbostyli* s sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Panicum natalense* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | 5 | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . |
| *Helichrysum* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Onopordum acanthium* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Gerbera* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | r |
| *Fuirena pubescens* | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Setaria* sp. | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Aristida* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Verbena bonariensis* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Eragrostis curvula* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 |
| *Acalypha* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | r | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Lycopodiella sarcocaulon* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Polygala hottentotta* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Crassocephalum picridifolium* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . |
| *Cyperus sphaerospermus* | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | + | . | . |
| *Sporledera* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | . | . | . | . | . | . |
| *Avena* sp. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| Unknown | | . | . | . | . | . | . | . | . | + | . | | . | | . | . | . | . | | | | | | 2 | 2 | 2 | 2 | 2 | + | . | + | . | . | 2 | 1 | . | 1 | + | + | . | 1 | . | + | . | . | . | 2 | . | . | r | . | . | 4 | . |

**APPENDIX B:** Contour Data

**Table 10**: Elevation data recorded at each transect, erosion position and a sample of the domes in the mire. Not all the domes were sampled accurately in terms of elevation during this assessment

| Name | Latitude (deg min sec) | Longitude (deg min sec) | Elevation (m.a.s.l.) |
|---|---|---|---|
| A1 | S24°27’39.58” | E27°36’13.20” | 1591.42 |
| A2 | S24°27’39.58” | E27°36’13.20” | 1591.47 |
| A3 | S24°27’39.70” | E27°36’11.97” | 1591.15 |
| A4 | S24°27’40.01” | E27°36’10.65” | 1590.51 |
| A5 | S24°27’40.13” | E27°36’09.63” | 1590.15 |
| A6 | S24°27’40.54” | E27°36’07.54” | 1592.79 |
| A7 | S24°27’40.87” | E27°36’06.13” | 1595.21 |
| B1 | S24°27’33.43” | E27°36’12.10” | 1580.66 |
| B2 | S24°27’33.50” | E27°36’11.62” | 1579.47 |
| B3 | S24°27’33.57” | E27°36’11.01” | 1579.44 |
| B4 | S24°27’33.34” | E27°36’09.52” | 1577.95 |
| B5 | S24°27’33.47” | E27°36’08.40” | 1576.92 |
| B6 | S24°27’33.54” | E27°36’06.87” | 1575.28 |
| B7 | S24°27’33.66” | E27°36’05.82” | 1575.64 |
| C1 | S24°27’28.70” | E27°36’13.34” | 1574.31 |
| C2 | S24°27’31.61” | E27°36’11.07” | 1574.64 |
| C3 | S24°27’31.52” | E27°36’09.99” | 1573.72 |
| C4 | S24°27’32.29” | E27°36’08.07” | 1575.24 |
| C5 | S24°27’31.45” | E27°36’06.79” | 1571.97 |
| C6 | S24°27’31.94” | E27°36’05.98” | 1572.61 |
| C7 | S24°27’31.98” | E27°36’05.24” | 1573.16 |
| D2 | S24°27’29.12” | E27°36’11.41” | 1570.98 |
| D3 | S24°27’29.23” | E27°36’09.97” | 1569.17 |
| D4 | S24°27’29.37” | E27°36’08.36” | 1568.91 |
| D6 | S24°27’29.73” | E27°36’05.64” | 1569.39 |
| D7 | S24°27’29.85” | E27°36’05.12” | 1569.93 |
| ME1B | S24°27’18.37” | E27°36’11.59” | 1552.47 |
| ME1O | S24°27’18.21” | E27°36’11.56” | 1550.55 |
| ME1O1 | S24°27’18.21” | E27°36’11.56” | 1550.53 |
| ME2B2 | S24°27’19.04” | E27°36’10.94” | 1552.62 |
| ME2O3 | S24°27’18.99” | E27°36’10.95” | 1551.73 |
| ME3B5 | S24°27’20.50” | E27°36’09.89” | 1553.52 |
| ME3O4 | S24°27’20.35” | E27°36’09.95” | 1553.16 |
| ME4B7 | S24°27’21.85” | E27°36’09.35” | 1555.49 |
| ME4O6 | S24°27’21.68” | E27°36’09.57” | 1554.27 |
| ROTSB | S24°27’17.08” | E27°36’11.94” | 1550.73 |
| ROTSO | S24°27’17.13” | E27°36’11.96” | 1549.85 |
| SAMVLOOIE2 | S24°27’24.10” | E27°36’08.11” | 1558.35 |
| SAMVLOOIO1 | S24°27’23.75” | E27°36’07.95” | 1557.31 |

| | | | |
|---|---|---|---|
| SAMVLOOIW3 | S24°27’24.30” | E27°36’07.47” | 1559.86 |
| WE1B | S24°27’26.73” | E27°36’07.92” | 1563.53 |
| WE2B101 | S24°27’27.52” | E27°36’08.05” | 1565.79 |
| WE2B102 | S24°27’27.46” | E27°36’07.46” | 1565.06 |
| WE2O | S24°27’26.58” | E27°36’07.95” | 1562.15 |
| WE2O100 | S24°27’27.05” | E27°36’07.82” | 1563.09 |
| Dome 1 | S24°27’39.87” | E27°36’07.78” | 1591.13 |
| Dome 1 | S24°27’39.96” | E27°36’07.82” | 1591.30 |
| Dome 1 | S24°27’39.87” | E27°36’07.92” | 1591.48 |
| Dome 1 | S24°27’39.77” | E27°36’07.82” | 1590.93 |
| Dome 1 | S24°27’39.62” | E27°36’07.89” | 1589.89 |
| Dome 1 | S24°27’39.60” | E27°36’07.99” | 1589.73 |
| Dome 1 | S24°27’39.69” | E27°36’08.11” | 1589.89 |
| Dome 1 | S24°27’39.78” | E27°36’08.22” | 1589.91 |
| Dome 1 | S24°27’39.92” | E27°36’08.19” | 1590.57 |
| Dome 1 | S24°27’40.01” | E27°36’08.06” | 1590.92 |
| Dome 1 | S24°27’40.02” | E27°36’07.93” | 1591.30 |
| Dome 2 | S24°27’39.54” | E27°36’07.57” | 1590.07 |
| Dome 2 | S24°27’39.39” | E27°36’07.56” | 1589.48 |
| Dome 2 | S24°27’39.26” | E27°36’07.48” | 1589.27 |
| Dome 2 | S24°27’39.19” | E27°36’07.35” | 1588.97 |
| Dome 2 | S24°27’39.30” | E27°36’07.26” | 1589.62 |
| Dome 2 | S24°27’39.43” | E27°36’07.27” | 1590.07 |
| Dome 2 | S24°27’39.53” | E27°36’07.28” | 1590.49 |
| Dome 2 | S24°27’39.44” | E27°36’07.39” | 1590.88 |
| Dome 3 | S24°27’38.15” | E27°36’06.82” | 1586.73 |
| Dome 3 | S24°27’38.09” | E27°36’06.71” | 1586.39 |
| Dome 3 | S24°27’37.97” | E27°36’06.71” | 1585.96 |
| Dome 3 | S24°27’37.84” | E27°36’06.80” | 1585.45 |
| Dome 3 | S24°27’37.73” | E27°36’06.10” | 1585.16 |
| Dome 3 | S24°27’37.72” | E27°36’07.18” | 1585.17 |
| Dome 3 | S24°27’37.84” | E27°36’07.30” | 1585.93 |
| Dome 3 | S24°27’37.99” | E27°36’07.28” | 1586.14 |
| Dome 3 | S24°27’38.13” | E27°36’07.03” | 1586.70 |
| Dome 3 | S24°27’38.03” | E27°36’06.92” | 1587.38 |
| Dome 3 | S24°27’38.17” | E27°36’06.96” | 1586.85 |
| Dome 4 | S24°27’38.05” | E27°36’05.34” | 1587.59 |
| Dome 4 | S24°27’37.90” | E27°36’05.31” | 1587.02 |
| Dome 4 | S24°27’37.81” | E27°36’05.17” | 1586.93 |
| Dome 4 | S24°27’37.85” | E27°36’04.97” | 1587.31 |
| Dome 4 | S24°27’37.98” | E27°36’04.88” | 1588.06 |
| Dome 4 | S24°27’38.14” | E27°36’05.03” | 1588.62 |
| Dome 4 | S24°27’38.01” | E27°36’05.10” | 1588.64 |
| Dome 5 | S24°27’37.88” | E27°36’04.78” | 1587.64 |

| | | | |
|---|---|---|---|
| Dome 5 | S24°27'37.69" | E27°36'04.71" | 1586.68 |
| Dome 5 | S24°27'37.63" | E27°36'04.53" | 1586.52 |
| Dome 5 | S24°27'37.721" | E27°36'04.41" | 1587.09 |
| Dome 5 | S24°27'37.82" | E27°36'04.40" | 1587.67 |
| Dome 5 | S24°27'37.92" | E27°36'04.44" | 1588.15 |
| Dome 5 | S24°27'37.97" | E27°36'04.58" | 1588.29 |
| Dome 5 | S24°27'37.84" | E27°36'04.58" | 1588.67 |
| Dome 6 | S24°27'38.16" | E27°36'04.66" | 1589.12 |
| Dome 6 | S24°27'38.25" | E27°36'04.56" | 1589.52 |
| Dome 6 | S24°27'38.20" | E27°36'04.38" | 1589.43 |
| Dome 6 | S24°27'38.09" | E27°36'04.31" | 1589.09 |
| Dome 6 | S24°27'38.00" | E27°36'04.37" | 1588.74 |
| Dome 6 | S24°27'38.13" | E27°36'04.48" | 1589.70 |
| Dome 6 | S24°27'38.01" | E27°36'04.61" | 1588.40 |
| Dome 7 | S24°27'37.48" | E27°36'03.92" | 1586.68 |
| Dome 7 | S24°27'37.08" | E27°36'02.63" | 1586.86 |
| Dome 7 | S24°27'37.30" | E27°36'02.89" | 1587.65 |
| Dome 7 | S24°27'37.56" | E27°36'03.08" | 1587.98 |
| Dome 7 | S24°27'37.65" | E27°36'03.23" | 1588.38 |
| Dome 7 | S24°27'37.76" | E27°36'03.37" | 1588.54 |
| Dome 7 | S24°27'37.77" | E27°36'03.62" | 1588.34 |
| Dome 7 | S24°27'37.36" | E27°36'03.60" | 1587.50 |
| Dome 7 | S24°27'37.22" | E27°36'03.53" | 1587.19 |
| Dome 7 | S24°27'37.15" | E27°36'03.35" | 1587.07 |
| Dome 7 | S24°27'37.13" | E27°36'03.02" | 1587.06 |
| Dome 7 | S24°27'37.29" | E27°36'03.99" | 1585.84 |
| Dome 7 | S24°27'37.08" | E27°36'03.94" | 1585.06 |
| Dome 7 | S24°27'36.90" | E27°36'03.81" | 1584.46 |
| Dome 7 | S24°27'36.77" | E27°36'03.61" | 1584.24 |
| Dome 7 | S24°27'36.72" | E27°36'03.37" | 1584.53 |
| Dome 7 | S24°27'36.76" | E27°36'03.15" | 1584.92 |
| Dome 7 | S24°27'36.80" | E27°36'02.83" | 1585.08 |
| Dome 7 | S24°27'36.90" | E27°36'02.66" | 1585.87 |
| Dome 7 | S24°27'33.54" | E27°36'06.84" | 1575.22 |
| Dome 8 | S24°27'36.98" | E27°36'02.46" | 1586.52 |
| Dome 8 | S24°27'36.68" | E27°36'02.33" | 1584.81 |
| Dome 8 | S24°27'37.12" | E27°36'02.24" | 1587.64 |
| Dome 8 | S24°27'37.11" | E27°36'02.03" | 1588.05 |
| Dome 8 | S24°27'36.98" | E27°36'02.09" | 1587.43 |
| Dome 8 | S24°27'36.91" | E27°36'01.92" | 1587.35 |
| Dome 8 | S24°27'36.85" | E27°36'01.75" | 1587.25 |
| Dome 8 | S24°27'36.71" | E27°36'01.86" | 1586.30 |
| Dome 8 | S24°27'36.60" | E27°36'02.05" | 1585.05 |
| Dome 8 | S24°27'36.60" | E27°36'02.17" | 1584.73 |

| | | | |
|---|---|---|---|
| Dome 9 | S24°27’33.66483” | E27°36’07.98041” | 1576.67 |
| Dome 9 | S24°27’33.71072” | E27°36’08.11931” | 1577.09 |
| Dome 9 | S24°27’33.80979” | E27°36’08.16530” | 1577.38 |
| Dome 9 | S24°27’33.96068” | E27°36’08.11198” | 1577.88 |
| Dome 9 | S24°27’33.99637” | E27°36’07.89006” | 1577.93 |
| Dome 9 | S24°27’33.89130” | E27°36’07.78311” | 1577.63 |
| Dome 9 | S24°27’33.79300” | E27°36’08.02366” | 1577.81 |
| Dome 11 | S24°27’29.48011” | E27°36’05.46786” | 1569.35 |
| Dome 11 | S24°27’29.38780” | E27°36’05.39879” | 1569.25 |
| Dome 11 | S24°27’29.29012” | E27°36’05.43351” | 1569.01 |
| Dome 11 | S24°27’29.24753” | E27°36’05.53653” | 1568.85 |
| Dome 11 | S24°27’29.33226” | E27°36’05.61060” | 1569.00 |
| Dome 11 | S24°27’29.41082” | E27°36’05.60874” | 1569.36 |
| Dome 11 | S24°27’29.48737” | E27°36’05.55535” | 1569.43 |
| Dome 11 | S24°27’29.48927” | E27°36’05.46943” | 1569.39 |
| Dome 12 | S24°27’32.09318” | E27°36’07.72173” | 1574.18 |
| Dome 12 | S24°27’32.32014” | E27°36’07.76030” | 1574.50 |
| Dome 12 | S24°27’32.28614” | E27°36’08.01529” | 1575.15 |
| Dome 12 | S24°27’31.97426” | E27°36’07.96665” | 1573.78 |
| Dome 12 | S24°27’32.00416” | E27°36’08.16371” | 1573.85 |
| Dome 12 | S24°27’32.09978” | E27°36’08.28538” | 1574.14 |
| Dome 12 | S24°27’32.25831” | E27°36’08.35072” | 1574.42 |
| Dome 12 | S24°27’32.36144” | E27°36’08.31766” | 1574.86 |
| Dome 12 | S24°27’32.44370” | E27°36’08.22591” | 1575.25 |
| Dome 12 | S24°27’32.48105” | E27°36’08.11073” | 1575.08 |
| Dome 12 | S24°27’32.43062” | E27°36’07.93616” | 1574.90 |
| Dome 50 | S24°27’32.33780” | E27°35’45.87719” | 1590.94 |
| Dome 50 | S24°27’32.26329” | E27°35’45.27146” | 1592.58 |
| Dome 50 | S24°27’32.43121” | E27°35’45.44839” | 1591.79 |
| Dome 50 | S24°27’32.23931” | E27°35’46.01363” | 1590.98 |
| Dome 50 | S24°27’32.03476” | E27°35’46.09409” | 1590.83 |
| Dome 50 | S24°27’31.82040” | E27°35’46.05118” | 1591.16 |
| Dome 50 | S24°27’31.71267” | E27°35’45.92349” | 1591.56 |
| Dome 50 | S24°27’31.74168” | E27°35’45.72266” | 1592.08 |
| Dome 50 | S24°27’31.75676” | E27°35’45.49109” | 1592.37 |
| Dome 50 | S24°27’31.93590” | E27°35’45.33475” | 1592.53 |
| Dome 50 | S24°27’32.10279” | E27°35’45.28395” | 1592.68 |

**APPENDIX C**: Surface water flow data

**Table 11:** Surface water flow data for 2012 (sample points where no flow was recorded are not shown)

| Name | Latitude (deg min sec) | Longitude (deg min sec) | Flow direction adjusted for declination of 15°44' in degree mins |
|---|---|---|---|
| TF1 | S24°27’39.8” | E27°36’13.9” | 224°16 |
| TF1.1 | S24°27’41.6” | E27°36’13.7” | 334°16’ |
| TF1.3 | S24°27’41.7” | E27°36’13.0” | 334°16’ |
| TF1.5 | S24°27’41.6” | E27°36’12.2” | 324°16’ |
| TF1.6 | S24°27’41.6” | E27°36’11.7” | 0°16’ |
| TF1.7 | S24°27’41.5” | E27°36’11.1” | 339°16’ |
| TF1.8 | S24°27’41.7” | E27°36’10.5” | 24°16’ |
| TF1.9 | S24°27’41.6” | E27°36’09.0” | 0°16’ |
| TF2.8 | S24°27’37.8” | E27°36’08.4” | 334°16’ |
| TF2.9 | S24°27’37.4” | E27°36’08.8” | 314°16’ |
| TF2.11 | S24°27’37.2” | E27°36’09.3” | 294°16’ |
| TF2.12 | S24°27’36.8” | E27°36’10.5” | 324°16’ |
| TF2.13 | S24°27’36.6” | E27°36’11.1” | 334°16’ |
| TF2.14 | S24°27’36.3” | E27°36’11.8” | 324°16’ |
| B2 | S24°27’33.5” | E27°36’11.6” | 324°16’ |
| B3 | S24°27’33.6” | E27°36’10.9” | -15°16’ |
| B4 | S24°27’33.6” | E27°36’10.9” | 329°16’ |
| B5 | S24°27’33.2” | E27°36’09.0” | -15°16’ |
| B4.1 | S24°27’34.7” | E27°36’08.7” | 294°16’ |
| xB5 | S24°27’33.4” | E27°36’08.6” | 329°16’ |
| xB5.1 | S24°27’33.7” | E27°36’07.8” | 342°16’ |
| B6 | S24°27’34.1” | E27°36’07.1” | 324°16’ |
| B6.1 | S24°27’33.9” | E27°36’06.2” | 324°16’ |
| C2.2 | S24°27’32.0” | E27°36’12.9” | 279°16’ |
| C3 | S24°27’31.7” | E27°36’12.0” | 319°16’ |
| C3.1 | S24°27’31.8” | E27°36’10.5” | 319°16’ |
| C4.2 | S24°27’32.2” | E27°36’08.1” | -15°16’ |

| | | | |
|---|---|---|---|
| C4.3 | S24°27'31.9" | E27°36'09.2" | -15°16' |
| FD2 | S24°27'29.5" | E27°36'05.7" | 39°16' |
| FD3 | S24°27'29.4" | E27°36'06.3" | 24°16' |
| FD4 | S24°27'29.4" | E27°36'09.6" | 24°16' |
| FD7 | S24°27'29.4" | E27°36'08.3" | 14°16' |
| FD8 | S24°27'29.3" | E27°36'08.8" | -15°16' |
| FD9 | S24°27'29.1" | E27°36'09.7" | 19°16' |

**Table 12:** Surface water flow data for 2013 (sample points where no flow was recorded are not shown)

| Name | Latitude (deg min sec) | Longitude (deg min sec) | Flow direction adjusted for declination of 15°44' in degree mins |
|---|---|---|---|
| M-RF1 | S24°27'43.5 | E27°36'13.6 | 316°16' |
| M-AF1 | S24°27'39.7 | E27°36'13.6 | 446°16' |
| M-TF1-1R | S24°27'41.7 | E27°36'13.7 | 338°16' |
| M-TF1-2R | S24°27'41.8 | E27°36'13.3 | 2°16' |
| M-TF1-7R | S24°27'41.1 | E27°36'09.3 | 346°16' |
| M-TF2-4R | S24°27'38.4 | E27°36'09.4 | -11°16' |
| M-TF2-5R | S24°27'38.2 | E27°36'10.5 | 304°16' |
| M-TF2-6R | S24°27'38.2 | E27°36'10.8 | 300°16' |
| M-TF2-7R | S24°27'37.5 | E27°36'12.1 | 278°16' |
| M-TF2-10R | S24°27'35.7 | E27°36'12.2 | 322°16' |
| M-FB2R | S24°27'33.7 | E27°36'10.7 | 332°16' |
| M-FB3R | S24°27'33.5 | E27°36'10.1 | 32°16' |
| M-FB4R | S24°27'33.4 | E27°36'09.9 | 282°16' |
| M-FB5R | S24°27'33.4 | E27°36'09.4 | 324°16' |
| M-FB6R | S24°27'33.8 | E27°36'07.9 | 330°16' |
| M-FCR | S24°27'31.8 | E27°36'06.1 | 268°16' |
| M-FC4-3R | S24°27'32.0 | E27°36'09.4 | 326°16' |
| M-FC4R1 | S24°27'31.9 | E27°36'10.0 | 256°16' |
| M-FO10R | S24°27'28.9 | E27°36'09.9 | 298°16' |
| M-FO9R | S24°27'21.4 | E27°36'08.4 | 393°16' |
| M-FO8R | S24°27'30.2 | E27°36'06.9 | 312°16' |

**APPENDIX D**: Soil Data

Tables 13 to 41 present the descriptive soil data recorded along the transects set out in the eastern section of the Matlabas Mire

## Transect A

**Table 13:** Soil profiles at points A0

| Transect A point 0 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 20 | Dark organic and Coarse sand |
| 20 – 30 | Dark sand with organic material |
| 30 – 50 | Sand, greyish brown colour |
| 50 – 70 | Sand, greyish brown colour |
| 70 – 90 | Sand, greyish brown colour with clay |
| 90 – 120 | Sand, greyish with clay |

**Table 14:** Soil profiles at points A1

| Transect A point 1 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 10 | Peat H3, brown |
| 10 – 30 | Peat H8 with sand, dark |
| 30 – 50 | Peat H7, brown |
| 50 – 80 | Peat H6, brown |
| 80 - 100 | Peat H4, dark brown |
| 100 - 150 | Peat H4, dark brown |
| 100 - 120 | Peat H4, dark brown |
| 120 - 130 | Peat H4, dark brown, with clay |
| 130 - 140 | Clay with sand, greyish brown |
| 140 - 150 | Sand with clay, greyish brown |
| 150 - 170 | Clay with sand, greyish brown |
| 170 - 200 | Sand with clay, greyish brown |

**Table 15:** Soil profiles at points A2

| Transect A point 2 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 10 | Peat H7, brown |
| 10 – 12 | Coarse sand |
| 12 - 25 | Peat H8 with Coarse sand, brown |
| 25 - 30 | Peat with ash, brownish grey |
| 30 – 50 | Peat H8 with sand, dark colour |
| 50 – 75 | Peat H8 with sand, dark colour |
| 75 – 85 | Peat H9 with sand, brown |
| 85 - 92 | Coarse sand, light brown |
| 92 - 100 | Peat H7 with sand, brownish grey |

| | |
|---|---|
| 100 - 103 | Peat H4, reddish brown |
| 103 - 108 | Coarse sand, brown |
| 108 - 120 | Peat H5, dark colour |
| 120 - 135 | Sand and fibre, reddish brown |
| 135 - 150 | Peat H4 with sand, brown |
| 150 - 160 | Peat H4 with sand, brown |
| 160 - 175 | Coarse sand, brown |
| 175 - 190 | Coarse sand with clay, dark organic |
| 190 - 200 | Coarse sand with clay, dark organic |
| 200 - 220 | Clay with coarse sand, greyish brown |

**Table 16:** Soil profiles at points A3

| **Transect A point 3** | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 10 | Peat H5, brown |
| 10 – 25 | Peat H7 with sand, brown |
| 25 - 35 | Coarse sand with organic matter, brown |
| 35 – 45 | Peat H8 with sand, dark colour |
| 45 - 50 | Coarse sand |
| 50 - 60 | Fine silt and clay with organic matter, greyish brown |
| 60 - 70 | Peat and sand, dark colour |
| 70 - 75 | Coarse sand |
| 75 – 100 | Peat with coarse sand, dark brown |
| 85 - 92 | Coarse sand, light brown |
| 92 - 100 | Peat H7 with sand, brownish grey |
| 100 - 120 | Coarse sand, greyish brown, lots of iron precipitation |

**Table 17:** Soil profiles at points A4

| **Transect A point 4** | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 10 | Peat H3, yellowish brown |
| 10 – 15 | Peat H5, dark colour |
| 15 - 30 | Sand with organic material |
| 30 - 50 | Peat, sand and clay, brown |
| 50 - 70 | Peat, sand and clay, brown |
| 90 - 90 | Clay and sand, grey |
| 90 - 120 | Clay and sand, grey |

**Table 18:** Soil profiles at points A5

| **Transect A point 5** | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 15 | Peat H6, brown |
| 15 - 30 | Sand with organic material |
| 30 - 60 | Clay, dark in colour |
| 60 - 90 | Clay and sand, grey |
| 90 - 110 | Clay and sand, grey |

**Table 19:** Soil profiles at points A6

| Transect A point 6 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 15 | Peat H4, dark in colour |
| 15 - 20 | Fine silt with some organic material, grey |
| 20 - 30 | Fine silt with some organic material, grey |
| 30 - 40 | Clay, grey matrix with orange mottles |
| 40 - 60 | Clay and sand, grey |
| 60 - 80 | Clay and sand, grey |
| 80 - 100 | Clay and sand, grey |
| 90 - 110 | Clay and sand, grey |

**Table 20:** Soil profiles at points A7

| Transect A point 7 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 20 | Sand and organic material, dark coloured |
| 20 - 40 | Greyish brown loamy soil with sand and red mottles |
| 40 - 45 | Greyish brown loamy soil with sand and red mottles |
| 45 - 60 | Red sand with some clay and orange mottles |
| 60 - 80 | Red sand with some clay and orange mottles |
| 80 - 100 | Sand, clay and orange mottles |

**<u>Transect B</u>**

**Table 21:** Soil profiles at points B2

| Transect B point 2 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 5 - 10 | Peat H5 |
| 10 – 20 | Peat H5 |
| 20 - 30 | Sand and high clay content |
| 30 - 40 | Sand and clay |
| 40 - 50 | Sand |
| 50 - 60 | Sand |
| 60 - 70 | Sand |
| 70 - 80 | Sand and organic material |
| 80 - 90 | Sand and organic material |
| 90 - 100 | Sand and organic material |

**Table 22:** Soil profiles at points B3

| Transect B point 3 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 5 - 10 | Fibrous material |
| 10 – 20 | Peat, H6, fine texture |
| 20 - 30 | Peat, H6, fine texture |
| 30 - 40 | Sand |
| 40 - 130 | Peat H5 |
| 130 - 140 | Peat H6 |

| | |
|---|---|
| 150 - 190 | Sand with some peat |
| 190 - 200 | Sand |

**Table 23:** Soil profiles at points B4

| Transect B point 4 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 30 | Peat H3, lots of non-organic material |
| 30 - 50 | Peat H4, medium fibre |
| 50 - 80 | Peat H5 |
| 80 - 90 | Coarse sand |
| 90 - 120 | Peat H3 |
| 120 - 140 | Sand |
| 10 - 180 | Peat H4, medium fibre |
| 180 - 190 | Sand |
| 190 - 200 | Peat H6 with sand |
| 200 - 250 | Sand |

**Table 24:** Soil profiles at points B5

| Transect B point 5 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 50 | Peat, H3, medium fibre |
| 50 - 80 | Peat H5, medium fibre |
| 80 - 110 | Peat H4, sand and fibre |
| 120 - 170 | Peat H5, sand and fibre |
| 170 - 230 | Peat, H2, long fibres with sand |
| 230 - 250 | Coarse sand |
| 250 - 260 | Clay, sand and some organic material |
| 260 - 270 | Sand |
| 270 - 280 | Clay, sand and some organic material |
| 280 - 300 | Sand |
| 300 - 320 | White clay with sand |

**Table 25:** Soil profiles at points B6

| Transect B point 6 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 30 | Peat, H2, very fibrous |
| 30 - 70 | Peat H5 with sand |
| 70 - 80 | Sand |
| 80 - 90 | Peat with sand |
| 90 - 100 | Very fine peat |
| 100 - 120 | Organic material with sand and clay |
| 120 - 130 | Clay |
| 130 - 140 | Clay, sand and organic material |

**Table 26:** Soil profiles at points B7

| Transect B point 7 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 5 | Peat, H1, very fibrous |
| 5 - 30 | Sand with Peat, H5 |
| 30 - 50 | Sand and clay |

**Transect C**

**Table 27:** Soil profiles at points C1

| Transect C point 1 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 30 | Peat, H2, very fibrous |
| 30 - 70 | Peat H5 with sand |
| 70 - 80 | Sand |
| 80 - 90 | Peat with sand |
| 90 - 100 | Very fine peat |
| 100 - 120 | Organic material with sand and clay |
| 120 - 130 | Clay |
| 130 - 140 | Clay, sand and organic material |

**Table 28:** Soil profiles at points C2

| Transect C point 2 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 05 | Peat H3, reddish brown |
| 05 - 25 | Peat H5, dark brown |
| 25 - 50 | Peat H8, dark colour |
| 50 - 70 | Clay, brownish grey |
| 70 - 100 | Sand and clay |
| 100 - 110 | Clay and sand, darkish grey |

**Table 29:** Soil profiles at points C3

| Transect C point 3 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 – 15 | Peat H3, reddish brown |
| 15 - 40 | Peat H5, dark brown |
| 40 - 50 | Peat H7, dark colour |
| 50 - 60 | Peat H7 with sand, dark colour |
| 60 - 85 | Coarse sand with organic material, greyish |
| 85 - 100 | Coarse sand, greyish brown |

**Table 30:** Soil profiles at points C4

| Transect C point 4 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 15 | Peat, greyish brown |
| 15 - 25 | Peat, greyish brown |
| 25 - 50 | Peat, greyish brown |
| 50 - 75 | Peat H4 |
| 75 - 100 | Peat H5, dark brown |
| 100 – 145 | Coarse sand with peat and yellowish |
| 145 - 150 | Yellow clay and fibre |
| 150 - 220 | Peat H6, sand and yellowish fibres, dark colour |
| 220 - 250 | Coarse sand, finer towards the bottom |
| 250 - 270 | Organic material |
| 270 - 280 | Coarse sand |
| 280 - 290 | Clay, reddish |

**Table 31:** Soil profiles at points C5

| Transect C point 5 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 25 | Peat H4, redish brown |
| 25 - 35 | Peat H5, brown |
| 35 - 50 | Peat H8 with sand, dark colour |
| 50 - 75 | Sand, organic material and clay |
| 75 - 100 | Clay, greyish |

**Table 32:** Soil profiles at points C6

| Transect C point 6 | |
|---|---|
| Depth below the soil surface in Cm | Description |
| 0 - 10 | Peat H2, brown |
| 10 - 30 | Peat H7, dark colour |
| 30 - 50 | Clay with orange mottles in a grey matrix |
| 50 - 110 | Clay with orange mottles in a grey matrix, with sand |

**Table 33:** Soil profiles at points C7

| Transect C point 7 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 15 | Clay and organic material, dark colour |
| 15 - 20 | Clay, dark grey matrix with red mottles |
| 20 - 40 | Clay and sand, grey matrix and red mottles |
| 40 - 60 | Clay, sand and fine silt, grey matrix and red mottles |
| 60 - 90 | Sandy silt |
| 90 - 100 | Sand, grey matrix with red mottles |
| 100 - | Clay and sand – reddish colour |

**Transect D**

**Table 34:** Soil profiles at points D2

| Transect D point 2 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 10 | Organic material, black |
| 10 - 20 | Sand and clay, brown |
| 20 - 40 | Sand and clay, grey matrix and red mottles |
| 40 - 80 | Sand and clay, grey matrix and orange mottles |
| 80 - 100 | Clay with few orange mottles |
| 100 - 110 | Sandy clay |

**Table 35:** Soil profiles at points D3

| Transect D point 3 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 10 | Peat H2 with fibres, brown |
| 10 - 25 | Peat H5, dark brown |
| 25 - 45 | Peat H6, dark brown |
| 45 - 50 | Peat H6 with sand, dark brown |
| 50 - 70 | Clay with organic material, brown |
| 70 - 90 | Coarse and, brown |
| 90 - 100 | Clay with roots |
| 100 - 110 | Organic material with sand and some clay |
| 110 - 135 | Coarse sand and clay |
| 135 - 155 | Clay and fibres, dark colour |
| 155 - 165 | Clay and fibres, greyish colour |

**Table 36:** Soil profiles at points D4

| Transect D point 4 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 20 | Peat H2 reddish brown |
| 20 - 35 | Peat H7, dark colour |
| 35 - 50 | Peat H8 with clay, dark grey |
| 50 - 90 | Coarse sand, brown |
| 90 - 100 | Clay and sand, greyish |
| 70 - 90 | Coarse and, brown |
| 90 - 100 | Clay with roots |
| 100 - 110 | Clay, brown |
| 110 - 120 | Sand, white |

**Table 37:** Soil profiles at points D5

| Transect D point 5 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 10 | Peat H4 greyish brown |
| 10 - 30 | Peat H7, dark colour |
| 30 - 70 | Peat H3 with sand, brown |
| 70 - 90 | Coarse sand, brown |

| | |
|---|---|
| 90 - 100 | Clay, sand and organic material, dark brown |
| 100 - 115 | Sand and organic material |
| 115 - 130 | Sandy stone |

**Table 38:** Soil profiles at points D6

| Transect D point 6 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 10 | Peat H3, reddish brown |
| 10 - 40 | Clay and organic material, dark colour |
| 40 - 60 | Clay, dark grey matrix with orange mottles |
| 60 - 120 | Clay, grey with orange mottles |

**Table 39:** Soil profiles at points D7

| Transect D point 7 | |
|---|---|
| Depth below the soil surface in cm | Description |
| 0 - 10 | Organic material, dark colour |
| 10 - 20 | Sandy clay and organic material, brown |
| 20 - 60 | Clay and sand, brown matrix with red mottles |
| 60 - 80 | Clay and sand, grey with orange mottles |

**APPENDIX E: Erosion Data**

**Table 40:** Erosion events recorded in the eastern section of the Matlabas mire

| Name | Coordinates | Depth and length | Notes |
|---|---|---|---|
| Upper seep | S 24°27’31.58” and E E27°36’13.92” | Channel is 0.5-0.7 m deep and 2-5 m wide | Associated with a game path on a slope in the seasonal to semi-permanent wetland zone. |
| Main stream erosion 1: ROTSB to ROTSO | S 24°27’17.08” and E E27°36’11.94”to S 24°27’17.13” and E E27°36’11.96” | 9 m difference between the two points | Possible headcut erosion, appears to be a stable point. |
| Main stream erosion 2: ME1B to ME1O | S 24°27’18.37” and E E27°36’11.59” to S 24°27’18.21” and E E27°36’11.56” | 1.95 m difference between the two points Channel 20 m wide. Headcut width: 18 m | Extensive headcut, serious problem point. |
| Main stream erosion 3: ME2B2 to ME2O3 | S 24°27’19.04” and E E27°36’10.94” to S 24°27’18.99” and E E27°36’10.95” | 0.9 m difference between the two points Channel 10 m wide. Headcut width: 4 m | Headcut and Gully erosion. Well defined macro channel, steeply incised. Well vegetated. Floor eroding. |
| Main stream erosion 4: ME3O4 to ME3B5 | S 24°27’20.35” and E E27°36’09.95” to S 24°27’20.50” and E E27°36’09.89” | 0.4 m difference between the two points Channel 8 m wide. Headcut width: 1 m | Headcut and Gully erosion. Well defined macro channel, steeply incised. Well vegetated. Floor eroding. |
| Main stream erosion 5: ME4B7 to ME4O6 | S 24°27’21.85” and E E27°36’09.35” to S 24°27’21.68” and E E27°36’09.57” | 1.2 m difference between the two points Channel 5 m wide. Headcut width: 1.5 m | Headcut and Gully erosion. Well defined macro channel, steeply incised. Well vegetated. Floor eroding. |
| Side Channel: SC1B8 to SC1BMT4 | S 24°27’22.68” and E E27°36’09.05” and S 24°27’22.31” and E E27°36’08.86” | 0.7 m difference between top of the macro bank and floor of the gully Channel 5 m wide. Headcut width: 1.5 m | Headcut and Gully erosion. Well defined macro channel, steeply incised. Well vegetated. Floor eroding. |
| Confluence of western and eastern wetland channels: SAMVLOOIO1 | S 24°27’23.75” and E E27°36’07.95” | Channel 12 m wide. Headcut width: 1.5 m | Well defined macro channel, broader floor. Well vegetated. Floor eroding. |
| Confluence of western and eastern wetland channels: SAMVLOOIE2 | S 24°27’24.01” and E E27°36’08.11” | Channel 10 m wide. Headcut width: 1 m | Confluence of western and eastern wetland channels. Differs 1.3 m from point SAMVLOOIO1. Well defined macro channel, broader floor. Well vegetated. Floor eroding. |
| Confluence of western and eastern wetland channels: SAMVLOOIW3 | S 24°27’24.30” and E E27°36’07.47” | Channel 15 m wide. Headcut width: 1 m | Confluence of western and eastern wetland channels. Differs 1.0 m from point SAMVLOOIO1. Well defined macro channel, broader floor. Well vegetated. Floor eroding. |
| Wetland East 1: WE1B to WE2O | S 24°27’26.73” and E E27°36’07.92” and S 24°27’26.58” and E E27°36’07.95” | 1.41 m difference between the two points Channel 8 m wide. Headcut width: 3-4 m | Extensive headcut, well vegetated, serious problem point. |
| Wetland East 2: WE2O100 | S 24°27’27.04” and E E27°36’07.82” | Channel 10 m wide. Headcut width: 1.5 m | Well vegetated. |

| | | | |
|---|---|---|---|
| Wetland East 2: WE2B101 | S 24°27'27.52" and E E27°36'08.05" | Channel 5 m wide. Headcut width: 1 m | Differs 2.3 m in elevation from WE2O100, well vegetated. |
| Wetland East 2: WE2B102 | S 24°27'27.46" and E E27°36'07.46" | Channel 12 m wide. Headcut width: 1 m | Differs 1.98 m in elevation from WE2O100, well vegetated. |
| Seasonal channel feeding into Eastern Wetland | S 24°27.61" and E E27°36.22" | Channel 1.2 m deep, 2-2.5 m wide. A plunge pool is about 0.5 m deep and 3 m long, 2-2.5 m long | Elephants recently visited this site – thus more trampling is expected in the future. Monitoring required. Intervention may be needed. |

**Appendix F:** Precipitation data logged at the Thabazimbi Towers weather station (LAT(S):24.29937, LONG (E):27.70002), managed as part of the Agricultural Research Council - Institute for Soil Climate and Water Agro-Climatology Programme.

**Table 41:** Summary of monthly rainfall recorded in 2011

| Month | Average Daily Rainfall [mm] |
|---|---|
| January | 7.86 |
| February | 2.05 |
| March | 2.54 |
| April | 3.04 |
| May | 0.12 |
| June | 0.21 |
| July | 0.01 |
| August | 0.17 |
| September | 0.00 |
| October | 1.60 |
| November | 1.65 |
| December | 7.23 |

**Table 42:** Summary of monthly rainfall recorded in 2012

| Month | Average Daily Rainfall [mm] |
|---|---|
| January | 4.29 |
| February | 2.99 |
| March | 4.71 |
| April | 0.19 |
| May | 0.00 |
| June | 0.00 |
| July | 0.00 |
| August | 0.00 |
| September | 0.08 |
| October | 5.92 |
| November | 2.71 |
| December | 5.76 |

**Table 43:** Summary of monthly rainfall recorded in 2013

| Month | Average Daily Rainfall [mm] |
|---|---|
| January | 3.08 |
| February | 2.21 |
| March | 2.36 |
| April | 2.55 |
| May | 0.09 |
| June | 0.00 |
| July | 0.00 |
| August | 0.00 |
| September | 0.00 |
| October | 2.79 |
| November | 1.76 |
| December | 5.57 |

**Appendix G**: Temperature data logged at the Thabazimbi Towers weather station (LAT(S):24.29937, LONG (E):27.70002), managed as part of the Agricultural Research Council - Institute for Soil Climate and Water Agro-Climatology Programme.

**Table 44**: Summary of ambient temperature recorded in 2011

| Month | Daily average °C | Daily Max °C | Daily Min °C |
|---|---|---|---|
| January | 17.04 | 20.22 | 14.49 |
| February | 16.76 | 20.30 | 13.51 |
| March | 18.58 | 22.45 | 14.99 |
| April | 14.40 | 17.38 | 11.92 |
| May | 13.33 | 16.77 | 10.03 |
| June | 10.40 | 14.56 | 6.68 |
| July | 9.75 | 13.25 | 5.08 |
| August | 12.36 | 17.15 | 7.89 |
| September | 17.15 | 22.38 | 12.20 |
| October | 15.94 | 22.06 | 12.55 |
| November | 18.47 | 23.14 | 14.06 |
| December | 16.46 | 21.46 | 13.88 |

**Table 45:** Summary of ambient temperature recorded in 2012

| Month | Daily average °C | Daily Max °C | Daily Min °C |
|---|---|---|---|
| January | 18.34 | 22.21 | 14.77 |
| February | 19.45 | 23.49 | 15.83 |
| March | 18.22 | 22.30 | 14.33 |
| April | 19.44 | 24.80 | 14.47 |
| May | 15.03 | 19.39 | 11.15 |
| June | 10.66 | 15.05 | 6.70 |
| July | 11.47 | 16.25 | 7.16 |
| August | 13.54 | 18.53 | 8.95 |
| September | 15.25 | 20.27 | 10.47 |
| October | 17.25 | 21.83 | 12.99 |
| November | 17.93 | 22.28 | 13.47 |
| December | 17.46 | 20.98 | 14.02 |

**Table 46:** Summary of ambient temperature recorded in 2013

| Month | Daily average °C | Daily Max °C | Daily Min °C |
|---|---|---|---|
| January | 18.66 | 22.53 | 15.12 |
| February | 19.24 | 23.60 | 15.04 |
| March | 17.40 | 21.96 | 13.52 |
| April | 14.96 | 18.92 | 11.38 |
| May | 13.04 | 17.07 | 9.52 |
| June | 12.48 | 16.94 | 8.53 |
| July | 11.22 | 15.65 | 7.48 |
| August | 12.41 | 17.00 | 7.88 |
| September | 17.50 | 22.36 | 12.99 |
| October | 16.87 | 22.28 | 11.70 |
| November | 18.40 | 23.18 | 13.85 |
| December | 17.12 | 20.78 | 13.82 |

**Appendix H**: Soil temperature data recorded on 29 April 2012, end of summer and 29 August 2013, end of winter

**Table 47:** Soil temperatures recorded in transect B in April 2012

| Legend, Temperature in °C |
|---|
| 10.5-10.9 |
| 11.0-11.4 |
| 11.5-11.9 |
| 12-12.4 |
| 12.5-12.9 |
| 13-13.4 |
| 13.5-13.9 |
| 14-14.4 |
| 14.5-14.9 |
| 15.0 15.4 |
| 15.5-15.9 |
| 16.0-16.4 |

| **Elevation in metres** | 1580.7 | 1579.5 | 1579.4 | 1579.4 | 1578 | 1576.9 | 1575.3 | 1575.643 |
|---|---|---|---|---|---|---|---|---|
| **Site** | B1 (slope) | B2 | B3 | edge reeds | B4 | B5 | B6 | 25 m from B7 |
| cm below the soil surface | | | | | | | | |
| -5 | 15.2 | | 14.8 | 14.3 | | 14.5 | 14.8 | |
| 5 | 15.7 | 14.3 | 15.2 | 14.9 | 14.7 | 14.6 | 15.5 | 15.2 |
| 20 | | 14.8 | 15.4 | 15.5 | 14.2 | 14.9 | 15.9 | 15.6 |
| 40 | | 15 | 15.6 | 15.7 | 15 | 15.2 | 16 | 15.9 |
| 60 | | 15.4 | 15.6 | 15.9 | 15.2 | 15.4 | 16.2 | |
| 80 | | | 15.9 | 15.9 | 15.5 | | | |
| 100 | | | | 16 | 15.9 | | | |
| 120 | | | | 16.1 | | | | |
| 140 | | | | 16.2 | | | | |

**Table 48:** Soil temperatures recorded in transect B in August 2013

| Legend, Temperature in °C |
|---|
| 10.5-10.9 |
| 11.0-11.4 |
| 11.5-11.9 |
| 12-12.4 |
| 12.5-12.9 |
| 13-13.4 |
| 13.5-13.9 |
| 14-14.4 |
| 14.5-14.9 |
| 15.0 15.4 |
| 15.5-15.9 |
| 16.0-16.4 |

| **Elevation in metres** | 1580.7 | 1579.5 | 1579.4 | 1579.4 | 1578 | 1576.9 | 1575.3 | 1575.643 |
|---|---|---|---|---|---|---|---|---|
| **Site** | B1 (slope) | B2 | B3 | edge reeds | B4 | B5 | B6 | 25 m from |
| cm below the soil surface | | | | | | | | |
| -5 | 14.4 | | | 11 | 10.9 | 11.5 | | |
| 5 | | 12.6 | 11.6 | 10.9 | 11.2 | 10.8 | 13.1 | 12.9 |
| 20 | | 11.8 | 11.3 | 11.3 | 12.1 | 11 | 12.4 | 12.2 |
| 40 | | 11.7 | 11.3 | 11.9 | 12.6 | 11.2 | 12.5 | 12.3 |
| 60 | | 12 | 11.6 | 12.5 | 13.3 | 11.6 | 12.5 | |
| 80 | | 12.4 | 12.2 | 13.6 | 13.9 | 11.9 | 12.6 | |
| 100 | | | 12.6 | 14 | 14.5 | 12.3 | | |
| 120 | | | 13.1 | 14.2 | 14.7 | 12.7 | | |
| 140 | | | 13.4 | 14.5 | 14.7 | 13 | | |
| 160 | | | 13.6 | | | 13.6 | | |

**Table 49:** Soil temperatures recorded in a longitudinal transect B in August 2013

| Legend, Temperature in °C |
|---|
| 10.5-10.9 |
| 11.0-11.4 |
| 11.5-11.9 |
| 12-12.4 |
| 12.5-12.9 |
| 13-13.4 |
| 13.5-13.9 |
| 14-14.4 |
| 14.5-14.9 |
| 15.0 15.4 |
| 15.5-15.9 |
| 16.0-16.4 |

| **Elevation in metres** estimated, not measured<br>**Site**<br>cm below the soil surface | A 2 | B edge reeds | Between B and C | C3 | Between D3 and D4 |
|---|---|---|---|---|---|
| 5 | 12.7 | 11 | 11.6 | 11.4 | 11.6 |
| 20 | 12.9 | 10.9 | 11.5 | 11.3 | 11.4 |
| 40 | 13.6 | 11.3 | 11.8 | 11.6 | 11.7 |
| 60 | 14 | 11.9 | 12.3 | 12.1 | 12.2 |
| 80 | 14.4 | 12.5 | 12.6 | 12.5 | 12.6 |
| 100 | 14.9 | 13.6 | 12.7 | 12.7 | 13 |
| 120 | 15.4 | 14 | | 13 | 13.3 |
| 140 | 15.9 | 14.2 | | 13.3 | 13.8 |
| 160 | 16 | 14.5 | | 13.6 | 14 |
| 180 | 16.3 | | | 13.8 | 14.5 |
| 200 | | | | | |

**Appendix I:** A summary of water pressure readings for each transect showing where discharge and recharge occur. From the larger dataset containing water pressure data from May 2011 to February 2013, two months were chosen as being representative of a wet season (March 2012) and a dry season (June 2012).

**Table 50:** Water movement readings in representative months, May 2012 and June 2012

| **Name of sample point** | | **March 12** | | | | **June 12** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Elevation of water level in the well in m.a.s.l. | Elevation of water level in the longest tube in m.a.s.l. | Elevation of water in the well- elevation of water in the tube in m.a.s.l. | Description of water movement | Elevation of water level in the well in m.a.s.l. | Elevation of water level in the longest tube in m.a.s.l. | Elevation of water in the well- elevation of water in the tube in m.a.s.l. | Description of water movement |
| A1 | A1W | 1591.43 | - | -11.54 | discharge | 1591.425 | - | -11.50 | discharge |
| | A1P1 | - | 1602.96 | | | - | 1602.93 | | |
| A2 | A2W | 1591.42 | - | -10.33 | discharge | 1591.14 | - | -10.55 | discharge |
| | A2P1 | - | 1601.75 | | | - | 1601.69 | | |
| A3 | A3W | 1591.15 | - | -9.88 | discharge | 1591.15 | - | -9.85 | discharge |
| | A3P1 | - | 1601.03 | | | - | 1601.00 | | |
| A4 | A4W | 1590.48 | - | -8.49 | discharge | 1590.45 | - | -8.49 | discharge |
| | A4P1 | - | 1598.97 | | | - | 1598.94 | | |
| A5 | A5W | 1590.13 | - | -10.06 | discharge | 1590.11 | - | -9.85 | discharge |
| | A5P1 | - | 1600.19 | | | - | 1599.96 | | |
| B2 | B2W | 1579.47 | - | -0.01 | not significant | 1579.47 | - | -0.01 | not significant |
| | B2P1 | - | 1579.48 | | | - | 1579.48 | | |
| B3 | B3W | 1579.42 | - | -0.05 | slight discharge | 1579.42 | - | -0.04 | slight discharge |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | B3P1 | - | 1579.47 | | | - | 1579.46 | | |
| B4 | B4W | 1577.89 | - | -0.13 | discharge | 1577.79 | - | -0.14 | discharge |
| | B4P2 | - | 1578.02 | | | - | 1577.92 | | |
| B5 | B5W | 1576.87 | - | 0.03 | not significant | 1576.87 | - | 0.04 | slight recharge |
| | B5P1 | - | 1576.85 | | | - | 1576.82 | | |
| B6 | B6W | 1575.27 | - | 0.00 | no movement | 1575.26 | - | 0.01 | not significant |
| | B6P1 | - | 1575.27 | | | - | 1575.25 | | |
| C2 | C2W | 1574.64 | - | -0.11 | discharge | 1574.643 | - | -0.09 | slight discharge |
| | C2P1 | - | 1574.76 | | | - | 1574.74 | | |
| C3 | C3W | 1573.74 | - | 0.01 | not significant | 1573.707 | - | 0.03 | not significant |
| | C3P2 | - | 1573.73 | | | - | 1573.68 | | |
| C4 | C4W | 1574.91 | - | -0.06 | slight discharge | 1574.921 | - | -0.06 | slight discharge |
| | C4P2 | - | 1574.97 | | | - | 1574.98 | | |
| C5 | C5W | 1571.97 | - | -0.02 | not significant | 1571.97 | - | -0.01 | not significant |
| | C5P2 | - | 1571.99 | | | - | 1571.97 | | |
| D2 | D2W | 1571.38 | - | 0.54 | recharge | 1571.382 | - | 0.00 | no movement |
| | D2P1 | - | 1570.84 | | | - | 1571.38 | | |
| D3 | D3W | 1569.17 | - | -0.20 | discharge | 1569.162 | - | -0.14 | discharge |
| | D3P2 | - | 1569.37 | | | - | 1569.31 | | |
| D4 | D4W | 1568.88 | - | -0.11 | discharge | 1568.87 | - | -0.02 | not significant |
| | D4P2 | - | 1568.99 | | | - | 1568.89 | | |
| D5 | D5W | 1568.73 | - | 0.18 | recharge | 1568.655 | - | 0.12 | recharge |
| | D5P2 | - | 1568.55 | | | - | 1568.53 | | |

**Appendix J:** Water Quality Data

**Table 51:** Selected chemical parameters shown in mg/ℓ recorded in Transect A during the winter dry season (June 2011) and the summer wet season (January 2013).

| Sample site | Iron (Fe) | | Ammonium (NH4+) | | pH | | Chloride (Cl-) | | Sodium (Na) | | Calcium (Ca) | | Bicarbonate (HCO3-) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 |
| A1 W | - | - | - | - | - | 6.43 | - | 2.93 | - | 4.98 | - | 3.14 | - | 42.70 |
| A1 P1 | - | 0.02 | - | 0.02 | - | 5.63 | - | 1.93 | - | 3.23 | - | 0.76 | - | 6.10 |
| A1 P2 | - | 0.00 | - | 0.14 | - | 5.46 | - | 1.60 | - | 1.86 | - | 1.02 | - | 9.76 |
| A2 W | - | 0.01 | - | 0.02 | - | 5.60 | - | 1.04 | - | 1.09 | - | 0.46 | - | 10.37 |
| A2 P1 | - | 0.05 | - | 0.49 | - | 5.61 | - | 2.39 | - | 3.56 | - | 1.02 | - | 13.42 |
| A2 P2 | 1.23 | 0.68 | 2.2 | 0.07 | 5.54 | 5.38 | 4.13 | 2.11 | 3.20 | 2.42 | 0.79 | 0.70 | 6.10 | 6.71 |
| A3 W | 0.21 | 1.33 | 0.64 | 0.07 | 5.75 | 5.18 | 3.17 | 0.79 | 3.20 | 1.03 | 0.81 | 1.13 | 4.88 | 12.20 |
| A3 P1 | 0.22 | 5.00 | 1.51 | 0.68 | 5.55 | 5.57 | 4.34 | 3.15 | 3.87 | 3.66 | 0.51 | 0.68 | 6.10 | 15.25 |
| A4 W | 1.59 | 1.29 | 0.14 | 0.18 | 5.37 | 5.33 | 0.59 | 0.95 | 1.66 | 1.56 | 0.03 | 1.12 | 4.88 | 10.92 |
| A5 W | 6.26 | 1.97 | 0.20 | 0.02 | 5.59 | 5.81 | 3.25 | 0.54 | 4.04 | 3.25 | 0.86 | 1.22 | 8.54 | 18.30 |

**Table 52:** Selected chemical parameters shown in mg/ℓ recorded in Transect B during the winter dry season (June 2011) and the summer wet season (January 2013).

| Sample site | Iron (Fe) | | Ammonium (NH4+) | | pH | | Chloride (Cl-) | | Sodium (Na) | | Calcium (Ca) | | Bicarbonate (HCO3-) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 |
| B2 P1 | 0.77 | 0.03 | 0.19 | 0.03 | 5.18 | - | 1.32 | - | 1.57 | - | 1.05 | - | 4.88 | - |
| B2 W | 0.09 | 1.21 | 0.18 | 0.07 | 5.23 | 4.96 | 1.09 | 0.54 | 1.60 | 1.84 | 0.21 | 1.10 | 4.88 | 12.20 |
| B3 P1 | 18.88 | 0.11 | 1.94 | 0.03 | 6.07 | 5.52 | 0.80 | 1.69 | 4.44 | 1.85 | 5.76 | 1.33 | 31.72 | 9.76 |
| B3 W | 3.72 | 2.02 | 0.26 | 0.02 | 5.80 | 5.37 | 1.38 | 0.86 | 1.28 | 2.77 | 0.54 | 0.41 | 6.10 | 7.32 |
| B3 P2 | 1.68 | 2.16 | 2.04 | 0.03 | 6.15 | 5.13 | 3.59 | 1.33 | 2.13 | 1.37 | 2.15 | 1.11 | 14.03 | 8.54 |
| B4 W | 16.86 | 2.27 | 0.83 | 0.02 | 6.15 | 5.58 | 2.45 | 0.70 | 1.70 | 1.20 | 1.72 | 0.74 | 9.15 | 6.71 |
| B4 P1 | 0.71 | 0.17 | 1.09 | 0.02 | 6.15 | 5.50 | 1.28 | 0.70 | 5.49 | 2.08 | 4.56 | 0.72 | 27.45 | 5.49 |
| B4 P2 | 9.32 | 7.61 | 0.19 | 1.94 | 6.27 | 6.48 | 1.82 | 1.25 | 3.42 | 4.33 | 6.13 | 2.40 | 38.43 | 43.92 |
| B5 W | 1.20 | 0.53 | 1.40 | 0.03 | 6.10 | 5.48 | 3.22 | 1.11 | 2.55 | 3.21 | 3.75 | 0.49 | 20.13 | 9.76 |
| B5 P2 | 23.22 | 1.07 | 12.83 | 0.03 | 6.32 | 5.87 | 3.09 | 1.01 | 8.11 | 2.75 | 13.39 | 2.16 | 94.55 | 15.86 |
| B6 P1 | 32.69 | 12.09 | 13.34 | 1.79 | 6.72 | 6.34 | 0.97 | 0.49 | 6.95 | 6.08 | 18.41 | 6.42 | 103.70 | 110.41 |
| B6 P2 | 13.56 | 0.11 | 0.86 | 0.39 | 6.75 | 6.62 | 1.72 | 3.58 | 5.05 | 5.70 | 9.06 | 5.63 | 54.90 | 52.46 |
| B6 W | 7.45 | 3.33 | 3.20 | 0.20 | 6.74 | 5.66 | 2.24 | 0.74 | 5.01 | 2.07 | 2.66 | 2.51 | 20.74 | 15.86 |

**Table 53:** Selected chemical parameters shown in mg/ℓ recorded in Transect C during the winter dry season (June 2011) and the summer wet season (January 2013).

| Sample site | Iron (Fe) | | Ammonium (NH4+) | | pH | | Chloride (Cl-) | | Sodium (Na) | | Calcium (Ca) | | Bicarbonate (HCO3-) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 |
| C2 W | 3.03 | 7.66 | 1.07 | 1.20 | 6.09 | 6.10 | 0.98 | 0.68 | 2.07 | 2.17 | 1.14 | 2.01 | 15.25 | 25.62 |
| C2 P1 | 1.84 | 2.17 | 1.03 | 4.15 | 5.83 | 6.05 | 1.32 | 6.61 | 0.00 | 5.84 | 0.00 | 2.37 | 1.83 | 39.65 |
| C3 W | 21.94 | 63.25 | 1.89 | 1.16 | 6.42 | 6.62 | 1.03 | 1.36 | 0.00 | 4.93 | 0.00 | 2.92 | 6.10 | 103.70 |
| C3 P1 | 1.20 | 0.87 | 4.06 | 0.04 | 6.07 | 5.80 | 1.31 | 1.12 | 0.00 | 3.28 | 0.00 | 2.92 | 46.36 | 28.06 |
| C3 P2 | 8.03 | 1.09 | 0.80 | 1.91 | 6.34 | 6.01 | 1.64 | 0.92 | 0.00 | 3.57 | 9.10 | 2.94 | 98.82 | 29.28 |
| C4 P1 | 1.82 | 0.20 | 0.91 | 0.05 | 5.93 | 5.58 | 1.30 | 1.17 | 6.35 | 2.28 | 8.67 | 3.72 | 62.22 | 23.18 |
| C4 P2 | 1.99 | 0.33 | 1.82 | 2.32 | 5.89 | 5.75 | 1.63 | 1.32 | 6.97 | 2.36 | 9.36 | 2.89 | 81.74 | 26.84 |
| C5 P1 | 38.67 | - | 3.89 | - | 6.45 | - | 1.66 | - | 8.35 | - | 12.30 | - | 128.71 | - |
| C5 P2 | 58.03 | 12.72 | 0.78 | 0.06 | 6.49 | 6.14 | 0.49 | 0.73 | 12.30 | 9.85 | 14.38 | 10.35 | 119.56 | 103.70 |
| C5 W | 1.80 | 34.04 | 3.86 | 0.10 | 6.40 | 6.25 | 1.14 | 0.76 | 3.98 | 3.88 | 2.53 | 1.74 | 36.60 | 109.80 |
| C6W | 31.47 | 6.45 | 0.78 | 0.36 | 6.38 | 6.44 | 2.81 | 2.35 | 10.27 | 5.20 | 5.40 | 6.25 | 81.74 | 56.12 |

**Table 54:** Selected chemical parameters sown in mg/ℓ recorded in Transect D during the winter dry season (June 2011) and the summer wet season (January 2013).

| Sample site | Iron (Fe) | | Ammonium (NH4+) | | pH | | Chloride (Cl-) | | Sodium (Na) | | Calcium (Ca) | | Bicarbonate (HCO3-) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 | 2011 | 2013 |
| D3 W | 7.58 | 4.89 | 0.48 | 0.12 | 5.90 | 5.73 | 1.66 | 1.39 | 5.40 | 1.88 | 2.04 | 1.64 | 30.50 | 10.98 |
| D3 P1 | 13.11 | 1.77 | 2.38 | 0.02 | 6.37 | 6.12 | 1.36 | 2.10 | 7.50 | 5.33 | 8.80 | 1.69 | 64.05 | 19.52 |
| D3 P2 | 3.10 | 0.58 | 0.72 | 0.07 | 6.41 | 6.17 | 1.67 | 1.11 | 7.26 | 4.46 | 23.14 | 4.75 | 101.26 | 27.45 |
| D4 W | 7.75 | 16.23 | 0.49 | 0.06 | 5.93 | 6.16 | 1.84 | 0.88 | 5.52 | 3.10 | 3.05 | 3.40 | 41.48 | 37.82 |
| D4 P1 | 0.94 | 4.22 | 0.91 | 0.48 | 6.38 | 5.73 | 0.69 | 1.58 | 1.38 | 4.49 | 2.58 | 2.55 | 14.03 | 26.23 |
| D4 P2 | 0.12 | 1.58 | 0.92 | 0.90 | 6.52 | 6.65 | 1.64 | 2.16 | 8.43 | 7.88 | 3.74 | 1.78 | 28.06 | 87.84 |
| D5 W | 0.89 | 1.53 | 0.51 | 0.04 | 5.84 | 6.21 | 1.83 | 2.21 | 2.45 | 6.20 | 0.57 | 3.73 | 7.93 | 31.72 |
| D5 P1 | 2.03 | 2.97 | 1.07 | 0.71 | 6.02 | 5.56 | 1.15 | 3.02 | 6.45 | 5.27 | 2.37 | 1.27 | 42.09 | 17.69 |
| D5 P2 | 0.52 | 2.56 | 0.77 | 0.04 | 6.24 | 5.67 | 0.72 | 2.29 | 4.61 | 5.78 | 3.94 | 2.21 | 40.87 | 26.23 |
| D6 W | 7.72 | 35.78 | 0.61 | 0.72 | 6.20 | 6.48 | 1.65 | 0.33 | 4.25 | 4.97 | 2.20 | 5.87 | 21.35 | 90.28 |